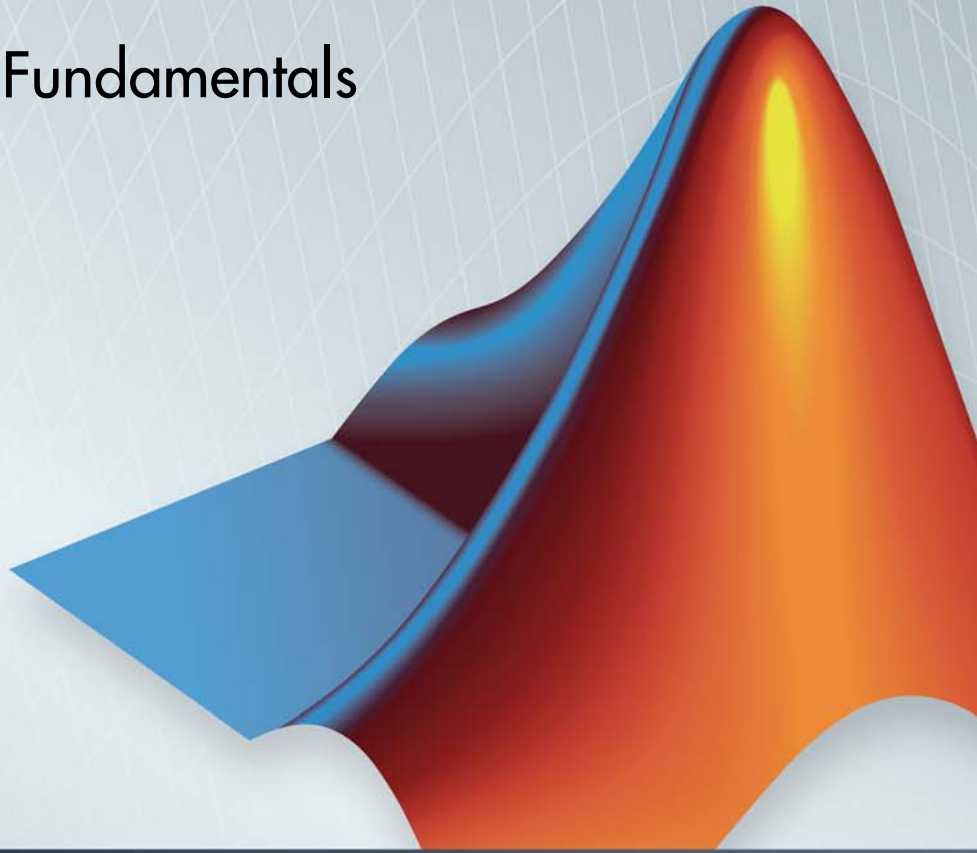


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# Programming Fundamentals

**R2014a**



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# Language

---

- Chapter 1, “Syntax Basics”
- Chapter 2, “Program Components”



# Syntax Basics

---

- “Create Variables” on page 1-2
- “Create Numeric Arrays” on page 1-3
- “Continue Long Statements on Multiple Lines” on page 1-5
- “Call Functions” on page 1-6
- “Ignore Function Outputs” on page 1-7
- “Variable Names” on page 1-8
- “Case and Space Sensitivity” on page 1-10
- “Command vs. Function Syntax” on page 1-12
- “Common Errors When Calling Functions” on page 1-16

## Create Variables

This example shows several ways to assign a value to a variable.

```
x = 5.71;  
A = [1 2 3; 4 5 6; 7 8 9];  
I = besseli(x,A);
```

You do not have to declare variables before assigning values.

If you do not end an assignment statement with a semicolon (;), MATLAB® displays the result in the Command Window. For example,

```
x = 5.71
```

displays

```
x =  
    5.7100
```

If you do not explicitly assign the output of a command to a variable, MATLAB generally assigns the result to the reserved word `ans`. For example,

```
5.71
```

returns

```
ans =  
    5.7100
```

The value of `ans` changes with every command that returns an output value that is not assigned to a variable.

## Create Numeric Arrays

This example shows how to create a numeric variable. In the MATLAB computing environment, all variables are arrays, and by default, numeric variables are of type `double` (that is, double-precision values). For example, create a scalar value.

```
A = 100;
```

Because scalar values are single element, 1-by-1 arrays,

```
whos A
```

returns

Name	Size	Bytes	Class	Attributes
A	1x1	8	double	

To create a *matrix* (a two-dimensional, rectangular array of numbers), you can use the `[]` operator.

```
B = [12, 62, 93, -8, 22; 16, 2, 87, 43, 91; -4, 17, -72, 95, 6]
```

When using this operator, separate columns with a comma or space, and separate rows with a semicolon. All rows must have the same number of elements. In this example, B is a 3-by-5 matrix (that is, B has three rows and five columns).

```
B =
    12    62    93    -8    22
    16     2    87    43    91
    -4    17   -72    95     6
```

A matrix with only one row or column (that is, a 1-by-n or n-by-1 array) is a *vector*, such as

```
C = [1, 2, 3]
```

or

```
D = [10; 20; 30]
```

For more information, see:

- “Multidimensional Arrays”
- “Matrix Indexing”

## Continue Long Statements on Multiple Lines

This example shows how to continue a statement to the next line using ellipses (...).

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

Build a long character string by concatenating shorter strings together:

```
mystring = ['Accelerating the pace of ' ...  
           'engineering and science'];
```

The start and end quotation marks for a string must appear on the same line. For example, this code returns an error, because each line contains only one quotation mark:

```
mystring = 'Accelerating the pace of ...  
           engineering and science'
```

An ellipses outside a quoted string is equivalent to a space. For example,

```
x = [1.23...  
     4.56];
```

is the same as

```
x = [1.23 4.56];
```

## Call Functions

These examples show how to call a MATLAB function. To run the examples, you must first create numeric arrays **A** and **B**, such as:

```
A = [1 3 5];  
B = [10 6 4];
```

Enclose inputs to functions in parentheses:

```
max(A)
```

Separate multiple inputs with commas:

```
max(A,B)
```

Store output from a function by assigning it to a variable:

```
maxA = max(A)
```

Enclose multiple outputs in square brackets:

```
[maxA, location] = max(A)
```

Call a function that does not require any inputs, and does not return any outputs, by typing only the function name:

```
clc
```

Enclose text string inputs in single quotation marks:

```
disp('hello world')
```

### Related Examples

- “Ignore Function Outputs” on page 1-7



## Ignore Function Outputs

This example shows how to request specific outputs from a function.

Request all three possible outputs from the `fileparts` function.

```
helpFile = which('help');  
[helpPath,name,ext] = fileparts(helpFile);
```

The current workspace now contains three variables from `fileparts`: `helpPath`, `name`, and `ext`. In this case, the variables are small. However, some functions return results that use much more memory. If you do not need those variables, they waste space on your system.

Request only the first output, ignoring the second and third.

```
helpPath = fileparts(helpFile);
```

For any function, you can request only the first  $N$  outputs (where  $N$  is less than or equal to the number of possible outputs) and ignore any remaining outputs. If you request more than one output, enclose the variable names in square brackets, `[ ]`.

Ignore the first output using a tilde (`~`).

```
[~,name,ext] = fileparts(helpFile);
```

You can ignore any number of function outputs, in any position in the argument list. Separate consecutive tildes with a comma, such as

```
[~,~,ext] = fileparts(helpFile);
```

## Variable Names

### In this section...

“Valid Names” on page 1-8

“Conflicts with Function Names” on page 1-8

### Valid Names

A valid variable name starts with a letter, followed by letters, digits, or underscores. MATLAB is case sensitive, so *A* and *a* are *not* the same variable. The maximum length of a variable name is the value that the `namelengthmax` command returns.

You cannot define variables with the same names as MATLAB keywords, such as `if` or `end`. For a complete list, run the `iskeyword` command.

Examples of valid names:

`x6`

`lastValue`

`n_factorial`

Invalid names:

`6x`

`end`

`n!`

### Conflicts with Function Names

Avoid creating variables with the same name as a function (such as `i`, `j`, `mode`, `char`, `size`, and `path`). In general, variable names take precedence over function names. If you create a variable that uses the name of a function, you sometimes get unexpected results.

Check whether a proposed name is already in use with the `exist` or `which` function. `exist` returns 0 if there are no existing variables, functions, or other artifacts with the proposed name. For example:

```
exist checkname
```

```
ans =  
    0
```

If you inadvertently create a variable with a name conflict, remove the variable from memory with the `clear` function.

Another potential source of name conflicts occurs when you define a function that calls `load` or `eval` (or similar functions) to add variables to the workspace. In some cases, `load` or `eval` add variables that have the same names as functions. Unless these variables are in the function workspace before the call to `load` or `eval`, the MATLAB parser interprets the variable names as function names. For more information, see:

- “Loading Variables within a Function”
- “Alternatives to the `eval` Function” on page 2-69

**See Also**

`clear` | `exist` | `iskeyword` | `namelengthmax` | `which`

## Case and Space Sensitivity

MATLAB code is sensitive to casing, and insensitive to blank spaces except when defining arrays.

### Uppercase and Lowercase

In MATLAB code, use an exact match with regard to case for variables, files, and functions. For example, if you have a variable, `a`, you cannot refer to that variable as `A`. It is a best practice to use lowercase only when naming functions. This is especially useful when you use both Microsoft® Windows® and UNIX®<sup>1</sup> platforms because their file systems behave differently with regard to case.

When you use the `help` function, the help displays some function names in all uppercase, for example, `PLOT`, solely to distinguish the function name from the rest of the text. Some functions for interfacing to Oracle® Java® software do use mixed case and the command-line help and the documentation accurately reflect that.

### Spaces

Blank spaces around operators such as `-`, `:`, and `( )`, are optional, but they can improve readability. For example, MATLAB interprets the following statements the same way.

```
y = sin (3 * pi) / 2
y=sin(3*pi)/2
```

However, blank spaces act as delimiters in horizontal concatenation. When defining row vectors, you can use spaces and commas interchangeably to separate elements:

```
A = [1, 0 2, 3 3]
```

```
A =
```

```
1    0    2    3    3
```

---

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

Because of this flexibility, check to ensure that MATLAB stores the correct values. For example, the statement `[1 sin (pi) 3]` produces a much different result than `[1 sin(pi) 3]` does.

```
[1 sin (pi) 3]
```

```
Error using sin  
Not enough input arguments.
```

```
[1 sin(pi) 3]
```

```
ans =
```

```
1.0000    0.0000    3.0000
```

## Command vs. Function Syntax

### In this section...

“Command and Function Syntaxes” on page 1-12

“Avoid Common Syntax Mistakes” on page 1-13

“How MATLAB Recognizes Command Syntax” on page 1-14

### Command and Function Syntaxes

In MATLAB, these statements are equivalent:

```
load durer.mat           % Command syntax
load('durer.mat')       % Function syntax
```

This equivalence is sometimes referred to as *command-function duality*.

All functions support this standard *function syntax*:

```
[output1, ..., outputM] = functionName(input1, ..., inputN)
```

If you do not require any outputs from the function, and all of the inputs are literal strings (that is, text enclosed in single quotation marks), you can use this simpler *command syntax*:

```
functionName input1 ... inputN
```

With command syntax, you separate inputs with spaces rather than commas, and do not enclose input arguments in parentheses. Because all inputs are literal strings, single quotation marks are optional, unless the input string contains spaces. For example:

```
disp 'hello world'
```

When a function input is a variable, you must use function syntax to pass the value to the function. Command syntax always passes inputs as literal text and cannot pass variable values. For example, create a variable and call the `disp` function with function syntax to pass the value of the variable:

```
A = 123;
disp(A)
```

This code returns the expected result,

```
123
```

You cannot use command syntax to pass the value of A, because this call

```
disp A
```

is equivalent to

```
disp('A')
```

and returns

```
A
```

## Avoid Common Syntax Mistakes

Suppose that your workspace contains these variables:

```
filename = 'accounts.txt';
A = int8(1:8);
B = A;
```

The following table illustrates common misapplications of command syntax.

This Command...	Is Equivalent to...	Correct Syntax for Passing Value
open filename	open('filename')	open(filename)
isequal A B	isequal('A','B')	isequal(A,B)
strcmp class(A) int8	strcmp('class(A)','int8')	strcmp(class(A),'int8')
cd matlabroot	cd('matlabroot')	cd(matlabroot)
isnumeric 500	isnumeric('500')	isnumeric(500)
round 3.499	round('3.499'), same as round([51 46 52 57 57])	round(3.499)

## Passing Variable Names

Some functions expect literal strings for variable names, such as `save`, `load`, `clear`, and `whos`. For example,

```
whos -file durer.mat X
```

requests information about variable `X` in the example file `durer.mat`. This command is equivalent to

```
whos('-file','durer.mat','X')
```

## How MATLAB Recognizes Command Syntax

Consider the potentially ambiguous statement

```
ls ./d
```

This could be a call to the `ls` function with the folder `./d` as its argument. It also could request elementwise division on the array `ls`, using the variable `d` as the divisor.

If you issue such a statement at the command line, MATLAB can access the current workspace and path to determine whether `ls` and `d` are functions or variables. However, some components, such as the Code Analyzer and the Editor/Debugger, operate without reference to the path or workspace. In those cases, MATLAB uses syntactic rules to determine whether an expression is a function call using command syntax.

In general, when MATLAB recognizes an identifier (which might name a function or a variable), it analyzes the characters that follow the identifier to determine the type of expression, as follows:

- An equal sign (=) implies assignment. For example:

```
ls =d
```

- An open parenthesis after an identifier implies a function call. For example:

```
ls('./d')
```

- Space after an identifier, but not after a potential operator, implies a function call using command syntax. For example:

```
ls ./d
```



- Spaces on both sides of a potential operator, or no spaces on either side of the operator, imply an operation on variables. For example, these statements are equivalent:

```
ls ./ d
```

```
ls./d
```

Therefore, the potentially ambiguous statement `ls ./d` is a call to the `ls` function using command syntax.

The best practice is to avoid defining variable names that conflict with common functions, to prevent any ambiguity.

## Common Errors When Calling Functions

<b>In this section...</b>
“Conflicting Function and Variable Names” on page 1-16
“Undefined Functions or Variables” on page 1-16

### Conflicting Function and Variable Names

MATLAB throws an error if a variable and function have been given the same name and there is insufficient information available for MATLAB to resolve the conflict. You may see an error message something like the following:

```
Error: <functionName> was previously used as a variable,  
      conflicting with its use here as the name of a function  
      or command.
```

where <functionName> is the name of the function.

Certain uses of the `eval` and `load` functions can also result in a similar conflict between variable and function names. For more information, see:

- “Conflicts with Function Names” on page 1-8
- “Loading Variables within a Function”
- “Alternatives to the `eval` Function” on page 2-69

### Undefined Functions or Variables

You may encounter the following error message, or something similar, while working with functions or variables in MATLAB:

```
Undefined function or variable 'x'.
```

These errors usually indicate that MATLAB cannot find a particular variable or MATLAB program file in the current directory or on the search path. The root cause is likely to be one of the following:

- The name of the function has been misspelled.

- The function name and name of the file containing the function are not the same.
- The toolbox to which the function belongs is not installed.
- The search path to the function has been changed.
- The function is part of a toolbox that you do not have a license for.

Follow the steps described in this section to resolve this situation.

### Verify the Spelling of the Function Name

One of the most common errors is misspelling the function name. Especially with longer function names or names containing similar characters (e.g., letter l and numeral one), it is easy to make an error that is not easily detected.

If you misspell a MATLAB function, a suggested function name appears in the Command Window. For example, this command fails because it includes an uppercase letter in the function name:

```
accumArray
```

```
Undefined function or variable 'accumArray'.
```

```
Did you mean:  
>> accumarray
```

Press **Enter** to execute the suggested command or **Esc** to dismiss it.

### Make Sure the Function Name Matches the File Name

You establish the name for a function when you write its function definition line. This name should always match the name of the file you save it to. For example, if you create a function named `curveplot`,


```
function curveplot(xVal, yVal)  
    - program code -
```

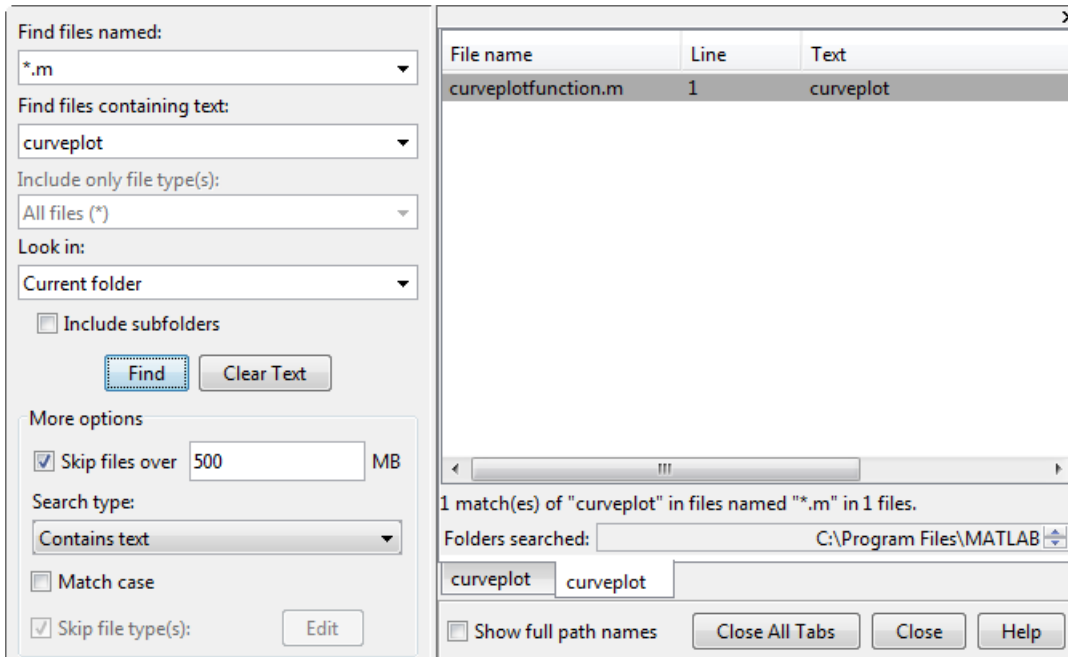
then you should name the file containing that function `curveplot.m`. If you create a `pcode` file for the function, then name that file `curveplot.p`. In the case of conflicting function and file names, the file name overrides the name given to the function. In this example, if you save the `curveplot` function to a

file named `curveplotfunction.m`, then attempts to invoke the function using the function name will fail:

```
curveplot
Undefined function or variable 'curveplot'.
```

If you encounter this problem, change either the function name or file name so that they are the same. If you have difficulty locating the file that uses this function, use the MATLAB **Find Files** utility as follows:

- 1 On the **Home** tab, in the **File** section, click  **Find Files**.
- 2 Under **Find files named:** enter `*.m`
- 3 Under **Find files containing text:** enter the function name.
- 4 Click the **Find** button



## Make Sure the Toolbox Is Installed

If you are unable to use a built-in function from MATLAB or its toolboxes, make sure that the function is installed.

If you do not know which toolbox supports the function you need, search for the function documentation at <http://www.mathworks.com/help>. The toolbox name appears at the top of the function reference page.

Once you know which toolbox the function belongs to, use the `ver` function to see which toolboxes are installed on the system from which you run MATLAB. The `ver` function displays a list of all currently installed MathWorks® products. If you can locate the toolbox you need in the output displayed by `ver`, then the toolbox is installed. For help with installing MathWorks products, see the Installation Guide documentation.

If you do not see the toolbox and you believe that it is installed, then perhaps the MATLAB path has been set incorrectly. Go on to the next section.

## Verify the Path Used to Access the Function

This step resets the path to the default. Because MATLAB stores the toolbox information in a cache file, you will need to first update this cache and then reset the path. To do this,

- 1 On the **Home** tab, in the **Environment** section, click  **Preferences**.

The Preference dialog box appears.

- 2 Under the **MATLAB > General** node, click the **Update Toolbox Path Cache** button.

- 3 On the **Home** tab, in the **Environment** section, click  **Set Path...**

The Set Path dialog box opens.

- 4 Click **Default**.

A small dialog box opens warning that you will lose your current path settings if you proceed. Click **Yes** if you decide to proceed.

(If you have added any custom paths to MATLAB, you will need to restore those later)

Run `ver` again to see if the toolbox is installed. If not, you may need to reinstall this toolbox to use this function. See the Related Solution 1-1CBD3, "How do I install additional toolboxes into my existing MATLAB" for more information about installing a toolbox.

Once `ver` shows your toolbox, run the following command to see if you can find the function:

```
which -all <functionname>
```

replacing `<functionname>` with the name of the function. You should be presented with the path(s) of the function file. If you get a message indicating that the function name was not found, you may need to reinstall that toolbox to make the function active.

### **Verify that Your License Covers The Toolbox**

If you receive the error message "Has no license available", there is a licensing related issue preventing you from using the function. To find the error that is occurring, you can use the following command:

```
license checkout <toolbox_license_key_name>
```

replacing `<toolbox_license_key_name>` with the proper key name for the toolbox that contains your function. To find the license key name, look at the `INCREMENT` lines in your license file. For information on how to find your license file see the related solution: 1-63ZIR6, "Where are the license files for MATLAB located?"

The license key names of all the toolboxes are located after each `INCREMENT` tag in the `license.dat` file. For example:

```
INCREMENT MATLAB MLM 17 00-jan-0000 0 k  
B454554BADECE4258 \HOSTID=123456 SN=123456
```

If your `license.dat` file has no `INCREMENT` lines, refer to your license administrator for them. For example, to test the licensing for Symbolic Math Toolbox™, you would run the following command:

`license checkout Symbolic_Toolbox`

A correct testing gives the result "ANS=1". An incorrect testing results in an error from the license manager. You can either troubleshoot the error by looking up the license manager error here:

<http://www.mathworks.com/support/install.html>

or you can contact the Installation Support Team with the error here:

[http://www.mathworks.com/support/contact\\_us/index.html](http://www.mathworks.com/support/contact_us/index.html)

When contacting support, provide your license number, your MATLAB version, the function you are using, and the license manager error (if applicable).





# Program Components

---

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- “Relational Operators” on page 2-7
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## Array vs. Matrix Operations

In this section...
“Introduction” on page 2-2
“Array Operations” on page 2-2
“Matrix Operations” on page 2-4

### Introduction

MATLAB has two different types of arithmetic operations: array operations and matrix operations. You can use these arithmetic operations to perform numeric computations, for example, adding two numbers, raising the elements of an array to a given power, or multiplying two matrices.

Matrix operations follow the rules of linear algebra. By contrast, array operations execute element by element operations and support multidimensional arrays. The period character (.) distinguishes the array operations from the matrix operations. However, since the matrix and array operations are the same for addition and subtraction, the character pairs `.+` and `.-` are unnecessary.

### Array Operations

Array operations work on corresponding elements of arrays with equal dimensions. For vectors, matrices, and multidimensional arrays, both operands must be the same size. Each element in the first input gets matched up with a similarly located element from the second input. If the inputs are different sizes, MATLAB cannot match the elements one-to-one.

As a simple example, you can add two vectors with the same length.

```
A = [1 1 1]
```

```
A =
```

```
    1    1    1
```

```
B = 1:3
```

```
B =
     1     2     3
```

```
A+B
```

```
ans =
     2     3     4
```

If the vectors are not the same size you get an error.

```
B = 1:4
```

```
B =
     1     2     3     4
```

```
A+B
```

```
Error using +
Matrix dimensions must agree.
```

If one operand is a scalar and the other is not, then MATLAB applies the scalar to every element of the other operand. This property is known as *scalar expansion* because the scalar expands into an array of the same size as the other input, then the operation executes as it normally does with two arrays.

For example, the element-wise product of a scalar and a matrix uses scalar expansion.

```
A = [1 0 2;3 1 4]
```

```
A =
     1     0     2
     3     1     4
```

```
3.*A
```

```
ans =
     3     0     6
     9     3    12
```

The following table provides a summary of array arithmetic operators in MATLAB. For function-specific information, click the link to the function reference page in the last column.

Operator	Purpose	Description	Reference Page
+	Addition	A+B adds A and B.	plus
+	Unary plus	+A returns A.	uplus
-	Subtraction	A-B subtracts B from A	minus
-	Unary minus	-A negates the elements of A.	uminus
.*	Element-wise multiplication	A.*B is the element-by-element product of A and B.	times
.^	Element-wise power	A.^B is the matrix with elements A(i,j) to the B(i,j) power.	power
./	Right array division	A./B is the matrix with elements A(i,j)/B(i,j).	rdivide
.\	Left array division	A.\B is the matrix with elements B(i,j)/A(i,j).	ldivide
.'	Array transpose	A.' is the array transpose of A. For complex matrices, this does not involve conjugation.	transpose

## Matrix Operations

Matrix operations follow the rules of linear algebra and are not compatible with multidimensional arrays. The required size and shape of the inputs in relation to one another depends on the operation. For nonscalar inputs,

the matrix operators generally calculate different answers than their array operator counterparts.

For example, if you use the matrix right division operator, `/`, to divide two matrices, the matrices must have the same number of columns. But if you use the matrix multiplication operator, `*`, to multiply two matrices, then the matrices must have a common *inner dimension*. That is, the number of columns in the first input must be equal to the number of rows in the second input. The matrix multiplication operator calculates the product of two matrices with the formula,

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

To see this, you can calculate the product of two matrices.

A = [1 3;2 4]

A =

```

     1     3
     2     4

```

B = [3 0;1 5]

B =

```

     3     0
     1     5

```

A\*B

ans =

```

     6     15
    10     20

```

The previous matrix product is not equal to the following element-wise product.

A.\*B

ans =

```

3     0
2    20

```

The following table provides a summary of matrix arithmetic operators in MATLAB. For function-specific information, click the link to the function reference page in the last column.

Operator	Purpose	Description	Reference Page
*	Matrix multiplication	$C = A*B$ is the linear algebraic product of the matrices A and B. The number of columns of A must equal the number of rows of B.	<a href="#">mtimes</a>
/	Matrix right division	$x = B/A$ is the solution to the equation $xA = B$ . Matrices A and B must have the same number of columns. In terms of the left division operator, $B/A = (A' \setminus B')'$ .	<a href="#">mrdivide</a>
\	Matrix left division	$x = A \setminus B$ is the solution to the equation $Ax = B$ . Matrices A and B must have the same number of rows.	<a href="#">mldivide</a>
^	Matrix power	$A^B$ is A to the power B, if B is a scalar. For other values of B, the calculation involves eigenvalues and eigenvectors.	<a href="#">mpower</a>
'	Complex conjugate transpose	$A'$ is the linear algebraic transpose of A. For complex matrices, this is the complex conjugate transpose.	<a href="#">ctranspose</a>

## Relational Operators

Relational operators compare operands quantitatively, using operators like “less than” and “not equal to.” The following table provides a summary. For more information, see the relational operators reference page.

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

### Relational Operators and Arrays

The MATLAB relational operators compare corresponding elements of arrays with equal dimensions. Relational operators always operate element-by-element. In this example, the resulting matrix shows where an element of A is equal to the corresponding element of B.

```
A = [2 7 6;9 0 5;3 0.5 6];
B = [8 7 0;3 2 5;4 -1 7];
```

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

For vectors and rectangular arrays, both operands must be the same size unless one is a scalar. For the case where one operand is a scalar and the other is not, MATLAB tests the scalar against every element of the other operand. Locations where the specified relation is true receive logical 1. Locations where the relation is false receive logical 0.

### **Relational Operators and Empty Arrays**

The relational operators work with arrays for which any dimension has size zero, as long as both arrays are the same size or one is a scalar. However, expressions such as

```
A == []
```

return an error if A is not 0-by-0 or 1-by-1. This behavior is consistent with that of all other binary operators, such as +, -, >, <, &, |, etc.

To test for empty arrays, use the function

```
isempty(A)
```



## Operator Precedence

You can build expressions that use any combination of arithmetic, relational, and logical operators. Precedence levels determine the order in which MATLAB evaluates an expression. Within each precedence level, operators have equal precedence and are evaluated from left to right. The precedence rules for MATLAB operators are shown in this list, ordered from highest precedence level to lowest precedence level:

- 1 Parentheses ( )
- 2 Transpose (.'), power (.^), complex conjugate transpose ('), matrix power (^)
- 3 Unary plus (+), unary minus (-), logical negation (~)
- 4 Multiplication (.\*), right division (./), left division (.\), matrix multiplication (\*), matrix right division (/), matrix left division (\)
- 5 Addition (+), subtraction (-)
- 6 Colon operator (:)
- 7 Less than (<), less than or equal to (<=), greater than (>), greater than or equal to (>=), equal to (==), not equal to (~=)
- 8 Element-wise AND (&)
- 9 Element-wise OR (|)
- 10 Short-circuit AND (&&)
- 11 Short-circuit OR (||)

### Precedence of AND and OR Operators

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

The same precedence rule holds true for the `&&` and `||` operators.

### Overriding Default Precedence

The default precedence can be overridden using parentheses, as shown in this example:

```
A = [3 9 5];
B = [2 1 5];
C = A./B.^2
C =
    0.7500    9.0000    0.2000

C = (A./B).^2
C =
    2.2500   81.0000    1.0000
```

## Special Values

Several functions return important special values that you can use in your own program files.

Function	Return Value
<code>ans</code>	Most recent answer (variable). If you do not assign an output variable to an expression, MATLAB automatically stores the result in <code>ans</code> .
<code>eps</code>	Floating-point relative accuracy. This is the tolerance the MATLAB software uses in its calculations.
<code>intmax</code>	Largest 8-, 16-, 32-, or 64-bit integer your computer can represent.
<code>intmin</code>	Smallest 8-, 16-, 32-, or 64-bit integer your computer can represent.
<code>realmax</code>	Largest floating-point number your computer can represent.
<code>realmin</code>	Smallest positive floating-point number your computer can represent.
<code>pi</code>	3.1415926535897...
<code>i, j</code>	Imaginary unit.
<code>inf</code>	Infinity. Calculations like $n/0$ , where $n$ is any nonzero real value, result in <code>inf</code> .
<code>NaN</code>	Not a Number, an invalid numeric value. Expressions like $0/0$ and $inf/inf$ result in a NaN, as do arithmetic operations involving a NaN. Also, if $n$ is complex with a zero real part, then $n/0$ returns a value with a NaN real part.
<code>computer</code>	Computer type.
<code>version</code>	MATLAB version string.

Here are some examples that use these values in MATLAB expressions.

```
x = 2 * pi
x =
    6.2832
```

```
A = [3+2i 7-8i]
A =
    3.0000 + 2.0000i    7.0000 - 8.0000i
```

```
tol = 3 * eps
tol =
    6.6613e-016
```

```
intmax('uint64')
ans =
    18446744073709551615
```

## Conditional Statements

Conditional statements enable you to select at run time which block of code to execute. The simplest conditional statement is an `if` statement. For example:

```
% Generate a random number
a = randi(100, 1);

% If it is even, divide by 2
if rem(a, 2) == 0
    disp('a is even')
    b = a/2;
end
```

`if` statements can include alternate choices, using the optional keywords `elseif` or `else`. For example:

```
a = randi(100, 1);

if a < 30
    disp('small')
elseif a < 80
    disp('medium')
else
    disp('large')
end
```

Alternatively, when you want to test for equality against a set of known values, use a `switch` statement. For example:

```
[dayNum, dayString] = weekday(date, 'long', 'en_US');

switch dayString
    case 'Monday'
        disp('Start of the work week')
    case 'Tuesday'
        disp('Day 2')
    case 'Wednesday'
        disp('Day 3')
    case 'Thursday'
        disp('Day 4')
```

```
        case 'Friday'
            disp('Last day of the work week')
        otherwise
            disp('Weekend!')
    end
```

For both `if` and `switch`, MATLAB executes the code corresponding to the first true condition, and then exits the code block. Each conditional statement requires the `end` keyword.

In general, when you have many possible discrete, known values, `switch` statements are easier to read than `if` statements. However, you cannot test for inequality between `switch` and `case` values. For example, you cannot implement this type of condition with a `switch`:

```
yourNumber = input('Enter a number: ');

if yourNumber < 0
    disp('Negative')
elseif yourNumber > 0
    disp('Positive')
else
    disp('Zero')
end
```

## Loop Control Statements

With loop control statements, you can repeatedly execute a block of code. There are two types of loops:

- **for** statements loop a specific number of times, and keep track of each iteration with an incrementing index variable.

For example, preallocate a 10-element vector, and calculate five values:

```
x = ones(1,10);
for n = 2:6
    x(n) = 2 * x(n - 1);
end
```

- **while** statements loop as long as a condition remains true.

For example, find the first integer  $n$  for which `factorial(n)` is a 100-digit number:

```
n = 1;
nFactorial = 1;
while nFactorial < 1e100
    n = n + 1;
    nFactorial = nFactorial * n;
end
```

Each loop requires the `end` keyword.

It is a good idea to indent the loops for readability, especially when they are nested (that is, when one loop contains another loop):

```
A = zeros(5,100);
for m = 1:5
    for n = 1:100
        A(m, n) = 1/(m + n - 1);
    end
end
```

You can programmatically exit a loop using a `break` statement, or skip to the next iteration of a loop using a `continue` statement. For example, count

the number of lines in the help for the `magic` function (that is, all comment lines until a blank line):

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

---

**Tip** If you inadvertently create an infinite loop (a loop that never ends on its own), stop execution of the loop by pressing **Ctrl+C**.

---



## Represent Dates and Times in MATLAB

MATLAB represents date and time information in any of three formats:

- Date String — A character string.

Example: `Thursday, August 23, 2012 9:45:44.946 AM`

- Date Vector — A 1-by-6 numeric vector containing the year, month, day, hour, minute, and second.

Example: `[2012 8 23 9 45 44.946]`

- Serial Date Number — A single number equal to the number of days since January 0, 0000.

Example: `7.3510e+005`

You can use any of these formats. If you work with more than one date and time format, you can convert from one format to another using the `datestr`, `datevec`, and `datenum` functions.

### Date Strings

A date string is a character string composed of fields related to a specific date and/or time. There are several ways to represent dates and times in character string format. For example, all of the following are date strings for August 23, 2010 at 04:35:42 PM:

```
'23-Aug-2010 04:35:06 PM'
```

```
'Wednesday, August 23'
```

```
'08/23/10 16:35'
```

```
'Aug 23 16:35:42.946'
```

You can represent time in a date string using either a 12-hour or 24-hour system.

When you create a date string, include any characters you might need to separate the fields, such as the hyphen, space, and colon used here:

```
d = '23-Aug-2010 16:35:42'
```

## Date Vectors

A date vector is a 1-by-6 matrix of double-precision numbers. Elements of a date vector are integer valued, with the exception of the seconds element, which can be fractional. A date vector is arranged in the following order:

year month day hour minute second

The following date vector represents 10:45:07 AM on October 24, 2012:

```
[2012 10 24 10 45 07]
```

Date vectors must follow these guidelines:

- Date vectors have no separate field in which to specify milliseconds. However, the seconds field has a fractional part and accurately keeps the milliseconds field.
- Time values are expressed in 24-hour notation. There is no AM or PM setting.

## Serial Date Numbers

A serial date number represents a calendar date as the number of days that has passed since a fixed base date. In MATLAB, serial date number 1 is January 1, 0000.

MATLAB also uses serial time to represent fractions of days beginning at midnight; for example, 6 p.m. equals 0.75 serial days. So the string '31-Oct-2003, 6:00 PM' in MATLAB is date number 731885.75.

If you pass date vectors or date strings to a MATLAB function that accepts such inputs, MATLAB first converts the input to serial date numbers. If you are working with a large number of dates or doing extensive calculations with dates, use serial date numbers for better performance.

## Compute Elapsed Time

### In this section...

“Compute Elapsed Time” on page 2-19

“Compute Future Date” on page 2-20

### Compute Elapsed Time

Compute the time elapsed between a specific time and the current time, to 0.01-second accuracy.

Define the initial date and time and convert to date vector form.

```
format shortg
str = 'March 28, 2012 11:51:00';
t1 = datevec(str, 'mmm dd, yyyy HH:MM:SS')
```

```
t1 =
    2012         3         28         11         51         0
```

Determine the current date and time.

```
t2 = clock
```

```
t2 =
    2014         1         17         16         0        30.
```

The `clock` function returns the current date and time as a date vector.

Use `etime` to compute the number of seconds between `t1` and `t2`.

```
e = etime(t2,t1)
```

```
e =  
  
5.7039e+07
```

### Compute Future Date

You can compute future dates by adding to a date. This topic shows two ways to do this.

- “Add Days to a Serial Date Number” on page 2-20
- “Add Years, Months, Days, or Time to a Date” on page 2-21

### Add Days to a Serial Date Number

This example shows how to add a rational number of days to a serial date number.

The `now` function returns the current date in serial date number format. You can add a number to this date. For this example, add 50 days.

```
futuredate = now+50
```

```
futuredate =  
  
7.3567e+05
```

Alternatively, the initial date might be in date string format. Convert the date to a serial date number using the `datenum` function.

```
initialdate = datenum('21.03.2012 13:15','dd.mm.yyyy HH:MM');
```

Add a rational number of dates to the initial date. In this example, add 5.5 days.

```
futuredate = initialdate + 5.5
```

```
futurdate =  
7.3496e+05
```

You can convert the future date to date string format.

```
datestr(futurdate, 'dd.mm.yyyy HH:MM')
```

```
ans =  
27.03.2012 01:15
```

### **Add Years, Months, Days, or Time to a Date**

This example shows how to add a number of years, months, days, hours, minutes, seconds, or milliseconds to a date in serial date number format. For example, add 5 months to January 3, 2012:

Convert the date string to serial date number format.

```
initialdate = datenum('03/01/2012', 'dd/mm/yyyy');
```

Use the `addtodate` function to add 5 months to the initial date.

```
futurdate = addtodate(initialdate,5,'month')
```

```
futurdate =  
735023
```

To convert the future date to a date string, use the `datestr` function.

```
datestr(futurdate, 'dddd, mmmm dd')
```

ans =

Sunday, June 03

### **See Also**

[addtodate](#) | [datenum](#) | [datestr](#) | [now](#)

## Carryover in Date Vectors and Strings

If an element falls outside the conventional range, MATLAB adjusts both that date vector element and the previous element. For example, if the minutes element is 70, MATLAB adjusts the hours element by 1 and sets the minutes element to 10. If the minutes element is -15, then MATLAB decreases the hours element by 1 and sets the minutes element to 45. Month values are an exception. MATLAB sets month values less than 1 to 1.

In the following example, the month element has a value of 22. MATLAB increments the year value to 2010 and sets the month to October.

```
datestr([2009 22 03 00 00 00])
```

```
ans =  
    03-Oct-2010
```

The carrying forward of values also applies to time and day values in date strings. For example, October 3, 2010 and September 33, 2010 are interpreted to be the same date, and correspond to the same serial date number.

```
datenum('03-Oct-2010')
```

```
ans =  
    734414
```

```
datenum('33-Sep-2010')
```

```
ans =  
    734414
```

The following example takes the input month (07, or July), finds the last day of the previous month (June 30), and subtracts the number of days in the field specifier (5 days) from that date to yield a return date of June 25, 2010.

```
datestr([2010 07 -05 00 00 00])
```

```
ans =  
    25-Jun-2010
```

## Troubleshooting: Converting Date Vector Returns Unexpected Output

Because a date vector is a 1-by-6 vector of numbers, `datestr` might interpret your input date vectors as vectors of serial date numbers, or vice versa, and return unexpected output.

Consider a date vector that includes the year 3000. This year is outside the range of years that `datestr` interprets as elements of date vectors. Therefore, the input is interpreted as a 1-by-6 vector of serial date numbers:

```
datestr([3000 11 05 10 32 56])
```

```
ans =
```

```
18-Mar-0008  
11-Jan-0000  
05-Jan-0000  
10-Jan-0000  
01-Feb-0000  
25-Feb-0000
```

Here `datestr` interprets 3000 as a serial date number, and converts it to the date string '18-Mar-0008'. Also, `datestr` converts the next five elements to date strings.

When converting such a date vector to a string, first convert it to a serial date number using `datenum`. Then, convert the date number to a string using `datestr`:

```
dn = datenum([3000 11 05 10 32 56]);  
ds = datestr(dn)
```

```
ds =
```

```
05-Nov-3000 10:32:56
```

When converting dates to strings, `datestr` interprets input as either date vectors or serial date numbers using a heuristic rule. Consider an  $m$ -by-6 matrix. `datestr` interprets the matrix as  $m$  date vectors when:



- The first five columns contain integers.
- The absolute value of the sum of each row is in the range 1500–2500.

If either condition is false, for any row, then `datestr` interprets the `m`-by-6 matrix as `m`-by-6 serial date numbers.

Usually, dates with years in the range 1700–2300 are interpreted as date vectors. However, `datestr` might interpret rows with month, day, hour, minute, or second values outside their normal ranges as serial date numbers. For example, `datestr` correctly interprets the following date vector for the year 2014:

```
datestr([2014 06 21 10 51 00])
```

```
ans =
```

```
21-Jun-2014 10:51:00
```

But given a day value outside the typical range (1–31), `datestr` returns a date for each element of the vector:

```
datestr([2014 06 2110 10 51 00])
```

```
ans =
```

```
06-Jul-0005
06-Jan-0000
10-Oct-0005
10-Jan-0000
20-Feb-0000
00-Jan-0000
```

When you have a matrix of date vectors that `datestr` might interpret incorrectly as serial date numbers, first convert the matrix to serial date numbers using `datenum`. Then, use `datestr` to convert the date numbers.

When you have a matrix of serial date numbers that `datestr` might interpret as date vectors, first convert the matrix to a column vector. Then, use `datestr` to convert the column vector.

## Regular Expressions

In this section...
“What Is a Regular Expression?” on page 2-26
“Steps for Building Expressions” on page 2-28
“Operators and Characters” on page 2-31

### What Is a Regular Expression?

A regular expression is a string of characters that defines a certain pattern. You normally use a regular expression to search text for a group of words that matches the pattern, for example, while parsing program input or while processing a block of text.

The string `'Joh?n\w*'` is an example of a regular expression. It defines a pattern that starts with the letters `Jo`, is optionally followed by the letter `h` (indicated by `'h?'`), is then followed by the letter `n`, and ends with any number of *word characters*, that is, characters that are alphabetic, numeric, or underscore (indicated by `'\w*'`). This pattern matches any of the following:

Jon, John, Jonathan, Johnny

Regular expressions provide a unique way to search a volume of text for a particular subset of characters within that text. Instead of looking for an exact character match as you would do with a function like `strfind`, regular expressions give you the ability to look for a particular *pattern* of characters.

For example, several ways of expressing a metric rate of speed are:

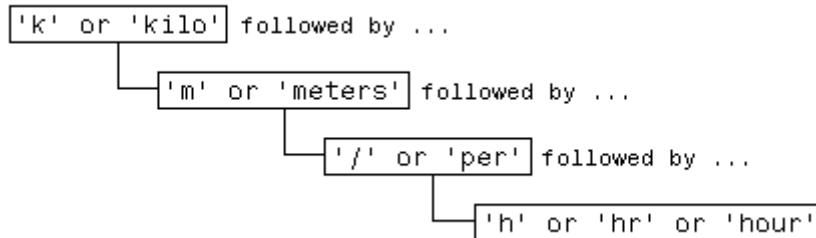
km/h  
km/hr  
km/hour  
kilometers/hour  
kilometers per hour

You could locate any of the above terms in your text by issuing five separate search commands:

```
strfind(text, 'km/h');
```

```
strfind(text, 'km/hour');
% etc.
```

To be more efficient, however, you can build a single phrase that applies to all of these search strings:



Translate this phrase it into a regular expression (to be explained later in this section) and you have:

```
pattern = 'k(ilo)?m(eters)?(/|\sper\s)h(r|our)?';
```

Now locate one or more of the strings using just a single command:

```
text = ['The high-speed train traveled at 250 ', ...
        'kilometers per hour alongside the automobile ', ...
        'travelling at 120 km/h.'];
regexp(text, pattern, 'match')
```

```
ans =
    'kilometers per hour'    'km/h'
```

There are four MATLAB functions that support searching and replacing characters using regular expressions. The first three are similar in the input values they accept and the output values they return. For details, click the links to the function reference pages.

Function	Description
regexp	Match regular expression.
regexp_i	Match regular expression, ignoring case.

Function	Description
<code>regexprep</code>	Replace part of string using regular expression.
<code>regexptranslate</code>	Translate string into regular expression.

When calling any of the first three functions, pass the string to be parsed and the regular expression in the first two input arguments. When calling `regexprep`, pass an additional input that is an expression that specifies a pattern for the replacement string.

## Steps for Building Expressions

There are three steps involved in using regular expressions to search text for a particular string:

### 1 Identify unique patterns in the string

This entails breaking up the string you want to search for into groups of like character types. These character types could be a series of lowercase letters, a dollar sign followed by three numbers and then a decimal point, etc.

### 2 Express each pattern as a regular expression

Use the *metacharacters* and operators described in this documentation to express each segment of your search string as a regular expression. Then combine these expression segments into the single expression to use in the search.

### 3 Call the appropriate search function

Pass the string you want to parse to one of the search functions, such as `regexp` or `regexpi`, or to the string replacement function, `regexprep`.

The example shown in this section searches a record containing contact information belonging to a group of five friends. This information includes each person's name, telephone number, place of residence, and email address. The goal is to extract specific information from one or more of the strings.

```
contacts = { ...
```

```
'Harry 287-625-7315 Columbus, OH hparker@hmail.com'; ...
'Janice 529-882-1759 Fresno, CA jan_stephens@horizon.net'; ...
'Mike 793-136-0975 Richmond, VA sue_and_mike@hmail.net'; ...
'Nadine 648-427-9947 Tampa, FL nadine_berry@horizon.net'; ...
'Jason 697-336-7728 Montrose, CO jason_blake@mymail.com'};
```

The first part of the example builds a regular expression that represents the format of a standard email address. Using that expression, the example then searches the information for the email address of one of the group of friends. Contact information for Janice is in row 2 of the `contacts` cell array:

```
contacts{2}
```

```
ans =
    Janice 529-882-1759 Fresno, CA jan_stephens@horizon.net
```

### Step 1 – Identify Unique Patterns in the String

A typical email address is made up of standard components: the user's account name, followed by an @ sign, the name of the user's internet service provider (ISP), a dot (period), and the domain to which the ISP belongs. The table below lists these components in the left column, and generalizes the format of each component in the right column.

Unique patterns of an email address	General description of each pattern
Start with the account name jan_stephens . . .	One or more lowercase letters and underscores
Add '@' jan_stephens@ . . .	@ sign
Add the ISP jan_stephens@horizon . . .	One or more lowercase letters, no underscores
Add a dot (period) jan_stephens@horizon. . . .	Dot (period) character
Finish with the domain jan_stephens@horizon.net	com or net

## Step 2 — Express Each Pattern as a Regular Expression

In this step, you translate the general formats derived in Step 1 into segments of a regular expression. You then add these segments together to form the entire expression.

The table below shows the generalized format descriptions of each character pattern in the left-most column. (This was carried forward from the right column of the table in Step 1.) The second column shows the operators or metacharacters that represent the character pattern.

Description of each segment	Pattern
One or more lowercase letters and underscores	[a-z_]+
@ sign	@
One or more lowercase letters, no underscores	[a-z]+
Dot (period) character	\.
com or net	(com net)

Assembling these patterns into one string gives you the complete expression:

```
email = '[a-z_]+@[a-z]+\.(com|net)';
```

## Step 3 — Call the Appropriate Search Function

In this step, you use the regular expression derived in Step 2 to match an email address for one of the friends in the group. Use the `regexp` function to perform the search.

Here is the list of contact information shown earlier in this section. Each person's record occupies a row of the `contacts` cell array:

```
contacts = { ...  
'Harry 287-625-7315 Columbus, OH hparker@hmail.com'; ...  
'Janice 529-882-1759 Fresno, CA jan_stephens@horizon.net'; ...  
'Mike 793-136-0975 Richmond, VA sue_and_mike@hmail.net'; ...  
'Nadine 648-427-9947 Tampa, FL nadine_berry@horizon.net'; ...  
'Jason 697-336-7728 Montrose, CO jason_blake@mymail.com'};
```

This is the regular expression that represents an email address, as derived in Step 2:

```
email = '[a-z_]+@[a-z]+\.(com|net)';
```

Call the `regexp` function, passing row 2 of the `contacts` cell array and the `email` regular expression. This returns the email address for Janice.

```
regexp(contacts{2}, email, 'match')
```

```
ans =  
    'jan_stephens@horizon.net'
```

MATLAB parses a string from left to right, “consuming” the string as it goes. If matching characters are found, `regexp` records the location and resumes parsing the string, starting just after the end of the most recent match.

Make the same call, but this time for the fifth person in the list:

```
regexp(contacts{5}, email, 'match')
```

```
ans =  
    'jason_blake@mymail.com'
```

You can also search for the email address of everyone in the list by using the entire cell array for the input string argument:

```
regexp(contacts, email, 'match');
```

## Operators and Characters

Regular expressions can contain characters, metacharacters, operators, tokens, and flags that specify patterns to match, as described in these sections:

- “Metacharacters” on page 2-32
- “Character Representation” on page 2-33
- “Quantifiers” on page 2-34
- “Grouping Operators” on page 2-35
- “Anchors” on page 2-36
- “Lookaround Assertions” on page 2-36

- “Logical and Conditional Operators” on page 2-37
- “Token Operators” on page 2-38
- “Dynamic Expressions” on page 2-40
- “Comments” on page 2-41
- “Search Flags” on page 2-41

### Metacharacters

Metacharacters represent letters, letter ranges, digits, and space characters. Use them to construct a generalized pattern of characters.

Metacharacter	Description	Example
.	Any single character, including white space	'..ain' matches sequences of five consecutive characters that end with 'ain'.
[c <sub>1</sub> c <sub>2</sub> c <sub>3</sub> ]	Any character contained within the brackets. The following characters are treated literally: \$   . * + ? and - when not used to indicate a range.	'[rp.]ain' matches 'rain' or 'pain' or '.ain'.
[^c <sub>1</sub> c <sub>2</sub> c <sub>3</sub> ]	Any character not contained within the brackets. The following characters are treated literally: \$   . * + ? and - when not used to indicate a range.	'[^*rp]ain' matches all four-letter sequences that end in 'ain', except 'rain' and 'pain' and '*ain'. For example, it matches 'gain', 'lain', or 'vain'.
[c <sub>1</sub> -c <sub>2</sub> ]	Any character in the range of c <sub>1</sub> through c <sub>2</sub>	'[A-G]' matches a single character in the range of A through G.
\w	Any alphabetic, numeric, or underscore character. For English character sets, \w is equivalent to [a-zA-Z_0-9]	'\w*' identifies a word.



Metacharacter	Description	Example
\W	Any character that is not alphabetic, numeric, or underscore. For English character sets, \W is equivalent to [^a-zA-Z_0-9]	'\W*' identifies a substring that is not a word.
\s	Any white-space character; equivalent to [ \f\n\r\t\v]	'\w*\s' matches words that end with the letter n, followed by a white-space character.
\S	Any non-white-space character; equivalent to [^\f\n\r\t\v]	'\d\S' matches a numeric digit followed by any non-white-space character.
\d	Any numeric digit; equivalent to [0-9]	'\d*' matches any number of consecutive digits.
\D	Any nondigit character; equivalent to [^0-9]	'\w*\D\>' matches words that do not end with a numeric digit.
\oN or \o{N}	Character of octal value N	'\o{40}' matches the space character, defined by octal 40.
\xN or \x{N}	Character of hexadecimal value N	'\x2C' matches the comma character, defined by hex 2C.

## Character Representation

Operator	Description
\a	Alarm (beep)
\b	Backspace
\f	Form feed
\n	New line
\r	Carriage return
\t	Horizontal tab
\v	Vertical tab
\char	Any character with special meaning in regular expressions that you want to match literally (for example, use \\ to match a single backslash)

### Quantifiers

Quantifiers specify the number of times a string pattern must occur in the matching string.

Quantifier	Matches the expression when it occurs...	Example
<code>expr*</code>	0 or more times consecutively.	' <code>\w*</code> ' matches a word of any length.
<code>expr?</code>	0 times or 1 time.	' <code>\w*(\..m)?</code> ' matches words that optionally end with the extension <code>.m</code> .
<code>expr+</code>	1 or more times consecutively.	' <code>&lt;img src="\w+\..gif"&gt;</code> ' matches an <code>&lt;img&gt;</code> HTML tag when the file name contains one or more characters.
<code>expr{m,n}</code>	At least <code>m</code> times, but no more than <code>n</code> times consecutively. <code>{0,1}</code> is equivalent to <code>?</code> .	' <code>\S{4,8}</code> ' matches between four and eight non-white-space characters.
<code>expr{m,}</code>	At least <code>m</code> times consecutively. <code>{0,}</code> and <code>{1,}</code> are equivalent to <code>*</code> and <code>+</code> , respectively.	' <code>&lt;a href="\w{1,}\..html"&gt;</code> ' matches an <code>&lt;a&gt;</code> HTML tag when the file name contains one or more characters.
<code>expr{n}</code>	Exactly <code>n</code> times consecutively. Equivalent to <code>{n,n}</code> .	' <code>\d{4}</code> ' matches four consecutive digits.

Quantifiers can appear in three modes, described in the following table. *q* represents any of the quantifiers in the previous table.

Mode	Description	Example
<code>exprq</code>	Greedy expression: match as many characters as possible.	Given the string ' <code>&lt;tr&gt;&lt;td&gt;&lt;p&gt;text&lt;/p&gt;&lt;/td&gt;</code> ', the expression ' <code>&lt;/?t.*&gt;</code> ' matches all characters between <code>&lt;tr</code> and <code>/td&gt;</code> :  ' <code>&lt;tr&gt;&lt;td&gt;&lt;p&gt;text&lt;/p&gt;&lt;/td&gt;</code> '
<code>exprq?</code>	Lazy expression: match as few characters as necessary.	Given the string ' <code>&lt;tr&gt;&lt;td&gt;&lt;p&gt;text&lt;/p&gt;&lt;/td&gt;</code> ', the expression ' <code>&lt;/?t.*?&gt;</code> ' ends each

Mode	Description	Example
		match at the first occurrence of the closing bracket (>):  '<tr>'    '<td>'    '</td>'
exprq+	Possessive expression: match as much as possible, but do not rescan any portions of the string.	Given the string '<tr><td><p>text</p></td>', the expression '</?t.*+>' does not return any matches, because the closing bracket is captured using .*, and is not rescanned.

## Grouping Operators

Grouping operators allow you to capture tokens, apply one operator to multiple elements, or disable backtracking in a specific group.

Grouping Operator	Description	Example
(expr)	Group elements of the expression and capture tokens.	'Joh?n\s(\w*)' captures a token that contains the last name of any person with the first name John or Jon.
(?:expr)	Group, but do not capture tokens.	'(?:[aeiou][^aeiou]){2}' matches two consecutive patterns of a vowel followed by a nonvowel, such as 'anon'.  Without grouping, '[aeiou][^aeiou]{2}' matches a vowel followed by two nonvowels.

<b>Grouping Operator</b>	<b>Description</b>	<b>Example</b>
(?>expr)	Group atomically. Do not backtrack within the group to complete the match, and do not capture tokens.	'A(?>.* )Z' does not match 'AtoZ', although 'A(?:.* )Z' does. Using the atomic group, Z is captured using .* and is not rescanned.
(expr1 expr2)	Match expression expr1 or expression expr2.  If there is a match with expr1, then expr2 is ignored.  You can include ?: or ?> after the opening parenthesis to suppress tokens or group atomically.	'(let tel)\w+' matches words in a string that start with let or tel.

### **Anchors**

Anchors in the expression match the beginning or end of the string or word.

<b>Anchor</b>	<b>Matches the...</b>	<b>Example</b>
^expr	Beginning of the input string.	'^M\w*' matches a word starting with M at the beginning of the string.
expr\$	End of the input string.	'\w*m\$' matches words ending with m at the end of the string.
\<expr	Beginning of a word.	'\<n\w*' matches any words starting with n.
expr\>	End of a word.	'\w*e\>' matches any words ending with e.

### **Lookaround Assertions**

Lookaround assertions look for string patterns that immediately precede or follow the intended match, but are not part of the match.

The pointer remains at the current location, and characters that correspond to the test expression are not captured or discarded. Therefore, lookahead assertions can match overlapping character groups.

Lookaround Assertion	Description	Example
<code>expr(?=test)</code>	Look ahead for characters that match test.	' <code>\w*(?=ing)</code> ' matches strings that are followed by <code>ing</code> , such as 'Fly' and 'fall' in the input string 'Flying, not falling.'
<code>expr(?!test)</code>	Look ahead for characters that do not match test.	' <code>i(?!ng)</code> ' matches instances of the letter <code>i</code> that are not followed by <code>ng</code> .
<code>(?&lt;=test)expr</code>	Look behind for characters that match test..	' <code>(?&lt;=re)\w*</code> ' matches strings that follow 're', such as 'new', 'use', and 'cycle' in the input string 'renew, reuse, recycle'
<code>(?&lt;!test)expr</code>	Look behind for characters that do not match test.	' <code>(?&lt;!\d)(\d)(?!\d)</code> ' matches single-digit numbers (digits that do not precede or follow other digits).

If you specify a lookahead assertion *before* an expression, the operation is equivalent to a logical AND.

Operation	Description	Example
<code>(?=test)expr</code>	Match both test and expr.	' <code>(?=[a-z])[^aeiou]</code> ' matches consonants.
<code>(?!test)expr</code>	Match expr and do not match test.	' <code>(?![aeiou])[a-z]</code> ' matches consonants.

For more information, see “Lookahead Assertions in Regular Expressions” on page 2-43.

## Logical and Conditional Operators

Logical and conditional operators allow you to test the state of a given condition, and then use the outcome to determine which string, if any, to match next. These operators support logical OR and `if` or `if/else` conditions. (For AND conditions, see “Lookaround Assertions” on page 2-36.)

Conditions can be tokens, lookaround assertions, or dynamic expressions of the form `(?@cmd)`. Dynamic expressions must return a logical or numeric value.

Conditional Operator	Description	Example
<code>expr1 expr2</code>	Match expression <code>expr1</code> or expression <code>expr2</code> . If there is a match with <code>expr1</code> , then <code>expr2</code> is ignored.	' <code>(let tel)\w+</code> ' matches words in a string that start with <code>let</code> or <code>tel</code> .
<code>(?(cond)expr)</code>	If condition <code>cond</code> is true, then match <code>expr</code> .	' <code>(?(?@ispc)[A-Z]:\\)</code> ' matches a drive name, such as <code>C:\</code> , when run on a Windows system.
<code>(?(cond)expr1 expr2)</code>	If condition <code>cond</code> is true, then match <code>expr1</code> . Otherwise, match <code>expr2</code> .	' <code>Mr(s?)\..*?(?(1)her his)\w*</code> ' matches strings that include <code>her</code> when the string begins with <code>Mrs</code> , or that include <code>his</code> when the string begins with <code>Mr</code> .

### Token Operators

Tokens are portions of the matched text that you define by enclosing part of the regular expression in parentheses. You can refer to a token by its sequence in the string (an ordinal token), or assign names to tokens for easier code maintenance and readable output.

Ordinal Token Operator	Description	Example
<code>(expr)</code>	Capture in a token the characters that match the enclosed expression.	' <code>Joh?n\s(\w*)</code> ' captures a token that contains the last name of any person with the first name <code>John</code> or <code>Jon</code> .
<code>\N</code>	Match the <code>N</code> th token.	' <code>&lt;(\w+).*&gt;.*&lt;/\1&gt;</code> ' captures tokens for HTML tags, such

Ordinal Token Operator	Description	Example
		as 'title' from the string '<title>Some text</title>'.
(? (N) expr1   expr2)	If the Nth token is found, then match expr1. Otherwise, match expr2.	'Mr (s?) \. \. * ? (? (1) her   his) \w*' matches strings that include her when the string begins with Mrs, or that include his when the string begins with Mr.
Named Token Operator	Description	Example
(? <name> expr)	Capture in a named token the characters that match the enclosed expression.	' (? <month> \d+ ) - (? <day> \d+ ) - (? <yr> \d+ ) ' creates named tokens for the month, day, and year in an input date string of the form mm-dd-yy.
\k <name>	Match the token referred to by name.	' < (? <tag> \w+ ) . * > . * < / \k <tag> > ' captures tokens for HTML tags, such as 'title' from the string '<title>Some text</title>'.
(? (name) expr1   expr2)	If the named token is found, then match expr1. Otherwise, match expr2.	'Mr (? <sex> s?) \. \. * ? (? (sex) her   his) \w*' matches strings that include her when the string begins with Mrs, or that include his when the string begins with Mr.

---

**Note** If an expression has nested parentheses, MATLAB captures tokens that correspond to the outermost set of parentheses. For example, given the search pattern '(and(y|rew))', MATLAB creates a token for 'andrew' but not for 'y' or 'rew'.

---

For more information, see “Tokens in Regular Expressions” on page 2-46.

## Dynamic Expressions

Dynamic expressions allow you to execute a MATLAB command or a regular expression to determine the text to match.

The parentheses that enclose dynamic expressions do *not* create a capturing group.

Operator	Description	Example
(??expr)	Parse <code>expr</code> and include the resulting string in the match expression.  When parsed, <code>expr</code> must correspond to a complete, valid regular expression. Dynamic expressions that use the backslash escape character ( <code>\</code> ) require two backslashes: one for the initial parsing of <code>expr</code> , and one for the complete match.	<code>'^\d+((??\w{\$1}))'</code> determines how many characters to match by reading a digit at the beginning of the string. The dynamic expression is enclosed in a second set of parentheses so that the resulting match is captured in a token. For instance, matching <code>'5XXXXX'</code> captures tokens for <code>'5'</code> and <code>'XXXXX'</code> .
(??@cmd)	Execute the MATLAB command represented by <code>cmd</code> , and include the string returned by the command in the match expression.	<code>'(.{2,}).?(??@flipr(\$1))'</code> finds palindromes that are at least four characters long, such as <code>'abba'</code> .
(?@cmd)	Execute the MATLAB command represented by <code>cmd</code> , but discard any output the command returns. (Helpful for diagnosing regular expressions.)	<code>'\w*?(?@disp(\$1))\1\w*'</code> matches words that include double letters (such as <code>pp</code> ), and displays intermediate results.

Within dynamic expressions, use the following operators to define replacement strings.

Replacement String Operator	Description
<code>\$&amp;</code> or <code>\$0</code>	Portion of the input string that is currently a match
<code>\$`</code>	Portion of the input string that precedes the current match



Replacement String Operator	Description
\$'	Portion of the input string that follows the current match (use '\$' to represent the string '\$')
\$N	Nth token
\$<name>	Named token
\${cmd}	String returned when MATLAB executes the command, cmd

For more information, see “Dynamic Regular Expressions” on page 2-52.

### Comments

The comment operator enables you to insert comments into your code to make it more maintainable. The text of the comment is ignored by MATLAB when matching against the input string.

Characters	Description	Example
(?#comment)	Insert a comment in the regular expression. The comment text is ignored when matching the input string.	'(?# Initial digit)\<\d\w+' includes a comment, and matches words that begin with a number.

### Search Flags

Search flags modify the behavior for matching expressions.

Flag	Description
(?-i)	Match letter case (default for regexp and regexprep).
(?i)	Do not match letter case (default for regexpi).
(?s)	Match dot (.) in the pattern string with any character (default).
(?-s)	Match dot in the pattern with any character that is not a newline character.

Flag	Description
(?-m)	Match the ^ and \$ metacharacters at the beginning and end of a string (default).
(?m)	Match the ^ and \$ metacharacters at the beginning and end of a line.
(?-x)	Include space characters and comments when matching (default).
(?x)	Ignore space characters and comments when matching. Use '\ ' and '\#' to match space and # characters.

The expression that the flag modifies can appear either after the parentheses, such as

```
(?i)\w*
```

or inside the parentheses and separated from the flag with a colon (:), such as

```
(?i:\w*)
```

The latter syntax allows you to change the behavior for part of a larger expression.

### See Also

`regexp` | `regexpi` | `regexpr` | `regexprtranslate`

### Concepts

- “Lookahead Assertions in Regular Expressions” on page 2-43
- “Tokens in Regular Expressions” on page 2-46
- “Dynamic Regular Expressions” on page 2-52

## Lookahead Assertions in Regular Expressions

### In this section...

“Lookahead Assertions” on page 2-43

“Overlapping Matches” on page 2-44

“Logical AND Conditions” on page 2-44

### Lookahead Assertions

There are two types of lookaround assertions for regular expressions: lookahead and lookbehind. In both cases, the assertion is a condition that must be satisfied to return a match to the expression.

A *lookahead* assertion has the form `(?=test)` and can appear anywhere in a regular expression. MATLAB looks ahead of the current location in the string for the test condition. If MATLAB matches the test condition, it continues processing the rest of the expression to find a match.

For example, look ahead in a path string to find the name of the folder that contains a program file (in this case, `fileread.m`).

```
str = which('fileread')

str =
    matlabroot\toolbox\matlab\iofun\fileread.m

regexp(str, '\w+(?=\w+\.[mp])', 'match')

ans =
    'iofun'
```

The match expression, `\w+`, searches for one or more alphanumeric or underscore characters. Each time `regexp` finds a string that matches this condition, it looks ahead for a backslash (specified with two backslashes, `\\`), followed by a file name (`\w+`) with an `.m` or `.p` extension (`\.[mp]`). The `regexp` function returns the match that satisfies the lookahead condition, which is the folder name `iofun`.

## Overlapping Matches

Lookahead assertions do not consume any characters in the string. As a result, you can use them to find overlapping character sequences.

For example, use lookahead to find *every* sequence of six nonwhitespace characters in a string by matching initial characters that precede five additional characters:

```
string = 'Locate several 6-char. phrases';  
startIndex = regexpi(string, '\S(?:\S{5})')
```

```
startIndex =  
    1     8     9    16    17    24    25
```

The starting indices correspond to these phrases:

```
Locate  severa  everal  6-char  -char.  phrase  hrases
```

Without the lookahead operator, MATLAB parses a string from left to right, consuming the string as it goes. If matching characters are found, `regexp` records the location and resumes parsing the string from the location of the most recent match. There is no overlapping of characters in this process.

```
string = 'Locate several 6-char. phrases';  
startIndex = regexpi(string, '\S{6}')
```

```
startIndex =  
    1     8    16    24
```

The starting indices correspond to these phrases:

```
Locate  severa  6-char  phrase
```

## Logical AND Conditions

Another way to use a lookahead operation is to perform a logical AND between two conditions. This example initially attempts to locate all lowercase consonants in a text string. The text string is the first 50 characters of the help for the `normest` function:

```
helptext = help('normest');  
str = helptext(1:50)
```

```
str =
  NORMEST Estimate the matrix 2-norm.
  NORMEST(S
```

Merely searching for non-vowels (`[^aeiou]`) does not return the expected answer, as the output includes capital letters, space characters, and punctuation:

```
c = regexp(str, '[^aeiou]', 'match')
```

```
c =
  Columns 1 through 14

   ' '   'N'   'O'   'R'   'M'   'E'   'S'   'T'   ' '   ' '
   'E'   's'   't'   'm'   't'
   ...
```

Try this again, using a lookahead operator to create the following AND condition:

(lowercase letter) AND (not a vowel)

This time, the result is correct:

```
c = regexp(str, '(?=[a-z])[^aeiou]', 'match')
```

```
c =
   's'  't'  'm'  't'  't'  'h'  'm'  't'  'r'  'x'
   'n'  'r'  'm'
```

Note that when using a lookahead operator to perform an AND, you need to place the match expression *expr* *after* the test expression *test*:

`(?=test)expr` or `(?!test)expr`

## See Also

`regexp` | `regexpi` | `regprep`

## Concepts

- “Regular Expressions” on page 2-26

## Tokens in Regular Expressions

### In this section...

“Introduction” on page 2-46  
“Multiple Tokens” on page 2-48  
“Unmatched Tokens” on page 2-48  
“Tokens in Replacement Strings” on page 2-50  
“Named Capture” on page 2-50

### Introduction

Parentheses used in a regular expression not only group elements of that expression together, but also designate any matches found for that group as *tokens*. You can use tokens to match other parts of the same string. One advantage of using tokens is that they remember what they matched, so you can recall and reuse matched text in the process of searching or replacing.

Each token in the expression is assigned a number, starting from 1, going from left to right. To make a reference to a token later in the expression, refer to it using a backslash followed by the token number. For example, when referencing a token generated by the third set of parentheses in the expression, use `\3`.

As a simple example, if you wanted to search for identical sequential letters in a string, you could capture the first letter as a token and then search for a matching character immediately afterwards. In the expression shown below, the `(\S)` phrase creates a token whenever `regexp` matches any nonwhitespace character in the string. The second part of the expression, `'\1'`, looks for a second instance of the same character immediately following the first:

```
poestr = ['While I nodded, nearly napping, ' ...  
         'suddenly there came a tapping,'];  
  
[mat,tok,ext] = regexp(poestr, '(\S)\1', 'match', ...  
                     'tokens', 'tokenExtents');  
mat
```

```
mat =
    'dd'    'pp'    'dd'    'pp'
```

The tokens returned in cell array `tok` are:

```
'd', 'p', 'd', 'p'
```

Starting and ending indices for each token in the input string `poestr` are:

```
11 11, 26 26, 35 35, 57 57
```

For another example, capture pairs of matching HTML tags (e.g., `<a>` and `</a>`) and the text between them. The expression used for this example is

```
expr = '<(\w+).*?>.*?</\1>';
```

The first part of the expression, `'<(\w+)'`, matches an opening bracket (`<`) followed by one or more alphabetic, numeric, or underscore characters. The enclosing parentheses capture token characters following the opening bracket.

The second part of the expression, `'.*?>.*?'`, matches the remainder of this HTML tag (characters up to the `>`), and any characters that may precede the next opening bracket.

The last part, `'</\1>'`, matches all characters in the ending HTML tag. This tag is composed of the sequence `</tag>`, where `tag` is whatever characters were captured as a token.

```
hstr = '<!comment><a name="752507"></a><b>Default</b><br>';
expr = '<(\w+).*?>.*?</\1>';
```

```
[mat,tok] = regexp(hstr, expr, 'match', 'tokens');
mat{:}
```

```
ans =
    <a name="752507"></a>
ans =
    <b>Default</b>
```

```
tok{:}
```

```
ans =  
    'a'  
ans =  
    'b'
```

## Multiple Tokens

Here is an example of how tokens are assigned values. Suppose that you are going to search the following text:

```
andy ted bob jim andrew andy ted mark
```

You choose to search the above text with the following search pattern:

```
and(y|rew)|(t)e(d)
```

This pattern has three parenthetical expressions that generate tokens. When you finally perform the search, the following tokens are generated for each match.

Match	Token 1	Token 2
andy	y	
ted	t	d
andrew	rew	
andy	y	
ted	t	d

Only the highest level parentheses are used. For example, if the search pattern `and(y|rew)` finds the text `andrew`, token 1 is assigned the value `rew`. However, if the search pattern `(and(y|rew))` is used, token 1 is assigned the value `andrew`.

## Unmatched Tokens

For those tokens specified in the regular expression that have no match in the string being evaluated, `regexp` and `regexp_i` return an empty string ('') as the token output, and an extent that marks the position in the string where the token was expected.



The example shown here executes `regexp` on the path string `str` returned from the MATLAB `tempdir` function. The regular expression `expr` includes six token specifiers, one for each piece of the path string. The third specifier `[a-z]+` has no match in the string because this part of the path, `Profiles`, begins with an uppercase letter:

```
str = tempdir

str =
     C:\WINNT\Profiles\bascal\LOCALS-1\Temp\

expr = ['([A-Z:)]\|(WINNT)\|([a-z]+)?.*\|' ...
        '([a-z]+)\|([A-Z]+\d)\|(Temp)\|'];

[tok ext] = regexp(str, expr, 'tokens', 'tokenExtents');
```

When a token is not found in a string, MATLAB still returns a token string and token extent. The returned token string is an empty character string (`''`). The first number of the extent is the string index that marks where the token was expected, and the second number of the extent is equal to one less than the first.

In the case of this example, the empty token is the third specified in the expression, so the third token string returned is empty:

```
tok{:}

ans =
     'C:'     'WINNT'     ''     'bascal'     'LOCALS-1'     'Temp'
```

The third token extent returned in the variable `ext` has the starting index set to 10, which is where the nonmatching substring, `Profiles`, begins in the string. The ending extent index is set to one less than the starting index, or 9:

```
ext{:}

ans =
     1     2
     4     8
    10     9
    19    25
    27    34
```

36 39

## Tokens in Replacement Strings

When using tokens in a replacement string, reference them using \$1, \$2, etc. instead of \1, \2, etc. This example captures two tokens and reverses their order. The first, \$1, is 'Norma Jean' and the second, \$2, is 'Baker'. Note that `regexprep` returns the modified string, not a vector of starting indices.

```
regexprep('Norma Jean Baker', '(\w+\s\w+)\s(\w+)', '$2, $1')  
  
ans =  
    Baker, Norma Jean
```

## Named Capture

If you use a lot of tokens in your expressions, it may be helpful to assign them names rather than having to keep track of which token number is assigned to which token.

When referencing a named token within the expression, use the syntax `\k<name>` instead of the numeric `\1`, `\2`, etc.:

```
poestr = ['While I nodded, nearly napping, ' ...  
         'suddenly there came a tapping,'];  
  
regexp(poestr, '(?<anychar>.)\k<anychar>', 'match')  
  
ans =  
    'dd'    'pp'    'dd'    'pp'
```

Named tokens can also be useful in labeling the output from the MATLAB regular expression functions. This is especially true when you are processing numerous strings.

For example, parse different pieces of street addresses from several strings. A short name is assigned to each token in the expression string:

```
str1 = '134 Main Street, Boulder, CO, 14923';  
str2 = '26 Walnut Road, Topeka, KA, 25384';  
str3 = '847 Industrial Drive, Elizabeth, NJ, 73548';
```

```
p1 = '(?<adrs>\d+\s\S+\s(Road|Street|Avenue|Drive))';
p2 = '(?<city>[A-Z][a-z]+)';
p3 = '(?<state>[A-Z]{2})';
p4 = '(?<zip>\d{5})';

expr = [p1 ' ', ' p2 ', ' p3 ', ' p4];
```

As the following results demonstrate, you can make your output easier to work with by using named tokens:

```
loc1 = regexp(str1, expr, 'names')
```

```
loc1 =
    adrs: '134 Main Street'
    city: 'Boulder'
    state: 'CO'
    zip: '14923'
```

```
loc2 = regexp(str2, expr, 'names')
```

```
loc2 =
    adrs: '26 Walnut Road'
    city: 'Topeka'
    state: 'KA'
    zip: '25384'
```

```
loc3 = regexp(str3, expr, 'names')
```

```
loc3 =
    adrs: '847 Industrial Drive'
    city: 'Elizabeth'
    state: 'NJ'
    zip: '73548'
```

## See Also

`regexp` | `regexpi` | `regexprep`

## Concepts

- “Regular Expressions” on page 2-26

## Dynamic Regular Expressions

### In this section...

“Introduction” on page 2-52

“Dynamic Match Expressions — (??expr)” on page 2-53

“Commands That Modify the Match Expression — (??@cmd)” on page 2-54

“Commands That Serve a Functional Purpose — (?@cmd)” on page 2-55

“Commands in Replacement Expressions — \${cmd}” on page 2-58

### Introduction

In a dynamic expression, you can make the pattern that you want `regexp` to match dependent on the content of the input string. In this way, you can more closely match varying input patterns in the string being parsed. You can also use dynamic expressions in replacement strings for use with the `regexprep` function. This gives you the ability to adapt the replacement text to the parsed input.

You can include any number of dynamic expressions in the `match_expr` or `replace_expr` arguments of these commands:

```
regexp(string, match_expr)
regexpi(string, match_expr)
regexprep(string, match_expr, replace_expr)
```

As an example of a dynamic expression, the following `regexprep` command correctly replaces the term `internationalization` with its abbreviated form, `i18n`. However, to use it on a different term such as `globalization`, you have to use a different replacement expression:

```
match_expr = ' (^w)(w*)(w$) ';
replace_expr1 = '$118$3';
regexprep('internationalization', match_expr, replace_expr1)

ans =
    i18n
```

```

replace_expr2 = '$111$3';
regexprep('globalization', match_expr, replace_expr2)

ans =
    g11n

```

Using a dynamic expression `#{num2str(length($2))}` enables you to base the replacement expression on the input string so that you do not have to change the expression each time. This example uses the dynamic replacement syntax `#{cmd}`.

```

match_expr = '^(^w)(\w*)(\w$)';
replace_expr = '$1$#{num2str(length($2))}$3';

regexprep('internationalization', match_expr, replace_expr)

ans =
    i18n

regexprep('globalization', match_expr, replace_expr)

ans =
    g11n

```

When parsed, a dynamic expression must correspond to a complete, valid regular expression. In addition, dynamic match expressions that use the backslash escape character (`\`) require two backslashes: one for the initial parsing of the expression, and one for the complete match. The parentheses that enclose dynamic expressions do *not* create a capturing group.

There are three forms of dynamic expressions that you can use in match expressions, and one form for replacement expressions, as described in the following sections

## Dynamic Match Expressions – (??expr)

The `(??expr)` operator parses expression `expr`, and inserts the results back into the match expression. MATLAB then evaluates the modified match expression.

Here is an example of the type of expression that you can use with this operator:

```
str = {'5XXXXX', '8XXXXXXXX', '1X'};  
regexp(str, '^(\\d+)(?X{\\$1})$', 'match', 'once');
```

The purpose of this particular command is to locate a series of X characters in each of the strings stored in the input cell array. Note however that the number of Xs varies in each string. If the count did not vary, you could use the expression `X{n}` to indicate that you want to match `n` of these characters. But, a constant value of `n` does not work in this case.

The solution used here is to capture the leading count number (e.g., the 5 in the first string of the cell array) in a token, and then to use that count in a dynamic expression. The dynamic expression in this example is `(?X{\\$1})`, where `\\$1` is the value captured by the token `\\d+`. The operator `{\\$1}` makes a quantifier of that token value. Because the expression is dynamic, the same pattern works on all three of the input strings in the cell array. With the first input string, `regexp` looks for five X characters; with the second, it looks for eight, and with the third, it looks for just one:

```
regexp(str, '^(\\d+)(?X{\\$1})$', 'match', 'once')  
  
ans =  
      '5XXXXX'      '8XXXXXXXX'      '1X'
```

## **Commands That Modify the Match Expression – (?@cmd)**

MATLAB uses the `(?@cmd)` operator to include the results of a MATLAB command in the match expression. This command must return a string that can be used within the match expression.

For example, use the dynamic expression `(?@fliplr(\\$1))` to locate a palindrome string, “Never Odd or Even”, that has been embedded into a larger string.

First, create the input string. Make sure that all letters are lowercase, and remove all nonword characters.

```
str = lower(...
```

```
'Find the palindrome Never Odd or Even in this string');
str = regexprep(str, '\W*', '')
str =
    findthepalindromeneveroddoeveninthisstring
```

Locate the palindrome within the string using the dynamic expression:

```
palstr = regexp(str, '(.{3,}).?(?@flip1r($1))', 'match')
str =
    'neveroddoeven'
```

The dynamic expression reverses the order of the letters that make up the string, and then attempts to match as much of the reversed-order string as possible. This requires a dynamic expression because the value for \$1 relies on the value of the token (.{3,}).

Dynamic expressions in MATLAB have access to the currently active workspace. This means that you can change any of the functions or variables used in a dynamic expression just by changing variables in the workspace. Repeat the last command of the example above, but this time define the function to be called within the expression using a function handle stored in the base workspace:

```
fun = @flip1r;
palstr = regexp(str, '(.{3,}).?(?@fun($1))', 'match')
palstr =
    'neveroddoeven'
```

## Commands That Serve a Functional Purpose — (?@cmd)

The (?@cmd) operator specifies a MATLAB command that `regexp` or `regexprep` is to run while parsing the overall match expression. Unlike the other dynamic expressions in MATLAB, this operator does not alter the contents of the expression it is used in. Instead, you can use this functionality to get MATLAB to report just what steps it is taking as it parses the contents

of one of your regular expressions. This functionality can be useful in diagnosing your regular expressions.

The following example parses a word for zero or more characters followed by two identical characters followed again by zero or more characters:

```
regexp('mississippi', '\w*(\w)\1\w*', 'match')
```

```
ans =  
    'mississippi'
```

To track the exact steps that MATLAB takes in determining the match, the example inserts a short script (`?@disp($1)`) in the expression to display the characters that finally constitute the match. Because the example uses greedy quantifiers, MATLAB attempts to match as much of the string as possible. So, even though MATLAB finds a match toward the beginning of the string, it continues to look for more matches until it arrives at the very end of the string. From there, it backs up through the letters `i` then `p` and the next `p`, stopping at that point because the match is finally satisfied:

```
regexp('mississippi', '\w*(\w)(?@disp($1))\1\w*', 'match')
```

```
i  
p  
p
```

```
ans =  
    'mississippi'
```

Now try the same example again, this time making the first quantifier lazy (`*?`). Again, MATLAB makes the same match:

```
regexp('mississippi', '\w*?(\w)\1\w*', 'match')
```

```
ans =  
    'mississippi'
```

But by inserting a dynamic script, you can see that this time, MATLAB has matched the string quite differently. In this case, MATLAB uses the very first match it can find, and does not even consider the rest of the string:

```
regexp('mississippi', '\w*?(\w)(?@disp($1))\1\w*', 'match')
```



```

m
i
s

ans =
    'mississippi'

```

To demonstrate how versatile this type of dynamic expression can be, consider the next example that progressively assembles a cell array as MATLAB iteratively parses the input string. The `(?!)` operator found at the end of the expression is actually an empty lookahead operator, and forces a failure at each iteration. This forced failure is necessary if you want to trace the steps that MATLAB is taking to resolve the expression.

MATLAB makes a number of passes through the input string, each time trying another combination of letters to see if a fit better than last match can be found. On any passes in which no matches are found, the test results in an empty string. The dynamic script `(?@if(~isempty($&))`) serves to omit these strings from the `matches` cell array:

```

matches = {};
expr = ['(Euler\s)?(Cauchy\s)?(Boole)?(?@if(~isempty($&)), ' ...
    'matches{end+1}=$&;end) (?!)'];

regexp('Euler Cauchy Boole', expr);

matches

matches =
    'Euler Cauchy Boole'    'Euler Cauchy '    'Euler '
    'Cauchy Boole'        'Cauchy '        'Boole'

```

The operators `$&` (or the equivalent `$0`), `$``, and `$'` refer to that part of the input string that is currently a match, all characters that precede the current match, and all characters to follow the current match, respectively. These operators are sometimes useful when working with dynamic expressions, particularly those that employ the `(?@cmd)` operator.

This example parses the input string looking for the letter `g`. At each iteration through the string, `regexp` compares the current character with `g`, and not

finding it, advances to the next character. The example tracks the progress of scan through the string by marking the current location being parsed with a `^` character.

(The `$`` and `$·` operators capture that part of the string that precedes and follows the current parsing location. You need two single-quotation marks (`$'` ) to express the sequence `$·` when it appears within a string.)

```
str = 'abcdefghij';  
expr = '(?@disp(sprintf('starting match: [%s^%s]','$', $'))g';  
  
regexp(str, expr, 'once');
```

```
starting match: [^abcdefghij]  
starting match: [a^bcdefghij]  
starting match: [ab^cdefghij]  
starting match: [abc^defghij]  
starting match: [abcd^efghij]  
starting match: [abcde^fghij]  
starting match: [abcdef^ghij]
```

## Commands in Replacement Expressions — `${cmd}`

The `${cmd}` operator modifies the contents of a regular expression replacement string, making this string adaptable to parameters in the input string that might vary from one use to the next. As with the other dynamic expressions used in MATLAB, you can include any number of these expressions within the overall replacement expression.

In the `regexprep` call shown here, the replacement string is `'${convertMe($1,$2)}'`. In this case, the entire replacement string is a dynamic expression:

```
regexprep('This highway is 125 miles long', ...  
          '(\d+\.\d*)\W(\w+)', '${convertMe($1,$2)}');
```

The dynamic expression tells MATLAB to execute a function named `convertMe` using the two tokens `(\d+\.\d*)` and `(\w+)`, derived from the string being matched, as input arguments in the call to `convertMe`. The replacement string requires a dynamic expression because the values of `$1` and `$2` are generated at runtime.

The following example defines the file named `convertMe` that converts measurements from imperial units to metric.

```
function valout = convertMe(valin, units)
switch(units)
  case 'inches'
    fun = @(in)in .* 2.54;    uout = 'centimeters';
  case 'miles'
    fun = @(mi)mi .* 1.6093; uout = 'kilometers';
  case 'pounds'
    fun = @(lb)lb .* 0.4536; uout = 'kilograms';
  case 'pints'
    fun = @(pt)pt .* 0.4731; uout = 'litres';
  case 'ounces'
    fun = @(oz)oz .* 28.35;  uout = 'grams';
end
val = fun(str2num(valin));
valout = [num2str(val) ' ' uout];
end
```

At the command line, call the `convertMe` function from `regexprep`, passing in values for the quantity to be converted and name of the imperial unit:

```
regexprep('This highway is 125 miles long', ...
          '(\d+\.?\d*)\W(\w+)', '${convertMe($1,$2)}')
```

```
ans =
  This highway is 201.1625 kilometers long
```

```
regexprep('This pitcher holds 2.5 pints of water', ...
          '(\d+\.?\d*)\W(\w+)', '${convertMe($1,$2)}')
```

```
ans =
  This pitcher holds 1.1828 litres of water
```

```
regexprep('This stone weighs about 10 pounds', ...
          '(\d+\.?\d*)\W(\w+)', '${convertMe($1,$2)}')
```

```
ans =
  This stone weighs about 4.536 kilograms
```

As with the (??@ ) operator discussed in an earlier section, the \${ } operator has access to variables in the currently active workspace. The following regexprep command uses the array A defined in the base workspace:

```
A = magic(3)
```

```
A =  
     8     1     6  
     3     5     7  
     4     9     2
```

```
regexprep('The columns of matrix _nam are _val', ...  
          {'_nam', '_val'}, ...  
          {'A', '${sprintf('%d%d%d ', A)}'})
```

```
ans =  
The columns of matrix A are 834 159 672
```

### See Also

regexp | regexpi | regexprep

### Concepts

- “Regular Expressions” on page 2-26

## Comma-Separated Lists

### In this section...

“What Is a Comma-Separated List?” on page 2-61

“Generating a Comma-Separated List” on page 2-61

“Assigning Output from a Comma-Separated List” on page 2-63

“Assigning to a Comma-Separated List” on page 2-64

“How to Use the Comma-Separated Lists” on page 2-65

“Fast Fourier Transform Example” on page 2-67

### What Is a Comma-Separated List?

Typing in a series of numbers separated by commas gives you what is called a *comma-separated list*. The MATLAB software returns each value individually:

```
1, 2, 3
ans =
     1
ans =
     2
ans =
     3
```

Such a list, by itself, is not very useful. But when used with large and more complex data structures like MATLAB structures and cell arrays, the comma-separated list can enable you to simplify your MATLAB code.

### Generating a Comma-Separated List

This section describes how to generate a comma-separated list from either a cell array or a MATLAB structure.

#### Generating a List from a Cell Array

Extracting multiple elements from a cell array yields a comma-separated list. Given a 4-by-6 cell array as shown here

```
C = cell(4, 6);
for k = 1:24, C{k} = k * 2; end
```

```
C
C =
     [2]     [10]     [18]     [26]     [34]     [42]
     [4]     [12]     [20]     [28]     [36]     [44]
     [6]     [14]     [22]     [30]     [38]     [46]
     [8]     [16]     [24]     [32]     [40]     [48]
```

extracting the fifth column generates the following comma-separated list:

```
C{:, 5}
ans =
    34
ans =
    36
ans =
    38
ans =
    40
```

This is the same as explicitly typing

```
C{1, 5}, C{2, 5}, C{3, 5}, C{4, 5}
```

### Generating a List from a Structure

For structures, extracting a field of the structure that exists across one of its dimensions yields a comma-separated list.

Start by converting the cell array used above into a 4-by-1 MATLAB structure with six fields: `f1` through `f6`. Read field `f5` for all rows and MATLAB returns a comma-separated list:

```
S = cell2struct(C, {'f1', 'f2', 'f3', 'f4', 'f5', 'f6'}, 2);

S.f5
ans =
    34
ans =
```

```

36
ans =
38
ans =
40

```

This is the same as explicitly typing

```
S(1).f5, S(2).f5, S(3).f5, S(4).f5
```

## Assigning Output from a Comma-Separated List

You can assign any or all consecutive elements of a comma-separated list to variables with a simple assignment statement. Using the cell array `C` from the previous section, assign the first row to variables `c1` through `c6`:

```

C = cell(4, 6);
for k = 1:24, C{k} = k * 2; end

[c1 c2 c3 c4 c5 c6] = C{1,1:6};

c5
c5 =
34

```

If you specify fewer output variables than the number of outputs returned by the expression, MATLAB assigns the first `N` outputs to those `N` variables, and then discards any remaining outputs. In this next example, MATLAB assigns `C{1,1:3}` to the variables `c1`, `c2`, and `c3`, and then discards `C{1,4:6}`:

```
[c1 c2 c3] = C{1,1:6};
```

You can assign structure outputs in the same manner:

```

S = cell2struct(C, {'f1', 'f2', 'f3', 'f4', 'f5', 'f6'}, 2);

[sf1 sf2 sf3] = S.f5;

sf3
sf3 =
38

```

You also can use the `deal` function for this purpose.

## Assigning to a Comma-Separated List

The simplest way to assign multiple values to a comma-separated list is to use the `deal` function. This function distributes all of its input arguments to the elements of a comma-separated list.

This example initializes a comma-separated list to a set of vectors in a cell array, and then uses `deal` to overwrite each element in the list:

```
c{1} = [31 07];    c{2} = [03 78];
```

```
c{:}
ans =
    31     7
ans =
     3    78
```

```
[c{:}] = deal([10 20],[14 12]);
```

```
c{:}
ans =
    10    20
ans =
    14    12
```

This example does the same as the one above, but with a comma-separated list of vectors in a structure field:

```
s(1).field1 = [31 07];    s(2).field1 = [03 78];
```

```
s.field1
ans =
    31     7
ans =
     3    78
```



```
[s.field1] = deal([10 20],[14 12]);
```

```
s.field1
ans =
    10    20
ans =
    14    12
```

## How to Use the Comma-Separated Lists

Common uses for comma-separated lists are

- “Constructing Arrays” on page 2-65
- “Displaying Arrays” on page 2-66
- “Concatenation” on page 2-66
- “Function Call Arguments” on page 2-66
- “Function Return Values” on page 2-67

The following sections provide examples of using comma-separated lists with cell arrays. Each of these examples applies to MATLAB structures as well.

### Constructing Arrays

You can use a comma-separated list to enter a series of elements when constructing a matrix or array. Note what happens when you insert a *list* of elements as opposed to adding the cell itself.

When you specify a list of elements with `C{: , 5}`, MATLAB inserts the four individual elements:

```
A = {'Hello', C{: , 5}, magic(4)}
A =
    'Hello'    [34]    [36]    [38]    [40]    [4x4 double]
```

When you specify the C cell itself, MATLAB inserts the entire cell array:

```
A = {'Hello', C, magic(4)}
A =
    'Hello'    {4x6 cell}    [4x4 double]
```

### Displaying Arrays

Use a list to display all or part of a structure or cell array:

```
A{:}
ans =
    Hello
ans =
    34
ans =
    36
ans =
    38
.
.
.
```

### Concatenation

Putting a comma-separated list inside square brackets extracts the specified elements from the list and concatenates them:

```
A = [C{:}, 5:6]
A =
    34    36    38    40    42    44    46    48

whos A
  Name      Size      Bytes  Class

  A         1x8         64    double array
```

### Function Call Arguments

When writing the code for a function call, you enter the input arguments as a list with each argument separated by a comma. If you have these arguments stored in a structure or cell array, then you can generate all or part of the argument list from the structure or cell array instead. This can be especially useful when passing in variable numbers of arguments.

This example passes several attribute-value arguments to the `plot` function:

```
X = -pi:pi/10:pi;
Y = tan(sin(X)) - sin(tan(X));

C{1,1} = 'LineWidth';           C{2,1} = 2;
C{1,2} = 'MarkerEdgeColor';    C{2,2} = 'k';
C{1,3} = 'MarkerFaceColor';    C{2,3} = 'g';

plot(X, Y, '--rs', C{:})
```

### Function Return Values

MATLAB functions can also return more than one value to the caller. These values are returned in a list with each value separated by a comma. Instead of listing each return value, you can use a comma-separated list with a structure or cell array. This becomes more useful for those functions that have variable numbers of return values.

This example returns three values to a cell array:

```
C = cell(1, 3);
[C{:}] = fileparts('work/mytests/strArrays.mat')
C =
    'work/mytests'    'strArrays'    '.mat'
```

### Fast Fourier Transform Example

The `fftshift` function swaps the left and right halves of each dimension of an array. For a simple vector such as `[0 2 4 6 8 10]` the output would be `[6 8 10 0 2 4]`. For a multidimensional array, `fftshift` performs this swap along each dimension.

`fftshift` uses vectors of indices to perform the swap. For the vector shown above, the index `[1 2 3 4 5 6]` is rearranged to form a new index `[4 5 6 1 2 3]`. The function then uses this index vector to reposition the elements. For a multidimensional array, `fftshift` must construct an index vector for each dimension. A comma-separated list makes this task much simpler.

Here is the `fftshift` function:

```
function y = fftshift(x)
```

```
numDims = ndims(x);
idx = cell(1, numDims);

for k = 1:numDims
    m = size(x, k);
    p = ceil(m/2);
    idx{k} = [p+1:m 1:p];
end

y = x(idx{:});
```

The function stores the index vectors in cell array `idx`. Building this cell array is relatively simple. For each of the  $N$  dimensions, determine the size of that dimension and find the integer index nearest the midpoint. Then, construct a vector that swaps the two halves of that dimension.

By using a cell array to store the index vectors and a comma-separated list for the indexing operation, `fftshift` shifts arrays of any dimension using just a single operation: `y = x(idx{:})`. If you were to use explicit indexing, you would need to write one `if` statement for each dimension you want the function to handle:

```
if ndims(x) == 1
    y = x(index1);
else if ndims(x) == 2
    y = x(index1, index2);
end
```

Another way to handle this without a comma-separated list would be to loop over each dimension, converting one dimension at a time and moving data each time. With a comma-separated list, you move the data just once. A comma-separated list makes it very easy to generalize the swapping operation to an arbitrary number of dimensions.

## Alternatives to the eval Function

### In this section...

“Why Avoid the eval Function?” on page 2-69

“Variables with Sequential Names” on page 2-69

“Files with Sequential Names” on page 2-70

“Function Names in Variables” on page 2-71

“Field Names in Variables” on page 2-72

“Error Handling” on page 2-72

### Why Avoid the eval Function?

Although the `eval` function is very powerful and flexible, it not always the best solution to a programming problem. Code that calls `eval` is often less efficient and more difficult to read and debug than code that uses other functions or language constructs. For example:

- MATLAB compiles code the first time you run it to enhance performance for future runs. However, because code in an `eval` statement can change at run time, it is not compiled.
- Code within an `eval` statement can unexpectedly create or assign to a variable already in the current workspace, overwriting existing data.
- Concatenating strings within an `eval` statement is often difficult to read. Other language constructs can simplify the syntax in your code.

For many common uses of `eval`, there are preferred alternate approaches, as shown in the following examples.

### Variables with Sequential Names

A frequent use of the `eval` function is to create sets of variables such as `A1`, `A2`, . . . , `An`, but this approach does not use the array processing power of MATLAB and is not recommended. The preferred method is to store related data in a single array. If the data sets are of different types or sizes, use a structure or cell array.

For example, create a cell array that contains 10 elements, where each element is a numeric array:

```
numArrays = 10;
A = cell(numArrays,1);
for n = 1:numArrays
    A{n} = magic(n);
end
```

Access the data in the cell array by indexing with curly braces. For example, display the fifth element of A:

```
A{5}

ans =
    17    24     1     8    15
    23     5     7    14    16
     4     6    13    20    22
    10    12    19    21     3
    11    18    25     2     9
```

The assignment statement `A{n} = magic(n)` is more elegant and efficient than this call to `eval`:

```
eval(['A', int2str(n), ' = magic(n)']) % Not recommended
```

For more information, see:

- “Create a Cell Array” on page 10-3
- “Create a Structure Array” on page 9-2

## Files with Sequential Names

Related data files often have a common root name with an integer index, such as `myfile1.mat` through `myfileN.mat`. A common (but not recommended) use of the `eval` function is to construct and pass each file name to a function using command syntax, such as

```
eval(['save myfile',int2str(n),'.mat']) % Not recommended
```

The best practice is to use function syntax, which allows you to pass variables as inputs. For example:

```
currentFile = 'myfile1.mat';
save(currentFile)
```

You can construct file names within a loop using the `sprintf` function (which is usually more efficient than `int2str`), and then call the `save` function without `eval`. This code creates 10 files in the current folder:

```
numFiles = 10;
for n = 1:numFiles
    randomData = rand(n);
    currentFile = sprintf('myfile%d.mat',n);
    save(currentFile,'randomData')
end
```

For more information, see:

- “Command vs. Function Syntax” on page 1-12
- “Import or Export a Sequence of Files”

## Function Names in Variables

A common use of `eval` is to execute a function when the name of the function is in a variable string. There are two ways to evaluate functions from variables that are more efficient than using `eval`:

- Create function handles with the `@` symbol or with the `str2func` function. For example, run a function from a list stored in a cell array:

```
examples = {@odedemo,@sunspots,@fitdemo};
n = input('Select an example (1, 2, or 3): ');
examples{n}()
```

- Use the `feval` function. For example, call a plot function (such as `plot`, `bar`, or `pie`) with data that you specify at run time:

```
plotFunction = input('Specify a plotting function: ','s');
data = input('Enter data to plot: ');
feval(plotFunction,data)
```

## Field Names in Variables

Access data in a structure with a variable field name by enclosing the expression for the field in parentheses. For example:

```
myData.height = [67, 72, 58];
myData.weight = [140, 205, 90];

fieldName = input('Select data (height or weight): ','s');
dataToUse = myData.(fieldName);
```

If you enter `weight` at the input prompt, then you can find the minimum `weight` value with the following command.

```
min(dataToUse)
```

```
ans =
     90
```

For an additional example, see “Generate Field Names from Variables” on page 9-11.

## Error Handling

The preferred method for error handling in MATLAB is to use a `try`, `catch` statement. For example:

```
try
    B = A;
catch exception
    disp('A is undefined')
end
```

If your workspace does not contain variable `A`, then this code returns:

```
A is undefined
```

Previous versions of the documentation for the `eval` function include the syntax `eval(expression,catch_expr)`. If evaluating the `expression` input returns an error, then `eval` evaluates `catch_expr`. However, an explicit `try/catch` is significantly clearer than an implicit catch in an `eval` statement. Using the implicit catch is not recommended.



## Shell Escape Functions

It is sometimes useful to access your own C or Fortran programs using *shell escape functions*. Shell escape functions use the shell escape command `!` to make external stand-alone programs act like new MATLAB functions.

For example, the following function, `garfield.m`, uses an external function, `gareqn`, to find the solution to Garfield's equation.

```
function y = garfield(a,b,q,r)
save gardata a b q r
!gareqn
load gardata
```

This function:

- 1** Saves the input arguments `a`, `b`, `q`, and `r` to a MAT-file in the workspace using the `save` command.
- 2** Uses the shell escape operator to access a C or Fortran program called `gareqn` that uses the workspace variables to perform its computation. `gareqn` writes its results to the `gardata` MAT-file.
- 3** Loads the `gardata` MAT-file to obtain the results.

For more information, see “Run External Commands, Scripts, and Programs”.

## Symbol Reference

In this section...
“Asterisk — *” on page 2-74
“At — @” on page 2-75
“Colon — :” on page 2-76
“Comma — ,” on page 2-77
“Curly Braces — { }” on page 2-78
“Dot — .” on page 2-78
“Dot-Dot — ..” on page 2-79
“Dot-Dot-Dot (Ellipsis) — ...” on page 2-79
“Dot-Parentheses — .( )” on page 2-80
“Exclamation Point — !” on page 2-81
“Parentheses — ( )” on page 2-81
“Percent — %” on page 2-82
“Percent-Brace — %{ %}” on page 2-82
“Plus — +” on page 2-83
“Semicolon — ;” on page 2-83
“Single Quotes — ’ ” on page 2-84
“Space Character” on page 2-84
“Slash and Backslash — / \” on page 2-85
“Square Brackets — [ ]” on page 2-85
“Tilde — ~” on page 2-86

### **Asterisk — \***

An asterisk in a filename specification is used as a wildcard specifier, as described below.

## Filename Wildcard

Wildcards are generally used in file operations that act on multiple files or folders. They usually appear in the string containing the file or folder specification. MATLAB matches all characters in the name exactly except for the wildcard character \*, which can match any one or more characters.

To locate all files with names that start with 'january\_' and have a mat file extension, use

```
dir('january_*.mat')
```

You can also use wildcards with the `who` and `whos` functions. To get information on all variables with names starting with 'image' and ending with 'Offset', use

```
whos image*Offset
```

## At — @

The @ sign signifies either a function handle constructor or a folder that supports a MATLAB class.

## Function Handle Constructor

The @ operator forms a handle to either the named function that follows the @ sign, or to the anonymous function that follows the @ sign.

**Function Handles in General.** Function handles are commonly used in passing functions as arguments to other functions. Construct a function handle by preceding the function name with an @ sign:

```
fhandle = @myfun
```

For more information, see `function_handle`.

**Handles to Anonymous Functions.** Anonymous functions give you a quick means of creating simple functions without having to create your function in a file each time. You can construct an anonymous function and a handle to that function using the syntax

```
fhandle = @(arglist) body
```

where `body` defines the body of the function and `arglist` is the list of arguments you can pass to the function.

See “Anonymous Functions” on page 17-23 for more information.

### **Class Folder Designator**

An @ sign can indicate the name of a class folder, such as

```
\@myclass\get.m
```

See the documentation on “Options for Class Folders” for more information.

### **Colon — :**

The colon operator generates a sequence of numbers that you can use in creating or indexing into arrays. See “Generating a Numeric Sequence” for more information on using the colon operator.

### **Numeric Sequence Range**

Generate a sequential series of regularly spaced numbers from `first` to `last` using the syntax `first:last`. For an incremental sequence from 6 to 17, use

```
N = 6:17
```

### **Numeric Sequence Step**

Generate a sequential series of numbers, each number separated by a `step` value, using the syntax `first:step:last`. For a sequence from 2 through 38, stepping by 4 between each entry, use

```
N = 2:4:38
```

### **Indexing Range Specifier**

Index into multiple rows or columns of a matrix using the colon operator to specify a range of indices:

```
B = A(7, 1:5);           % Read columns 1-5 of row 7.  
B = A(4:2:8, 1:5);      % Read columns 1-5 of rows 4, 6, and 8.  
B = A(:, 1:5);         % Read columns 1-5 of all rows.
```

## Conversion to Column Vector

Convert a matrix or array to a column vector using the colon operator as a single index:

```
A = rand(3,4);  
B = A(:);
```

## Preserving Array Shape on Assignment

Using the colon operator on the left side of an assignment statement, you can assign new values to array elements without changing the shape of the array:

```
A = rand(3,4);  
A(:) = 1:12;
```

## Comma — ,

A comma is used to separate the following types of elements.

## Row Element Separator

When constructing an array, use a comma to separate elements that belong in the same row:

```
A = [5.92, 8.13, 3.53]
```

## Array Index Separator

When indexing into an array, use a comma to separate the indices into each dimension:

```
X = A(2, 7, 4)
```

### **Function Input and Output Separator**

When calling a function, use a comma to separate output and input arguments:

```
function [data, text] = xlsread(file, sheet, range, mode)
```

### **Command or Statement Separator**

To enter more than one MATLAB command or statement on the same line, separate each command or statement with a comma:

```
for k = 1:10, sum(A(k)), end
```

### **Curly Braces — { }**

Use curly braces to construct or get the contents of cell arrays.

### **Cell Array Constructor**

To construct a cell array, enclose all elements of the array in curly braces:

```
C = {[2.6 4.7 3.9], rand(8)*6, 'C. Coolidge'}
```

### **Cell Array Indexing**

Index to a specific cell array element by enclosing all indices in curly braces:

```
A = C{4,7,2}
```

For more information, see “Cell Arrays”

### **Dot — .**

The single dot operator has the following different uses in MATLAB.

### **Decimal Point**

MATLAB uses a period to separate the integral and fractional parts of a number.

## Structure Field Definition

Add fields to a MATLAB structure by following the structure name with a dot and then a field name:

```
funds(5,2).bondtype = 'Corporate';
```

For more information, see “Structures”

## Object Method Specifier

Specify the properties of an instance of a MATLAB class using the object name followed by a dot, and then the property name:

```
val = asset.current_value
```

## Dot-Dot — ..

Two dots in sequence refer to the parent of the current folder.

## Parent Folder

Specify the folder immediately above your current folder using two dots. For example, to go up two levels in the folder tree and down into the `test` folder, use

```
cd ..\..\test
```

## Dot-Dot-Dot (Ellipsis) — ...

A series of three consecutive periods (`...`) is the line continuation operator in MATLAB. This is often referred to as an *ellipsis*, but it should be noted that the line continuation operator is a three-character operator and is different from the single-character ellipsis represented in ASCII by the hexadecimal number 2026.

## Line Continuation

Continue any MATLAB command or expression by placing an ellipsis at the end of the line to be continued:

```
sprintf('The current value of %s is %d', ...  
       vname, value)
```

**Entering Long Strings.** You cannot use an ellipsis within single quotes to continue a string to the next line:

```
string = 'This is not allowed and will generate an ...  
        error in MATLAB.'
```

To enter a string that extends beyond a single line, piece together shorter strings using either the concatenation operator ([ ]) or the `sprintf` function.

Here are two examples:

```
quote1 = [  
    'Tiger, tiger, burning bright in the forests of the night,' ...  
    'what immortal hand or eye could frame thy fearful symmetry?'];  
quote2 = sprintf('%s%s%s', ...  
    'In Xanadu did Kubla Khan a stately pleasure-dome decree,', ...  
    'where Alph, the sacred river, ran ', ...  
    'through caverns measureless to man down to a sunless sea.');
```

**Defining Arrays.** MATLAB interprets the ellipsis as a space character. For statements that define arrays or cell arrays within [ ] or { } operators, a space character separates array elements. For example,

```
not_valid = [1 2 zeros...  
(1,3)]
```

is equivalent to

```
not_valid = [1 2 zeros (1,3)]
```

which returns an error. Place the ellipses so that the interpreted statement is valid, such as

```
valid = [1 2 ...  
        zeros(1,3)]
```

## **Dot-Parentheses — .( )**

Use dot-parentheses to specify the name of a dynamic structure field.



## Dynamic Structure Fields

Sometimes it is useful to reference structures with field names that can vary. For example, the referenced field might be passed as an argument to a function. Dynamic field names specify a variable name for a structure field.

The variable `fundtype` shown here is a dynamic field name:

```
type = funds(5,2).(fundtype);
```

See “Generate Field Names from Variables” on page 9-11 for more information.

## Exclamation Point – !

The exclamation point precedes operating system commands that you want to execute from within MATLAB.

## Shell Escape

The exclamation point initiates a shell escape function. Such a function is to be performed directly by the operating system:

```
!rmdir oldtests
```

See “Shell Escape Functions” on page 2-73 for more information.

## Parentheses – ( )

Parentheses are used mostly for indexing into elements of an array or for specifying arguments passed to a called function. Parenthesis also control the order of operations, and can group a vector visually (such as `x = (1:10)`) without calling a concatenation function.

## Array Indexing

When parentheses appear to the right of a variable name, they are indices into the array stored in that variable:

```
A(2, 7, 4)
```

### **Function Input Arguments**

When parentheses follow a function name in a function declaration or call, the enclosed list contains input arguments used by the function:

```
function sendmail(to, subject, message, attachments)
```

### **Percent — %**

The percent sign is most commonly used to indicate nonexecutable text within the body of a program. This text is normally used to include comments in your code. Two percent signs, `%%`, serve as a cell delimiter described in “Run Code Sections” on page 16-6. Some functions also interpret the percent sign as a conversion specifier.

### **Single Line Comments**

Precede any one-line comments in your code with a percent sign. MATLAB does not execute anything that follows a percent sign (that is, unless the sign is quoted, `'%'`):

```
% The purpose of this routine is to compute  
% the value of ...
```

See “Add Comments to Programs” on page 16-4 for more information.

### **Conversion Specifiers**

Some functions, like `sscanf` and `sprintf`, precede conversion specifiers with the percent sign:

```
sprintf('%s = %d', name, value)
```

### **Percent-Brace — %{ %}**

The `%{` and `%}` symbols enclose a block of comments that extend beyond one line.

### **Block Comments**

Enclose any multiline comments with percent followed by an opening or closing brace.

```
%{  
The purpose of this routine is to compute  
the value of ...  
%}
```

---

**Note** With the exception of whitespace characters, the %{ and %} operators must appear alone on the lines that immediately precede and follow the block of help text. Do not include any other text on these lines.

---

## Plus — +

The + sign appears most frequently as an arithmetic operator, but is also used to designate the names of package folders. For more information, see “Packages Create Namespaces”.

## Semicolon — ;

The semicolon can be used to construct arrays, suppress output from a MATLAB command, or to separate commands entered on the same line.

## Array Row Separator

When used within square brackets to create a new array or concatenate existing arrays, the semicolon creates a new row in the array:

```
A = [5, 8; 3, 4]  
A =  
     5     8  
     3     4
```

## Output Suppression

When placed at the end of a command, the semicolon tells MATLAB not to display any output from that command. In this example, MATLAB does not display the resulting 100-by-100 matrix:

```
A = ones(100, 100);
```

## Command or Statement Separator

Like the comma operator, you can enter more than one MATLAB command on a line by separating each command with a semicolon. MATLAB suppresses output for those commands terminated with a semicolon, and displays the output for commands terminated with a comma.

In this example, assignments to variables **A** and **C** are terminated with a semicolon, and thus do not display. Because the assignment to **B** is comma-terminated, the output of this one command is displayed:

```
A = 12.5; B = 42.7, C = 1.25;  
B =  
    42.7000
```

## Single Quotes – ' '

Single quotes are the constructor symbol for MATLAB character arrays.

## Character and String Constructor

MATLAB constructs a character array from all characters enclosed in single quotes. If only one character is in quotes, then MATLAB constructs a 1-by-1 array:

```
S = 'Hello World'
```

For more information, see “Characters and Strings”

## Space Character

The space character serves a purpose similar to the comma in that it can be used to separate row elements in an array constructor, or the values returned by a function.

## Row Element Separator

You have the option of using either commas or spaces to delimit the row elements of an array when constructing the array. To create a 1-by-3 array, use

```
A = [5.92 8.13 3.53]
```

```
A =  
    5.9200    8.1300    3.5300
```

When indexing into an array, you must always use commas to reference each dimension of the array.

### Function Output Separator

Spaces are allowed when specifying a list of values to be returned by a function. You can use spaces to separate return values in both function declarations and function calls:

```
function [data text] = xlsread(file, sheet, range, mode)
```

### Slash and Backslash – / \

The slash (/) and backslash (\) characters separate the elements of a path or folder string. On Microsoft Windows-based systems, both slash and backslash have the same effect. On The Open Group UNIX-based systems, you must use slash only.

On a Windows system, you can use either backslash or slash:

```
dir([matlabroot '\toolbox\matlab\elmat\shiftdim.m'])  
dir([matlabroot '/toolbox/matlab/elmat/shiftdim.m'])
```

On a UNIX system, use only the forward slash:

```
dir([matlabroot '/toolbox/matlab/elmat/shiftdim.m'])
```

### Square Brackets – [ ]

Square brackets are used in array construction and concatenation, and also in declaring and capturing values returned by a function.

### Array Constructor

To construct a matrix or array, enclose all elements of the array in square brackets:

```
A = [5.7, 9.8, 7.3; 9.2, 4.5, 6.4]
```

### Concatenation

To combine two or more arrays into a new array through concatenation, enclose all array elements in square brackets:

```
A = [B, eye(6), diag([0:2:10])]
```

### Function Declarations and Calls

When declaring or calling a function that returns more than one output, enclose each return value that you need in square brackets:

```
[data, text] = xlsread(file, sheet, range, mode)
```

### Tilde — ~

The tilde character is used in comparing arrays for unequal values, finding the logical NOT of an array, and as a placeholder for an input or output argument you want to omit from a function call.

### Not Equal to

To test for inequality values of elements in arrays a and b for inequality, use `a~=b`:

```
a = primes(29);    b = [2 4 6 7 11 13 20 22 23 29];
not_prime = b(a~=b)
not_prime =
     4     6    20    22
```

### Logical NOT

To find those elements of an array that are zero, use:

```
a = [35 42 0 18 0 0 0 16 34 0];
~a
ans =
     0     0     1     0     1     1     1     0     0     1
```

## Argument Placeholder

To have the `fileparts` function return its third output value and skip the first two, replace arguments one and two with a tilde character:

```
[~, ~, filenameExt] = fileparts(fileSpec);
```

See “Ignore Function Inputs” on page 18-13 in the MATLAB Programming documentation for more information.





# Classes (Data Types)

---

- Chapter 3, “Overview of MATLAB Classes”
- Chapter 4, “Numeric Classes”
- Chapter 5, “The Logical Class”
- Chapter 6, “Characters and Strings”
- Chapter 7, “Categorical Arrays”
- Chapter 8, “Tables”
- Chapter 9, “Structures”
- Chapter 10, “Cell Arrays”
- Chapter 11, “Function Handles”
- Chapter 12, “Map Containers”
- Chapter 13, “Combining Unlike Classes”
- Chapter 14, “Using Objects”
- Chapter 15, “Defining Your Own Classes”



# Overview of MATLAB Classes

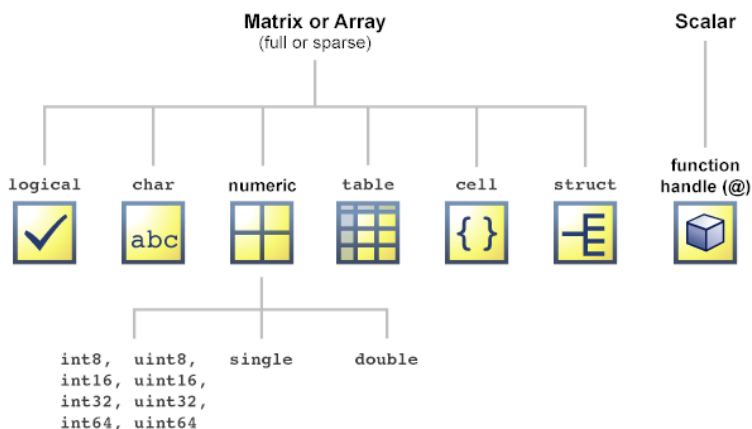
---

## Fundamental MATLAB Classes

There are many different data types, or *classes*, that you can work with in the MATLAB software. You can build matrices and arrays of floating-point and integer data, characters and strings, and logical `true` and `false` states. Function handles connect your code with any MATLAB function regardless of the current scope. Tables, structures, and cell arrays provide a way to store dissimilar types of data in the same container.

There are 16 fundamental classes in MATLAB. Each of these classes is in the form of a matrix or array. With the exception of function handles, this matrix or array is a minimum of 0-by-0 in size and can grow to an n-dimensional array of any size. A function handle is always scalar (1-by-1).

All of the fundamental MATLAB classes are shown in the diagram below:



Numeric classes in the MATLAB software include signed and unsigned integers, and single- and double-precision floating-point numbers. By default, MATLAB stores all numeric values as double-precision floating point. (You cannot change the default type and precision.) You can choose to store any number, or array of numbers, as integers or as single-precision. Integer and single-precision arrays offer more memory-efficient storage than double-precision.

All numeric types support basic array operations, such as subscripting, reshaping, and mathematical operations.

You can create two-dimensional `double` and `logical` matrices using one of two storage formats: `full` or `sparse`. For matrices with mostly zero-valued elements, a sparse matrix requires a fraction of the storage space required for an equivalent full matrix. Sparse matrices invoke methods especially tailored to solve sparse problems

These classes require different amounts of storage, the smallest being a `logical` value or 8-bit integer which requires only 1 byte. It is important to keep this minimum size in mind if you work on data in files that were written using a precision smaller than 8 bits.

The following table describes the fundamental classes in more detail.

<b>Class Name</b>	<b>Documentation</b>	<b>Intended Use</b>
<code>double</code> , <code>single</code>	Floating-Point Numbers	<ul style="list-style-type: none"> <li>• Required for fractional numeric data.</li> <li>• Double and Single precision.</li> <li>• Use <code>realmin</code> and <code>realmax</code> to show range of values.</li> <li>• Two-dimensional arrays can be sparse.</li> <li>• Default numeric type in MATLAB.</li> </ul>
<code>int8</code> , <code>uint8</code> , <code>int16</code> , <code>uint16</code> , <code>int32</code> , <code>uint32</code> , <code>int64</code> , <code>uint64</code>	Integers	<ul style="list-style-type: none"> <li>• Use for signed and unsigned whole numbers.</li> <li>• More efficient use of memory.</li> <li>• Use <code>intmin</code> and <code>intmax</code> to show range of values.</li> <li>• Choose from 4 sizes (8, 16, 32, and 64 bits).</li> </ul>

<b>Class Name</b>	<b>Documentation</b>	<b>Intended Use</b>
char	“Characters and Strings”	<ul style="list-style-type: none"><li>• Data type for text.</li><li>• Native or Unicode®.</li><li>• Converts to/from numeric.</li><li>• Use with regular expressions.</li><li>• For multiple strings, use cell arrays.</li></ul>
logical	“Logical Operations”	<ul style="list-style-type: none"><li>• Use in relational conditions or to test state.</li><li>• Can have one of two values: true or false.</li><li>• Also useful in array indexing.</li><li>• Two-dimensional arrays can be sparse.</li></ul>
function_handle	“Function Handles”	<ul style="list-style-type: none"><li>• Pointer to a function.</li><li>• Enables passing a function to another function</li><li>• Can also call functions outside usual scope.</li><li>• Useful in Handle Graphics callbacks.</li><li>• Save to MAT-file and restore later.</li></ul>

<b>Class Name</b>	<b>Documentation</b>	<b>Intended Use</b>
table	“Tables”	<ul style="list-style-type: none"> <li>• Rectangular container for mixed-type, column-oriented data.</li> <li>• Row and variable names identify contents.</li> <li>• Use <code>Table Properties</code> to store metadata such as variable units.</li> <li>• Manipulation of elements similar to numeric or logical arrays.</li> <li>• Access data by numeric or named index.</li> <li>• Can select a subset of data and preserve the table container or can extract the data from a table.</li> </ul>
struct	“Structures”	<ul style="list-style-type: none"> <li>• Fields store arrays of varying classes and sizes.</li> <li>• Access one or all fields/indices in single operation.</li> <li>• Field names identify contents.</li> <li>• Method of passing function arguments.</li> <li>• Use in comma-separated lists.</li> <li>• More memory required for overhead</li> </ul>
cell	“Cell Arrays”	<ul style="list-style-type: none"> <li>• Cells store arrays of varying classes and sizes.</li> <li>• Allows freedom to package data as you want.</li> <li>• Manipulation of elements is similar to numeric or logical arrays.</li> <li>• Method of passing function arguments.</li> <li>• Use in comma-separated lists.</li> <li>• More memory required for overhead</li> </ul>

## Concepts

- “Valid Combinations of Unlike Classes” on page 13-2





# Numeric Classes

---

- “Overview of Numeric Classes” on page 4-2
- “Integers” on page 4-3
- “Floating-Point Numbers” on page 4-7
- “Complex Numbers” on page 4-18
- “Infinity and NaN” on page 4-20
- “Identifying Numeric Classes” on page 4-22
- “Display Format for Numeric Values” on page 4-23
- “Function Summary” on page 4-26

# Overview of Numeric Classes

Numeric classes in the MATLAB software include signed and unsigned integers, and single- and double-precision floating-point numbers. By default, MATLAB stores all numeric values as double-precision floating point. (You cannot change the default type and precision.) You can choose to store any number, or array of numbers, as integers or as single-precision. Integer and single-precision arrays offer more memory-efficient storage than double-precision.

All numeric types support basic array operations, such as subscripting, reshaping, and mathematical operations.

# Integers

## In this section...

“Integer Classes” on page 4-3

“Creating Integer Data” on page 4-4

“Arithmetic Operations on Integer Classes” on page 4-5

“Largest and Smallest Values for Integer Classes” on page 4-6

“Integer Functions” on page 4-6

## Integer Classes

MATLAB has four signed and four unsigned integer classes. Signed types enable you to work with negative integers as well as positive, but cannot represent as wide a range of numbers as the unsigned types because one bit is used to designate a positive or negative sign for the number. Unsigned types give you a wider range of numbers, but these numbers can only be zero or positive.

MATLAB supports 1-, 2-, 4-, and 8-byte storage for integer data. You can save memory and execution time for your programs if you use the smallest integer type that accommodates your data. For example, you do not need a 32-bit integer to store the value 100.

Here are the eight integer classes, the range of values you can store with each type, and the MATLAB conversion function required to create that type:

Class	Range of Values	Conversion Function
Signed 8-bit integer	$-2^7$ to $2^7-1$	int8
Signed 16-bit integer	$-2^{15}$ to $2^{15}-1$	int16
Signed 32-bit integer	$-2^{31}$ to $2^{31}-1$	int32
Signed 64-bit integer	$-2^{63}$ to $2^{63}-1$	int64
Unsigned 8-bit integer	0 to $2^8-1$	uint8
Unsigned 16-bit integer	0 to $2^{16}-1$	uint16

Class	Range of Values	Conversion Function
Unsigned 32-bit integer	0 to $2^{32}-1$	uint32
Unsigned 64-bit integer	0 to $2^{64}-1$	uint64

## Creating Integer Data

MATLAB stores numeric data as double-precision floating point (`double`) by default. To store data as an integer, you need to convert from `double` to the desired integer type. Use one of the conversion functions shown in the table above.

For example, to store 325 as a 16-bit signed integer assigned to variable `x`, type

```
x = int16(325);
```

If the number being converted to an integer has a fractional part, MATLAB rounds to the nearest integer. If the fractional part is exactly 0.5, then from the two equally nearby integers, MATLAB chooses the one for which the absolute value is larger in magnitude:

```
x = 325.499;          x = x + .001;

int16(x)              int16(x)
ans =                 ans =
    325                326
```

If you need to round a number using a rounding scheme other than the default, MATLAB provides four rounding functions: `round`, `fix`, `floor`, and `ceil`. The `fix` function enables you to override the default and round *towards zero* when there is a nonzero fractional part:

```
x = 325.9;

int16(fix(x))
ans =
    325
```

Arithmetic operations that involve both integers and floating-point always result in an integer data type. MATLAB rounds the result, when necessary,

according to the default rounding algorithm. The example below yields an exact answer of 1426.75 which MATLAB then rounds to the next highest integer:

```
int16(325) * 4.39
ans =
    1427
```

The integer conversion functions are also useful when converting other classes, such as strings, to integers:

```
str = 'Hello World';

int8(str)
ans =
    72  101  108  108  111  32  87  111  114  108  100
```

## Arithmetic Operations on Integer Classes

MATLAB can perform integer arithmetic on the following types of data:

- Integers or integer arrays of the same integer data type. This yields a result that has the same data type as the operands:

```
x = uint32([132 347 528]) .* uint32(75);
class(x)
ans =
    uint32
```

- Integers or integer arrays and scalar double-precision floating-point numbers. This yields a result that has the same data type as the integer operands:

```
x = uint32([132 347 528]) .* 75.49;
class(x)
ans =
    uint32
```

For all binary operations in which one operand is an array of integer data type (except 64-bit integers) and the other is a scalar double, MATLAB computes the operation using elementwise double-precision arithmetic, and then converts the result back to the original integer data type. For binary

operations involving a 64-bit integer array and a scalar double, MATLAB computes the operation as if 80-bit extended-precision arithmetic were used, to prevent loss of precision.

## Largest and Smallest Values for Integer Classes

For each integer data type, there is a largest and smallest number that you can represent with that type. The table shown under “Integers” on page 4-3 lists the largest and smallest values for each integer data type in the “Range of Values” column.

You can also obtain these values with the `intmax` and `intmin` functions:

```
intmax('int8')           intmin('int8')
ans =                    ans =
    127                  -128
```

If you convert a number that is larger than the maximum value of an integer data type to that type, MATLAB sets it to the maximum value. Similarly, if you convert a number that is smaller than the minimum value of the integer data type, MATLAB sets it to the minimum value. For example,

```
x = int8(300)           x = int8(-300)
x =                    x =
    127                  -128
```

Also, when the result of an arithmetic operation involving integers exceeds the maximum (or minimum) value of the data type, MATLAB sets it to the maximum (or minimum) value:

```
x = int8(100) * 3       x = int8(-100) * 3
x =                    x =
    127                  -128
```

## Integer Functions

See Integer Functions on page 4-26 for a list of functions most commonly used with integers in MATLAB.

## Floating-Point Numbers

### In this section...

“Double-Precision Floating Point” on page 4-7

“Single-Precision Floating Point” on page 4-8

“Creating Floating-Point Data” on page 4-8

“Arithmetic Operations on Floating-Point Numbers” on page 4-10

“Largest and Smallest Values for Floating-Point Classes” on page 4-11

“Accuracy of Floating-Point Data” on page 4-12

“Avoiding Common Problems with Floating-Point Arithmetic” on page 4-14

“Floating-Point Functions” on page 4-16

“References” on page 4-16

MATLAB represents floating-point numbers in either double-precision or single-precision format. The default is double precision, but you can make any number single precision with a simple conversion function.

### Double-Precision Floating Point

MATLAB constructs the double-precision (or `double`) data type according to IEEE® Standard 754 for double precision. Any value stored as a `double` requires 64 bits, formatted as shown in the table below:

Bits	Usage
63	Sign (0 = positive, 1 = negative)
62 to 52	Exponent, biased by 1023
51 to 0	Fraction <i>f</i> of the number $1.f$

## Single-Precision Floating Point

MATLAB constructs the single-precision (or `single`) data type according to IEEE Standard 754 for single precision. Any value stored as a `single` requires 32 bits, formatted as shown in the table below:

Bits	Usage
31	Sign (0 = positive, 1 = negative)
30 to 23	Exponent, biased by 127
22 to 0	Fraction $f$ of the number $1.f$

Because MATLAB stores numbers of type `single` using 32 bits, they require less memory than numbers of type `double`, which use 64 bits. However, because they are stored with fewer bits, numbers of type `single` are represented to less precision than numbers of type `double`.

## Creating Floating-Point Data

Use double-precision to store values greater than approximately  $3.4 \times 10^{38}$  or less than approximately  $-3.4 \times 10^{38}$ . For numbers that lie between these two limits, you can use either double- or single-precision, but single requires less memory.

## Creating Double-Precision Data

Because the default numeric type for MATLAB is `double`, you can create a `double` with a simple assignment statement:

```
x = 25.783;
```

The `whos` function shows that MATLAB has created a 1-by-1 array of type `double` for the value you just stored in `x`:

```
whos x
  Name      Size      Bytes  Class
  x         1x1         8      double
```



Use `isfloat` if you just want to verify that `x` is a floating-point number. This function returns logical 1 (true) if the input is a floating-point number, and logical 0 (false) otherwise:

```
isfloat(x)
ans =
     1
```

You can convert other numeric data, characters or strings, and logical data to double precision using the MATLAB function, `double`. This example converts a signed integer to double-precision floating point:

```
y = int64(-589324077574);           % Create a 64-bit integer

x = double(y)                       % Convert to double
x =
    -5.8932e+11
```

## Creating Single-Precision Data

Because MATLAB stores numeric data as a `double` by default, you need to use the `single` conversion function to create a single-precision number:

```
x = single(25.783);
```

The `whos` function returns the attributes of variable `x` in a structure. The `bytes` field of this structure shows that when `x` is stored as a single, it requires just 4 bytes compared with the 8 bytes to store it as a `double`:

```
xAttrib = whos('x');
xAttrib.bytes
ans =
     4
```

You can convert other numeric data, characters or strings, and logical data to single precision using the `single` function. This example converts a signed integer to single-precision floating point:

```
y = int64(-589324077574);           % Create a 64-bit integer

x = single(y)                       % Convert to single
```

```
x =  
-5.8932e+11
```

## Arithmetic Operations on Floating-Point Numbers

This section describes which classes you can use in arithmetic operations with floating-point numbers.

### Double-Precision Operations

You can perform basic arithmetic operations with `double` and any of the following other classes. When one or more operands is an integer (scalar or array), the `double` operand must be a scalar. The result is of type `double`, except where noted otherwise:

- `single` — The result is of type `single`
- `double`
- `int*` or `uint*` — The result has the same data type as the integer operand
- `char`
- `logical`

This example performs arithmetic on data of types `char` and `double`. The result is of type `double`:

```
c = 'uppercase' - 32;
```

```
class(c)  
ans =  
    double
```

```
char(c)  
ans =  
    UPPERCASE
```

### Single-Precision Operations

You can perform basic arithmetic operations with `single` and any of the following other classes. The result is always `single`:

- single
- double
- char
- logical

In this example, 7.5 defaults to type double, and the result is of type single:

```
x = single([1.32 3.47 5.28]) .* 7.5;

class(x)
ans =
    single
```

## Largest and Smallest Values for Floating-Point Classes

For the double and single classes, there is a largest and smallest number that you can represent with that type.

### Largest and Smallest Double-Precision Values

The MATLAB functions `realmax` and `realmin` return the maximum and minimum values that you can represent with the double data type:

```
str = 'The range for double is:\n\t%g to %g and\n\t %g to %g';
sprintf(str, -realmax, -realmin, realmin, realmax)

ans =
The range for double is:
-1.79769e+308 to -2.22507e-308 and
 2.22507e-308 to 1.79769e+308
```

Numbers larger than `realmax` or smaller than `-realmax` are assigned the values of positive and negative infinity, respectively:

```
realmax + .0001e+308
ans =
    Inf

-realmax - .0001e+308
```

```
ans =  
    -Inf
```

### **Largest and Smallest Single-Precision Values**

The MATLAB functions `realmax` and `realmin`, when called with the argument `'single'`, return the maximum and minimum values that you can represent with the `single` data type:

```
str = 'The range for single is:\n\t%g to %g and\n\t %g to %g';  
sprintf(str, -realmax('single'), -realmin('single'), ...  
        realmin('single'), realmax('single'))
```

```
ans =  
The range for single is:  
-3.40282e+38 to -1.17549e-38 and  
 1.17549e-38 to  3.40282e+38
```

Numbers larger than `realmax('single')` or smaller than `-realmax('single')` are assigned the values of positive and negative infinity, respectively:

```
realmax('single') + .0001e+038  
ans =  
    Inf  
  
-realmax('single') - .0001e+038  
ans =  
   -Inf
```

### **Accuracy of Floating-Point Data**

If the result of a floating-point arithmetic computation is not as precise as you had expected, it is likely caused by the limitations of your computer's hardware. Probably, your result was a little less exact because the hardware had insufficient bits to represent the result with perfect accuracy; therefore, it truncated the resulting value.

## Double-Precision Accuracy

Because there are only a finite number of double-precision numbers, you cannot represent all numbers in double-precision storage. On any computer, there is a small gap between each double-precision number and the next larger double-precision number. You can determine the size of this gap, which limits the precision of your results, using the `eps` function. For example, to find the distance between 5 and the next larger double-precision number, enter

```
format long

eps(5)
ans =
    8.881784197001252e-16
```

This tells you that there are no double-precision numbers between 5 and  $5 + \text{eps}(5)$ . If a double-precision computation returns the answer 5, the result is only accurate to within  $\text{eps}(5)$ .

The value of  $\text{eps}(x)$  depends on  $x$ . This example shows that, as  $x$  gets larger, so does  $\text{eps}(x)$ :

```
eps(50)
ans =
    7.105427357601002e-15
```

If you enter `eps` with no input argument, MATLAB returns the value of  $\text{eps}(1)$ , the distance from 1 to the next larger double-precision number.

## Single-Precision Accuracy

Similarly, there are gaps between any two single-precision numbers. If  $x$  has type `single`,  $\text{eps}(x)$  returns the distance between  $x$  and the next larger single-precision number. For example,

```
x = single(5);
eps(x)

returns

ans =
    4.7684e-07
```

Note that this result is larger than `eps(5)`. Because there are fewer single-precision numbers than double-precision numbers, the gaps between the single-precision numbers are larger than the gaps between double-precision numbers. This means that results in single-precision arithmetic are less precise than in double-precision arithmetic.

For a number `x` of type `double`, `eps(single(x))` gives you an upper bound for the amount that `x` is rounded when you convert it from `double` to `single`. For example, when you convert the double-precision number `3.14` to `single`, it is rounded by

```
double(single(3.14) - 3.14)
ans =
    1.0490e-07
```

The amount that `3.14` is rounded is less than

```
eps(single(3.14))
ans =
    2.3842e-07
```

## Avoiding Common Problems with Floating-Point Arithmetic

Almost all operations in MATLAB are performed in double-precision arithmetic conforming to the IEEE standard 754. Because computers only represent numbers to a finite precision (double precision calls for 52 mantissa bits), computations sometimes yield mathematically nonintuitive results. It is important to note that these results are not bugs in MATLAB.

Use the following examples to help you identify these cases:

### Example 1 — Round-Off or What You Get Is Not What You Expect

The decimal number  $4/3$  is not exactly representable as a binary fraction. For this reason, the following calculation does not give zero, but rather reveals the quantity `eps`.

```
e = 1 - 3*(4/3 - 1)
```

```
e =  
    2.2204e-16
```

Similarly, 0.1 is not exactly representable as a binary number. Thus, you get the following nonintuitive behavior:

```
a = 0.0;  
for i = 1:10  
    a = a + 0.1;  
end  
a == 1
```

```
ans =  
    0
```

Note that the order of operations can matter in the computation:

```
b = 1e-16 + 1 - 1e-16;  
c = 1e-16 - 1e-16 + 1;  
b == c
```

```
ans =  
    0
```

There are gaps between floating-point numbers. As the numbers get larger, so do the gaps, as evidenced by:

```
(2^53 + 1) - 2^53
```

```
ans =  
    0
```

Since  $\pi$  is not really  $\pi$ , it is not surprising that  $\sin(\pi)$  is not exactly zero:

```
sin(pi)
```

```
ans =  
    1.224646799147353e-16
```

### **Example 2 – Catastrophic Cancellation**

When subtractions are performed with nearly equal operands, sometimes cancellation can occur unexpectedly. The following is an example of a cancellation caused by swamping (loss of precision that makes the addition insignificant).

```
sqrt(1e-16 + 1) - 1
```

```
ans =  
    0
```

Some functions in MATLAB, such as `expm1` and `log1p`, may be used to compensate for the effects of catastrophic cancellation.

### **Example 3 – Floating-Point Operations and Linear Algebra**

Round-off, cancellation, and other traits of floating-point arithmetic combine to produce startling computations when solving the problems of linear algebra. MATLAB warns that the following matrix `A` is ill-conditioned, and therefore the system  $Ax = b$  may be sensitive to small perturbations:

```
A = diag([2 eps]);  
b = [2; eps];  
y = A\b;  
Warning: Matrix is close to singular or badly scaled.  
Results may be inaccurate. RCOND = 1.110223e-16.
```

These are only a few of the examples showing how IEEE floating-point arithmetic affects computations in MATLAB. Note that all computations performed in IEEE 754 arithmetic are affected, this includes applications written in C or FORTRAN, as well as MATLAB.

## **Floating-Point Functions**

See [Floating-Point Functions](#) on page 4-27 for a list of functions most commonly used with floating-point numbers in MATLAB.

## **References**

The following references provide more information about floating-point arithmetic.



## References

- [1] Moler, Cleve, "Floating Points," *MATLAB News and Notes*, Fall, 1996. A PDF version is available on the MathWorks Web site at [http://www.mathworks.com/company/newsletters/news\\_notes/pdf/Fall96Cleve.pdf](http://www.mathworks.com/company/newsletters/news_notes/pdf/Fall96Cleve.pdf)
- [2] Moler, Cleve, *Numerical Computing with MATLAB*, S.I.A.M. A PDF version is available on the MathWorks Web site at <http://www.mathworks.com/moler/>.

## Complex Numbers

### In this section...

“Creating Complex Numbers” on page 4-18

“Complex Number Functions” on page 4-19

### Creating Complex Numbers

Complex numbers consist of two separate parts: a real part and an imaginary part. The basic imaginary unit is equal to the square root of -1. This is represented in MATLAB by either of two letters: `i` or `j`.

The following statement shows one way of creating a complex value in MATLAB. The variable `x` is assigned a complex number with a real part of 2 and an imaginary part of 3:

```
x = 2 + 3i;
```

Another way to create a complex number is using the `complex` function. This function combines two numeric inputs into a complex output, making the first input real and the second imaginary:

```
x = rand(3) * 5;
y = rand(3) * -8;
```

```
z = complex(x, y)
```

```
z =
    4.7842 -1.0921i    0.8648 -1.5931i    1.2616 -2.2753i
    2.6130 -0.0941i    4.8987 -2.3898i    4.3787 -3.7538i
    4.4007 -7.1512i    1.3572 -5.2915i    3.6865 -0.5182i
```

You can separate a complex number into its real and imaginary parts using the `real` and `imag` functions:

```
zr = real(z)
zr =
    4.7842    0.8648    1.2616
    2.6130    4.8987    4.3787
    4.4007    1.3572    3.6865
```

```
zi = imag(z)
zi =
    -1.0921    -1.5931    -2.2753
    -0.0941    -2.3898    -3.7538
    -7.1512    -5.2915    -0.5182
```

## Complex Number Functions

See Complex Number Functions on page 4-27 for a list of functions most commonly used with MATLAB complex numbers in MATLAB.

## Infinity and NaN

### In this section...

“Infinity” on page 4-20

“NaN” on page 4-20

“Infinity and NaN Functions” on page 4-21

### Infinity

MATLAB represents infinity by the special value `inf`. Infinity results from operations like division by zero and overflow, which lead to results too large to represent as conventional floating-point values. MATLAB also provides a function called `inf` that returns the IEEE arithmetic representation for positive infinity as a `double` scalar value.

Several examples of statements that return positive or negative infinity in MATLAB are shown here.

<pre>x = 1/0 x = Inf</pre>	<pre>x = 1.e1000 x = Inf</pre>
<pre>x = exp(1000) x = Inf</pre>	<pre>x = log(0) x = -Inf</pre>

Use the `isinf` function to verify that `x` is positive or negative infinity:

```
x = log(0);
```

```
isinf(x)
ans =
    1
```

### NaN

MATLAB represents values that are not real or complex numbers with a special value called NaN, which stands for Not a Number. Expressions like `0/0` and `inf/inf` result in NaN, as do any arithmetic operations involving a NaN:

```
x = 0/0
x =
    NaN
```

Use the `isnan` function to verify that the real part of `x` is NaN:

```
isnan(x)
ans =
     1
```

MATLAB also provides a function called `NaN` that returns the IEEE arithmetic representation for NaN as a `double` scalar value:

```
x = NaN;

whos x
      Name      Size      Bytes  Class
      x         1x1         8      double
```

### Logical Operations on NaN

Because two NaNs are not equal to each other, logical operations involving NaN always return false, except for a test for inequality, (`NaN ~= NaN`):

```
NaN > NaN
ans =
     0
```

```
NaN ~= NaN
ans =
     1
```

### Infinity and NaN Functions

See [Infinity and NaN Functions](#) on page 4-28 for a list of functions most commonly used with `inf` and `NaN` in MATLAB.

## Identifying Numeric Classes

You can check the data type of a variable `x` using any of these commands.

Command	Operation
<code>whos x</code>	Display the data type of <code>x</code> .
<code>xType = class(x);</code>	Assign the data type of <code>x</code> to a variable.
<code>isnumeric(x)</code>	Determine if <code>x</code> is a numeric type.
<code>isa(x, 'integer')</code> <code>isa(x, 'uint64')</code> <code>isa(x, 'float')</code> <code>isa(x, 'double')</code> <code>isa(x, 'single')</code>	Determine if <code>x</code> is the specified numeric type. (Examples for any integer, unsigned 64-bit integer, any floating point, double precision, and single precision are shown here).
<code>isreal(x)</code>	Determine if <code>x</code> is real or complex.
<code>isnan(x)</code>	Determine if <code>x</code> is Not a Number (NaN).
<code>isinf(x)</code>	Determine if <code>x</code> is infinite.
<code>isfinite(x)</code>	Determine if <code>x</code> is finite.

# Display Format for Numeric Values

## In this section...

“Default Display” on page 4-23

“Display Format Examples” on page 4-23

“Setting Numeric Format in a Program” on page 4-24

## Default Display

By default, MATLAB displays numeric output as 5-digit scaled, fixed-point values. You can change the way numeric values are displayed to any of the following:

- 5-digit scaled fixed point, floating point, or the best of the two
- 15-digit scaled fixed point, floating point, or the best of the two
- A ratio of small integers
- Hexadecimal (base 16)
- Bank notation

All available formats are listed on the format reference page.

To change the numeric display setting, use either the `format` function or the **Preferences** dialog box (accessible from the MATLAB **File** menu). The `format` function changes the display of numeric values for the duration of a single MATLAB session, while your Preferences settings remain active from one session to the next. These settings affect only how numbers are displayed, not how MATLAB computes or saves them.

## Display Format Examples

Here are a few examples of the various formats and the output produced from the following two-element vector `x`, with components of different magnitudes.

Check the current format setting:

```
get(0, 'format')
```

```
ans =  
short
```

Set the value for x and display in 5-digit scaled fixed point:

```
x = [4/3 1.2345e-6]  
x =  
1.3333    0.0000
```

Set the format to 5-digit floating point:

```
format short e  
x  
x =  
1.3333e+00    1.2345e-06
```

Set the format to 15-digit scaled fixed point:

```
format long  
x  
x =  
1.333333333333333    0.000001234500000
```

Set the format to 'rational' for small integer ratio output:

```
format rational  
x  
x =  
4/3          1/810045
```

Set an integer value for x and display it in hexadecimal (base 16) format:

```
format hex  
x = uint32(876543210)  
x =  
343efcea
```

### Setting Numeric Format in a Program

To temporarily change the numeric format inside a program, get the original format using the `get` function and save it in a variable. When you finish



working with the new format, you can restore the original format setting using the `set` function as shown here:

```
origFormat = get(0, 'format');  
format('rational');  
  
-- Work in rational format --  
  
set(0,'format', origFormat);
```

## Function Summary

MATLAB provides these functions for working with numeric classes:

- Integer Functions on page 4-26
- Floating-Point Functions on page 4-27
- Complex Number Functions on page 4-27
- Infinity and NaN Functions on page 4-28
- Class Identification Functions on page 4-28
- Output Formatting Functions on page 4-28

### Integer Functions

Function	Description
int8, int16, int32, int64	Convert to signed 1-, 2-, 4-, or 8-byte integer.
uint8, uint16, uint32, uint64	Convert to unsigned 1-, 2-, 4-, or 8-byte integer.
ceil	Round towards plus infinity to nearest integer
class	Return the data type of an object.
fix	Round towards zero to nearest integer
floor	Round towards minus infinity to nearest integer
isa	Determine if input value has the specified data type.
isinteger	Determine if input value is an integer array.
isnumeric	Determine if input value is a numeric array.
round	Round towards the nearest integer

### Floating-Point Functions

Function	Description
double	Convert to double precision.
single	Convert to single precision.
class	Return the data type of an object.
isa	Determine if input value has the specified data type.
isfloat	Determine if input value is a floating-point array.
isnumeric	Determine if input value is a numeric array.
eps	Return the floating-point relative accuracy. This value is the tolerance MATLAB uses in its calculations.
realmax	Return the largest floating-point number your computer can represent.
realmin	Return the smallest floating-point number your computer can represent.

### Complex Number Functions

Function	Description
complex	Construct complex data from real and imaginary components.
i or j	Return the imaginary unit used in constructing complex data.
real	Return the real part of a complex number.
imag	Return the imaginary part of a complex number.
isreal	Determine if a number is real or imaginary.

**Infinity and NaN Functions**

<b>Function</b>	<b>Description</b>
inf	Return the IEEE value for infinity.
isnan	Detect NaN elements of an array.
isinf	Detect infinite elements of an array.
isfinite	Detect finite elements of an array.
nan	Return the IEEE value for Not a Number.

**Class Identification Functions**

<b>Function</b>	<b>Description</b>
class	Return data type (or class).
isa	Determine if input value is of the specified data type.
isfloat	Determine if input value is a floating-point array.
isinteger	Determine if input value is an integer array.
isnumeric	Determine if input value is a numeric array.
isreal	Determine if input value is real.
whos	Display the data type of input.

**Output Formatting Functions**

<b>Function</b>	<b>Description</b>
format	Control display format for output.

# The Logical Class

---

- “Find Array Elements That Meet a Condition” on page 5-2
- “Determine if Arrays Are Logical” on page 5-8
- “Reduce Logical Arrays to Single Value” on page 5-12
- “Truth Table for Logical Operations” on page 5-15

## Find Array Elements That Meet a Condition

You can filter the elements of an array by applying one or more conditions to the array. For instance, if you want to examine only the even elements in a matrix, find the location of all 0s in a multidimensional array, or replace NaN values in a discrete set of data. You can perform these tasks using a combination of the relational and logical operators. The relational operators ( $>$ ,  $<$ ,  $>=$ ,  $<=$ ,  $=$ ,  $\neq$ ) impose conditions on the array, and you can apply multiple conditions by connecting them with the logical operators **and**, **or**, and **not**, respectively denoted by  $\&$ ,  $|$ , and  $\sim$ .

### In this section...

“Apply a Single Condition” on page 5-2

“Apply Multiple Conditions” on page 5-4

“Replace Values that Meet a Condition” on page 5-5

### Apply a Single Condition

To apply a single condition, start by creating a 5-by-5 matrix, *A*, that contains random integers between 1 and 15.

```
rng(0);
A = randi(15,5)
```

A =

```
    13     2     3     3    10
    14     5    15     7     1
     2     9    15    14    13
    14    15     8    12    15
    10    15    13    15    11
```

Use the relational *less than* operator,  $<$ , to determine which elements of *A* are less than 9. Store the result in *B*.

```
B = A < 9
```

B =

```

0     1     1     1     0
0     1     0     1     1
1     0     0     0     0
0     0     1     0     0
0     0     0     0     0

```

The result is a logical matrix. Each value in **B** represents a logical 1 (**true**) or logical 0 (**false**) state to indicate whether the corresponding element of **A** fulfills the condition  $A < 9$ . For example,  $A(1,1)$  is 13, so  $B(1,1)$  is logical 0 (**false**). However,  $A(1,2)$  is 2, so  $B(1,2)$  is logical 1 (**true**).

Although **B** contains information about *which* elements in **A** are less than 9, it doesn't tell you what their *values* are. Rather than comparing the two matrices element by element, use **B** to index into **A**.

```
A(B)
```

```
ans =
```

```

2
2
5
3
8
3
7
1

```

The result is a column vector of the elements in **A** that are less than 9. Since **B** is a logical matrix, this operation is called *logical indexing*. In this case, the logical array being used as an index is the same size as the other array, but this is not a requirement. For more information, see “Using Logicals in Array Indexing”.

Some problems require information about the *locations* of the array elements that meet a condition rather than their actual values. In this example, use the `find` function to locate all of the elements in **A** less than 9.

```
I = find(A < 9)
```

```
I =
```

```
3
6
7
11
14
16
17
22
```

The result is a column vector of linear indices. Each index describes the location of an element in A that is less than 9, so in practice A(I) returns the same result as A(B). The difference is that A(B) uses logical indexing, whereas A(I) uses linear indexing.

## Apply Multiple Conditions

You can use the logical and, or, and not operators to apply any number of conditions to an array; the number of conditions is not limited to one or two.

First, use the logical and operator, denoted &, to specify two conditions: the elements must be less than 9 AND greater than 2. Specify the conditions as a logical index to view the elements that satisfy both conditions.

```
A(A<9 & A>2)
```

```
ans =
```

```
5
3
8
3
7
```

The result is a list of the elements in A that satisfy both conditions. Be sure to specify each condition with a separate statement connected by a logical operator. For example, you cannot specify the conditions above by A(2<A<9), since it evaluates to A(2<A | A<9).

Next, find the elements in A that are less than 9 AND even numbered.



```
A(A<9 & ~mod(A,2))
```

```
ans =
```

```
2
2
8
```

The result is a list of all even elements in A that are less than 9. The use of the logical NOT operator, ~, converts the matrix `mod(A,2)` into a logical matrix, with a value of logical 1 (true) located where an element is evenly divisible by 2.

Finally, find the elements in A that are less than 9 AND even numbered AND not equal to 2.

```
A(A<9 & ~mod(A,2) & A~=2)
```

```
ans =
```

```
8
```

The result, 8, is even, less than 9, and not equal to 2. It is the only element in A that satisfies all three conditions.

Use the `find` function to get the index of the 8 element that satisfies the conditions.

```
find(A<9 & ~mod(A,2) & A~=2)
```

```
ans =
```

```
14
```

The result indicates that `A(14) = 8`.

## Replace Values that Meet a Condition

Sometimes it is useful to simultaneously change the values of several existing array elements. Use logical indexing with a simple assignment statement to replace the values in an array that meet a condition.

Replace all values in A that are greater than 10 with the number 10.

```
A(A>10) = 10
```

```
A =
```

10	2	3	3	10
10	5	10	7	1
2	9	10	10	10
10	10	8	10	10
10	10	10	10	10

A now has a maximum value of 10.

Replace all values in A that are not equal to 10 with a NaN value.

```
A(A~=10) = NaN
```

```
A =
```

10	NaN	NaN	NaN	10
10	NaN	10	NaN	NaN
NaN	NaN	10	10	10
10	10	NaN	10	10
10	10	10	10	10

The resulting matrix has element values of 10 or NaN.

Replace all of the NaN values in A with zeros and apply the logical NOT operator, ~A.

```
A(isnan(A)) = 0;
```

```
C = ~A
```

```
C =
```

0	1	1	1	0
0	1	0	1	1
1	1	0	0	0
0	0	1	0	0
0	0	0	0	0

The resulting matrix has values of logical 1 (`true`) in place of the NaN values, and logical 0 (`false`) in place of the 10s. The logical NOT operation, `~A`, converts the numeric array into a logical array such that `A&C` returns a matrix of logical 0 (`false`) values and `A|C` returns a matrix of logical 1 (`true`) values.

**See Also**

`nan` | Logical Operators: Short Circuit | `isnan` | `find` | `and` | `or`  
| `xor` | `not`

## Determine if Arrays Are Logical

To determine whether an array is logical, you can test the entire array or each element individually. This is useful when you want to confirm the output data type of a function.

This page shows several ways to determine if an array is logical.

In this section...
“Identify Logical Matrix” on page 5-8
“Test an Entire Array” on page 5-9
“Test Each Array Element” on page 5-9
“Summary Table” on page 5-10

### Identify Logical Matrix

Create a 3-by-6 matrix and locate all elements greater than 0.5.

```
A = gallery('uniformdata',[3,6],0) > 0.5
```

```
A =
```

```

     1     0     0     0     1     0
     0     1     0     1     1     1
     1     1     1     1     0     1

```

The result, A, is a 3-by-6 logical matrix.

Use the whos function to confirm the size, byte count, and class (or data type) of the matrix, A.

```
whos A
```

```

Name      Size      Bytes  Class      Attributes
A         3x6         18    logical

```

The result confirms that A is a 3-by-6 logical matrix.

## Test an Entire Array

Use the `islogical` function to test whether `A` is logical.

```
islogical(A)
```

```
ans =
```

```
1
```

The result is logical 1 (true).

Use the `class` function to display a string with the class name of `A`.

```
class(A)
```

```
ans =
```

```
logical
```

The result confirms that `A` is logical.

## Test Each Array Element

Create a cell array, `C`, and use the `'islogical'` option of the `cellfun` function to identify which cells contain logical values.

```
C = {1, 0, true, false, pi, A};  
cellfun('islogical',C)
```

```
ans =
```

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

The result is a logical array of the same size as `C`.

To test each element in a numeric matrix, use the `arrayfun` function.

```
arrayfun(@islogical,A)
```

```
ans =
```

```
1    1    1    1    1    1
```

```

1     1     1     1     1     1
1     1     1     1     1     1

```

The result is a matrix of logical values of the same size as `A`. `arrayfun(@islogical,A)` always returns a matrix of all logical 1 (true) or logical 0 (false) values.

## Summary Table

Use these MATLAB functions to determine if an array is logical.

Function Syntax	Output Size	Description
<code>whos(A)</code>	N/A	Displays the name, size, storage bytes, class, and attributes of variable <code>A</code> .
<code>islogical(A)</code>	scalar	Returns logical 1 (true) if <code>A</code> is a logical array; otherwise, it returns logical 0 (false). The result is the same as using <code>isa(A,'logical')</code> .
<code>isa(A,'logical')</code>	scalar	Returns logical 1 (true) if <code>A</code> is a logical array; otherwise, it returns logical 0 (false). The result is the same as using <code>islogical(A)</code> .
<code>class(A)</code>	single string	Returns a string with the name of the class of variable <code>A</code> .

Function Syntax	Output Size	Description
<code>cellfun('islogical',A)</code>	Array of the same size as A	For cell arrays only. Returns logical 1 (true) for each cell that contains a logical array; otherwise, it returns logical 0 (false).
<code>arrayfun(@islogical,A)</code>	Array of the same size as A	Returns an array of logical 1 (true) values if A is logical; otherwise, it returns an array of logical 0 (false) values.

**See Also**

`islogical` | `isa` | `class` | `cellfun` | `arrayfun` | `whos`

## Reduce Logical Arrays to Single Value

Sometimes the result of a calculation produces an entire numeric or logical array when you need only a single logical `true` or `false` value. In this case, use the `any` or `all` functions to reduce the array to a single scalar logical for further computations.

The `any` and `all` functions are natural extensions of the logical `|` (OR) and `&` (AND) operators, respectively. However, rather than comparing just two elements, the `any` and `all` functions compare all of the elements in a particular dimension of an array. It is as if all of those elements are connected by `&` or `|` operators and the `any` or `all` functions evaluate the resulting long logical expression(s). Therefore, unlike the core logical operators, the `any` and `all` functions reduce the size of the array dimension that they operate on so that it has size 1. This enables the reduction of many logical values into a single logical condition.

First, create a matrix, `A`, that contains random integers between 1 and 25.

```
rng(0)
A = randi(25,5)
```

A =

```
    21     3     4     4    17
    23     7    25    11     1
     4    14    24    23    22
    23    24    13    20    24
    16    25    21    24    17
```

Next, use the `mod` function along with the logical NOT operator, `~`, to determine which elements in `A` are even.

```
A = ~mod(A,2)
```

A =

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



```

0   1   0   1   1
1   0   0   1   0

```

The resulting matrices have values of logical 1 (true) where an element is even, and logical 0 (false) where an element is odd.

Since the `any` and `all` functions reduce the dimension that they operate on to size 1, it normally takes two applications of one of the functions to reduce a 2-D matrix into a single logical condition, such as `any(any(A))`. However, if you use the notation `A(:)` to regard all of the elements of `A` as a single column vector, you can use `any(A(:))` to get the same logical information without nesting the function calls.

Determine if any elements in `A` are even.

```
any(A(:))
```

```
ans =
```

```
1
```

The result is logical 1 (true).

You can perform logical and relational comparisons within the function call to `any` or `all`. This makes it easy to quickly test an array for a variety of properties.

Determine if all elements in `A` are odd.

```
all(~A(:))
```

```
ans =
```

```
0
```

The result is logical 0 (false).

Determine whether any main or super diagonal elements in `A` are even.

```
any(diag(A) | diag(A,1))
```

```
Error using |
```

Inputs must have the same size.

MATLAB returns an error since the vectors returned by `diag(A)` and `diag(A,1)` are not the same size.

To reduce each diagonal to a single scalar logical condition and allow logical short-circuiting, use the `any` function on each side of the short-circuit OR operator, `||`.

```
any(diag(A)) || any(diag(A,1))
```

```
ans =
```

```
1
```

The result is logical 1 (true). It no longer matters that `diag(A)` and `diag(A,1)` are not the same size.

### See Also

`any` | `all` | `and` | `or` | `xor` | Logical Operators: Short Circuit

## Truth Table for Logical Operations

The following reference table shows the results of applying the binary logical operators to a series of logical 1 (true) and logical 0 (false) scalar pairs. To calculate NAND, NOR or XNOR logical operations, simply apply the logical NOT operator to the result of a logical AND, OR, or XOR operation, respectively.

Inputs A and B		andA & B	orA   B	xorxor(A,B)	not-A
0	0	0	0	0	1
0	1	0	1	1	1
1	0	0	1	1	0
1	1	1	1	0	0

### See Also

and | or | xor | not | Logical Operators: Short Circuit



# Characters and Strings

---

- “Creating Character Arrays” on page 6-2
- “Cell Arrays of Strings” on page 6-7
- “Formatting Strings” on page 6-10
- “String Comparisons” on page 6-25
- “Searching and Replacing” on page 6-28
- “Converting from Numeric to String” on page 6-30
- “Converting from String to Numeric” on page 6-32
- “Function Summary” on page 6-35

## Creating Character Arrays

### In this section...

“Creating a Character String” on page 6-2

“Creating a Rectangular Character Array” on page 6-3

“Identifying Characters in a String” on page 6-4

“Working with Space Characters” on page 6-5

“Expanding Character Arrays” on page 6-6

### Creating a Character String

Create a string by enclosing a sequence of letters in single quotation marks, such as

```
myString = 'Hello, world';
```

If the text contains a single quotation mark, include two quotation marks within the string definition.

```
otherString = 'You''re right';
```

In the MATLAB computing environment, all variables are arrays, and strings are of type `char` (character arrays).

```
whos myString
```

Name	Size	Bytes	Class	Attributes
myString	1x12	24	char	

Functions such as `uint16` convert characters to their numeric codes:

```
str_numeric = uint16(str)
```

```
str_numeric =
    72  101  108  108  111
```

The `char` function converts the integer vector back to characters:

```
str_alpha = char([72 101 108 108 111])
```

```
str_alpha =
    Hello
```

## Creating a Rectangular Character Array

You can join two or more strings together to create a new character array. This is called *concatenation* and is explained for numeric arrays in the section “Concatenating Matrices”. As with numeric arrays, you can combine character arrays vertically or horizontally to create a new character array.

Alternatively, combine strings into a cell array. Cell arrays are flexible containers that allow you to easily combine strings of varying length.

## Combining Strings Vertically

To combine strings into a two-dimensional character array, use either of these methods:

- Apply the MATLAB concatenation operator, `[]`. Separate each row with a semicolon (`;`). Each row must contain the same number of characters. For example, combine three strings of equal length:

```
dev_title = ['Thomas R. Lee'; ...
            'Sr. Developer'; ...
            'SFTware Corp.'];
```

If the strings have different lengths, pad with space characters as needed. For example:

```
mgr_title = ['Harold A. Jorgensen      '; ...
            'Assistant Project Manager'; ...
            'SFTware Corp.           '];
```

- Call the `char` function. If the strings are different length, `char` pads the shorter strings with trailing blanks so that each row has the same number of characters. For example, combine three strings of different lengths:

```
mgr_title = char('Harold A. Jorgensen', ...
                'Assistant Project Manager', 'SFTware Corp.');
```

The `char` function creates a 3-by-25 character array `mgr_title`.

### Combining Strings Horizontally

To combine strings into a single row vector, use either of these methods:

- Apply the MATLAB concatenation operator, `[]`. Separate the input strings with a comma or a space. This method preserves any trailing spaces in the input arrays. For example, combine several strings:

```
name = 'Thomas R. Lee';
title = 'Sr. Developer';
company = 'SFTware Corp.';

full_name = [name ' ', ' title ', ' company]
```

MATLAB returns

```
full_name =
    Thomas R. Lee, Sr. Developer, SFTware Corp.
```

- Call the string concatenation function, `strcat`. This method removes trailing spaces in the inputs. For example, combine strings to create a hypothetical email address:

```
name = 'myname ';
domain = 'mydomain ';
ext = 'com ';

address = strcat(name, '@', domain, '.', ext)
```

MATLAB returns

```
address =
    myname@mydomain.com
```

### Identifying Characters in a String

Use any of the following functions to identify a character or string, or certain characters in a string:



Function	Description
<code>ischar</code>	Determine whether the input is a character array.
<code>isletter</code>	Find all alphabetic letters in the input string.
<code>isspace</code>	Find all space characters in the input string.
<code>isstrprop</code>	Find all characters of a specific category.

```
str = 'Find the space characters in this string';
%           |   |   |           |   |   |
%           5   9   15           26 29   34

find(isspace(str))
ans =
     5     9    15    26    29    34
```

## Working with Space Characters

The `blanks` function creates a string of space characters. The following example creates a string of 15 space characters:

```
s = blanks(15)
s =
```

To make the example more useful, append a `|` character to the beginning and end of the blank string so that you can see the output:

```
[ '|' s '|' ]           % Make result visible.
ans =
 |               |
```

Insert a few nonspace characters in the middle of the blank string:

```
s(6:10) = 'AAAAA';

[ '|' s '|' ]           % Make result visible.
ans =
 |       AAAAA       |
```

You can justify the positioning of these characters to the left or right using the `strjust` function:

```
sLeft = strjust(s, 'left');  
  
['|' sLeft '|']          % Make result visible.  
ans =  
    |AAAAA|
```

```
sRight = strjust(s, 'right');  
  
['|' sRight '|']        % Make result visible.  
ans =  
    |          AAAAA|
```

Remove all trailing space characters with `deblank`:

```
sDeblank = deblank(s);  
  
['|' sDeblank '|']      % Make result visible.  
ans =  
    |          AAAAA|
```

Remove all leading and trailing spaces with `strtrim`:

```
sTrim = strtrim(s);  
  
['|' sTrim '|']        % Make result visible.  
ans =  
    |AAAAA|
```

### Expanding Character Arrays

Generally, MathWorks does not recommend expanding the size of an existing character array by assigning additional characters to indices beyond the bounds of the array such that part of the array becomes padded with zeros.

## Cell Arrays of Strings

### In this section...

“Converting to a Cell Array of Strings” on page 6-7

“Functions for Cell Arrays of Strings” on page 6-8

### Converting to a Cell Array of Strings

Creating strings in a regular MATLAB array requires that all strings in the array be of the same length. This often means that you have to pad blanks at the end of strings to equalize their length. However, another type of MATLAB array, the cell array, can hold different sizes and types of data in an array without padding. Cell arrays provide a more flexible way to store strings of varying length.

The `cellstr` function converts a character array into a cell array of strings. Consider this character array:

```
data = ['Allison Jones'; 'Development   '; 'Phoenix       '];
```

Each row of the matrix is padded so that all have equal length (in this case, 13 characters).

Now use `cellstr` to create a column vector of cells, each cell containing one of the strings from the `data` array:

```
celldata = cellstr(data)
celldata =
    'Allison Jones'
    'Development'
    'Phoenix'
```

Note that the `cellstr` function strips off the blanks that pad the rows of the input string matrix:

```
length(celldata{3})
ans =
    7
```

The `iscellstr` function determines if the input argument is a cell array of strings. It returns a logical 1 (`true`) in the case of `celldata`:

```
iscellstr(celldata)
ans =
     1
```

Use `char` to convert back to a standard padded character array:

```
strings = char(celldata)
strings =
    Allison Jones
    Development
    Phoenix
```

```
length(strings(3,:))
ans =
    13
```

For more information on cell arrays, see “Access Data in a Cell Array” on page 10-5.

### Functions for Cell Arrays of Strings

This table describes the MATLAB functions for working with cell arrays.

Function	Description
<code>cellstr</code>	Convert a character array to a cell array of strings.
<code>char</code>	Convert a cell array of strings to a character array.
<code>deblank</code>	Remove trailing blanks from a string.
<code>iscellstr</code>	Return <code>true</code> for a cell array of strings.
<code>sort</code>	Sort elements in ascending or descending order.
<code>strcat</code>	Concatenate strings.
<code>strcmp</code>	Compare strings.

You can also use the following `set` functions with cell arrays of strings.

<b>Function</b>	<b>Description</b>
<code>intersect</code>	Set the intersection of two vectors.
<code>ismember</code>	Detect members of a set.
<code>setdiff</code>	Return the set difference of two vectors.
<code>setxor</code>	Set the exclusive OR of two vectors.
<code>union</code>	Set the union of two vectors.
<code>unique</code>	Set the unique elements of a vector.

## Formatting Strings

In this section...
“Functions that Use Format Strings” on page 6-10
“The Format String” on page 6-11
“Input Value Arguments” on page 6-12
“The Formatting Operator” on page 6-13
“Constructing the Formatting Operator” on page 6-14
“Setting Field Width and Precision” on page 6-20
“Restrictions for Using Identifiers” on page 6-23

### Functions that Use Format Strings

The following MATLAB functions offer the capability to compose a string that includes ordinary text and data formatted to your specification:

- `fprintf` — Write formatted data to an output string
- `fprintf` — Write formatted data to an output file or the Command Window
- `warning` — Display formatted data in a warning message
- `error` — Display formatted data in an error message and abort
- `assert` — Generate an error when a condition is violated
- `MException` — Capture error information

The syntax of each of these functions includes formatting operators similar to those used by the `printf` function in the C programming language. For example, `%s` tells MATLAB to interpret an input value as a string, and `%d` means to format an integer using decimal notation.

The general formatting syntax for these functions is

```
functionname(..., format_string, value1, value2, ..., valueN)
```

where the `format_string` argument expresses the basic content and formatting of the final output string, and the `value` arguments that follow supply data values to be inserted into the string.

Here is a sample `sprintf` statement, also showing the resulting output string:

```
sprintf('The price of %s on %d/%d/%d was $%.2f.', ...
        'bread', 7, 1, 2006, 2.49)
ans =
    The price of bread on 7/1/2006 was $2.49.
```

---

**Note** The examples in this section of the documentation use only the `sprintf` function to demonstrate how string formatting works. However, you can run the examples using the `fprintf`, `warning`, and `error` functions as well.

---

## The Format String

The first input argument in the `sprintf` statement shown above is the `format_string`:

```
'The price of %s on %d/%d/%d was $%.2f.'
```

This argument can include ordinary text, formatting operators and, in some cases, special characters. The formatting operators for this particular string are: `%s`, `%d`, `%d`, `%d`, and `%.2f`.

Following the `format_string` argument are five additional input arguments, one for each of the formatting operators in the string:

```
'bread', 7, 1, 2006, 2.49
```

When MATLAB processes the format string, it replaces each operator with one of these input values.

## Special Characters

Special characters are a part of the text in the string. But, because they cannot be entered as ordinary text, they require a unique character sequence to represent them. Use any of the following character sequences to insert special characters into the output string.

To Insert a . . .	Use . . .
Single quotation mark	' '
Percent character	%
Backslash	\\
Alarm	\a
Backspace	\b
Form feed	\f
New line	\n
Carriage return	\r
Horizontal tab	\t
Vertical tab	\v
Hexadecimal number, N	\xN
Octal number, N	\N

## Input Value Arguments

In the syntax

```
functionname(..., format_string, value1, value2, ..., valueN)
```

The value arguments must immediately follow `format_string` in the argument list. In most instances, you supply one of these value arguments for each formatting operator used in the `format_string`. Scalars, vectors, and numeric and character arrays are valid value arguments. You cannot use cell arrays or structures.

If you include fewer formatting operators than there are values to insert, MATLAB reuses the operators on the additional values. This example shows two formatting operators and six values to insert into the string:

```
sprintf('%s = %d\n', 'A', 479, 'B', 352, 'C', 651)
ans =
  A = 479
  B = 352
  C = 651
```



You can also specify multiple value arguments as a vector or matrix. The `format_string` needs one `%s` operator for the entire matrix or vector:

```
mvec = [77 65 84 76 65 66];

sprintf('%s ', char(mvec))
ans =
    MATLAB
```

## Sequential and Numbered Argument Specification

You can place value arguments in the argument list either sequentially (that is, in the same order in which their formatting operators appear in the string), or by identifier (adding a number to each operator that identifies which value argument to replace it with). By default, MATLAB uses sequential ordering.

To specify arguments by a numeric identifier, add a positive integer followed by a `$` sign immediately after the `%` sign in the operator. Numbered argument specification is explained in more detail under the topic “Value Identifiers” on page 6-20.

Ordered Sequentially	Ordered By Identifier
<pre>sprintf('%s %s %s', ...     '1st', '2nd', '3rd') ans =     1st 2nd 3rd</pre>	<pre>sprintf('%3\$s %2\$s %1\$s', ...     '1st', '2nd', '3rd') ans =     3rd 2nd 1st</pre>

## The Formatting Operator

Formatting operators tell MATLAB how to format the numeric or character value arguments and where to insert them into the string. These operators control the notation, alignment, significant digits, field width, and other aspects of the output string.

A formatting operator begins with a `%` character, which may be followed by a series of one or more numbers, characters, or symbols, each playing a role in further defining the format of the insertion value. The final entry in this series is a single *conversion character* that MATLAB uses to define the notation

style for the inserted data. Conversion characters used in MATLAB are based on those used by the `printf` function in the C programming language.

Here is a simple example showing five formatting variations for a common value:

```
A = pi*100*ones(1,5);

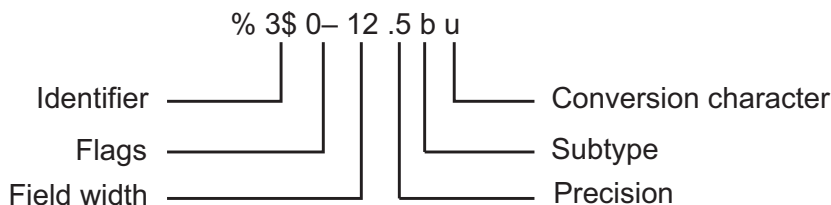
sprintf(' %f \n %.2f \n %+.2f \n %12.2f \n %012.2f \n', A)
ans =
    314.159265      % Display in fixed-point notation (%f)
    314.16         % Display 2 decimal digits (%.2f)
   +314.16        % Display + for positive numbers (%+.2f)
         314.16   % Set width to 12 characters (%12.2f)
000000314.16    % Replace leading spaces with 0 (%012.2f)
```

## Constructing the Formatting Operator

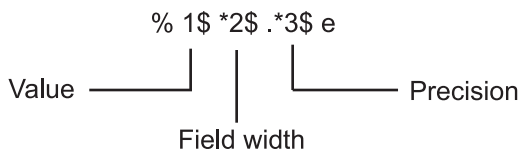
The fields that make up a formatting operator in MATLAB are as shown here, in the order they appear from right to left in the operator. The rightmost field, the conversion character, is required; the five to the left of that are optional. Each of these fields is explained in a section below:

- Conversion Character — Specifies the notation of the output.
- Subtype — Further specifies any nonstandard types.
- Precision — Sets the number of digits to display to the right of the decimal point, or the number of significant digits to display.
- Field Width — Sets the minimum number of digits to display.
- Flags — Controls the alignment, padding, and inclusion of plus or minus signs.
- Value Identifiers — Map formatting operators to value input arguments. Use the identifier field when value arguments are not in a sequential order in the argument list.

Here is an example of a formatting operator that uses all six fields. (Space characters are not allowed in the operator. They are shown here only to improve readability of the figure).



An alternate syntax, that enables you to supply values for the field width and precision fields from values in the argument list, is shown below. See the section “Specifying Field Width and Precision Outside the format String” on page 6-21 for information on when and how to use this syntax. (Again, space characters are shown only to improve readability of the figure.)



Each field of the formatting operator is described in the following sections. These fields are covered as they appear going from right to left in the formatting operator, starting with the Conversion Character and ending with the Identifier field.

### Conversion Character

The conversion character specifies the notation of the output. It consists of a single character and appears last in the format specifier. It is the only required field of the format specifier other than the leading `%` character.

Specifier	Description
c	Single character
d	Decimal notation (signed)
e	Exponential notation (using a lowercase e as in 3.1415e+00)
E	Exponential notation (using an uppercase E as in 3.1415E+00)
f	Fixed-point notation

Specifier	Description
g	The more compact of %e or %f. (Insignificant zeros do not print.)
G	Same as %g, but using an uppercase E
o	Octal notation (unsigned)
s	String of characters
u	Decimal notation (unsigned)
x	Hexadecimal notation (using lowercase letters a–f)
X	Hexadecimal notation (using uppercase letters A–F)

This example uses conversion characters to display the number 46 in decimal, fixed-point, exponential, and hexadecimal formats:

```
A = 46*ones(1,4);  
  
sprintf('%d %f %e %X', A)  
ans =  
46 46.000000 4.600000e+01 2E
```

### Subtype

The subtype field is a single alphabetic character that immediately precedes the conversion character. The following nonstandard subtype specifiers are supported for the conversion characters %o, %x, %X, and %u.

b	The underlying C data type is a double rather than an unsigned integer. For example, to print a double-precision value in hexadecimal, use a format like '%bx'.
t	The underlying C data type is a float rather than an unsigned integer.

To specify the number of bits for the conversion of an integer value (corresponding to conversion characters %d, %i, %u, %o, %x, or %X), use one of the following subtypes.

l	64-bit value.
h	16-bit value.

## Precision

precision in a formatting operator is a nonnegative integer that immediately follows a period. For example, the specifier `%7.3f`, has a precision of 3. For the `%g` specifier, precision indicates the number of significant digits to display. For the `%f`, `%e`, and `%E` specifiers, precision indicates how many digits to display to the right of the decimal point.

Here are some examples of how the precision field affects different types of notation:

```
sprintf('%g  %.2g  %f  %.2f', pi*50*ones(1,4))
ans =
157.08  1.6e+02  157.079633  157.08
```

Precision is not usually used in format specifiers for strings (i.e., `%s`). If you do use it on a string and if the value `p` in the precision field is less than the number of characters in the string, MATLAB displays only `p` characters of the string and truncates the rest.

You can also supply the value for a precision field from outside of the format specifier. See the section “Specifying Field Width and Precision Outside the format String” on page 6-21 for more information on this.

For more information on the use of precision in formatting, see “Setting Field Width and Precision” on page 6-20.

## Field Width

Field width in a formatting operator is a nonnegative integer that tells MATLAB the minimum number of digits or characters to use when formatting the corresponding input value. For example, the specifier `%7.3f`, has a width of 7.

Here are some examples of how the width field affects different types of notation:

```
sprintf('%e|%15e|%f|%15f|', pi*50*ones(1,4))
ans =
|1.570796e+02| 1.570796e+02|157.079633| 157.079633|
```

When used on a string, the `field width` can determine whether MATLAB pads the string with spaces. If `width` is less than or equal to the number of characters in the string, it has no effect.

```
sprintf('%30s', 'Pad left with spaces')
ans =
      Pad left with spaces
```

You can also supply a value for `field width` from outside of the format specifier. See the section “Specifying Field Width and Precision Outside the format String” on page 6-21 for more information on this.

For more information on the use of `field width` in formatting, see “Setting Field Width and Precision” on page 6-20.

### Flags

You can control the output using any of these optional flags:

Character	Description	Example
A minus sign (-)	Left-justifies the converted argument in its field.	<code>%-5.2d</code>
A plus sign (+)	Always prints a sign character (+ or -).	<code>%+5.2d</code>
A space ( )	Inserts a space before the value.	<code>% 5.2f</code>

Character	Description	Example
Zero (0)	Pads with zeros rather than spaces.	<code>%05.2f</code>
A pound sign (#)	Modifies selected numeric conversions: <ul style="list-style-type: none"> <li>• For <code>%o</code>, <code>%x</code>, or <code>%X</code>, print <code>0</code>, <code>0x</code>, or <code>0X</code> prefix.</li> <li>• For <code>%f</code>, <code>%e</code>, or <code>%E</code>, print decimal point even when precision is 0.</li> <li>• For <code>%g</code> or <code>%G</code>, do not remove trailing zeros or decimal point.</li> </ul>	<code>##5.0f</code>

Right- and left-justify the output. The default is to right-justify:

```
printf('right-justify: %12.2f\nleft-justify: %-12.2f', ...
      12.3, 12.3)
ans =
    right-justify:      12.30
    left-justify: 12.30
```

Display a + sign for positive numbers. The default is to omit the + sign:

```
printf('no sign: %12.2f\nsign: %+12.2f', ...
      12.3, 12.3)
ans =
    no sign:      12.30
    sign:      +12.30
```

Pad to the left with spaces or zeros. The default is to use space-padding:

```
printf('space-padded: %12.2f\nzero-padded: %012.2f', ...
      5.2, 5.2)
ans =
    space-padded:      5.20
```

zero-padded: 000000005.20

---

**Note** You can specify more than one flag in a formatting operator.

---

### Value Identifiers

By default, MATLAB inserts data values from the argument list into the string in a sequential order. If you have a need to use the value arguments in a nonsequential order, you can override the default by using a numeric identifier in each format specifier. Specify nonsequential arguments with an integer immediately following the % sign, followed by a \$ sign.

Ordered Sequentially	Ordered By Identifier
<pre>sprintf('%s %s %s', ...     '1st', '2nd', '3rd') ans =     1st 2nd 3rd</pre>	<pre>sprintf('%3\$s %2\$s %1\$s', ...     '1st', '2nd', '3rd') ans =     3rd 2nd 1st</pre>

### Setting Field Width and Precision

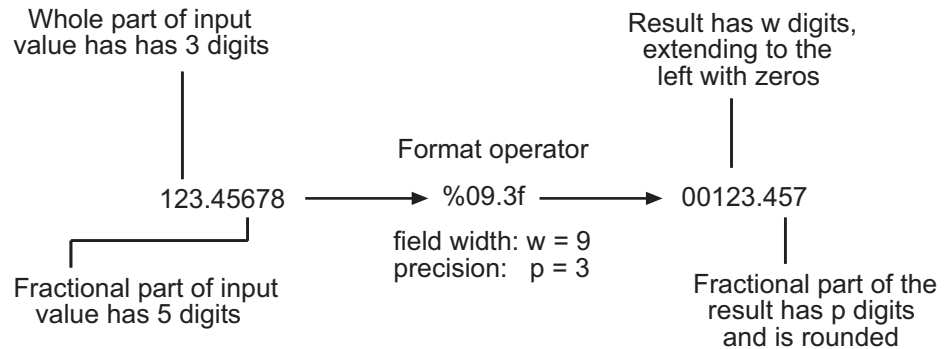
This section provides further information on the use of the field width and precision fields of the formatting operator:

- “Effect on the Output String” on page 6-20
- “Specifying Field Width and Precision Outside the format String” on page 6-21
- “Using Identifiers In the Width and Precision Fields” on page 6-22

### Effect on the Output String

The figure below illustrates the way in which the field width and precision settings affect the output of the string formatting functions. In this figure, the zero following the % sign in the formatting operator means to add leading zeros to the output string rather than space characters:





### General rules for formatting

- If precision is not specified, it defaults to 6.
- If precision ( $p$ ) is less than the number of digits in the fractional part of the input value ( $f$ ), then only  $p$  digits are shown to the right of the decimal point in the output, and that fractional value is rounded.
- If precision ( $p$ ) is greater than the number of digits in the fractional part of the input value ( $f$ ), then  $p$  digits are shown to the right of the decimal point in the output, and the fractional part is extended to the right with  $p - f$  zeros.
- If field width is not specified, it defaults to  $\text{precision} + 1 + \text{the number of digits in the whole part of the input value}$ .
- If field width ( $w$ ) is greater than  $p+1$  plus the number of digits in the whole part of the input value ( $n$ ), then the whole part of the output value is extended to the left with  $w - (n+1+p)$  space characters or zeros, depending on whether or not the zero flag is set in the `Flags` field. The default is to extend the whole part of the output with space characters.

### Specifying Field Width and Precision Outside the format String

To specify field width or precision using values from a sequential argument list, use an asterisk (\*) in place of the field width or precision field of the formatting operator.

This example formats and displays three numbers. The formatting operator for the first, `%*f`, has an asterisk in the field width location of the formatting operator, specifying that just the field width, 15, is to be taken from the argument list. The second operator, `%.*f` puts the asterisk after the decimal point meaning, that it is the precision that is to take its value from the argument list. And the third operator, `%*.*f`, specifies both field width and precision in the argument list:

```
printf('%*f  %.*f  %*.*f', ...
      15, 123.45678, ...      % Width for 123.45678 is 15
      3, 16.42837, ...      % Precision for rand*20 is .3
      6, 4, pi)             % Width & Precision for pi is 6.4
ans =
    123.456780    16.428    3.1416
```

You can mix the two styles. For example, this statement gets the field width from the argument list and the precision from the format string:

```
printf('%*.*2f', 5, 123.45678)
ans =
    123.46
```

### Using Identifiers In the Width and Precision Fields

You can also derive field width and precision values from a nonsequential (i.e., numbered) argument list. Inside the formatting operator, specify field width and/or precision with an asterisk followed by an identifier number, followed by a \$ sign.

This example from the previous section shows how to obtain field width and precision from a sequential argument list:

```
printf('%*f  %.*f  %*.*f', ...
      15, 123.45678, ...
      3, 16.42837, ...
      6, 4, pi)

ans =
    123.456780    16.428    3.1416
```

Here is an example of how to do the same thing using numbered ordering. Field width for the first output value is 15, precision for the second value is 3, and field width and precision for the third value is 6 and 4, respectively. If you specify field width or precision with identifiers, then you must specify the value with an identifier as well:

```
sprintf('%1$*4$f %2$.*5$f %3$*6$.*7$f', ...
123.45678, 16.42837, pi, 15, 3, 6, 4)

ans =
    123.456780    16.428    3.1416
```

## Restrictions for Using Identifiers

If any of the formatting operators in a string include an identifier field, then all of the operators in that string must do the same; you cannot use both sequential and nonsequential ordering in the same function call.

Valid Syntax	Invalid Syntax
<pre>sprintf('%d %d %d %d', ...     1, 2, 3, 4) ans =     1 2 3 4</pre>	<pre>sprintf('%d %3\$d %d %d', ...     1, 2, 3, 4) ans =     1</pre>

If your command provides more value arguments than there are formatting operators in the format string, MATLAB reuses the operators. However, MATLAB allows this only for commands that use sequential ordering. You cannot reuse formatting operators when making a function call with numbered ordering of the value arguments.

Valid Syntax	Invalid Syntax
<pre>sprintf('%d', 1, 2, 3, 4) ans =     1234</pre>	<pre>sprintf('%1\$d', 1, 2, 3, 4) ans =     1</pre>

Also, do not use identifiers when the value arguments are in the form of a vector or array:

Valid Syntax	Invalid Syntax
<pre>v = [1.4 2.7 3.1];  sprintf('%.4f %.4f %.4f', v) ans =     1.4000 2.7000 3.1000</pre>	<pre>v = [1.4 2.7 3.1];  sprintf('%3\$.4f %1\$.4f %2\$.4f', v) ans =     Empty string: 1-by-0</pre>

## String Comparisons

There are several ways to compare strings and substrings:

- You can compare two strings, or parts of two strings, for equality.
- You can compare individual characters in two strings for equality.
- You can categorize every element within a string, determining whether each element is a character or white space.

These functions work for both character arrays and cell arrays of strings.

### Comparing Strings for Equality

You can use any of four functions to determine if two input strings are identical:

- `strcmp` determines if two strings are identical.
- `strncmp` determines if the first `n` characters of two strings are identical.
- `strcmpi` and `strncmpi` are the same as `strcmp` and `strncmp`, except that they ignore case.

Consider the two strings

```
str1 = 'hello';  
str2 = 'help';
```

Strings `str1` and `str2` are not identical, so invoking `strcmp` returns logical 0 (false). For example,

```
C = strcmp(str1,str2)  
C =  
    0
```

---

**Note** For C programmers, this is an important difference between the MATLAB `strcmp` and C `strcmp()` functions, where the latter returns 0 if the two strings are the same.

---

The first three characters of `str1` and `str2` are identical, so invoking `strncmp` with any value up to 3 returns 1:

```
C = strncmp(str1, str2, 2)
C =
     1
```

These functions work cell-by-cell on a cell array of strings. Consider the two cell arrays of strings

```
A = {'pizza'; 'chips'; 'candy'};
B = {'pizza'; 'chocolate'; 'pretzels'};
```

Now apply the string comparison functions:

```
strcmp(A,B)
ans =
     1
     0
     0
strncmp(A,B,1)
ans =
     1
     1
     0
```

## Comparing for Equality Using Operators

You can use MATLAB relational operators on character arrays, as long as the arrays you are comparing have equal dimensions, or one is a scalar. For example, you can use the equality operator (`==`) to determine where the matching characters are in two strings:

```
A = 'fate';
B = 'cake';

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

All of the relational operators (`>`, `>=`, `<`, `<=`, `==`, `~=`) compare the values of corresponding characters.

## Categorizing Characters Within a String

There are three functions for categorizing characters inside a string:

- 1 `isletter` determines if a character is a letter.
- 2 `isspace` determines if a character is white space (blank, tab, or new line).
- 3 `isstrprop` checks characters in a string to see if they match a category you specify, such as
  - Alphabetic
  - Alphanumeric
  - Lowercase or uppercase
  - Decimal digits
  - Hexadecimal digits
  - Control characters
  - Graphic characters
  - Punctuation characters
  - Whitespace characters

For example, create a string named `mystring`:

```
mystring = 'Room 401';
```

`isletter` examines each character in the string, producing an output vector of the same length as `mystring`:

```
A = isletter(mystring)
A =
     1     1     1     1     0     0     0     0
```

The first four elements in `A` are logical 1 (true) because the first four characters of `mystring` are letters.

## Searching and Replacing

MATLAB provides several functions for searching and replacing characters in a string. (MATLAB also supports search and replace operations using regular expressions. See Regular Expressions.)

Consider a string named `label`:

```
label = 'Sample 1, 10/28/95';
```

The `strrep` function performs the standard search-and-replace operation. Use `strrep` to change the date from '10/28' to '10/30':

```
newlabel = strrep(label, '28', '30')
newlabel =
    Sample 1, 10/30/95
```

`strfind` returns the starting position of a substring within a longer string. To find all occurrences of the string 'amp' inside `label`, use

```
position = strfind(label, 'amp')
position =
     2
```

The position within `label` where the only occurrence of 'amp' begins is the second character.

The `textscan` function parses a string to identify numbers or substrings. Describe each component of the string with conversion specifiers, such as %s for strings, %d for integers, or %f for floating-point numbers. Optionally, include any literal text to ignore.

For example, identify the sample number and date string from `label`:

```
parts = textscan(label, 'Sample %d, %s');
parts{:}

ans =
     1
ans =
    '10/28/95'
```



To parse strings in a cell array, use the `strtok` function. For example:

```
c = {'all in good time'; ...  
    'my dog has fleas'; ...  
    'leave no stone unturned'};  
first_words = strtok(c)
```

## Converting from Numeric to String

In this section...
“Function Summary” on page 6-30
“Converting to a Character Equivalent” on page 6-31
“Converting to a String of Numbers” on page 6-31
“Converting to a Specific Radix” on page 6-31

### Function Summary

The functions listed in this table provide a number of ways to convert numeric data to character strings.

Function	Description	Example
char	Convert a positive integer to an equivalent character. (Truncates any fractional parts.)	[72 105] → 'Hi'
int2str	Convert a positive or negative integer to a character type. (Rounds any fractional parts.)	[72 105] → '72 105'
num2str	Convert a numeric type to a character type of the specified precision and format.	[72 105] → '72/105/' (format set to %1d/)
mat2str	Convert a numeric type to a character type of the specified precision, returning a string MATLAB can evaluate.	[72 105] → '[72 105]'
dec2hex	Convert a positive integer to a character type of hexadecimal base.	[72 105] → '48 69'
dec2bin	Convert a positive integer to a character type of binary base.	[72 105] → '1001000 1101001'
dec2base	Convert a positive integer to a character type of any base from 2 through 36.	[72 105] → '110 151' (base set to 8)

## Converting to a Character Equivalent

The `char` function converts integers to Unicode character codes and returns a string composed of the equivalent characters:

```
x = [77 65 84 76 65 66];  
char(x)  
ans =  
    MATLAB
```

## Converting to a String of Numbers

The `int2str`, `num2str`, and `mat2str` functions convert numeric values to strings where each character represents a separate digit of the input value. The `int2str` and `num2str` functions are often useful for labeling plots. For example, the following lines use `num2str` to prepare automated labels for the *x*-axis of a plot:

```
function plotlabel(x, y)  
plot(x, y)  
str1 = num2str(min(x));  
str2 = num2str(max(x));  
out = ['Value of f from ' str1 ' to ' str2];  
xlabel(out);
```

## Converting to a Specific Radix

Another class of conversion functions changes numeric values into strings representing a decimal value in another base, such as binary or hexadecimal representation. This includes `dec2hex`, `dec2bin`, and `dec2base`.

## Converting from String to Numeric

### In this section...

“Function Summary” on page 6-32

“Converting from a Character Equivalent” on page 6-33

“Converting from a Numeric String” on page 6-33

“Converting from a Specific Radix” on page 6-34

### Function Summary

The functions listed in this table provide a number of ways to convert character strings to numeric data.

Function	Description	Example
uintN (e.g., uint8)	Convert a character to an integer code that represents that character.	'Hi' → 72 105
str2num	Convert a character type to a numeric type.	'72 105' → [72 105]
str2double	Similar to str2num, but offers better performance and works with cell arrays of strings.	{'72' '105'} → [72 105]
hex2num	Convert a numeric type to a character type of specified precision, returning a string that MATLAB can evaluate.	'A' → '-1.4917e-154'
hex2dec	Convert a character type of hexadecimal base to a positive integer.	'A' → 10
bin2dec	Convert a positive integer to a character type of binary base.	'1010' → 10
base2dec	Convert a positive integer to a character type of any base from 2 through 36.	'12' → 10 (if base == 8)

## Converting from a Character Equivalent

Character arrays store each character as a 16-bit numeric value. Use one of the integer conversion functions (e.g., `uint8`) or the `double` function to convert strings to their numeric values, and `char` to revert to character representation:

```
name = 'Thomas R. Lee';

name = double(name)
name =
    84  104  111  109  97  115  32  82  46  32  76  101  101

name = char(name)
name =
    Thomas R. Lee
```

## Converting from a Numeric String

Use `str2num` to convert a character array to the numeric value represented by that string:

```
str = '37.294e-1';

val = str2num(str)
val =
    3.7294
```

The `str2double` function converts a cell array of strings to the double-precision values represented by the strings:

```
c = {'37.294e-1'; '-58.375'; '13.796'};

d = str2double(c)
d =
    3.7294
   -58.3750
    13.7960

whos
  Name      Size      Bytes  Class
  ----      -
  c         3x1         224   cell
```

d                    3x1                                    24    double

### **Converting from a Specific Radix**

To convert from a character representation of a nondecimal number to the value of that number, use one of these functions: `hex2num`, `hex2dec`, `bin2dec`, or `base2dec`.

The `hex2num` and `hex2dec` functions both take hexadecimal (base 16) inputs, but `hex2num` returns the IEEE double-precision floating-point number it represents, while `hex2dec` converts to a decimal integer.

## Function Summary

MATLAB provides these functions for working with character arrays:

- Functions to Create Character Arrays on page 6-35
- Functions to Modify Character Arrays on page 6-35
- Functions to Read and Operate on Character Arrays on page 6-36
- Functions to Search or Compare Character Arrays on page 6-36
- Functions to Determine Class or Content on page 6-36
- Functions to Convert Between Numeric and String Classes on page 6-37
- Functions to Work with Cell Arrays of Strings as Sets on page 6-37

### Functions to Create Character Arrays

Function	Description
'str'	Create the string specified between quotes.
blanks	Create a string of blanks.
sprintf	Write formatted data to a string.
strcat	Concatenate strings.
char	Concatenate strings vertically.

### Functions to Modify Character Arrays

Function	Description
deblank	Remove trailing blanks.
lower	Make all letters lowercase.
sort	Sort elements in ascending or descending order.
strjust	Justify a string.
strrep	Replace one string with another.
strtrim	Remove leading and trailing white space.
upper	Make all letters uppercase.

**Functions to Read and Operate on Character Arrays**

<b>Function</b>	<b>Description</b>
eval	Execute a string with MATLAB expression.
sscanf	Read a string under format control.

**Functions to Search or Compare Character Arrays**

<b>Function</b>	<b>Description</b>
regexp	Match regular expression.
strcmp	Compare strings.
strcmpi	Compare strings, ignoring case.
strfind	Find one string within another.
strncmp	Compare the first N characters of strings.
strncmpi	Compare the first N characters, ignoring case.
strtok	Find a token in a string.
textscan	Read data from a string.

**Functions to Determine Class or Content**

<b>Function</b>	<b>Description</b>
iscellstr	Return true for a cell array of strings.
ischar	Return true for a character array.
isletter	Return true for letters of the alphabet.
isstrprop	Determine if a string is of the specified category.
isspace	Return true for white-space characters.



### Functions to Convert Between Numeric and String Classes

Function	Description
char	Convert to a character or string.
cellstr	Convert a character array to a cell array of strings.
double	Convert a string to numeric codes.
int2str	Convert an integer to a string.
mat2str	Convert a matrix to a string you can run eval on.
num2str	Convert a number to a string.
str2num	Convert a string to a number.
str2double	Convert a string to a double-precision value.

### Functions to Work with Cell Arrays of Strings as Sets

Function	Description
intersect	Set the intersection of two vectors.
ismember	Detect members of a set.
setdiff	Return the set difference of two vectors.
setxor	Set the exclusive OR of two vectors.
union	Set the union of two vectors.
unique	Set the unique elements of a vector.



# Categorical Arrays

---

- “Create Categorical Arrays” on page 7-2
- “Convert Table Variables Containing Strings to Categorical” on page 7-7
- “Plot Categorical Data” on page 7-13
- “Compare Categorical Array Elements” on page 7-20
- “Combine Categorical Arrays” on page 7-24
- “Access Data Using Categorical Arrays” on page 7-28
- “Work with Protected Categorical Arrays” on page 7-35
- “Advantages of Using Categorical Arrays” on page 7-41
- “Ordinal Categorical Arrays” on page 7-44
- “Other MATLAB Functions Supporting Categorical Arrays” on page 7-48

## Create Categorical Arrays

This example shows how to create a categorical array. `categorical` is a data type for storing data with values from a finite set of discrete categories. These categories can have a natural order, but it is not required. A categorical array provides efficient storage and convenient manipulation of data, while also maintaining meaningful names for the values. Categorical arrays are often used in a table to define groups of rows.

By default, categorical arrays contain categories that have no mathematical ordering. For example, the discrete set of pet categories {'dog' 'cat' 'bird'} has no meaningful mathematical ordering, so MATLAB® uses the alphabetical ordering {'bird' 'cat' 'dog'}. *ordinal* categorical arrays contain categories that have a meaningful mathematical ordering. For example, the discrete set of size categories {'small', 'medium', 'large'} has the mathematical ordering `small < medium < large`.

### Create Categorical Array from Cell Array of Strings

You can use the `categorical` function to create a categorical array from a numeric array, logical array, cell array of strings, or an existing categorical array.

Create a 1-by-11 cell array of strings containing state names from New England.

```
state = {'MA','ME','CT','VT','ME','NH','VT','MA','NH','CT','RI'};
```

Convert the cell array of strings, `state`, to a categorical array that has no mathematical order.

```
state = categorical(state)
```

```
class(state)
```

```
state =
```

```
Columns 1 through 9
```

```

      MA      ME      CT      VT      ME      NH      VT      MA      NH
Columns 10 through 11
      CT      RI

```

```
ans =
```

```
categorical
```

List the discrete categories in the variable `state`.

```
categories(state)
```

```
ans =
```

```

'CT'
'MA'
'ME'
'NH'
'RI'
'VT'

```

The categories are listed in alphabetical order.

### Create Ordinal Categorical Array from Cell Array of Strings

Create a 1-by-8 cell array of strings containing the sizes of eight objects.

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

The cell array of strings, `AllSizes`, has three distinct values: `'large'`, `'medium'`, and `'small'`. With the cell array of strings, there is no convenient way to indicate that `small < medium < large`.

Convert the cell array of strings, `AllSizes`, to an ordinal categorical array. Use `valueset` to specify the values `small`, `medium`, and `large`, which define the categories. For an ordinal categorical array, the first category specified is the smallest and the last category is the largest.

```
valueset = {'small','medium','large'};  
sizeOrd = categorical(AllSizes,valueset,'Ordinal',true)
```

```
class(sizeOrd)
```

```
sizeOrd =
```

```
Columns 1 through 6
```

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

```
Columns 7 through 8
```

```
medium small
```

```
ans =
```

```
categorical
```

The order of the values in the categorical array, `sizeOrd`, remains unchanged.

List the discrete categories in the categorical variable, `sizeOrd`.

```
categories(sizeOrd)
```

```
ans =
```

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

The categories are listed in the specified order to match the mathematical ordering `small < medium < large`.

### Create Ordinal Categorical Array by Binning Data

Create a vector of 100 integers between 1 and 44.

```
x = gallery('integerdata',44,[100,1],1);
```

Use the `histc` function to create three bins for the data from `x`. Put all values between 1 and 15 into bin one, all the values between 15 and 30 into bin two, and all the values between 30 and 45 into bin three. Each bin includes the left endpoint, but does not include the right endpoint.

```
[~,bin] = histc(x,[1,15,30,45]);
```

`bin` is a 100-by-1 vector indicating the bin number for each entry from `x`.

Create an ordinal categorical array, `sizeOrd2`, where the three bins become the categories, `small`, `medium`, and `large`.

```
valueset = 1:3;
catnames = {'small','medium','large'};
```

```
sizeOrd2 = categorical(bin,valueset,catnames,'Ordinal',true);
```

`sizeOrd2` is a 100-by-1 ordinal categorical array with three categories, such that `small < medium < large`.

Use the `summary` function to print a summary of the categorical array.

```
summary(sizeOrd2)
```

```

small      33
medium     36
large      31
```

There are 33 elements in the category `small`, 36 in the category `medium`, and 31 in the category `large`.

### **See Also**

[categorical](#) | [categories](#) | [summary](#)

### **Related Examples**

- “Convert Table Variables Containing Strings to Categorical” on page 7-7
- “Access Data Using Categorical Arrays” on page 7-28
- “Compare Categorical Array Elements” on page 7-20

### **Concepts**

- “Advantages of Using Categorical Arrays” on page 7-41
- “Ordinal Categorical Arrays” on page 7-44



## Convert Table Variables Containing Strings to Categorical

This example shows how to convert a variable in a table from a cell array of strings to a categorical array.

### Load Sample Data and Create a Table

Load sample data gathered from 100 patients.

```
load patients
```

```
whos
```

Name	Size	Bytes	Class	Attributes
Age	100x1	800	double	
Diastolic	100x1	800	double	
Gender	100x1	12212	cell	
Height	100x1	800	double	
LastName	100x1	12416	cell	
Location	100x1	15008	cell	
SelfAssessedHealthStatus	100x1	12340	cell	
Smoker	100x1	100	logical	
Systolic	100x1	800	double	
Weight	100x1	800	double	

Store the patient data from Age, Gender, Height, Weight, SelfAssessedHealthStatus, and Location in a table. Use the unique identifiers in the variable LastName as row names.

```
T = table(Age,Gender,Height,Weight,...
         SelfAssessedHealthStatus,Location,...
         'RowNames',LastName);
```

### Convert Table Variables from Cell Arrays of Strings to Categorical Arrays

The cell arrays of strings, Gender and Location, contain small a discrete set of unique values.

Convert Gender and Location to categorical arrays.

```
T.Gender = categorical(T.Gender);  
T.Location = categorical(T.Location);
```

The variable, `SelfAssessedHealthStatus`, contains four unique values: Excellent, Fair, Good, and Poor.

Convert `SelfAssessedHealthStatus` to an ordinal categorical array, such that the categories have the mathematical ordering Poor < Fair < Good < Excellent.

```
T.SelfAssessedHealthStatus = categorical(SelfAssessedHealthStatus,...  
    {'Poor','Fair','Good','Excellent'},'Ordinal',true);
```

### **Print a Summary**

View the data type, description, units, and other descriptive statistics for each variable by using `summary` to summarize the table.

```
format compact
```

```
summary(T)
```

```
Variables:
```

```
Age: 100x1 double
```

```
Values:
```

```
min      25
```

```
median   39
```

```
max      50
```

```
Gender: 100x1 categorical
```

```
Values:
```

```
Female   53
```

```
Male     47
```

```
Height: 100x1 double
```

```
Values:
```

```
min      60
```

```
median   67
```

```
max      72
```

```
Weight: 100x1 double
```

```

Values:
  min      111
  median  142.5
  max      202
SelfAssessedHealthStatus: 100x1 ordinal categorical
Values:
  Poor      11
  Fair     15
  Good     40
  Excellent 34
Location: 100x1 categorical
Values:
  County General Hospital    39
  St. Mary's Medical Center  24
  VA Hospital                37

```

The table variables `Gender`, `SelfAssessedHealthStatus`, and `Location` are categorical arrays. The summary contains the counts of the number of elements in each category. For example, the summary indicates that 53 of the 100 patients are female and 47 are male.

### Select Data Based on Categories

Create a subtable, `T1`, containing the age, height, and weight of all female patients who were observed at County General Hospital. You can easily create a logical vector based on the values in the categorical arrays `Gender` and `Location`.

```
rows = T.Location=='County General Hospital' & T.Gender=='Female';
```

`rows` is a 100-by-1 logical vector with logical true (1) for the table rows where the gender is female and the location is County General Hospital.

Define the subset of variables.

```
vars = {'Age', 'Height', 'Weight'};
```

Use parentheses to create the subtable, `T1`.

```
T1 = T(rows,vars)
```

T1 =

	Age	Height	Weight
Brown	49	64	119
Taylor	31	66	132
Anderson	45	68	128
Lee	44	66	146
Walker	28	65	123
Young	25	63	114
Campbell	37	65	135
Evans	39	62	121
Morris	43	64	135
Rivera	29	63	130
Richardson	30	67	141
Cox	28	66	111
Torres	45	70	137
Peterson	32	60	136
Ramirez	48	64	137
Bennett	35	64	131
Patterson	37	65	120
Hughes	49	63	123
Bryant	48	66	134

A is a 19-by-3 table.

Since ordinal categorical arrays have a mathematical ordering for their categories, you can perform element-wise comparisons of strings with relational operations, such as greater than and less than.

Create a subtable, T2, of the gender, age, height, and weight of all patients who assessed their health status as poor or fair.

First, define the subset of rows to include in table T2.

```
rows = T.SelfAssessedHealthStatus<='Fair';
```

Then, define the subset of variables to include in table T2.

```
vars = {'Gender','Age','Height','Weight'};
```

Use parentheses to create the subtable T2.

T2 = T(rows, vars)

T2 =

	Gender	Age	Height	Weight
Johnson	Male	43	69	163
Jones	Female	40	67	133
Thomas	Female	42	66	137
Jackson	Male	25	71	174
Garcia	Female	27	69	131
Rodriguez	Female	39	64	117
Lewis	Female	41	62	137
Lee	Female	44	66	146
Hall	Male	25	70	189
Hernandez	Male	36	68	166
Lopez	Female	40	66	137
Gonzalez	Female	35	66	118
Mitchell	Male	39	71	164
Campbell	Female	37	65	135
Parker	Male	30	68	182
Stewart	Male	49	68	170
Morris	Female	43	64	135
Watson	Female	40	64	127
Kelly	Female	41	65	127
Price	Male	31	72	178
Bennett	Female	35	64	131
Wood	Male	32	68	183
Patterson	Female	37	65	120
Foster	Female	30	70	124
Griffin	Male	49	70	186
Hayes	Male	48	66	177

T2 is a 26-by-4 table.

## Related Examples

- “Create a Table” on page 8-2
- “Create Categorical Arrays” on page 7-2
- “Access Data in a Table” on page 8-29
- “Access Data Using Categorical Arrays” on page 7-28

### **Concepts**

- “Advantages of Using Categorical Arrays” on page 7-41
- “Ordinal Categorical Arrays” on page 7-44

## Plot Categorical Data

This example shows how to plot data from a categorical array.

### Load Sample Data

Load sample data gathered from 100 patients.

```
load patients
```

```
whos
```

Name	Size	Bytes	Class	Attribu
Age	100x1	800	double	
Diastolic	100x1	800	double	
Gender	100x1	12212	cell	
Height	100x1	800	double	
LastName	100x1	12416	cell	
Location	100x1	15008	cell	
SelfAssessedHealthStatus	100x1	12340	cell	
Smoker	100x1	100	logical	
Systolic	100x1	800	double	
Weight	100x1	800	double	

### Create Categorical Arrays from Cell Arrays of Strings

The workspace variable, `Location`, is a cell array of strings that contains the three unique medical facilities where patients were observed.

To access and compare data more easily, convert `Location` to a categorical array.

```
Location = categorical(Location);
```

Summarize the categorical array.

```
summary(Location)
```

```
County General Hospital    39
St. Mary's Medical Center  24
VA Hospital                37
```

39 patients were observed at County General Hospital, 24 at St. Mary's Medical Center, and 37 at the VA Hospital.

The workspace variable, `SelfAssessedHealthStatus`, contains four unique values, `Excellent`, `Fair`, `Good`, and `Poor`.

Convert `SelfAssessedHealthStatus` to an ordinal categorical array, such that the categories have the mathematical ordering `Poor < Fair < Good < Excellent`.

```
SelfAssessedHealthStatus = categorical(SelfAssessedHealthStatus,...
    {'Poor' 'Fair' 'Good' 'Excellent'}, 'Ordinal', true);
```

Summarize the categorical array, `SelfAssessedHealthStatus`.

```
summary(SelfAssessedHealthStatus)
```

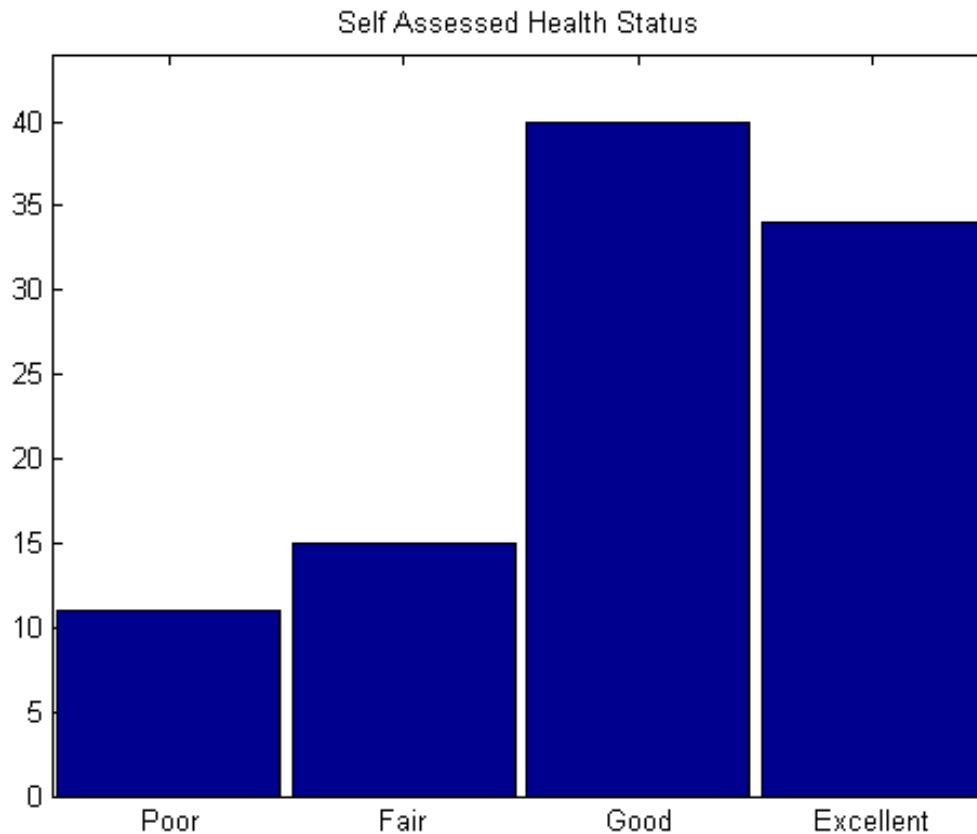
```
Poor          11
Fair          15
Good          40
Excellent     34
```

### **Plot a Histogram**

Create a histogram bar plot directly from a categorical array.

```
figure()
hist(SelfAssessedHealthStatus)
title('Self Assessed Health Status')
```

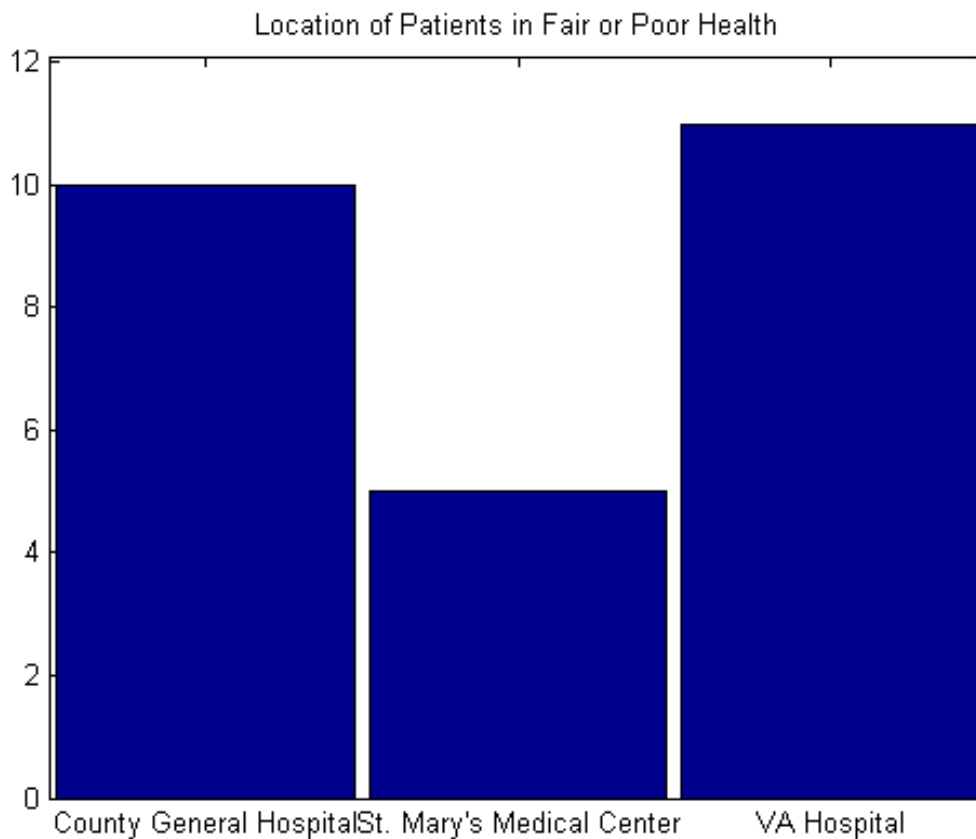




The function `hist` accepts the categorical array, `SelfAssessedHealthStatus`, and plots the category counts for each of the four categories.

Create a histogram of the hospital location for only the patients who assessed their health as `Fair` or `Poor`.

```
figure()  
hist(Location(SelfAssessedHealthStatus<='Fair'))  
title('Location of Patients in Fair or Poor Health')
```

**Create a Pie Chart**

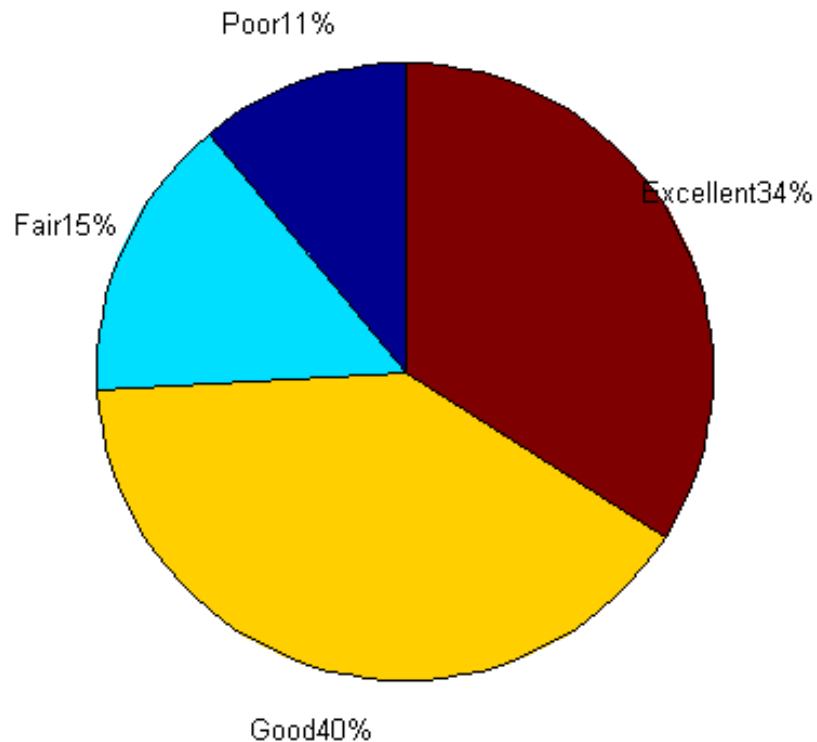
You can use the numeric output from the `countcats` function to create other types of plots.

Create a pie chart of the self assessed health status of the 100 patients.

```
figure()  
h = pie(countcats(SelfAssessedHealthStatus));  
title('Self Assessed Health Status From 100 Patients')
```

```
% Add the category names to the pie chart labels. Use strcat to prepend  
% the category names to the percentage labels.  
textObjs = findobj(h,'Type','text');  
oldStr = get(textObjs,{'String'});  
  
set(textObjs,{'String'},...  
    strcat(categories(SelfAssessedHealthStatus),oldStr))
```

Self Assessed Health Status From 100 Patients



**Create a Scatter Plot**

Convert the cell array of strings to a categorical array.

```
Gender = categorical(Gender);
```

Summarize the categorical array, Gender.

```
summary(Gender)
```

```
      Female      53  
      Male      47
```

Gender is a 100-by-1 categorical array with two categories, Female and Male.

Use the categorical array, Gender, to access Weight and Height data for each gender separately.

```
X1 = Weight(Gender=='Female');
```

```
Y1 = Height(Gender=='Female');
```

```
X2 = Weight(Gender=='Male');
```

```
Y2 = Height(Gender=='Male');
```

X1 and Y1 are 53-by-1 numeric arrays containing data from the female patients.

X2 and Y2 are 47-by-1 numeric arrays containing data from the male patients.

Create a scatter plot of height vs. weight. Indicate data from the female patients with a circle and data from the male patients with a cross.

```
figure()
```

```
h1 = scatter(X1,Y1,'o');
```

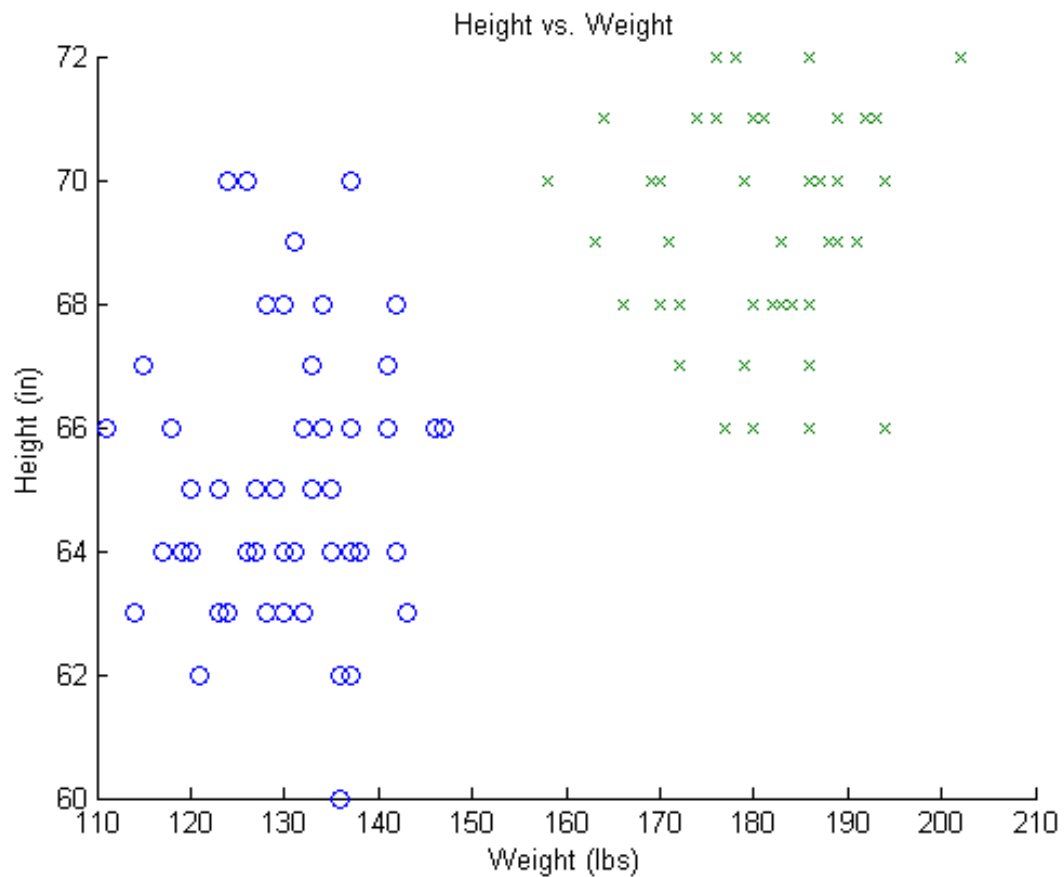
```
hold on
```

```
h2 = scatter(X2,Y2,'x');
```

```
title('Height vs. Weight')
```

```
xlabel('Weight (lbs)')
```

```
ylabel('Height (in)')
```

**See Also**

categorical | summary | countcats | hist | pie | bar | rose | scatter

**Related Examples**

- “Access Data Using Categorical Arrays” on page 7-28

## Compare Categorical Array Elements

This example shows how to use relational operations with a categorical array.

### Create Categorical Array from Cell Array of Strings

Create a 2-by-4 cell array of strings.

```
C = {'blue' 'red' 'green' 'blue';...  
    'blue' 'green' 'green' 'blue'};
```

```
colors = categorical(C)
```

```
colors =
```

```
    blue    red    green    blue  
    blue    green  green    blue
```

colors is a 2-by-4 categorical array.

List the categories of the categorical array.

```
categories(colors)
```

```
ans =
```

```
    'blue'  
    'green'  
    'red'
```

### Determine If Elements Are Equal

Use the relational operator, eq (==), to compare the first and second rows of colors.

```
colors(1,:) == colors(2,:)
```

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

Only the values in the second column differ between the rows.

### Compare Entire Array to String

Compare the entire categorical array, `colors`, to the string `'blue'` to find the location of all `blue` values.

```
colors == 'blue'
```

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

There are four `blue` entries in `colors`, one in each corner of the array.

### Convert to an Ordinal Categorical Array

Add a mathematical ordering to the categories in `colors`. Specify the category order that represents the ordering of color spectrum, `red < green < blue`.

```
colors = categorical(colors,{'red','green','blue'},'Ordinal',true)
```

```
colors =
      blue      red      green      blue
      blue      green      green      blue
```

The elements in the categorical array remain the same.

List the discrete categories in `colors`.

```
categories(colors)
```

```
ans =
```

```
    'red'  
    'green'  
    'blue'
```

### Compare Elements Based on Order

Determine if elements in the first column of `colors` are greater than the elements in the second column.

```
colors(:,1) > colors(:,2)
```

```
ans =
```

```
    1  
    1
```

Both values in the second column, `red` and `green`, are greater than the corresponding values in the first column, `blue`.

Find all the elements in `colors` that are less than `'blue'`.

```
colors < 'blue'
```

```
ans =
```

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



The function `lt (<)` indicates the location of all green and red values with 1.

## See Also

`categorical | categories`

## Related Examples

- “Access Data Using Categorical Arrays” on page 7-28

## Concepts

- “Relational Operations”
- “Advantages of Using Categorical Arrays” on page 7-41
- “Ordinal Categorical Arrays” on page 7-44

## Combine Categorical Arrays

This example shows how to combine two categorical arrays.

### Create Categorical Arrays

Create a categorical array, A, containing the preferred lunchtime beverage of 25 students in classroom A.

```
A = gallery('integerdata',3,[25,1],1);  
A = categorical(A,1:3,{'milk' 'water' 'juice'});
```

A is a 25-by-1 categorical array with three distinct categories: milk, water, and juice.

Summarize the categorical array, A.

```
summary(A)
```

```
      milk      8  
      water     8  
      juice     9
```

Eight students in classroom A prefer milk, eight prefer water, and nine prefer juice.

Create another categorical array, B, containing the preferences of 28 students in classroom B.

```
B = gallery('integerdata',3,[28,1],3);  
B = categorical(B,1:3,{'milk' 'water' 'juice'});
```

B is a 28-by-1 categorical array containing the same categories as A.

Summarize the categorical array, B.

```
summary(B)
```

```
      milk     12  
      water     10
```

```
juice      6
```

Twelve students in classroom B prefer milk, ten prefer water, and six prefer juice.

### Concatenate Categorical Arrays

Concatenate the data from classrooms A and B into a single categorical array, Group1.

```
Group1 = [A;B];
```

Summarize the categorical array, Group1

```
summary(Group1)
```

```
   milk      20
   water     18
   juice     15
```

Group1 is a 53-by-1 categorical array with three categories: milk, water, and juice.

### Create Categorical Array with Different Categories

Create a categorical array, Group2, containing data from 50 students who were given the additional beverage option of soda.

```
Group2 = gallery('integerdata',4,[50,1],2);
Group2 = categorical(Group2,1:4,{'juice' 'milk' 'soda' 'water'});
```

Summarize the categorical array, Group2.

```
summary(Group2)
```

```
   juice     18
   milk     10
   soda     13
   water     9
```

Group2 is a 50-by-1 categorical array with four categories: juice, milk, soda, and water.

### **Concatenate Arrays with Different Categories**

Concatenate the data from Group1 and Group2.

```
students = [Group1;Group2];
```

Summarize the resulting categorical array, students.

```
summary(students)
```

```
      milk      30
      water      27
      juice      33
      soda       13
```

Concatenation appends the categories exclusive to the second input, soda, to the end of the list of categories from the first input, milk, water, juice, soda.

Use `reordercats` to change the order of the categories in the categorical array, students.

```
students = reordercats(students,{'juice','milk','water','soda'});
```

```
categories(students)
```

```
ans =
```

```
      'juice'
      'milk'
      'water'
      'soda'
```

### **Union of Categorical Arrays**

Use the function `union` to find the unique responses from `Group1` and `Group2`.

```
C = union(Group1,Group2)
```

```
C =
```

```
    milk  
    water  
    juice  
    soda
```

`union` returns the combined values from `Group1` and `Group2` with no repetitions. In this case, `C` is equivalent to the categories of the concatenation, `students`.

All of the categorical arrays in this example were nonordinal. To combine ordinal categorical arrays, they must have the same sets of categories including their order.

## See Also

[categorical](#) | [categories](#) | [summary](#) | [union](#) | [cat](#) | [horzcat](#) | [vertcat](#)

## Related Examples

- “Create Categorical Arrays” on page 7-2
- “Convert Table Variables Containing Strings to Categorical” on page 7-7
- “Access Data Using Categorical Arrays” on page 7-28

## Concepts

- “Ordinal Categorical Arrays” on page 7-44

## Access Data Using Categorical Arrays

### In this section...

“Select Data By Category” on page 7-28

“Common Ways to Access Data Using Categorical Arrays” on page 7-28

### Select Data By Category

Selecting data based on its values is often useful. This type of data selection can involve creating a logical vector based on values in one variable, and then using that logical vector to select a subset of values in other variables. You can create a logical vector for selecting data by finding values in a numeric array that fall within a certain range. Additionally, you can create the logical vector by finding specific discrete values. When using categorical arrays, you can easily:

- **Select elements from particular categories.** For categorical arrays, use the logical operators `==` or `~=` to select data that is in, or not in, a particular category. To select data in a particular group of categories, use the `ismember` function.

For ordinal categorical arrays, use inequalities `>`, `>=`, `<`, or `<=` to find data in categories above or below a particular category.

- **Delete data that is in a particular category.** Use logical operators to include or exclude data from particular categories.
- **Find elements that are not in a defined category.** Categorical arrays indicate which elements do not belong to a defined category by `<undefined>`. Use the `isundefined` function to find observations without a defined value.

### Common Ways to Access Data Using Categorical Arrays

This example shows how to index and search using categorical arrays. You can access data using categorical arrays stored within a table in a similar manner.

#### Load Sample Data

Load sample data gathered from 100 patients.

```
load patients
```

```
whos
```

Name	Size	Bytes	Class	Attribu
Age	100x1	800	double	
Diastolic	100x1	800	double	
Gender	100x1	12212	cell	
Height	100x1	800	double	
LastName	100x1	12416	cell	
Location	100x1	15008	cell	
SelfAssessedHealthStatus	100x1	12340	cell	
Smoker	100x1	100	logical	
Systolic	100x1	800	double	
Weight	100x1	800	double	

### Create Categorical Arrays from Cell Arrays of Strings

To compare strings in character arrays and cell arrays of strings, you must use `strcmp`, which can be cumbersome. To access and compare data more easily, convert `Gender` and `Location` to categorical arrays.

```
Gender = categorical(Gender);
Location = categorical(Location);
```

### Search for Members of a Single Category

For categorical arrays, you can use the logical operators `==` and `~=` to find the data that is in, or not in, a particular category.

Determine if there are any patients observed at the location, 'Rampart General Hospital'.

```
any(Location=='Rampart General Hospital')
```

```
ans =  
  
    0
```

There are no patients observed at Rampart General Hospital.

### **Search for Members of a Group of Categories**

You can use `ismember` to find data in a particular group of categories. Create a logical vector for the patients observed at County General Hospital or VA Hospital.

```
VA_CountyGenIndex = ...  
    ismember(Location,{'County General Hospital','VA Hospital'});
```

`VA_CountyGenIndex` is a 100-by-1 logical array containing logical true (1) for each element in the categorical array `Location` that is a member of the category `County General Hospital` or `VA Hospital`. The output, `VA_CountyGenIndex` contains 76 nonzero elements.

Use the logical vector, `VA_CountyGenIndex` to select the `LastName` of the patients observed at either `County General Hospital` or `VA Hospital`.

```
VA_CountyGenPatients = LastName(VA_CountyGenIndex);
```

`VA_CountyGenPatients` is a 76-by-1 cell array of strings.

### **Select Elements in a Particular Category to Plot**

Use the `summary` function to print a summary containing the category names and the number of elements in each category.

```
summary(Location)  
  
County General Hospital      39  
St. Mary's Medical Center   24  
VA Hospital                  37
```



Location is a 100-by-1 categorical array with three categories. County General Hospital occurs in 39 elements, St. Mary s Medical Center in 24 elements, and VA Hospital in 37 elements.

Use the summary function to print a summary of Gender.

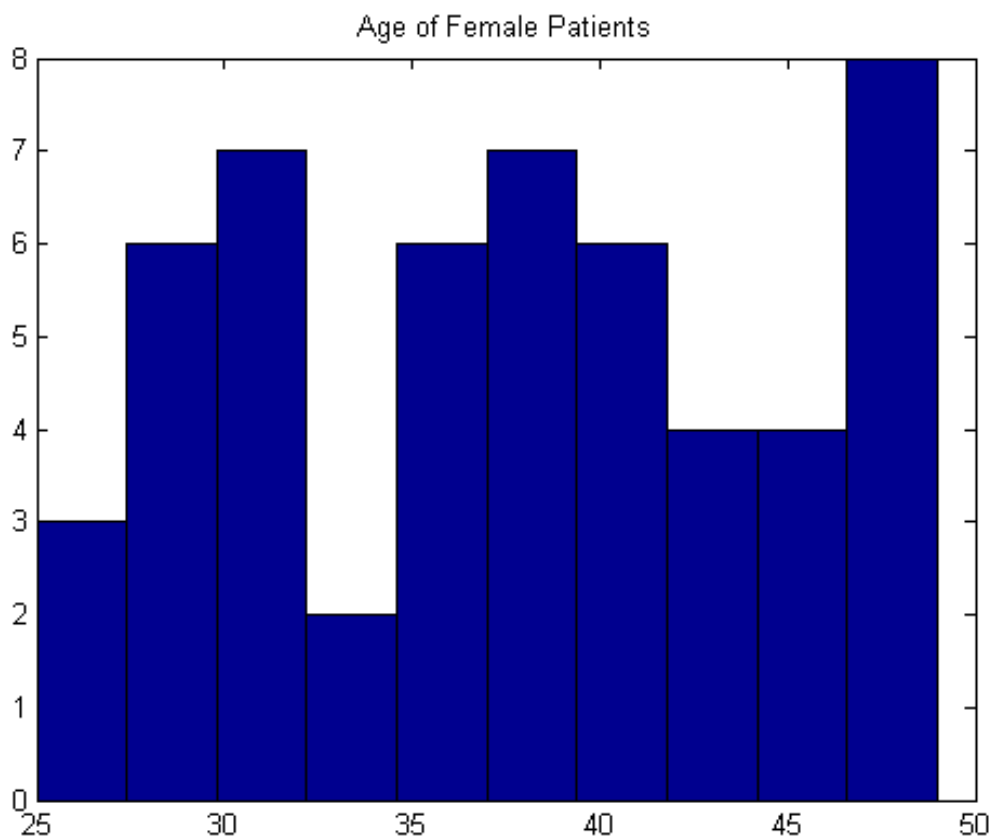
```
summary(Gender)
```

```
Female    53  
Male     47
```

Gender is a 100-by-1 categorical array with two categories. Female occurs in 53 elements and Male occurs in 47 elements.

Use logical operator == to access the age of only the female patients. Then plot a histogram of this data.

```
figure()  
hist(Age(Gender=='Female'))  
title('Age of Female Patients')
```



`hist(Age(Gender=='Female'))` plots the age data for the 53 female patients.

#### **Delete Data from a Particular Category**

You can use logical operators to include or exclude data from particular categories. Delete all patients observed at VA Hospital from the workspace variables, `Location` and `Age`.

```
Location = Location(Location~='VA Hospital');  
Age = Age(Location~='VA Hospital');
```

Now, `Location` is a 63-by-1 categorical array, and `Age` is a 63-by-1 numeric array.

List the categories of `Location`, as well as the number of elements in each category.

```
summary(Location)
```

```
County General Hospital    39
St. Mary's Medical Center  24
VA Hospital                 0
```

The patients observed at `VA Hospital` are deleted from `Location`, but `VA Hospital` is still a category.

Use the `removecats` function to remove `VA Hospital` from the categories of `Location`.

```
Location = removecats(Location,'VA Hospital');
```

Verify that the category, `VA Hospital`, was removed.

```
categories(Location)
```

```
ans =
```

```
'County General Hospital'
'St. Mary's Medical Center'
```

`Location` is a 63-by-1 categorical array that has two categories.

#### **Check for Undefined Data**

Remove the category `County General Hospital` from `Location`.

```
Location = removecats(Location,'County General Hospital');
```

Display the first eight elements of the categorical array, `Location`.

```
Location(1:8)
```

```
ans =
```

```
<undefined>  
St. Mary's Medical Center  
<undefined>  
St. Mary's Medical Center  
St. Mary's Medical Center  
<undefined>  
<undefined>  
St. Mary's Medical Center
```

After removing the category, `County General Hospital`, elements that previously belonged to that category no longer belong to any category defined for `Location`. Categorical arrays denote these elements as `undefined`.

Use the function `isundefined` to find observations that do not belong to any category.

```
undefinedIndex = isundefined(Location);
```

`undefinedIndex` is a 63-by-1 categorical array containing logical true (1) for all undefined elements in `Location`.

## See Also

```
categorical | categories | summary | any | hist | removecats |  
isundefined
```

## Related Examples

- “Create Categorical Arrays” on page 7-2
- “Convert Table Variables Containing Strings to Categorical” on page 7-7
- “Plot Categorical Data” on page 7-13
- “Compare Categorical Array Elements” on page 7-20
- “Work with Protected Categorical Arrays” on page 7-35

## Concepts

- “Advantages of Using Categorical Arrays” on page 7-41
- “Ordinal Categorical Arrays” on page 7-44

## Work with Protected Categorical Arrays

This example shows how to work with a categorical array with protected categories.

When you create a categorical array with the function `categorical`, you have the option of specifying whether or not the categories are protected. Ordinal categorical arrays always have protected categories, but you also can create a nonordinal categorical array that is protected using the `'Protected'`, `true` name-value pair argument.

When you assign values that are not in the array's list of categories, the array updates automatically so that its list of categories includes the new values. Similarly, you can combine (nonordinal) categorical arrays that have different categories. The categories in the result include the categories from both arrays.

When you assign new values to a *protected* categorical array, the values must belong to one of the existing categories. Similarly, you can only combine protected arrays that have the same categories.

- If you want to combine two nonordinal categorical arrays that have protected categories, they must have the same categories, but the order does not matter. The resulting categorical array uses the category order from the first array.
- If you want to combine two ordinal categorical array (that always have protected categories), they must have the same categories, including their order.

To add new categories to the array, you must use the function `addcats`.

### Create an Ordinal Categorical Array

Create a categorical array containing the sizes of 10 objects. Use the names `small`, `medium`, and `large` for the values `'S'`, `'M'`, and `'L'`.

```
A = categorical({'M';'L';'S';'S';'M';'L';'M';'L';'M';'S'},...
    {'S','M','L'},{'small','medium','large'},'Ordinal',true)
```

```
A =
```

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

A is a 10-by-1 categorical array.

Display the categories of A.

```
categories(A)
```

```
ans =
```

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

### Verify That the Categories Are Protected

When you create an ordinal categorical array, the categories are always protected.

Use the `isprotected` function to verify that the categories of A are protected.

```
tf = isprotected(A)
```

```
tf =
```

```
1
```

The categories of A are protected.

### Assign a Value in a New Category

Try to add the value 'xlarge' to the categorical array, A.

```
A(2) = 'xlarge'
```

```
Error using categorical/subsasgn (line 55)
Cannot add a new category 'xlarge' to this categorical array
because its categories are protected. Use ADDCATEGORIES to
add the new category.
```

If you try to assign a new value, that does not belong to one of the existing categories, then MATLAB returns an error.

Use `addcats` to add a new category for `xlarge`. Since A is ordinal you must specify the order for the new category.

```
A = addcats(A, 'xlarge', 'After', 'large');
```

Now, you assign a value for 'xlarge', since it has an existing category.

```
A(2) = 'xlarge'
```

```
A =
    medium
    xlarge
    small
    small
    medium
    large
    medium
    large
    medium
    small
```

A is now a 10-by-1 categorical array with four categories, such that `small < medium < large < xlarge`.

### Combine Two Ordinal Categorical Arrays

Create another ordinal categorical array, B, containing the sizes of five items.

```
B = categorical([2;1;1;2;2],1:2,{'xsmall','small'},'Ordinal',true)
```

```
B =  
  
    small  
    xsmall  
    xsmall  
    small  
    small
```

B is a 5-by-1 categorical array with two categories such that `xsmall < small`.

To combine two ordinal categorical arrays (which always have protected categories), they must have the same categories and the categories must be in the same order.

Add the category 'xsmall' to A before the category 'small'.

```
A = addcats(A, 'xsmall', 'Before', 'small');
```

```
categories(A)
```

```
ans =  
  
    'xsmall'  
    'small'  
    'medium'  
    'large'  
    'xlarge'
```

Add the categories {'medium', 'large', 'xlarge'} to B after the category 'small'.

```
B = addcats(B, {'medium', 'large', 'xlarge'}, 'After', 'small');
```

```
categories(B)
```

```
ans =  
  
    'xsmall'  
    'small'  
    'medium'  
    'large'
```



```
'xlarge'
```

The categories of A and B are now the same including their order.

Vertically concatenate A and B.

```
C = [A;B]
```

```
C =
```

```
medium  
large  
small  
small  
medium  
large  
medium  
large  
medium  
small  
xlarge  
small  
xsmall  
xsmall  
small  
small
```

The values from B are appended to the values from A.

List the categories of C.

```
categories(C)
```

```
ans =
```

```
'xsmall'  
'small'  
'medium'  
'large'  
'xlarge'
```

C is a 16-by-1 ordinal categorical array with five categories, such that `xsmall < small < medium < large < xlarge`.

### See Also

`categorical` | `categories` | `summary` | `isprotected` | `isordinal` | `addcats`

### Related Examples

- “Create Categorical Arrays” on page 7-2
- “Convert Table Variables Containing Strings to Categorical” on page 7-7
- “Access Data Using Categorical Arrays” on page 7-28
- “Combine Categorical Arrays” on page 7-24

### Concepts

- “Ordinal Categorical Arrays” on page 7-44

## Advantages of Using Categorical Arrays

### In this section...

“Natural Representation of Categorical Data” on page 7-41

“Mathematical Ordering for Strings” on page 7-41

“Reduce Memory Requirements” on page 7-42

### Natural Representation of Categorical Data

`categorical` is a data type to store data with values from a finite set of discrete categories. One common alternative to using categorical arrays is to use character arrays or cell arrays of strings. To compare strings in character arrays and cell arrays of strings, you must use `strcmp` which can be cumbersome. With categorical arrays, you can use the logical operator `eq (==)` to compare strings in the same way that you compare numeric arrays. The other common alternative to using categorical arrays is to store categorical data using integers in numeric arrays. Using numeric arrays loses all the useful descriptive information from the category names, and also tends to suggest that the integer values have their usual numeric meaning, which, for categorical data, they do not.

### Mathematical Ordering for Strings

Categorical arrays are convenient and memory efficient containers for nonnumeric data with values from a finite set of discrete categories. They are especially useful when the categories have a meaningful mathematical ordering, such as an array with entries from the discrete set of categories `{ 'small', 'medium', 'large' }` where `small < medium < large`.

An ordering other than alphabetical order is not possible with character arrays or cell arrays of strings. Thus, inequality comparisons, such as greater and less than, are not possible. With categorical arrays, you can use relational operations to test for equality and perform element-wise comparisons of strings that have a meaningful mathematical ordering.

## Reduce Memory Requirements

This example shows how to compare the memory required to store data as a cell array of strings versus a categorical array. Categorical arrays have categories that are defined as strings, which can be costly to store and manipulate in a cell array of strings or char array. Categorical arrays store only one copy of each category name, often reducing the amount of memory required to store the array.

Create a sample cell array of strings.

```
state = [ repmat({'MA'},25,1); repmat({'NY'},25,1); ...  
         repmat({'CA'},50,1); ...  
         repmat({'MA'},25,1); repmat({'NY'},25,1) ];
```

Display information about the variable `state`.

```
whos state
```

Name	Size	Bytes	Class	Attributes
state	150x1	17400	cell	

The variable `state` is a cell array of strings requiring 17,400 bytes of memory.

Convert `state` to a categorical array.

```
state = categorical(state);
```

Display the discrete categories in the variable `state`.

```
categories(state)
```

```
ans =
```

```
'CA'  
'MA'  
'NY'
```

`state` contains 150 elements, but only three distinct categories.

Display information about the variable `state`.

```
whos state
```

Name	Size	Bytes	Class	Attributes
<code>state</code>	150x1	754	categorical	

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

## See Also

`categorical` | `categories`

## Related Examples

- “Create Categorical Arrays” on page 7-2
- “Convert Table Variables Containing Strings to Categorical” on page 7-7
- “Compare Categorical Array Elements” on page 7-20
- “Access Data Using Categorical Arrays” on page 7-28

## Concepts

- “Ordinal Categorical Arrays” on page 7-44

## Ordinal Categorical Arrays

### In this section...

“Order of Categories” on page 7-44

“How to Create Ordinal Categorical Arrays” on page 7-44

“Working with Ordinal Categorical Arrays” on page 7-47

### Order of Categories

`categorical` is a data type to store data with values from a finite set of discrete categories, which can have a natural order. You can specify and rearrange the order of categories in all categorical arrays. However, you only can treat *ordinal* categorical arrays as having a mathematical ordering to their categories. Use an ordinal categorical array if you want to use the functions `min`, `max`, or relational operations, such as greater than and less than.

The discrete set of pet categories `{'dog' 'cat' 'bird'}` has no meaningful mathematical ordering. You are free to use any category order and the meaning of the associated data does not change. For example, `pets = categorical({'bird', 'cat', 'dog', 'dog', 'cat'})` creates a categorical array and the categories are listed in alphabetical order, `{'bird' 'cat' 'dog'}`. You can choose to specify or change the order of the categories to `{'dog' 'cat' 'bird'}` and the meaning of the data does not change.

*ordinal* categorical arrays contain categories that have a meaningful mathematical ordering. For example, the discrete set of size categories `{'small', 'medium', 'large'}` has the mathematical ordering `small < medium < large`. The first category listed is the smallest and the last category is the largest. The order of the categories in an ordinal categorical array affects the result from relational comparisons of ordinal categorical arrays.

### How to Create Ordinal Categorical Arrays

This example shows how to create an ordinal categorical array using the `categorical` function with the `'Ordinal', true` name-value pair argument.

#### Ordinal Categorical Array from a Cell Array of Strings

Create an ordinal categorical array, `sizes`, from a cell array of strings, `A`. Use `valueset`, specified as a vector of unique values, to define the categories for `sizes`.

```
A = {'medium' 'large'; 'small' 'medium'; 'large' 'small'};
valueset = {'small', 'medium', 'large'};

sizes = categorical(A,valueset,'Ordinal',true)
```

```
sizes =

      medium      large
      small      medium
      large      small
```

`sizes` is 3-by-2 ordinal categorical array with three categories such that `small < medium < large`. The order of the values in `valueset` becomes the order of the categories of `sizes`.

### Ordinal Categorical Array from Integers

Create an equivalent categorical array from an array of integers. Use the values 1, 2, and 3 to define the categories `small`, `medium`, and `large`, respectively.

```
A2 = [2 3; 1 2; 3 1];
valueset = 1:3;
catnames = {'small', 'medium', 'large'};

sizes2 = categorical(A2,valueset,catnames,'Ordinal',true)
```

```
sizes2 =

      medium      large
      small      medium
      large      small
```

Compare `sizes` and `sizes2`

```
isequal(sizes,sizes2)
```

```
ans =
```

```
1
```

`sizes` and `sizes2` are equivalent categorical arrays with the same ordering of categories.

### **Convert a Categorical Array from Nonordinal to Ordinal**

Create a nonordinal categorical array from the cell array of strings, `A`.

```
sizes3 = categorical(A)
```

```
sizes3 =
```

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

Determine if the categorical array is ordinal.

```
isordinal(sizes3)
```

```
ans =
```

```
0
```

`sizes3` is a nonordinal categorical array with three categories, `{'large', 'medium', 'small'}`. The categories of `sizes3` are the sorted



unique values from A. You must use the input argument, `valueset`, to specify a different category order.

Convert `sizes3` to an ordinal categorical array, such that `small < medium < large`.

```
sizes3 = categorical(sizes3,{'small','medium','large'},'Ordinal',true);
```

`sizes3` is now a 3-by-2 ordinal categorical array equivalent to `sizes` and `sizes2`.

## Working with Ordinal Categorical Arrays

In order to combine or compare two categorical arrays, the sets of categories for both input arrays must be identical, including their order. Furthermore, ordinal categorical arrays are always protected. Therefore, when you assign values to an ordinal categorical array, the values must belong to one of the existing categories. For more information see “Work with Protected Categorical Arrays” on page 7-35.

### See Also

`categorical` | `categories` | `isordinal` | `isequal`

### Related Examples

- “Create Categorical Arrays” on page 7-2
- “Convert Table Variables Containing Strings to Categorical” on page 7-7
- “Compare Categorical Array Elements” on page 7-20
- “Access Data Using Categorical Arrays” on page 7-28

### Concepts

- “Advantages of Using Categorical Arrays” on page 7-41

## Other MATLAB Functions Supporting Categorical Arrays

Many functions in MATLAB operate on categorical arrays in much the same way that they operate on other arrays. A few of these functions might exhibit special behavior when operating on a categorical array. If multiple input arguments are ordinal categorical arrays, the function often requires that they have the same set of categories, including order. Furthermore, a few functions, such as `max` and `gt`, require that the input categorical arrays are ordinal.

The following table lists notable MATLAB functions that operate on categorical arrays in addition to other arrays.

<code>size</code>	<code>isequal</code>	<code>intersect</code>	<code>hist</code>	<code>double</code>
<code>length</code>	<code>isequaln</code>	<code>ismember</code>	<code>times</code>	<code>single</code>
<code>ndims</code>		<code>setdiff</code>		<code>int8</code>
<code>numel</code>	<code>eq</code>	<code>setxor</code>	<code>sort</code>	<code>int16</code>
	<code>ne</code>	<code>unique</code>	<code>sortrows</code>	<code>int32</code>
<code>isrow</code>	<code>lt</code>	<code>union</code>	<code>issorted</code>	<code>int64</code>
<code>iscolumn</code>	<code>le</code>			<code>uint8</code>
	<code>ge</code>		<code>permute</code>	<code>uint16</code>
<code>cat</code>	<code>gt</code>		<code>reshape</code>	<code>uint32</code>
<code>horzcat</code>			<code>transpose</code>	<code>uint64</code>
<code>vertcat</code>	<code>min</code>		<code>ctranspose</code>	<code>char</code>
	<code>max</code>			<code>cellstr</code>

# Tables

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## Create a Table

This example shows how to create a table. `table` is a data type to collect heterogeneous data and metadata properties, such as variable names, row names, descriptions, and variable units, in a single container.

Tables are suitable for column-oriented or tabular data that are often stored as columns in a text file or in a spreadsheet. Each column in a file becomes a variable in the table. Each variable (column) in a table can have a different data type and a different size, but each variable must have the same number of rows. For example, you can use a table to store experimental data, with rows representing different observations and columns representing different measured variables.

### View Sample Data from a File

The sample comma-delimited text file, `patients.dat`, contains information on 100 different patients. You can use `type patients.dat` to view the contents of the file. Below are the first six lines.

```
LastName,Gender,Age,Location,Height,Weight,Smoker,Systolic,Diastolic,SelfAs  
Smith,Male,38,County General Hospital,71,176,1,124,93,Excellent  
Johnson,Male,43,VA Hospital,69,163,0,109,77,Fair  
Williams,Female,38,St. Mary's Medical Center,64,131,0,125,83,Good  
Jones,Female,40,VA Hospital,67,133,0,117,75,Fair  
Brown,Female,49,County General Hospital,64,119,0,122,80,Good
```

The first line contains column headings and each tabular entry is separated by a comma.

### Create a Table Using Default Settings

Convert the sample delimited text file, `patients.dat`, to a table using the `readtable` function with default settings. You also can use the `readtable` function to convert an Excel® spreadsheet file to a table. The `readtable` function accepts delimited text files with extensions `.txt`, `.dat`, or `.csv` and spreadsheet files with extensions `.xls` or `.xlsx`.

```
T = readtable('patients.dat');
```

Return the size of the table.

```
size(T)
```

```
ans =
```

```
100    10
```

The table, T, contains 100 rows and ten variables.

Display the first five rows and first five variables of the table.

```
T(1:5,1:5)
```

```
ans =
```

LastName	Gender	Age	Location	Height
'Smith'	'Male'	38	'County General Hospital'	71
'Johnson'	'Male'	43	'VA Hospital'	69
'Williams'	'Female'	38	'St. Mary's Medical Center'	64
'Jones'	'Female'	40	'VA Hospital'	67
'Brown'	'Female'	49	'County General Hospital'	64

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

Additionally, you can create a table by combining or converting variables that exist in the MATLAB workspace. This table summarizes the functions you can use to create a table from workspace variables.

Data Source in MATLAB Workspace	Function for Conversion to Table
Heterogeneous collection of workspace variables	<code>table</code>
Numeric array	<code>array2table</code>

Data Source in MATLAB Workspace	Function for Conversion to Table
Cell array	cell2table
Structure array	struct2table

### Summarize the Table

View the data type, description, units, and other descriptive statistics for each variable by using `summary` to summarize the table.

```
format compact
```

```
summary(T)
```

```
Variables:
```

```
  LastName: 100x1 cell string
```

```
  Gender: 100x1 cell string
```

```
  Age: 100x1 double
```

```
    Values:
```

```
      min      25
```

```
      median   39
```

```
      max      50
```

```
  Location: 100x1 cell string
```

```
  Height: 100x1 double
```

```
    Values:
```

```
      min      60
```

```
      median   67
```

```
      max      72
```

```
  Weight: 100x1 double
```

```
    Values:
```

```
      min      111
```

```
      median  142.5
```

```
      max      202
```

```
  Smoker: 100x1 double
```

```
    Values:
```

```
      min      0
```

```
      median   0
```

```
      max      1
```

```
  Systolic: 100x1 double
```

```

Values:
    min      109
    median   122
    max      138
Diastolic: 100x1 double
Values:
    min      68
    median   81.5
    max      99
SelfAssessedHealthStatus: 100x1 cell string

```

The table is heterogeneous. The variables `LastName`, `Gender`, `Location`, and `SelfAssessedHealthStatus` are cell arrays of strings, and the other variables are numeric with a data type of `double`.

Set the format back to the default.

```
format
```

### Add Row Names

Tables can be subscripted using parentheses much like ordinary numeric arrays. But in addition to numeric and logical indices, you can use variable and row names as indices. Use the unique identifiers in the variable, `LastName`, as row names. Then, delete the variable `LastName` from the table.

```
T.Properties.RowNames = T.LastName;
T.LastName = [];
```

Alternatively, you can import the file using `readtable` with the `'ReadRowNames'`, `true` name-value pair argument to indicate that the first column contains row names.

Return the size of the table.

```
size(T)
```

```
ans =
```

```
100    9
```

T contains 100 rows and nine variables. The row and variable names, respectively, are not included in the size of a table.

Display the first five rows and last four variables of the table.

```
T(1:5,6:9)
```

```
ans =
```

	Smoker	Systolic	Diastolic	SelfAssessedHealthStatus
Smith	1	124	93	'Excellent'
Johnson	0	109	77	'Fair'
Williams	0	125	83	'Good'
Jones	0	117	75	'Fair'
Brown	0	122	80	'Good'

The elements of the first column in the text file, `LastName`, are now row names. Row names and variable names are table properties. You can always add or change the row names of an existing table by modifying the property `T.Properties.RowNames`.

### Combine Two Variables into a Single Variable

Create a new variable for blood pressure as a horizontal concatenation of the two variables `Systolic` and `Diastolic`. Then, delete the variables `Systolic` and `Diastolic`.

```
T.BloodPressure = [T.Systolic T.Diastolic];
T(:,{'Systolic' 'Diastolic'}) = [];
```

Return the size of the table.

```
size(T)
```

```
ans =
```

```
100    8
```

T contains 100 rows and eight variables. The row and variable names, respectively, are not included in the size of a table. Furthermore, `size`



counts eight variables, even though the variable `BloodPressure` contains two columns.

Display the first five rows and last four variables of the table.

```
T(1:5,5:8)
```

```
ans =
```

	Weight	Smoker	SelfAssessedHealthStatus	BloodPressure
Smith	176	1	'Excellent'	124
Johnson	163	0	'Fair'	109
Williams	131	0	'Good'	125
Jones	133	0	'Fair'	117
Brown	119	0	'Good'	122

The new variable, `BloodPressure` contains two columns of data and is the last variable in the table.

### Create a New Variable from Existing Variables

Create a new variable in the table, `BMI`, based on data in existing variables, `Weight` and `Height`. Then populate the variable units and variable descriptions properties for this variable.

```
T.BMI = (T.Weight*0.453592)./(T.Height*0.0254).^2;
T.Properties.VariableUnits{'BMI'} = 'kg/m^2';
T.Properties.VariableDescriptions{'BMI'} = 'Body Mass Index';
```

Return the size of the table.

```
size(T)
```

```
ans =
```

```
100    9
```

`T` contains 100 rows and nine variables.

Display the first five rows and last four variables of the table.

```
T(1:5,6:9)
```

```
ans =
```

	Smoker	SelfAssessedHealthStatus	BloodPressure	B	
Smith	1	'Excellent'	124	93	24
Johnson	0	'Fair'	109	77	24
Williams	0	'Good'	125	83	22
Jones	0	'Fair'	117	75	20
Brown	0	'Good'	122	80	20

## See Also

[readtable](#) | [table](#) | [array2table](#) | [cell2table](#) | [struct2table](#) | [Table Properties](#) | [summary](#)

## Related Examples

- “Add and Delete Table Rows” on page 8-9
- “Add and Delete Table Variables” on page 8-13
- “Clean Messy and Missing Data in Tables” on page 8-18
- “Modify Units, Descriptions and Table Variable Names” on page 8-25
- “Access Data in a Table” on page 8-29

## Concepts

- “Advantages of Using Tables” on page 8-43

## Add and Delete Table Rows

This example shows how to add and delete rows in a table. You can also edit tables using the Variables Editor.

### Load Sample Data

Load the sample patients data and create a table, T.

```
load patients
```

```
T = table(LastName,Gender,Age,Height,Weight,Smoker,Systolic,Diastolic);  
size(T)
```

```
ans =
```

```
100    8
```

The table, T, has 100 rows and 8 variables (columns).

### Add Rows by Concatenation

Create a comma-delimited file, `morePatients.txt`, with the following additional patient data.

```
LastName,Gender,Age,Height,Weight,Smoker,Systolic,Diastolic  
Abbot,Female,31,65,156,1,128,85  
Bailey,Female,38,68,130,0,113,81  
Cho,Female,35,61,130,0,124,80  
Daniels,Female,48,67,142,1,123,74
```

Append the rows in the file to the end of the table, T.

```
T2 = readtable('morePatients.txt');  
Tnew = [T;T2];  
size(Tnew)
```

```
ans =
```

```
104    8
```

The table `Tnew` has 104 rows. In order to vertically concatenate two tables, both tables must have the same number of variables, with the same variable names. If the variable names are different, you can directly assign new rows in a table to rows from another table. For example, `T(end+1:end+4,:) = T2`.

### Add Rows from a Cell Array

If you want to append new rows stored in a cell array, first convert the cell array to a table, and then concatenate the tables.

```
cellPatients = {'LastName', 'Gender', 'Age', 'Height', 'Weight', ...
               'Smoker', 'Systolic', 'Diastolic';
               'Edwards', 'Male', 42, 70, 158, 0, 116, 83;
               'Falk', 'Female', 28, 62, 125, 1, 120, 71};
T2 = cell2table(cellPatients(2:end,:));
T2.Properties.VariableNames = cellPatients(1,:);

Tnew = [Tnew;T2];
size(Tnew)
```

```
ans =
```

```
    106     8
```

### Add Rows from a Structure

You also can append new rows stored in a structure. Convert the structure to a table, and then concatenate the tables.

```
structPatients(1,1).LastName = 'George';
structPatients(1,1).Gender = 'Male';
structPatients(1,1).Age = 45;
structPatients(1,1).Height = 76;
structPatients(1,1).Weight = 182;
structPatients(1,1).Smoker = 1;
structPatients(1,1).Systolic = 132;
structPatients(1,1).Diastolic = 85;

structPatients(2,1).LastName = 'Hadley';
structPatients(2,1).Gender = 'Female';
structPatients(2,1).Age = 29;
```

```
structPatients(2,1).Height = 58;  
structPatients(2,1).Weight = 120;  
structPatients(2,1).Smoker = 0;  
structPatients(2,1).Systolic = 112;  
structPatients(2,1).Diastolic = 70;
```

```
Tnew = [Tnew;struct2table(structPatients)];  
size(Tnew)
```

```
ans =
```

```
108    8
```

### **Omit Duplicate Rows**

Use `unique` to omit any rows in a table that are duplicated.

```
Tnew = unique(Tnew);  
size(Tnew)
```

```
ans =
```

```
106    8
```

Two duplicated rows are deleted.

### **Delete Rows by Row Number**

Delete rows 18, 20, and 21 from the table.

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

```
ans =
```

```
103    8
```

The table contains information on 103 patients now.

### **Delete Rows by Row Name**

First, specify the variable of identifiers, `LastName`, as row names. Then, delete the variable, `LastName`, from `Tnew`. Finally, use the row name to index and delete rows.

```
Tnew.Properties.RowNames = Tnew.LastName;  
Tnew.LastName = [];  
Tnew('Smith',:) = [];  
size(Tnew)
```

```
ans =
```

```
102    7
```

The table now has one less row and one less variable.

### **Search for Rows To Delete**

You also can search for observations in the table. For example, delete rows for any patients under the age of 30.

```
toDelete = Tnew.Age<30;  
Tnew(toDelete,:) = [];  
size(Tnew)
```

```
ans =
```

```
85    7
```

The table now has 17 fewer rows.

### **See Also**

[table](#) | [readtable](#) | [array2table](#) | [cell2table](#) | [struct2table](#) | [Table Properties](#)

### **Related Examples**

- “Add and Delete Table Variables” on page 8-13
- “Clean Messy and Missing Data in Tables” on page 8-18

## Add and Delete Table Variables

This example shows how to add and delete column-oriented variables in a table. You also can edit tables using the Variables Editor.

### Load Sample Data

Load the sample patients data and create two tables. Create one table, T, with information collected from a patient questionnaire and create another table, T1, with data measured from the patient.

```
load patients
```

```
T = table(Age,Gender,Smoker);
T1 = table(Height,Weight,Systolic,Diastolic);
```

Display the first five rows of each table.

```
T(1:5,:)
T1(1:5,:)
```

```
ans =
```

Age	Gender	Smoker
38	'Male'	true
43	'Male'	false
38	'Female'	false
40	'Female'	false
49	'Female'	false

```
ans =
```

Height	Weight	Systolic	Diastolic
71	176	124	93

```

69      163      109      77
64      131      125      83
67      133      117      75
64      119      122      80

```

The table `T` has 100 rows and 3 variables.

The table `T1` has 100 rows and 4 variables.

### Add Variables by Concatenating Tables

Add variables to the table, `T`, by horizontally concatenating it with `T1`.

```
T = [T T1];
```

Display the first five rows of the table, `T`.

```
T(1:5, :)
```

```
ans =
```

Age	Gender	Smoker	Height	Weight	Systolic	Diastolic
38	'Male'	true	71	176	124	93
43	'Male'	false	69	163	109	77
38	'Female'	false	64	131	125	83
40	'Female'	false	67	133	117	75
49	'Female'	false	64	119	122	80

The table, `T`, now has 7 variables and 100 rows.

If the tables that you are horizontally concatenating have row names, `horzcat` concatenates the tables by matching the row names. Therefore, the tables must use the same row names, but the row order does not matter.

### Add and Delete Variables by Name



First create a new variable for blood pressure as a horizontal concatenation of the two variables `Systolic` and `Diastolic`. Then, delete the variables `Systolic` and `Diastolic` by name using dot indexing.

```
T.BloodPressure = [T.Systolic T.Diastolic];

T.Systolic = [];
T.Diastolic = [];
```

Alternatively, you can also use parentheses with named indexing to delete the variables `Systolic` and `Diastolic` at once, `T(:,{'Systolic','Diastolic'}) = [];`

Display the first five rows of the table, `T`.

```
T(1:5,:)
```

```
ans =
```

Age	Gender	Smoker	Height	Weight	BloodPressure	
38	'Male'	true	71	176	124	93
43	'Male'	false	69	163	109	77
38	'Female'	false	64	131	125	83
40	'Female'	false	67	133	117	75
49	'Female'	false	64	119	122	80

`T` now has 6 variables and 100 rows.

Add a new variable, `BMI`, in the table, `T`, to contain the body mass index for each patient. `BMI` is a function of height and weight.

```
T.BMI = (T.Weight*0.453592)./(T.Height*0.0254).^2;
```

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

Display the first five rows of the table, T.

```
T(1:5, :)
```

```
ans =
```

Age	Gender	Smoker	Height	Weight	BloodPressure	BMI
38	'Male'	true	71	176	124 93	24.54
43	'Male'	false	69	163	109 77	24.07
38	'Female'	false	64	131	125 83	22.48
40	'Female'	false	67	133	117 75	20.83
49	'Female'	false	64	119	122 80	20.42

T has 100 rows and 7 variables.

### Delete Variables by Number

Delete the third variable, Smoker, and the sixth variable, BloodPressure, from the table.

```
T(:, [3,6]) = [];
```

Display the first five rows of the table, T.

```
T(1:5, :)
```

```
ans =
```

Age	Gender	Height	Weight	BMI
38	'Male'	71	176	24.547
43	'Male'	69	163	24.071
38	'Female'	64	131	22.486
40	'Female'	67	133	20.831
49	'Female'	64	119	20.426

T has 100 rows and 5 variables.

**See Also**

[table](#) | [array2table](#) | [cell2table](#) | [struct2table](#) | [readtable](#)

**Related Examples**

- “Add and Delete Table Rows” on page 8-9
- “Clean Messy and Missing Data in Tables” on page 8-18
- “Modify Units, Descriptions and Table Variable Names” on page 8-25

## Clean Messy and Missing Data in Tables

This example shows how to find, clean, and delete table rows with missing data.

### Create and Load Sample Data

Create a comma-separated text file, `messy.csv`, that contains the following data.

```
afe1,3,yes,3,3
egh3,.,no,7,7
wth4,3,yes,3,3
atn2,23,no,23,23
arg1,5,yes,5,5
jre3,34.6,yes,34.6,34.6
wen9,234,yes,234,234
ple2,2,no,2,2
dbo8,5,no,5,5
oii4,5,yes,5,5
wnk3,245,yes,245,245
abk6,563,,563,563
pnj5,463,no,463,463
wnn3,6,no,6,6
oks9,23,yes,23,23
wba3,,yes,NaN,14
pkn4,2,no,2,2
adw3,22,no,22,22
poj2,-99,yes,-99,-99
bas8,23,no,23,23
gry5,NA,yes,NaN,21
```

There are many different missing data indicators in `messy.csv`.

- Empty string ( ' ' )
- period ( . )
- NA
- NaN

- -99

Create a table from the comma-separated text file and indicate that the first row of the file does not represent variable names. Use the 'TreatAsEmpty' name-value pair argument with `readtable` to specify strings to treat as empty values.

```
T = readtable('messy.csv',...
    'ReadVariableNames',false,...
    'TreatAsEmpty',{' ','NA'})
```

T =

Var1	Var2	Var3	Var4	Var5
'afe1'	3	'yes'	3	3
'egh3'	NaN	'no'	7	7
'wth4'	3	'yes'	3	3
'atn2'	23	'no'	23	23
'arg1'	5	'yes'	5	5
'jre3'	34.6	'yes'	34.6	34.6
'wen9'	234	'yes'	234	234
'ple2'	2	'no'	2	2
'dbo8'	5	'no'	5	5
'oii4'	5	'yes'	5	5
'wnk3'	245	'yes'	245	245
'abk6'	563	' '	563	563
'pnj5'	463	'no'	463	463
'wnn3'	6	'no'	6	6
'oks9'	23	'yes'	23	23
'wba3'	NaN	'yes'	NaN	14
'pkn4'	2	'no'	2	2
'adw3'	22	'no'	22	22
'poj2'	-99	'yes'	-99	-99
'bas8'	23	'no'	23	23
'gry5'	NaN	'yes'	NaN	21

T is a table with 21 rows and 5 variables. 'TreatAsEmpty' only applies to numeric columns in the file and cannot handle numeric literals, such as '-99'.

### Summarize the Table

View the data type, description, units, and other descriptive statistics for each variable by using `summary` to summarize the table.

```
summary(T)
```

```
Variables:
```

```
Var1: 21x1 cell string
```

```
Var2: 21x1 double
```

```
Values:
```

```
min      -99
median    14
max      563
NaNs      3
```

```
Var3: 21x1 cell string
```

```
Var4: 21x1 double
```

```
Values:
```

```
min      -99
median     7
max      563
NaNs      2
```

```
Var5: 21x1 double
```

```
Values:
```

```
min      -99
median    14
max      563
```

When you import data from a file, the default is for `readtable` to read any variables with nonnumeric elements as a cell array of strings.

### Find Rows with Missing Values

Display the subset of rows from the table, T, that have at least one missing value.

```
TF = ismissing(T,{' ' '.' 'NA' NaN -99});
T(any(TF,2),:)
```

ans =

Var1	Var2	Var3	Var4	Var5
'egh3'	NaN	'no'	7	7
'abk6'	563	' '	563	563
'wba3'	NaN	'yes'	NaN	14
'poj2'	-99	'yes'	-99	-99
'gry5'	NaN	'yes'	NaN	21

readtable replaced '.' and 'NA' with NaN in the numeric variables, Var2, Var4, and Var5.

### Replace Missing Value Indicators

Clean the data so that the missing values indicated by code -99 have the standard MATLAB numeric missing value indicator, NaN.

```
T = standardizeMissing(T, -99)
```

T =

Var1	Var2	Var3	Var4	Var5
'afe1'	3	'yes'	3	3
'egh3'	NaN	'no'	7	7
'wth4'	3	'yes'	3	3
'atn2'	23	'no'	23	23
'arg1'	5	'yes'	5	5
'jre3'	34.6	'yes'	34.6	34.6
'wen9'	234	'yes'	234	234
'ple2'	2	'no'	2	2
'dbo8'	5	'no'	5	5

'oii4'	5	'yes'	5	5
'wnk3'	245	'yes'	245	245
'abk6'	563	' '	563	563
'pnj5'	463	'no'	463	463
'wnn3'	6	'no'	6	6
'oks9'	23	'yes'	23	23
'wba3'	NaN	'yes'	NaN	14
'pkn4'	2	'no'	2	2
'adw3'	22	'no'	22	22
'poj2'	NaN	'yes'	NaN	NaN
'bas8'	23	'no'	23	23
'gry5'	NaN	'yes'	NaN	21

`standardizeMissing` replaces three instances of `-99` with `NaN`.

### Create a Table with Complete Rows

Create a new table, `T2`, that contains only the complete rows—those without missing data.

```
TF = ismissing(T);
T2 = T(~any(TF,2),:)
```

`T2 =`

Var1	Var2	Var3	Var4	Var5
'afe1'	3	'yes'	3	3
'wth4'	3	'yes'	3	3
'atn2'	23	'no'	23	23
'arg1'	5	'yes'	5	5
'jre3'	34.6	'yes'	34.6	34.6
'wen9'	234	'yes'	234	234
'ple2'	2	'no'	2	2
'dbo8'	5	'no'	5	5
'oii4'	5	'yes'	5	5
'wnk3'	245	'yes'	245	245
'pnj5'	463	'no'	463	463
'wnn3'	6	'no'	6	6
'oks9'	23	'yes'	23	23



'pkn4'	2	'no'	2	2
'adw3'	22	'no'	22	22
'bas8'	23	'no'	23	23

T2 contains 16 rows and 5 variables.

### Organize the Data

Sort the rows of T2 in descending order by Var3, and then in ascending order by Var1.

```
T2 = sortrows(T2, {'Var3', 'Var1'}, {'descend', 'ascend'})
```

T2 =

Var1	Var2	Var3	Var4	Var5
'afe1'	3	'yes'	3	3
'arg1'	5	'yes'	5	5
'jre3'	34.6	'yes'	34.6	34.6
'oii4'	5	'yes'	5	5
'oks9'	23	'yes'	23	23
'wen9'	234	'yes'	234	234
'wnk3'	245	'yes'	245	245
'wth4'	3	'yes'	3	3
'adw3'	22	'no'	22	22
'atn2'	23	'no'	23	23
'bas8'	23	'no'	23	23
'dbo8'	5	'no'	5	5
'pkn4'	2	'no'	2	2
'ple2'	2	'no'	2	2
'pnj5'	463	'no'	463	463
'wnn3'	6	'no'	6	6

In Var3, the rows are grouped first grouped by 'yes', followed by 'no'. Then in Var1, the rows are listed alphabetically.

### See Also

[readtable](#) | [summary](#) | [ismissing](#) | [sortrows](#)

### **Related Examples**

- “Add and Delete Table Rows” on page 8-9
- “Add and Delete Table Variables” on page 8-13
- “Modify Units, Descriptions and Table Variable Names” on page 8-25
- “Access Data in a Table” on page 8-29

## Modify Units, Descriptions and Table Variable Names

This example shows how to access and modify table properties for variable units, descriptions and names. You also can edit these property values using the Variables Editor.

### Load Sample Data

Load the sample patients data and create a table.

```
load patients
BloodPressure = [Systolic Diastolic];

T = table(Gender, Age, Height, Weight, Smoker, BloodPressure);
```

Display the first five rows of the table, T.

```
T(1:5, :)
```

```
ans =
```

Gender	Age	Height	Weight	Smoker	BloodPressure
'Male'	38	71	176	true	124 93
'Male'	43	69	163	false	109 77
'Female'	38	64	131	false	125 83
'Female'	40	67	133	false	117 75
'Female'	49	64	119	false	122 80

T has 100 rows and 6 variables.

### Add Variable Units

Specify units for each variable in the table by modifying the table property, VariableUnits. Specify the variable units as a cell array of strings.

```
T.Properties.VariableUnits = {' ' 'Yrs' 'In' 'Lbs' ' ' ' '};
```

An individual empty string within the cell array indicates that the corresponding variable does not have units.

### **Add a Variable Description for a Single Variable**

Add a variable description for the variable, `BloodPressure`. Assign a single string to the element of the cell array of strings containing the description for `BloodPressure`.

```
T.Properties.VariableDescriptions{'BloodPressure'} = 'Systolic/Diastolic';
```

You can use the variable name, 'BloodPressure', or the numeric index of the variable, 6, to index into the cell array of strings containing the variable descriptions.

### **Summarize the Table**

View the data type, description, units, and other descriptive statistics for each variable by using `summary` to summarize the table.

```
summary(T)
```

```
Variables:
```

```
Gender: 100x1 cell string
```

```
Age: 100x1 double
```

```
Units: Yrs
```

```
Values:
```

```
min      25
```

```
median   39
```

```
max      50
```

```
Height: 100x1 double
```

```
Units: In
```

```
Values:
```

```
min      60
```

```
median   67
```

```

        max          72

Weight: 100x1 double
Units:  Lbs
Values:

        min          111
        median       142.5
        max          202

Smoker: 100x1 logical
Values:

        true         34
        false        66

BloodPressure: 100x2 double
Description:  Systolic/Diastolic
Values:
           BloodPressure_1   BloodPressure_2
           _____       _____

        min          109           68
        median       122           81.5
        max          138           99
    
```

The `BloodPressure` variable has a description and the `Age`, `Height`, `Weight`, and `BloodPressure` variables have units.

### Change a Variable Name

Change the variable name for the first variable from `Gender` to `Sex`.

```
T.Properties.VariableNames{'Gender'} = 'Sex';
```

Display the first five rows of the table, `T`.

```
T(1:5,:)
```

```
ans =
```

Sex	Age	Height	Weight	Smoker	BloodPressure
'Male'	38	71	176	true	124 93
'Male'	43	69	163	false	109 77
'Female'	38	64	131	false	125 83
'Female'	40	67	133	false	117 75
'Female'	49	64	119	false	122 80

In addition to properties for variable units, descriptions and names, there are table properties for row and dimension names, a table description, and user data.

## See Also

[readtable](#) | [table](#) | [array2table](#) | [cell2table](#) | [struct2table](#) | [summary](#)  
| [Table Properties](#)

## Related Examples

- “Add and Delete Table Variables” on page 8-13
- “Access Data in a Table” on page 8-29

## Access Data in a Table

### In this section...

“Ways to Index into a Table” on page 8-29

“Create Table from Subset of Larger Table” on page 8-30

“Create Array from the Contents of Table” on page 8-34

### Ways to Index into a Table

A table is a container for storing column-oriented variables that have the same number of rows. Parentheses allow you to select a subset of the data in a table and preserve the table container. Curly braces and dot indexing allow you to extract data from a table.

If you use curly braces, the resulting array is the horizontal concatenation of the specified table variables containing only the specified rows. The data types of all the specified variables must be compatible for concatenation. You can then perform calculations using MATLAB functions.

Dot indexing extracts data from one table variable. The result is an array of the same data type as extracted variable. You can follow the dot indexing with parentheses to specify a subset of rows to extract from a variable.

### Summary of Table Indexing Methods

Consider a table, T.

Type of Indexing	Result	Syntax	rows	vars/var
Parentheses	table	T(rows,vars)	One or more rows	One or more variables
Curly Braces	extracted data	T{rows,vars}	One or more rows	One or more variables

Type of Indexing	Result	Syntax	rows	vars/var
Dot Indexing	extracted data	T.var T.(varindex)	All rows	One variable
Dot Indexing	extracted data	T.var (rows)	One or more rows	One variable

### How to Specify Rows to Access

When indexing into a table with parentheses, curly braces, or dot indexing, you can specify rows as a colon, numeric indices, or logical expressions. Furthermore, you can index by name using a single row name or a cell array of row names.

A logical expression can contain curly braces or dot indexing to extract data from which you can define the subset of rows. For example, `rows = T.Var2>0` returns a logical array with logical true (1) for rows where the value in the variable `Var2` is greater than zero.

### How to Specify Variables to Access

When indexing into a table with parentheses or curly braces, you can specify vars as a colon, numeric indices, logical expressions, a single variable name, or a cell array of row names.

When using dot indexing, you must specify a single variable to access. For a single variable name, use `T.var`. For a single variable index, specified as a positive integer, use `T.(varindex)`.

## Create Table from Subset of Larger Table

This example shows how to create a table from a subset of a larger table.

### Load Sample Data

Load the sample patients data and create a table. Use the unique identifiers in `LastName` as row names.

```
load patients
```



```
patients = table(Age,Gender,Height,Weight,Smoker,...  
                'RowNames',LastName);
```

The table, `patients`, contains 100 rows and 5 variables.

View the data type, description, units, and other descriptive statistics for each variable by using `summary` to summarize the table.

```
summary(patients)
```

Variables:

Age: 100x1 double

Values:

min	25
median	39
max	50

Gender: 100x1 cell string

Height: 100x1 double

Values:

min	60
median	67
max	72

Weight: 100x1 double

Values:

min	111
median	142.5
max	202

Smoker: 100x1 logical

Values:

```

true      34
false     66

```

### Index Using Numeric Indices

Create a subtable containing the first five rows and all the variables from the table, `patients`. Use numeric indexing within the parentheses to specify the desired rows and variables. This is similar to indexing with numeric arrays.

```
T1 = patients(1:5,:)
```

```
T1 =
```

	Age	Gender	Height	Weight	Smoker
Smith	38	'Male'	71	176	true
Johnson	43	'Male'	69	163	false
Williams	38	'Female'	64	131	false
Jones	40	'Female'	67	133	false
Brown	49	'Female'	64	119	false

T1 is a 5-by-5 table. In addition to numeric indices, you can use row or variable names inside the parentheses. In this case, using row indices and a colon is more compact than using row or variable names.

### Index Using Names

Select all the data for the patients with the last names 'Adams' and 'Brown'. In this case, it is simpler to use the row names than to use the numeric index.

```
T2 = patients({'Adams', 'Brown'}, :)
```

```
T2 =
```

	Age	Gender	Height	Weight	Smoker
--	-----	--------	--------	--------	--------

Adams	48	'Female'	66	137	false
Brown	49	'Female'	64	119	false

T2 is a 2-by-5 table.

### Index Using a Logical Expression

Create a new table, T3, containing the gender, height, and weight of the patients under the age of 30. Select only the rows where the value in the variable, Age, is less than 30.

Use dot notation to extract data from a table variable and a logical expression to define the subset of rows based on that extracted data.

```
rows = patients.Age<30;
vars = {'Gender','Height','Weight'};
```

rows is a 100-by-1 logical array containing logical true (1) for rows where the value in the variable, Age, is less than 30.

Use parentheses to return a table containing the desired subset of the data.

```
T3 = patients(rows,vars)
```

T3 =

	Gender	Height	Weight
Moore	'Male'	68	183
Jackson	'Male'	71	174
Garcia	'Female'	69	131
Walker	'Female'	65	123
Hall	'Male'	70	189
Young	'Female'	63	114
Hill	'Female'	64	138

Rivera	'Female'	63	130
Cooper	'Female'	65	127
Cox	'Female'	66	111
Howard	'Female'	68	134
James	'Male'	66	186
Jenkins	'Male'	69	189
Perry	'Female'	64	120
Alexander	'Male'	69	171

T3 is a 15-by-3 table.

## Create Array from the Contents of Table

This example shows how to extract the contents of a table using curly braces or dot indexing.

### Load Sample Data

Load the sample patients data and create a table. Use the unique identifiers in `LastName` as row names.

```
load patients
```

```
patients = table(Age,Gender,Height,Weight,Smoker,...  
                'RowNames',LastName);
```

The table, `patients`, contains 100 rows and 5 variables.

### Extract Multiple Rows and Multiple Variables

Extract data from multiple variables in the table, `patients` by using curly braces. Since dot indexing extracts data from a single variable at a time, braces are more convenient when you want to extract more than one variable.

Extract the height and weight for the first five patients. Use numeric indices to select the subset of rows, `1:5`, and variable names to select the subset of variables, `{Height,Weight}`.

```
A = patients{1:5,{'Height','Weight'}}
```

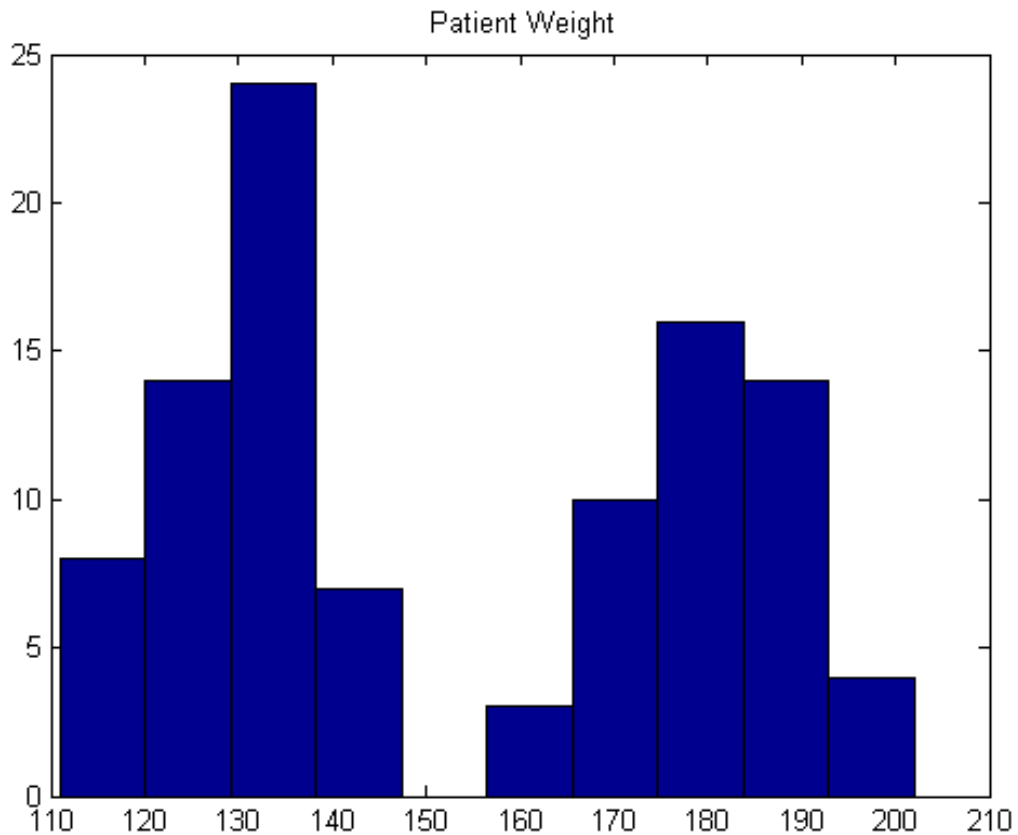
```
A =  
    71    176  
    69    163  
    64    131  
    67    133  
    64    119
```

A is a 5-by-2 numeric array.

### **Extract Data from One Variable**

Use dot indexing to easily extract the contents of a single variable. Plot a histogram of the numeric data in the variable, `Weight`.

```
figure()  
hist(patients.Weight)  
title(' Patient Weight')
```



`patients.Weight` is a double-precision column vector with 100 rows. Alternatively, you can use curly braces, `patients{:,'Weight'}`, to extract all the rows for the variable `Weight`.

To specify a subset of rows for a single variable, you can follow the dot indexing with parentheses or curly braces. Extract the heights of the nonsmoker patients under the age of 30.

Use dot notation to extract data from table variables and a logical expression to define the subset of rows based on that extracted data.

```
rows = patients.Smoker==false & patients.Age<30;
```

Use dot notation to extract the desired rows from the variable, Height.

```
patients.Height(rows)
```

```
ans =
```

```
68  
71  
70  
63  
64  
63  
65  
66  
68  
66  
64
```

The output is a 11-by-1 numeric array. Alternatively, you can specify the single variable, Height, within curly braces to extract the desired data, `patients{rows, 'Height'}`.

## See Also

[table](#) | [Table Properties](#) | [summary](#)

## Related Examples

- “Create a Table” on page 8-2
- “Modify Units, Descriptions and Table Variable Names” on page 8-25
- “Calculations on Tables” on page 8-38

## Concepts

- “Advantages of Using Tables” on page 8-43

## Calculations on Tables

This example shows how to perform calculation on tables.

The functions `rowfun` and `varfun` apply a specified function to a table, yet many other functions require numeric or homogeneous arrays as input arguments. You can extract data from individual variables using dot indexing or from one or more variables using curly braces. The extracted data is then an array that you can use as input to other functions.

### Create and Load Sample Data

Create a comma-separated text file, `testScores.csv`, that contains the following data.

```
LastName,Gender,Test1,Test2,Test3
HOWARD,male,90,87,93
WARD,male,87,85,83
TORRES,male,86,85,88
PETERSON,female,75,80,72
GRAY,female,89,86,87
RAMIREZ,female,96,92,98
JAMES,male,78,75,77
WATSON,female,91,94,92
BROOKS,female,86,83,85
KELLY,male,79,76,82
```

Create a table from the comma-separated text file and use the unique identifiers in the first column as row names.

```
T = readtable('testScores.csv','ReadRowNames',true)
```

```
T =
```

	Gender	Test1	Test2	Test3
	-----	-----	-----	-----
HOWARD	'male'	90	87	93
WARD	'male'	87	85	83
TORRES	'male'	86	85	88
PETERSON	'female'	75	80	72
GRAY	'female'	89	86	87



RAMIREZ	'female'	96	92	98
JAMES	'male'	78	75	77
WATSON	'female'	91	94	92
BROOKS	'female'	86	83	85
KELLY	'male'	79	76	82

T is a table with 10 rows and 4 variables.

### Summarize the Table

View the data type, description, units, and other descriptive statistics for each variable by using `summary` to summarize the table.

```
summary(T)
```

```
Variables:
```

```
Gender: 10x1 cell string
```

```
Test1: 10x1 double
```

```
Values:
```

```
min      75
median   86.5
max      96
```

```
Test2: 10x1 double
```

```
Values:
```

```
min      75
median   85
max      94
```

```
Test3: 10x1 double
```

```
Values:
```

```
min      72
median   86
max      98
```

The summary contains the minimum, average, and maximum score for each test.

### Find the Average Across Each Row

Extract the data from the second, third, and fourth variables using curly braces, {}, find the average of each row, and store it in a new variable, TestAvg.

```
T.TestAvg = mean(T{: ,2:end},2)
```

```
T =
```

	Gender	Test1	Test2	Test3	TestAvg
	-----	-----	-----	-----	-----
HOWARD	'male'	90	87	93	90
WARD	'male'	87	85	83	85
TORRES	'male'	86	85	88	86.333
PETERSON	'female'	75	80	72	75.667
GRAY	'female'	89	86	87	87.333
RAMIREZ	'female'	96	92	98	95.333
JAMES	'male'	78	75	77	76.667
WATSON	'female'	91	94	92	92.333
BROOKS	'female'	86	83	85	84.667
KELLY	'male'	79	76	82	79

Alternatively, you can use the variable names, T{:, {'Test1', 'Test2', 'Test3'}} or the variable indices, T{:, 2:4} to select the subset of data.

### Compute Statistics Using a Grouping Variable

Compute the mean and maximum of TestAvg for each gender.

```
varfun(@mean,T,'InputVariables','TestAvg',...
      'GroupingVariables','Gender')
```

```
ans =
```

	Gender	GroupCount	mean_TestAvg
	-----	-----	-----
female	'female'	5	87.067
male	'male'	5	83.4

### Replace Data Values

The maximum score for each test is 100. Use curly braces to extract the data from the table and convert the test scores to a 25 point scale.

```
T{:,2:end} = T{:,2:end}*25/100
```

```
T =
```

	Gender	Test1	Test2	Test3	TestAvg
	-----	-----	-----	-----	-----
HOWARD	'male'	22.5	21.75	23.25	22.5
WARD	'male'	21.75	21.25	20.75	21.25
TORRES	'male'	21.5	21.25	22	21.583
PETERSON	'female'	18.75	20	18	18.917
GRAY	'female'	22.25	21.5	21.75	21.833
RAMIREZ	'female'	24	23	24.5	23.833
JAMES	'male'	19.5	18.75	19.25	19.167
WATSON	'female'	22.75	23.5	23	23.083
BROOKS	'female'	21.5	20.75	21.25	21.167
KELLY	'male'	19.75	19	20.5	19.75

### Change a Variable Name

Change the variable name from TestAvg to Final.

```
T.Properties.VariableNames{end} = 'Final'
```

```
T =
```

	Gender	Test1	Test2	Test3	Final
	-----	-----	-----	-----	-----
HOWARD	'male'	22.5	21.75	23.25	22.5
WARD	'male'	21.75	21.25	20.75	21.25
TORRES	'male'	21.5	21.25	22	21.583
PETERSON	'female'	18.75	20	18	18.917
GRAY	'female'	22.25	21.5	21.75	21.833
RAMIREZ	'female'	24	23	24.5	23.833
JAMES	'male'	19.5	18.75	19.25	19.167
WATSON	'female'	22.75	23.5	23	23.083
BROOKS	'female'	21.5	20.75	21.25	21.167
KELLY	'male'	19.75	19	20.5	19.75

### **See Also**

table | Table Properties | summary | rowfun | varfun

### **Related Examples**

- “Access Data in a Table” on page 8-29

## Advantages of Using Tables

### In this section...

“Conveniently Store Mixed-Type Data in Single Container” on page 8-43

“Access Data Using Numeric or Named Indexing” on page 8-46

“Use Table Properties to Store Metadata” on page 8-48

### Conveniently Store Mixed-Type Data in Single Container

You can use the `table` data type to collect mixed-type data and metadata properties, such as variable name, row names, descriptions, and variable units, in a single container. Tables are suitable for column-oriented or tabular data that is often stored as columns in a text file or in a spreadsheet. For example, you can use a table to store experimental data, with rows representing different observations and columns representing different measured variables.

Tables consist of rows and column-oriented variables. Each variable in a table can have a different data type and a different size, but each variable must have the same number of rows.

For example, load sample patients data.

```
load patients
```

Then, combine the workspace variables, `Systolic` and `Diastolic` into a single `BloodPressure` variable and convert the workspace variable, `Gender`, from a cell array of strings to a categorical array.

```
BloodPressure = [Systolic Diastolic];
Gender = categorical(Gender);
```

```
whos('Gender','Age','Smoker','BloodPressure')
```

Name	Size	Bytes	Class	Attributes
Age	100x1	800	double	

```

BloodPressure    100x2          1600 double
Gender           100x1          550  categorical
Smoker           100x1          100   logical

```

The variables `Age`, `BloodPressure`, `Gender`, and `Smoker` have varying data types and are candidates to store in a table since they all have the same number of rows, 100.

Now, create a table from the variables and display the first five rows.

```

T = table(Gender, Age, Smoker, BloodPressure);
T(1:5, :)

```

```
ans =
```

Gender	Age	Smoker	BloodPressure	
Male	38	true	124	93
Male	43	false	109	77
Female	38	false	125	83
Female	40	false	117	75
Female	49	false	122	80

The table displays in a tabular format with the variable names at the top.

Each variable in a table is a single data type. For example, if you add a new row to the table, MATLAB forces consistency of the data type between the new data and the corresponding table variables. If you try to add information for a new patient where the first column contains the patient's age instead of gender, you receive an error.

```
T(end+1, :) = {37, {'Female'}, true, [130 84]}
```

```
Error using table/subsasgnParens (line 200)
Invalid RHS for assignment to a categorical array.
```

```
Error in table/subsasgn (line 61)
    t = subsasgnParens(t,s,b,creating);
```

The error occurs because MATLAB cannot assign numeric data to the categorical array, `Gender`.

For comparison of tables with structures, consider the structure array, `StructArray`, that is equivalent to the table, `T`.

```
StructArray = table2struct(T)
```

```
'StructArray =  
101x1 struct array with fields:
```

```
    Gender  
    Age  
    Smoker  
    BloodPressure
```

Structure arrays organize records using named fields. Each field's value can have a different data type or size. Now, display the named fields for the first element of `StructArray`.

```
StructArray(1)
```

```
ans =  
  
    Gender: [1x1 categorical]  
    Age: 38  
    Smoker: 1  
    BloodPressure: [124 93]
```

Fields in a structure array are analogous to variables in a table. However, unlike with tables, you cannot enforce homogeneity within a field. For example, you can have some values of `S.Gender` that are categorical array elements, 'Male' or 'Female', others that are strings, 'Male' or 'Female', and others that are integers, 0 or 1.

Now consider the same data stored in a *scalar* structure, with four fields each containing one variable from the table.

```
ScalarStruct = struct(...  
    'Gender', {Gender}, ...
```

```

    'Age',Age,...
    'Smoker',Smoker,...
    'BloodPressure',BloodPressure)

ScalarStruct =

    Gender: [100x1 categorical]
    Age: [100x1 double]
    Smoker: [100x1 logical]
    BloodPressure: [100x2 double]

```

Unlike with tables, you cannot enforce that the data is rectangular. For example, the field `ScalarStruct.Age` can be a different length than the other fields.

A table allows you to maintain the rectangular structure (like a structure array) and enforce homogeneity of variables (like fields in a scalar structure). Although cell arrays do not have named fields, they have many of the same disadvantages as structure arrays and scalar structures. If you have rectangular data that is homogeneous in each variable, consider using a table. Then you can use numeric or named indexing, and you can use table properties to store metadata.

## Access Data Using Numeric or Named Indexing

You can index into a table using parentheses, curly braces, or dot indexing. Parentheses allow you to select a subset of the data in a table and preserve the table container. Curly braces and dot indexing allow you to extract data from a table. Within each table indexing method, you can specify the rows or variables to access by name or by numeric index.

Consider the sample table from above. Each row in the table, `T`, represents a different patient. The workspace variable, `LastName`, contains unique identifiers for the 100 rows. Add row names to the table by setting the `RowNames` property to `LastName` and display the first five rows of the updated table.

```

T.Properties.RowNames = LastName;
T(1:5,:)

ans =

```



	Gender	Age	Smoker	BloodPressure	
	_____	_____	_____	_____	_____
Smith	Male	38	true	124	93
Johnson	Male	43	false	109	77
Williams	Female	38	false	125	83
Jones	Female	40	false	117	75
Brown	Female	49	false	122	80

In addition to labeling the data, you can use row and variable names to access data in the table. For example, use named indexing to display the gender and blood pressure of the patients Williams and Brown.

```
T({'Williams', 'Brown'}, {'Age', 'BloodPressure'})
```

```
ans =
```

	Age	BloodPressure	
	_____	_____	_____
Williams	38	125	83
Brown	49	122	80

Now, use numeric indexing to return an equivalent subtable. Return the third and fifth row from the second and fourth variables.

```
T(3:2:5, 2:2:4)
```

```
ans =
```

	Age	BloodPressure	
	_____	_____	_____
Williams	38	125	83
Brown	49	122	80

With cell arrays or structures, you do not have the same flexibility to use named or numeric indexing.

- With a cell array, you must use `strcmp` to find desired named data, and then you can index into the array.
- With a scalar structure or structure array, it is not possible to refer to a field by number. Furthermore, with a scalar structure, you cannot easily select a subset of variables or a subset of observations. With a structure array, you can select a subset of observations, but you cannot select a subset of variables.
- With a table, you can access data by named index or by numeric index. Furthermore, you can easily select a subset of variables and a subset of rows.

For more information on table indexing, see “Access Data in a Table” on page 8-29.

## Use Table Properties to Store Metadata

In addition to storing data, tables have properties to store metadata, such as variable names, row names, descriptions, and variable units. You can access a property using `T.Properties.PropName`, where `T` is the name of the table and `PropName` is one of the table properties.

For example, add a table description, variable descriptions, and variable units for `Age`.

```
T.Properties.Description = 'Simulated Patient Data';
```

```
T.Properties.VariableDescriptions = ...  
    {'Male or Female' ...  
    '' ...  
    'true or false' ...  
    'Systolic/Diastolic'};
```

```
T.Properties.VariableUnits{'Age'} = 'Yrs';
```

Individual empty strings within the cell array for `VariableDescriptions` indicate that the corresponding variable does not have a description. For more information, see `Table Properties`.

To print a table summary, use the `summary` function.

**summary(T)**

Description: Simulated Patient Data

Variables:

Gender: 100x1 cell string  
Description: Male or Female

Age: 100x1 double  
Units: Yrs  
Values:

min	25
median	39
max	50

Smoker: 100x1 logical  
Description: true or false  
Values:

true	34
false	66

BloodPressure: 100x2 double  
Description: Systolic/Diastolic  
Values:

	BloodPressure_1	BloodPressure_2
	_____	_____
min	109	68
median	122	81.5
max	138	99

Structures and cell arrays do not have properties for storing metadata.

**See Also**

table | summary

### **Related Examples**

- “Create a Table” on page 8-2
- “Modify Units, Descriptions and Table Variable Names” on page 8-25
- “Access Data in a Table” on page 8-29

# Structures

---

- “Create a Structure Array” on page 9-2
- “Access Data in a Structure Array” on page 9-5
- “Concatenate Structures” on page 9-9
- “Generate Field Names from Variables” on page 9-11
- “Access Data in Nested Structures” on page 9-12
- “Access Elements of a Nonscalar Struct Array” on page 9-14
- “Ways to Organize Data in Structure Arrays” on page 9-16
- “Memory Requirements for a Structure Array” on page 9-20

## Create a Structure Array

This example shows how to create a structure array. A structure is a data type that groups related data using data containers called fields. Each field can contain data of any type or size.

Store a patient record in a scalar structure with fields `name`, `billing`, and `test`.

```
patient.name = 'John Doe';
patient.billing = 127.00;
patient.test = [79, 75, 73; 180, 178, 177.5; 220, 210, 205];
patient
```

```
patient =
    name: 'John Doe'
  billing: 127
    test: [3x3 double]
```

Add records for other patients to the array by including subscripts after the array name.

```
patient(2).name = 'Ann Lane';
patient(2).billing = 28.50;
patient(2).test = [68, 70, 68; 118, 118, 119; 172, 170, 169];
patient
```

```
patient =
1x2 struct array with fields:
```

```
name
billing
test
```

Each patient record in the array is a structure of class `struct`. An array of structures is often referred to as a struct array. Like other MATLAB arrays, a struct array can have any dimensions.

A struct array has the following properties:

- All structs in the array have the same number of fields.
- All structs have the same field names.
- Fields of the same name in different structs can contain different types or sizes of data.

Any unspecified fields for new structs in the array contain empty arrays.

```
patient(3).name = 'New Name';
patient(3)
```

```
ans =
```

```
    name: 'New Name'
  billing: []
    test: []
```

Access data in the structure array to find how much the first patient owes, and to create a bar graph of his test results.

```
amount_due = patient(1).billing
bar(patient(1).test)
title(['Test Results for ', patient(1).name])
```

```
amount_due =
```

**Related  
Examples**

- “Create a Cell Array” on page 10-3
- “Create a Table” on page 8-2

**Concepts**

- “Cell vs. Struct Arrays” on page 10-18
- “Advantages of Using Tables” on page 8-43



## Access Data in a Structure Array

This example shows how to access the contents of a structure array. To run the code in this example, load several variables into a scalar (1-by-1) structure named `S`.

```
S = load('clown.mat')
```

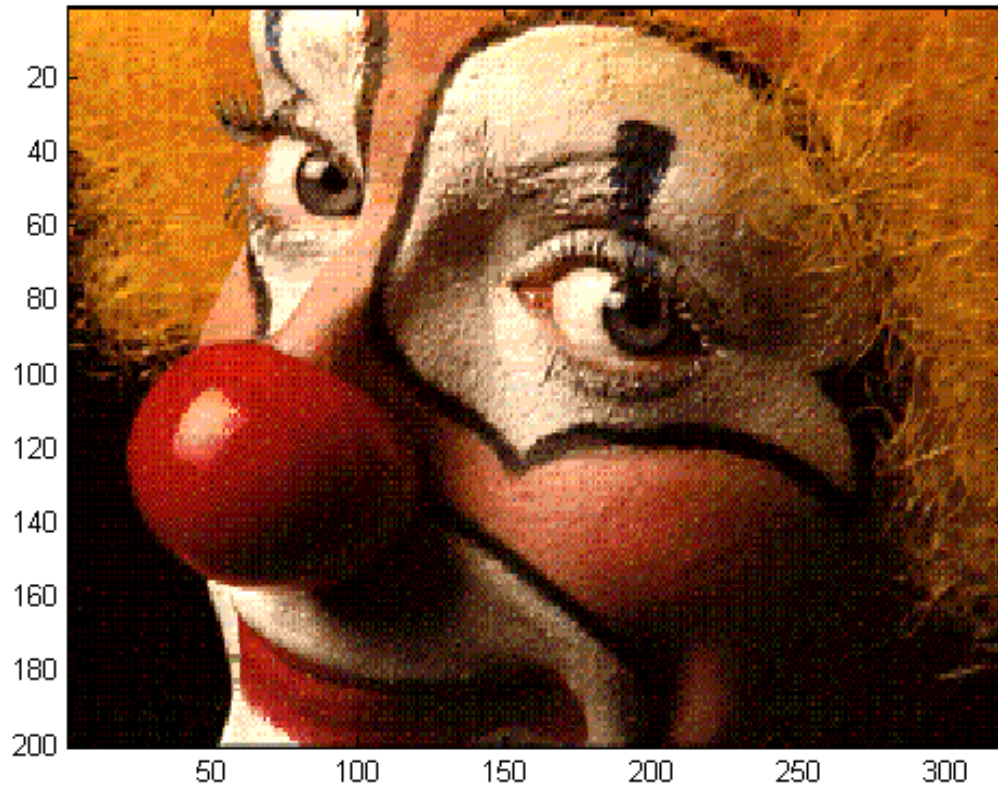
```
S =
```

```
      X: [200x320 double]  
      map: [81x3 double]  
      caption: [2x1 char]
```

The variables from the file (`X`, `caption`, and `map`) are now fields in the struct.

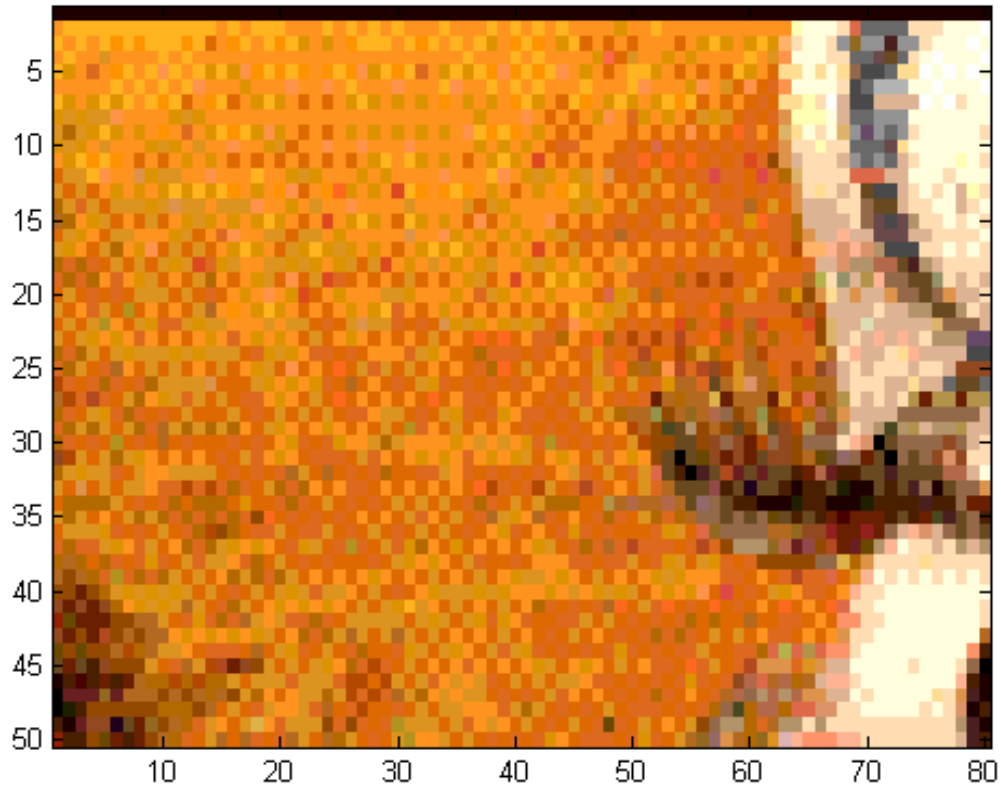
Access the data using dot notation of the form `structName.fieldName`. For example, pass the numeric data in field `X` to the `image` function:

```
image(S.X)  
colormap(S.map)
```



To access part of a field, add indices as appropriate for the size and type of data in the field. For example, pass the upper left corner of X to the `image` function:

```
upperLeft = S.X(1:50,1:80);  
image(upperLeft);
```



If a particular field contains a cell array, use curly braces to access the data, such as `S.cellField{1:50,1:80}`.

### Data in Nonscalar Structure Arrays

Create a nonscalar array by loading data from the file `mandrill.mat` into a second element of array `S`:

```
S(2) = load('mandrill.mat')
```

Each element of a structure array must have the same fields. Both `clown.mat` and `mandrill.mat` contain variables `X`, `map`, and `caption`.

`S` is a 1-by-2 array.

```
S =  
1x2 struct array with fields:  
    X  
    map  
    caption
```

For nonscalar structures, the syntax for accessing a particular field is `structName(indices).fieldName`. Redisplay the clown image, specifying the index for the clown struct (1):

```
image(S(1).X)  
colormap(S(1).map)
```

Add indices to select and redisplay the upper left corner of the field contents:

```
upperLeft = S(1).X(1:50,1:80);  
image(upperLeft)
```

---

**Note** You can index into part of a field only when you refer to a single element of a structure array. MATLAB does not support statements such as `S(1:2).X(1:50,1:80)`, which attempt to index into a field for multiple elements of the structure.

---

### Related Information

- “Access Data in Nested Structures” on page 9-12
- “Access Elements of a Nonscalar Struct Array” on page 9-14
- “Generate Field Names from Variables” on page 9-11

## Concatenate Structures

This example shows how to concatenate structure arrays using the `[]` operator. To concatenate structures, they must have the same set of fields, but the fields do not need to contain the same sizes or types of data.

Create scalar (1-by-1) structure arrays `struct1` and `struct2`, each with fields `a` and `b`:

```
struct1.a = 'first';  
struct1.b = [1,2,3];
```

```
struct2.a = 'second';  
struct2.b = rand(5);
```

Just as concatenating two scalar values such as `[1, 2]` creates a 1-by-2 numeric array, concatenating `struct1` and `struct2`,

```
combined = [struct1, struct2]
```

creates a 1-by-2 structure array:

```
combined =  
    1x2 struct array with fields:  
    a  
    b
```

When you want to access the contents of a particular field, specify the index of the structure in the array. For example, access field `a` of the first structure:

```
combined(1).a
```

This code returns

```
ans =  
    first
```

Concatenation also applies to nonscalar structure arrays. For example, create a 2-by-2 structure array named `new`:

```
new(1,1).a = 1;    new(1,1).b = 10;  
new(1,2).a = 2;    new(1,2).b = 20;
```

```
new(2,1).a = 3;   new(2,1).b = 30;  
new(2,2).a = 4;   new(2,2).b = 40;
```

Because the 1-by-2 structure `combined` and the 2-by-2 structure `new` both have two columns, you can concatenate them vertically with a semicolon separator:

```
larger = [combined; new]
```

This code returns a 3-by-2 structure array,

```
larger =  
    3x2 struct array with fields:  
        a  
        b
```

where, for example,

```
larger(2,1).a =  
    1
```

For related information, see:

- “Creating and Concatenating Matrices”
- “Access Data in a Structure Array” on page 9-5
- “Access Elements of a Nonscalar Struct Array” on page 9-14

## Generate Field Names from Variables

This example shows how to derive a structure field name at run time from a variable or expression. The general syntax is

```
structName.(dynamicExpression)
```

where `dynamicExpression` is a variable or expression that returns a character or string. Field names that you reference with expressions are called *dynamic field names*.

For example, create a field name from the current date:

```
currentDate = datestr(now, 'mmdd');  
myStruct.(currentDate) = [1,2,3]
```

If the current date reported by your system is February 29, then this code assigns data to a field named `Feb29`:

```
myStruct =  
    Feb29: [1 2 3]
```

Field names, like variable names, must begin with a letter, can contain letters, digits, or underscore characters, and are case sensitive. To avoid potential conflicts, do not use the names of existing variables or functions as field names. For more information, see “Variable Names” on page 1-8.

## Access Data in Nested Structures

This example shows how to index into a structure that is nested within another structure. The general syntax for accessing data in a particular field is

```
structName(index).nestedStructName(index).fieldName(indices)
```

When a structure is scalar (1-by-1), you do not need to include the indices to refer to the single element. For example, create a scalar structure `s`, where field `n` is a nested scalar structure with fields `a`, `b`, and `c`:

```
s.n.a = ones(3);  
s.n.b = eye(4);  
s.n.c = magic(5);
```

Access the third row of field `b`:

```
third_row_b = s.n.b(3,:)
```

Variable `third_row_b` contains the third row of `eye(4)`.

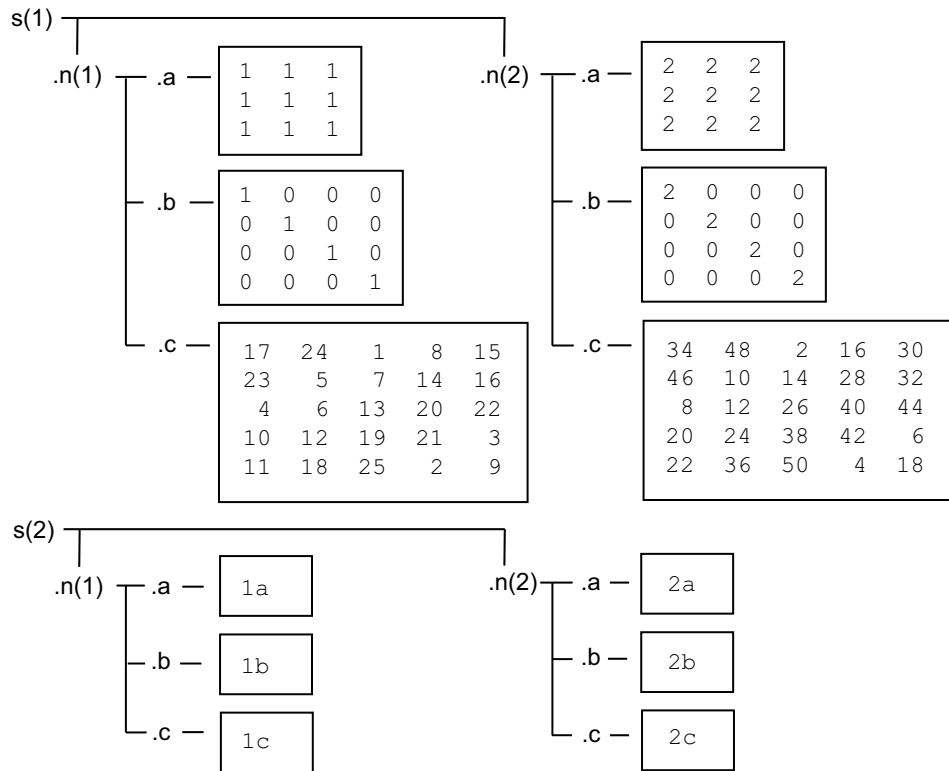
```
third_row_b =  
    0     0     1     0
```

Expand `s` so that both `s` and `n` are nonscalar (1-by-2):

```
s(1).n(2).a = 2 * ones(3);  
s(1).n(2).b = 2 * eye(4);  
s(1).n(2).c = 2 * magic(5);  
  
s(2).n(1).a = '1a';    s(2).n(2).a = '2a';  
s(2).n(1).b = '1b';    s(2).n(2).b = '2b';  
s(2).n(1).c = '1c';    s(2).n(2).c = '2c';
```

Structure `s` now contains the data shown in the following figure.





Access part of the array in field `b` of the second element in `n` within the first element of `s`:

```
part_two_eye = s(1).n(2).b(1:2,1:2)
```

This returns the 2-by-2 upper left corner of `2 * eye(4)`:

```
part_two_eye =
    2    0
    0    2
```

## Access Elements of a Nonscalar Struct Array

This example shows how to access and process data from multiple elements of a nonscalar structure array:

Create a 1-by-3 structure `s` with field `f`:

```
s(1).f = 1;  
s(2).f = 'two';  
s(3).f = 3 * ones(3);
```

Although each structure in the array must have the same number of fields and the same field names, the contents of the fields can be different types and sizes. When you refer to field `f` for multiple elements of the structure array, such as

```
s(1:3).f
```

or

```
s.f
```

MATLAB returns the data from the elements in a *comma-separated list*, which displays as follows:

```
ans =  
    1  
  
ans =  
    two  
  
ans =  
    3    3    3  
    3    3    3  
    3    3    3
```

You cannot assign the list to a single variable with the syntax `v = s.f` because the fields can contain different types of data. However, you can assign the list items to the same number of variables, such as

```
[v1, v2, v3] = s.f;
```

or assign to elements of a cell array, such as

```
c = {s.f};
```

If all of the fields contain the same type of data and can form a hyperrectangle, you can concatenate the list items. For example, create a structure `nums` with scalar numeric values in field `f`, and concatenate the data from the fields:

```
nums(1).f = 1;
nums(2).f = 2;
nums(3).f = 3;

allNums = [nums.f]
```

This code returns

```
allNums =
     1     2     3
```

If you want to process each element of an array with the same operation, use the `arrayfun` function. For example, count the number of elements in field `f` of each struct in array `s`:

```
numElements = arrayfun(@(x) numel(x.f), s)
```

The syntax `@(x)` creates an anonymous function. This code calls the `numel` function for each element of array `s`, such as `numel(s(1).f)`, and returns

```
numElements =
     1     3     9
```

For related information, see:

- “Comma-Separated Lists” on page 2-61
- “Anonymous Functions” on page 17-23

## Ways to Organize Data in Structure Arrays

There are at least two ways you can organize data in a structure array: plane organization and element-by-element organization. The method that best fits your data depends on how you plan to access the data, and, for very large data sets, whether you have system memory constraints.

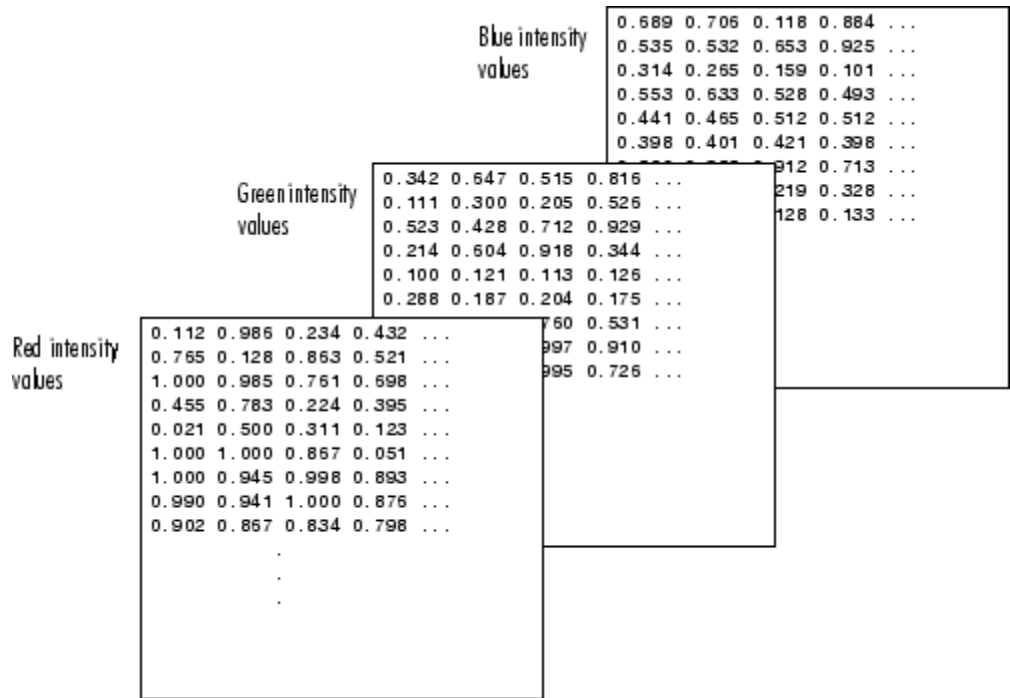
Plane organization allows easier access to all values within a field. Element-by-element organization allows easier access to all information related to a single element or record. The following sections include an example of each type of organization:

- “Plane Organization” on page 9-16
- “Element-by-Element Organization” on page 9-18

When you create a structure array, MATLAB stores information about each element and field in the array header. As a result, structures with more elements and fields require more memory than simpler structures that contain the same data. For more information on memory requirements for arrays, see “Memory Allocation” on page 26-2.

### Plane Organization

Consider an RGB image with three arrays corresponding to color intensity values.



If you have arrays RED, GREEN, and BLUE in your workspace, then these commands create a scalar structure named `img` that uses plane organization:

```

img.red = RED;
img.green = GREEN;
img.blue = BLUE;

```

Plane organization allows you to easily extract entire image planes for display, filtering, or other processing. For example, multiply the red intensity values by 0.9:

```

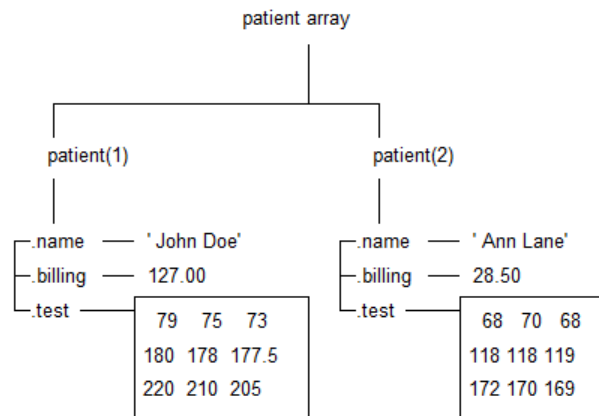
adjustedRed = .9 * img.red;

```

If you have multiple images, you can add them to the `img` structure, so that each element `img(1)`, ..., `img(n)` contains an entire image. For an example that adds elements to a structure, see the following section.

## Element-by-Element Organization

Consider a database with patient information. Each record contains data for the patient's name, test results, and billing amount.



These statements create an element in a structure array named patient:

```

patient(1).name = 'John Doe';
patient(1).billing = 127.00;
patient(1).test = [79, 75, 73; 180, 178, 177.5; 220, 210, 205];
  
```

Additional patients correspond to new elements in the structure. For example, add an element for a second patient:

```

patient(2).name = 'Ann Lane';
patient(2).billing = 28.50;
patient(2).test = [68, 70, 68; 118, 118, 119; 172, 170, 169];
  
```

Element-by-element organization supports simple indexing to access data for a particular patient. For example, find the average of the first patient's test results, calculating by rows (dimension 2) rather than by columns:

```
aveResultsDoe = mean(patient(1).test,2)
```

This code returns

```
aveResultsDoe =
```

75.6667  
178.5000  
212.0000

For information on processing data from more than one element at a time, see “Access Data in a Structure Array” on page 9-5.

## Memory Requirements for a Structure Array

Structure arrays do not require completely contiguous memory. However, each field requires contiguous memory, as does the header that MATLAB creates to describe the array. For very large arrays, incrementally increasing the number of fields or the number of elements in a field results in Out of Memory errors.

Allocate memory for the contents by assigning initial values with the `struct` function, such as

```
newStruct(1:25,1:50) = struct('a',ones(20),'b',zeros(30),'c',rand(40));
```

This code creates and populates a 25-by-50 structure array `S` with fields `a`, `b`, and `c`.

If you prefer not to assign initial values, you can initialize a structure array by assigning empty arrays to each field of the last element in the structure array, such as

```
newStruct(25,50).a = [];  
newStruct(25,50).b = [];  
newStruct(25,50).c = [];
```

or, equivalently,

```
newStruct(25,50) = struct('a',[],'b',[],'c',[]);
```

However, in this case, MATLAB only allocates memory for the header, and not for the contents of the array.

For more information, see:

- “Preallocating Memory”
- “Memory Allocation” on page 26-2



# Cell Arrays

---

- “What Is a Cell Array?” on page 10-2
- “Create a Cell Array” on page 10-3
- “Access Data in a Cell Array” on page 10-5
- “Add Cells to a Cell Array” on page 10-8
- “Delete Data from a Cell Array” on page 10-9
- “Combine Cell Arrays” on page 10-10
- “Pass Contents of Cell Arrays to Functions” on page 10-11
- “Preallocate Memory for a Cell Array” on page 10-17
- “Cell vs. Struct Arrays” on page 10-18
- “Multilevel Indexing to Access Parts of Cells” on page 10-20

## What Is a Cell Array?

A cell array is a data type with indexed data containers called cells. Each cell can contain any type of data. Cell arrays commonly contain lists of text strings, combinations of text and numbers from spreadsheets or text files, or numeric arrays of different sizes.

There are two ways to refer to the elements of a cell array. Enclose indices in smooth parentheses, ( ), to refer to sets of cells — for example, to define a subset of the array. Enclose indices in curly braces, {}, to refer to the text, numbers, or other data within individual cells.

For more information, see:

- “Create a Cell Array” on page 10-3
- “Access Data in a Cell Array” on page 10-5

## Create a Cell Array

This example shows how to create a cell array using the `{}` operator or the `cell` function.

When you have data to put into a cell array, create the array using the cell array construction operator, `{}`:

```
myCell = {1, 2, 3;
          'text', rand(5,10,2), {11; 22; 33}}
```

Like all MATLAB arrays, cell arrays are rectangular, with the same number of cells in each row. `myCell` is a 2-by-3 cell array:

```
myCell =
    [ 1]    [          2]    [ 3]
    'text'  [5x10x2 double]  {3x1 cell}
```

You also can use the `{}` operator to create an empty 0-by-0 cell array,

```
C = {}
```

If you plan to add values to a cell array over time or in a loop, you can create an empty *n*-dimensional array using the `cell` function:

```
emptyCell = cell(3,4,2)
```

`emptyCell` is a 3-by-4-by-2 cell array, where each cell contains an empty array, `[]`:

```
emptyCell(:,:,1) =
    []    []    []    []
    []    []    []    []
    []    []    []    []
```

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

### **Related Examples**

- “Access Data in a Cell Array” on page 10-5
- “Multidimensional Cell Arrays”
- “Create a Structure Array” on page 9-2
- “Create a Table” on page 8-2

### **Concepts**

- “Cell vs. Struct Arrays” on page 10-18
- “Advantages of Using Tables” on page 8-43

## Access Data in a Cell Array

This example shows how to read and write data to and from a cell array. To run the code in this example, create a 2-by-3 cell array of text and numeric data:

```
C = {'one', 'two', 'three';
     1, 2, 3};
```

There are two ways to refer to the elements of a cell array. Enclose indices in smooth parentheses, `()`, to refer to sets of cells—for example, to define a subset of the array. Enclose indices in curly braces, `{}`, to refer to the text, numbers, or other data within individual cells.

### Cell Indexing with Smooth Parentheses, `()`

Cell array indices in smooth parentheses refer to sets of cells. For example, the command

```
upperLeft = C(1:2,1:2)
```

creates a 2-by-2 cell array:

```
upperLeft =
    'one'    'two'
    [ 1]    [ 2]
```

Update sets of cells by replacing them with the same number of cells. For example, the statement

```
C(1,1:3) = {'first','second','third'}
```

replaces the cells in the first row of `C` with an equivalent-sized (1-by-3) cell array:

```
C =
    'first'    'second'    'third'
    [ 1]    [ 2]    [ 3]
```

If cells in your array contain numeric data, you can convert the cells to a numeric array using the `cell2mat` function:

```
numericCells = C(2,1:3)
numericVector = cell2mat(numericCells)
```

numericCells is a 1-by-3 cell array, but numericVector is a 1-by-3 array of type double:

```
numericCells =
    [1]    [2]    [3]

numericVector =
     1     2     3
```

### **Content Indexing with Curly Braces, {}**

Access the contents of cells—the numbers, text, or other data within the cells—by indexing with curly braces. For example, the command

```
last = C{2,3}
```

creates a numeric variable of type `double`, because the cell contains a `double` value:

```
last =
     3
```

Similarly, this command

```
C{2,3} = 300
```

replaces the contents of the last cell of `C` with a new, numeric value:

```
C =
    'first'    'second'    'third'
    [    1]    [    2]    [  300]
```

When you access the contents of multiple cells, such as

```
C{1:2,1:2}
```

MATLAB creates a *comma-separated list*. Because each cell can contain a different type of data, you cannot assign this list to a single variable. However, you can assign the list to the same number of variables as cells. MATLAB assigns to the variables in column order. For example,

```
[r1c1, r2c1, r1c2, r2c2] = C{1:2,1:2}
```

returns

```
r1c1 =  
    first
```

```
r2c1 =  
    1
```

```
r1c2 =  
    second
```

```
r2c2 =  
    2
```

If each cell contains the same type of data, you can create a single variable by applying the array concatenation operator, `[ ]`, to the comma-separated list. For example,

```
nums = [C{2, :}]
```

returns

```
nums =  
    1     2   300
```

For more information, see:

- “Multilevel Indexing to Access Parts of Cells” on page 10-20
- “Comma-Separated Lists” on page 2-61

## Add Cells to a Cell Array

This example shows how to add cells to a cell array.

Create a 1-by-3 cell array:

```
C = {1, 2, 3};
```

Assign data to a cell outside the current dimensions:

```
C{4,4} = 44
```

MATLAB expands the cell array to a rectangle that includes the specified subscripts. Any intervening cells contain empty arrays:

```
C =
     [1]     [2]     [3]     []
     []     []     []     []
     []     []     []     []
     []     []     []    [44]
```

Add cells without specifying a value by assigning an empty array as the contents of a cell:

```
C{5,5} = []
```

C is now a 5-by-5 cell array:

```
C =
     [1]     [2]     [3]     []     []
     []     []     []     []     []
     []     []     []     []     []
     []     []     []    [44]     []
     []     []     []     []     []
```

For related examples, see:

- “Access Data in a Cell Array” on page 10-5
- “Combine Cell Arrays” on page 10-10
- “Delete Data from a Cell Array” on page 10-9



## Delete Data from a Cell Array

This example shows how to remove data from individual cells, and how to delete entire cells from a cell array. To run the code in this example, create a 3-by-3 cell array:

```
C = {1, 2, 3; 4, 5, 6; 7, 8, 9};
```

Delete the contents of a particular cell by assigning an empty array to the cell, using curly braces for content indexing, {}:

```
C{2,2} = []
```

This code returns

```
C =  
    [1]    [2]    [3]  
    [4]     []    [6]  
    [7]    [8]    [9]
```

Delete sets of cells using standard array indexing with smooth parentheses, (). For example, this command

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

removes the second row of C:

```
C =  
    [1]    [2]    [3]  
    [7]    [8]    [9]
```

For related examples, see:

- “Add Cells to a Cell Array” on page 10-8
- “Access Data in a Cell Array” on page 10-5

## Combine Cell Arrays

This example shows how to combine cell arrays by concatenation or nesting. To run the code in this example, create several cell arrays with the same number of columns:

```
C1 = {1, 2, 3};  
C2 = {'A', 'B', 'C'};  
C3 = {10, 20, 30};
```

Concatenate cell arrays with the array concatenation operator, `[]`. In this example, vertically concatenate the cell arrays by separating them with semicolons:

```
C4 = [C1; C2; C3]
```

C4 is a 3-by-3 cell array:

```
C4 =  
    [ 1]    [ 2]    [ 3]  
    'A'    'B'    'C'  
    [10]    [20]    [30]
```

Create a nested cell array with the cell array construction operator, `{}`:

```
C5 = {C1; C2; C3}
```

C5 is a 3-by-1 cell array, where each cell contains a cell array:

```
C5 =  
    {1x3 cell}  
    {1x3 cell}  
    {1x3 cell}
```

For more information, see “Concatenating Matrices”.

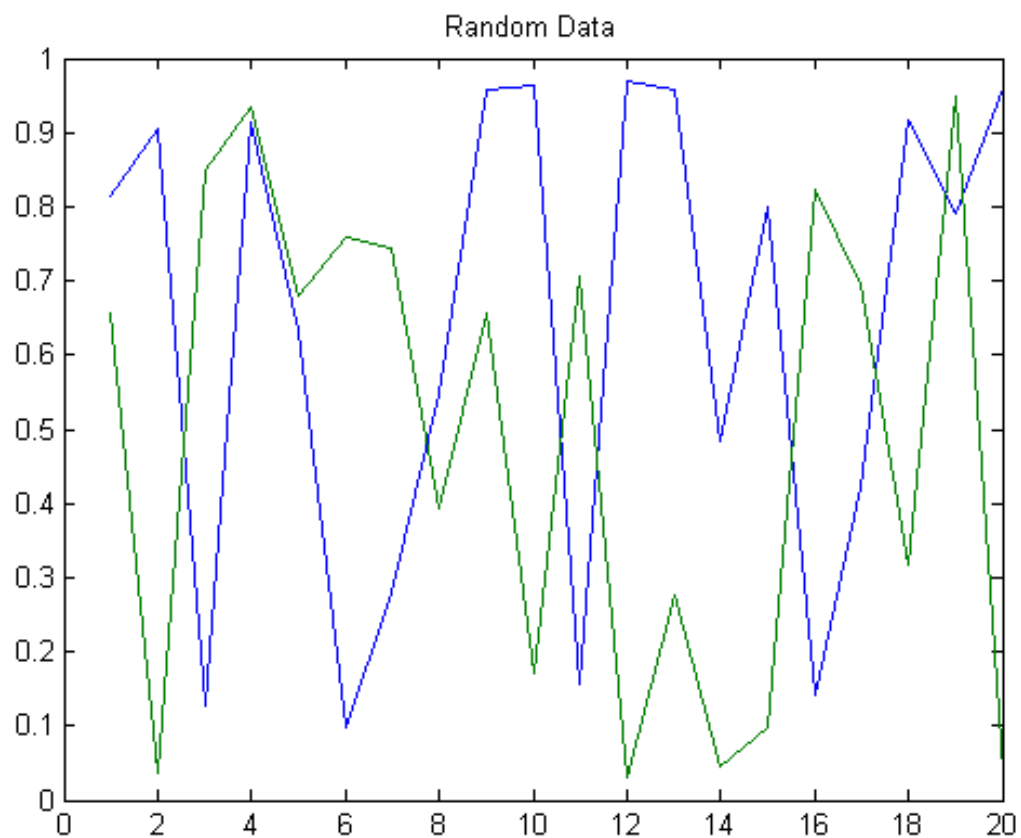
## Pass Contents of Cell Arrays to Functions

These examples show several ways to pass data from a cell array to a MATLAB® function that does not recognize cell arrays as inputs.

**Pass the contents of a single cell by indexing with curly braces, {}.**

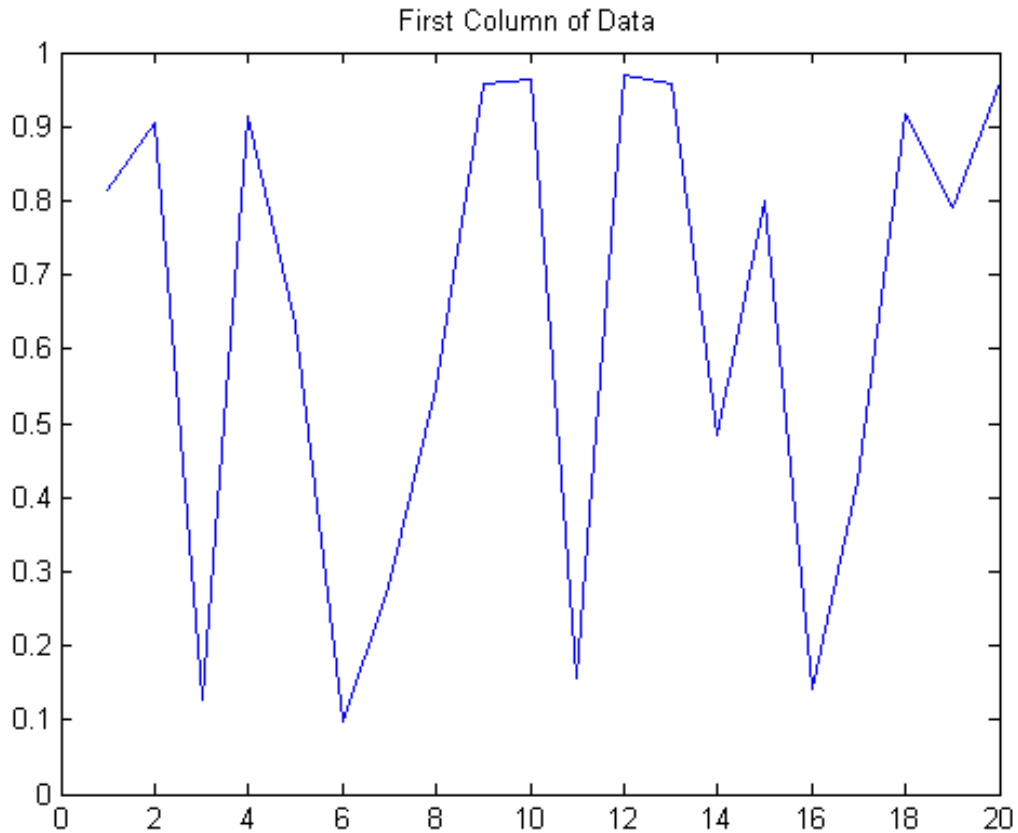
This example creates a cell array that contains text and a 20-by-2 array of random numbers.

```
randCell = {'Random Data', rand(20,2)};  
plot(randCell{1,2})  
title(randCell{1,1})
```



Plot only the first column of data by indexing further into the content (multilevel indexing).

```
figure
plot(randCell{1,2}(:,1))
title('First Column of Data')
```

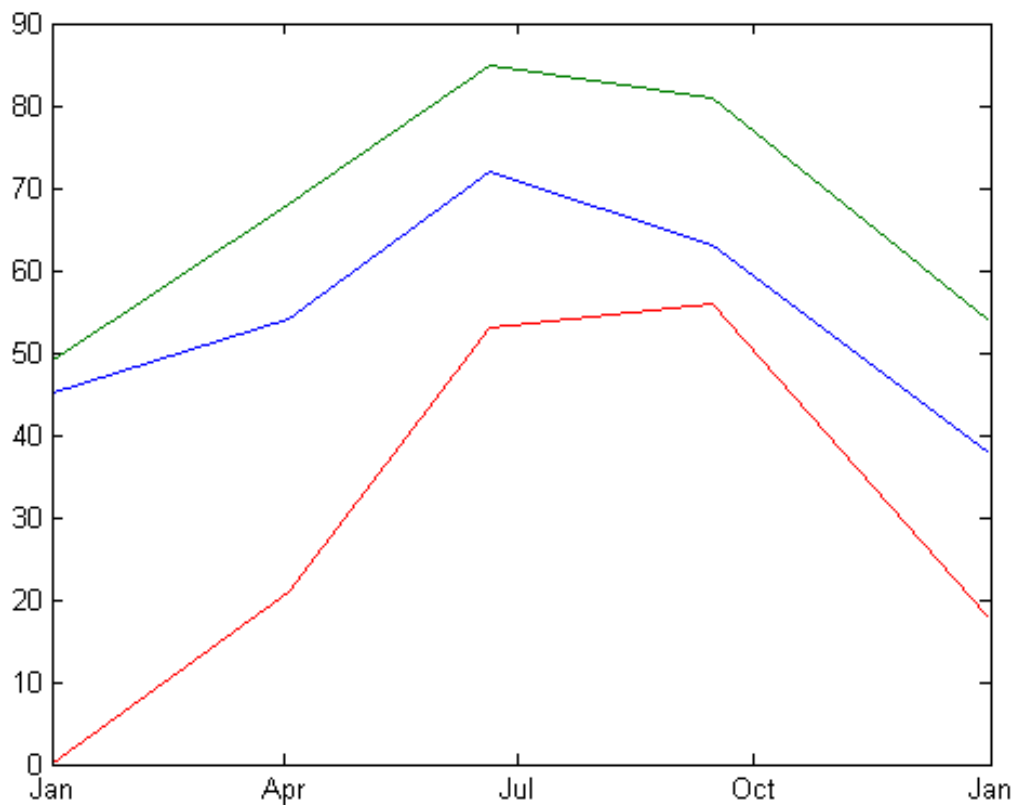


**Combine numeric data from multiple cells using the `cel12mat` function.**

This example creates a 5-by-2 cell array that stores temperature data for three cities, and plots the temperatures for each city by date.

```
temperature(1,:) = {'01-Jan-2010', [45, 49, 0]};  
temperature(2,:) = {'03-Apr-2010', [54, 68, 21]};  
temperature(3,:) = {'20-Jun-2010', [72, 85, 53]};  
temperature(4,:) = {'15-Sep-2010', [63, 81, 56]};  
temperature(5,:) = {'31-Dec-2010', [38, 54, 18]};
```

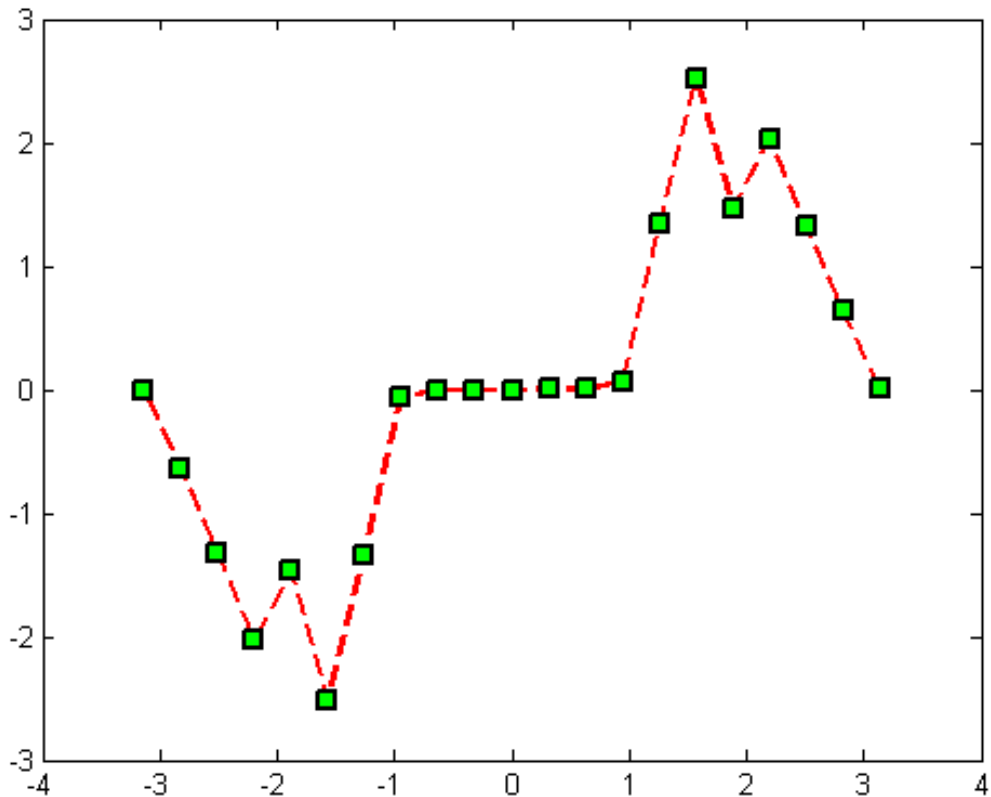
```
allTemps = cell2mat(temperature(:,2));  
dates = datenum(temperature(:,1), 'dd-mmm-yyyy');  
  
plot(dates, allTemps)  
datetick('x', 'mmm')
```



**Pass the contents of multiple cells as a comma-separated list to functions that accept multiple inputs.**

This example plots  $X$  against  $Y$ , and applies line styles from a 2-by-3 cell array  $C$ .

```
X = -pi:pi/10:pi;  
Y = tan(sin(X)) - sin(tan(X));  
  
C(:,1) = {'LineWidth'; 2};  
C(:,2) = {'MarkerEdgeColor'; 'k'};  
C(:,3) = {'MarkerFaceColor'; 'g'};  
  
plot(X, Y, '--rs', C{:})
```



### **Concepts**

- “Access Data in a Cell Array” on page 10-5
- “Multilevel Indexing to Access Parts of Cells” on page 10-20
- “Comma-Separated Lists” on page 2-61



## Preallocate Memory for a Cell Array

This example shows how to initialize and allocate memory for a cell array.

Cell arrays do not require completely contiguous memory. However, each cell requires contiguous memory, as does the cell array header that MATLAB creates to describe the array. For very large arrays, incrementally increasing the number of cells or the number of elements in a cell results in **Out of Memory** errors.

Initialize a cell array by calling the `cell` function, or by assigning to the last element. For example, these statements are equivalent:

```
C = cell(25,50);  
C{25,50} = [];
```

MATLAB creates the header for a 25-by-50 cell array. However, MATLAB does not allocate any memory for the contents of each cell.

For more information, see:

- “Preallocating Memory”
- “Memory Allocation” on page 26-2

## Cell vs. Struct Arrays

This example compares cell and structure arrays, and shows how to store data in each type of array. Both cell and structure arrays allow you to store data of different types and sizes.

### Structure Arrays

Structure arrays contain data in fields that you access by name.

For example, store patient records in a structure array.

```
patient(1).name = 'John Doe';  
patient(1).billing = 127.00;  
patient(1).test = [79, 75, 73; 180, 178, 177.5; 220, 210, 205];
```

```
patient(2).name = 'Ann Lane';  
patient(2).billing = 28.50;  
patient(2).test = [68, 70, 68; 118, 118, 119; 172, 170, 169];
```

Create a bar graph of the test results for each patient.

```
numPatients = numel(patient);  
for p = 1:numPatients  
    figure  
    bar(patient(p).test)  
    title(patient(p).name)  
end
```

### Cell Arrays

Cell arrays contain data in cells that you access by numeric indexing. Common applications of cell arrays include storing lists of text strings and storing heterogeneous data from spreadsheets.

For example, store temperature data for three cities over time in a cell array.

```
temperature(1,:) = {'01-Jan-2010', [45, 49, 0]};  
temperature(2,:) = {'03-Apr-2010', [54, 68, 21]};  
temperature(3,:) = {'20-Jun-2010', [72, 85, 53]};  
temperature(4,:) = {'15-Sep-2010', [63, 81, 56]};
```

```
temperature(5,:) = {'31-Dec-2010', [38, 54, 18]};
```

Plot the temperatures for each city by date.

```
allTemps = cell2mat(temperature(:,2));  
dates = datenum(temperature(:,1), 'dd-mmm-yyyy');
```

```
plot(dates,allTemps)  
datetick('x','mmm')
```

### Other Container Arrays

Struct and cell arrays are the most commonly used containers for storing heterogeneous data. Tables are convenient for storing heterogeneous column-oriented or tabular data. Alternatively, use map containers, or create your own class.

### See Also

[cell](#) | [containers.Map](#) | [table](#) | [struct](#)

### Related Examples

- “Access Data in a Cell Array” on page 10-5
- “Access Data in a Structure Array” on page 9-5
- “Access Data in a Table” on page 8-29

### Concepts

- “Advantages of Using Tables” on page 8-43

## Multilevel Indexing to Access Parts of Cells

This example explains techniques for accessing data in arrays stored within cells of cell arrays. To run the code in this example, create a sample cell array:

```
myNum = [1, 2, 3];  
myCell = {'one', 'two'};  
myStruct.Field1 = ones(3);  
myStruct.Field2 = 5*ones(5);
```

```
C = {myNum, 100*myNum;  
     myCell, myStruct};
```

Access the complete contents of a particular cell using curly braces, {}. For example,

```
C{1,2}
```

returns the numeric vector from that cell:

```
ans =  
    100    200    300
```

Access part of the contents of a cell by appending indices, using syntax that matches the data type of the contents. For example:

- Enclose numeric indices in smooth parentheses. For example, `C{1,1}` returns the 1-by-3 numeric vector, `[1, 2, 3]`. Access the second element of that vector with the syntax

```
C{1,1}(1,2)
```

which returns

```
ans =  
     2
```

- Enclose cell array indices in curly braces. For example, `C{2,1}` returns the cell array `{'one', 'two'}`. Access the contents of the second cell within that cell array with the syntax

```
C{2,1}{1,2}
```

which returns

```
ans =
     two
```

- Refer to fields of a struct array with dot notation, and index into the array as described for numeric and cell arrays. For example, `C{2,2}` returns a structure array, where `Field2` contains a 5-by-5 numeric array of fives. Access the element in the fifth row and first column of that field with the syntax

```
C{2,2}.Field2(5,1)
```

which returns

```
ans =
     5
```

You can nest any number of cell and structure arrays. For example, add nested cells and structures to `C`.

```
C{2,1}{2,2} = {pi, eps};
C{2,2}.Field3 = struct('NestedField1', rand(3), ...
                    'NestedField2', magic(4), ...
                    'NestedField3', {'text'; 'more text'}) );
```

These assignment statements access parts of the new data:

```
copy_pi = C{2,1}{2,2}{1,1}
part_magic = C{2,2}.Field3.NestedField2(1:2,1:2)
nested_cell = C{2,2}.Field3.NestedField3{2,1}
```

MATLAB displays:

```
copy_pi =
     3.1416

part_magic =
     16     2
     5     11
```

```
nested_cell =  
    more text
```

### **Related Examples**

- “Access Data in a Cell Array” on page 10-5

# Function Handles

---

- “What Is a Function Handle?” on page 11-2
- “Creating a Function Handle” on page 11-3
- “Calling a Function Using Its Handle” on page 11-7
- “Preserving Data from the Workspace” on page 11-10
- “Applications of Function Handles” on page 11-13
- “Saving and Loading Function Handles” on page 11-19
- “Advanced Operations on Function Handles” on page 11-20
- “Functions That Operate on Function Handles” on page 11-27

## What Is a Function Handle?

A *function handle* is a callable association to a MATLAB function. It contains an association to that function that enables you to invoke the function regardless of where you call it from. This means that, even if you are outside the normal scope of a function, you can still call it if you use its handle.

With function handles, you can:

- Pass a function to another function
- Capture data values for later use by a function
- Call functions outside of their normal scope
- Save the handle in a MAT-file to be used in a later MATLAB session

See “Applications of Function Handles” on page 11-13 for an explanation of each of these applications.



## Creating a Function Handle

### In this section...

“Maximum Length of a Function Name” on page 11-4

“The Role of Scope, Precedence, and Overloading When Creating a Function Handle” on page 11-4

“Obtaining Permissions from Class Methods” on page 11-5

“Using Function Handles for Anonymous Functions” on page 11-6

“Arrays of Function Handles” on page 11-6

You construct a handle for a specific function by preceding the function name with an @ sign. The syntax is:

```
h = @functionname
```

where *h* is the variable to which the returned function handle is assigned.

Use only the function *name*, with no path information, after the @ sign. If there is more than one function with this name, MATLAB associates with the handle the one function source it would dispatch to if you were actually calling the function.

Create a handle *h* for a function `plot` that is on your MATLAB path:

```
h = @plot;
```

Once you create a handle for a function, you can invoke the function by means of the handle instead of using the function name. Because the handle contains the absolute path to its function, you can invoke the function from any location that MATLAB is able to reach, as long as the program file for the function still exists at this location. This means that functions in one file can call functions that are not on the MATLAB path, local functions in a separate file, or even functions that are private to another folder, and thus not normally accessible to that caller.

## Maximum Length of a Function Name

Function names used in handles are unique up to  $N$  characters, where  $N$  is the number returned by the function `namelengthmax`. If the function name exceeds that length, MATLAB truncates the latter part of the name.

For function handles created for Java constructors, the length of any segment of the package name or class name must not exceed `namelengthmax` characters. (The term *segment* refers to any portion of the name that lies before, between, or after a dot. For example, `java.lang.String` has three segments). The overall length of the string specifying the package and class has no limit.

## The Role of Scope, Precedence, and Overloading When Creating a Function Handle

At the time you create a function handle, MATLAB must decide exactly which function it is to associate the handle to. In doing so, MATLAB uses the same rules used to determine which file to invoke when you make a function call. To make this determination, MATLAB considers the following:

- **Scope** — The function named must be on the MATLAB path at the time the handle is constructed.
- **Precedence** — MATLAB selects which function(s) to associate the handle with, according to the function precedence rules described under *Determining Which Function Gets Called*.
- **Overloading** — If additional files on the path overload the function for any of the fundamental MATLAB classes, such as `double` or `char`, then MATLAB associates the handle with these files, as well.

Program files that overload a function for classes other than the standard MATLAB classes are not associated with the function handle at the time it is constructed. Function handles do operate on these types of overloaded functions, but MATLAB determines which implementation to call at the time of evaluation in this case.

## Obtaining Permissions from Class Methods

When creating a function handle inside a method of a class, the function is resolved using the permissions of that method. When MATLAB invokes the function handle, it does so using the permissions of the class. This gives MATLAB the same access as the location where the function handle was created, including access to private and protected methods accessible to that class.

### Example

This example defines two methods. One, `updateObj`, defines a listener for an event called `Update`, and the other, `callbackfcn`, responds to this event whenever it should occur. The latter function is a private function and thus would not normally be within the scope of the `notify` function. However, because `@callbackfcn` is actually a function handle, it retains the permissions of the context that created the function handle:

```
classdef updateObj < handle
    events
        Update
    end

    methods
        function obj = updateObj(varargin)
            addlistener(obj, 'Update', @callbackfcn);
            notify(obj, 'Update');
        end
    end

    methods (Access = private)
        function obj = callbackfcn(obj, varargin)
            disp('Object Updated')
            disp(obj);
        end
    end
end
```

To run this function, invoke `updateObj` at the MATLAB command line.

## Using Function Handles for Anonymous Functions

Function handles also serve as the means of invoking anonymous functions. An anonymous function is a one-line expression-based MATLAB function that does not require a program file.

For example, the statement

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

creates an anonymous function that computes the square of its input argument  $x$ . The `@` operator makes `sqr` a function handle, giving you a means of calling the function:

```
sqr(20)
ans =
    400
```

Like nested functions, a handle to an anonymous function also stores all data that will be needed to resolve the handle when calling the function. Shares same issues as nested functions do.

See the documentation on “Anonymous Functions” on page 17-23 for more information.

## Arrays of Function Handles

To create an array of function handles, you must use a cell array:

```
trigFun = {@sin, @cos, @tan};
```

For example, to plot the cosine of the range  $-\pi$  to  $\pi$  at 0.01 intervals, use

```
plot(trigFun{2}(-pi:0.01:pi))
```

## Calling a Function Using Its Handle

### In this section...

“Calling Syntax” on page 11-7

“Calling a Function with Multiple Outputs” on page 11-8

“Returning a Handle for Use Outside of a Function File” on page 11-8

“Example — Using Function Handles in Optimization” on page 11-9

Function handles can give you access to functions you might not be able to execute. For instance, with a handle you can call a function even if it is no longer on your MATLAB path. You can also call a local function from outside of the file that defines that function.

### Calling Syntax

The syntax for calling a function using a function handle is the same as that used when calling the function directly. For example, if you call function `myFun` like this:

```
[out1, out2, ...] = myFun(in1, in2, ...);
```

then you would call it using a handle in the same way, but using the handle name instead:

```
fHandle = @myFun;
[out1, out2, ...] = fHandle(in1, in2, ...);
```

There is one small difference. If the function being called takes no input arguments, then you must call the function with empty parentheses placed after the handle name. If you use only the handle name, MATLAB just identifies the name of the function:

<pre>% This identifies the handle.  fHandle = @computer; fHandle ans =     @computer</pre>	<pre>% This invokes the function.  fHandle = @computer; fHandle() ans =     PCWIN</pre>
--	---

## Calling a Function with Multiple Outputs

The example below returns multiple values from a call to an anonymous function. Create anonymous function `f` that locates the nonzero elements of an array, and returns the row, column, and value of each element in variables `row`, `col`, and `val`:

```
f = @(X)find(X);
```

Call the function on matrix `m` using the function handle `f`. Because the function uses the MATLAB `find` function which returns up to three outputs, you can specify from 0 to 3 outputs in the call:

```
m = [3 2 0; -5 0 7; 0 0 1]
m =
     3     2     0
    -5     0     7
     0     0     1
```

```
[row col val] = f(m);
```

```
val
val =
     3
    -5
     2
     7
     1
```

## Returning a Handle for Use Outside of a Function File

As stated previously, you can use function handles to call a function that may otherwise be hidden or out of scope. This example function `getHandle` returns a function handle `fHandle` to a caller that is outside of the file:

```
function fHandle = getHandle
fHandle = @subFun;

function res = subFun(t1, t2, varargin);
...
```

Call `getHandle` to obtain a function handle with which to invoke the local function. You can now call the local function as you would any function that is in scope:

```
f1 = getHandle;  
result = f1(startTime, endTime, procedure);
```

## **Example — Using Function Handles in Optimization**

Function handles can be particularly useful in optimization work. If you have the MathWorks Optimization Toolbox™ installed, click on any of the links below to find information and examples on this topic:

- “Passing Extra Parameters” — Calling objective or constraint functions that have parameters in addition to the independent variable.
- “Anonymous Function Objectives” — Use function handles in writing simple objective functions.
- “Nonlinear Curve Fitting with `lsqcurvefit`” — An example using `lsqcurvefit`, which takes two inputs for the objective.

## Preserving Data from the Workspace

### In this section...

“Preserving Data with Anonymous Functions” on page 11-10

“Preserving Data with Nested Functions” on page 11-11

Both anonymous functions and nested functions make use of variable data that is stored outside the body of the function itself. For example, the anonymous function shown here uses two variables:  $X$  and  $K$ . You pass the  $X$  variable into the anonymous function whenever you invoke the function. The value for  $K$  however is taken from the currently active workspace:

```
K = 200;  
fAnon = @(X)K * X;  
  
fAnon([2.54 1.43 0.68 1.90 1.02 2.13]);
```

What would happen if you tried to invoke this function after you cleared  $K$  from the workspace? Or if you saved the anonymous function to a `.mat` file and then loaded it into an entirely separate computing environment where  $K$  is not defined?

The answer is that MATLAB stores any values needed by an anonymous (or nested) function within the handle itself. It does this at the time you construct the handle. This does not include values from the argument list as these values get passed in whenever you call the function.

### Preserving Data with Anonymous Functions

If you create an anonymous function at the MATLAB command window, that function has access to the workspace of your current MATLAB session. If you create the function inside of another function, then it has access to the outer function’s workspace. Either way, if your anonymous function depends upon variables from an outside workspace, then MATLAB stores the variables and their values within the function handle at the time the handle is created.

This example puts a 3-by-5 matrix into the base workspace, and then creates a function handle to an anonymous function that requires access to the matrix.



Create matrix A and anonymous function testAnon:

```
A = magic(5); A(4:5,:) = []
A =
    17    24     1     8    15
    23     5     7    14    16
     4     6    13    20    22

testAnon = @(x)x * A;           % Anonymous function
```

Call the anonymous function via its handle, passing in a multiplier value. This multiplies all elements by 5.2:

```
testAnon(5.2)
ans =
    88.4000   124.8000     5.2000    41.6000    78.0000
   119.6000    26.0000    36.4000    72.8000    83.2000
    20.8000    31.2000    67.6000   104.0000   114.4000
```

Clear variable A from the base workspace and verify that this action has no effect on the output of the anonymous function:

```
clear A

testAnon(5.2)
ans =
    88.4000   124.8000     5.2000    41.6000    78.0000
   119.6000    26.0000    36.4000    72.8000    83.2000
    20.8000    31.2000    67.6000   104.0000   114.4000
```

This works because the variable A and its value at the time the anonymous function is created is preserved within the function handle that also provides access to the anonymous function. See “Variables in the Expression” on page 17-24 for more information.

## Preserving Data with Nested Functions

Nested functions are similar to anonymous functions in their ability to preserve workspace data needed by a function handle. In this case however, the workspace belongs to one of the functions inside of which the handle is being created. See “Sharing Variables Between Parent and Nested Functions”

on page 17-33 and “Using Handles to Store Function Parameters” on page 17-35 for more information on this subject.

This example shows a function `getHandles` that returns a handle to nested function `getApproxVal_V4`. The nested function uses two variables, `const` and `adjust`, from the workspace of the outer function. Calling `getHandles` creates a function handle to the nested function and also stores these two variables within that handle so that they will be available whenever the nested function is invoked:

```
function handle = getHandles(adjust)
const = 16.3;
handle = @getApproxVal_V4;

    function vOut = getApproxVal_V4(vectIn)
        vOut = ((vectIn+adjust)*const) + ((vectIn-adjust)*const);
    end
end
```

Call the `getHandles` function to obtain a handle to the nested function:

```
adjustVal = 0.023;
getApproxValue = getHandles(adjustVal);

getApproxValue([0.67 -0.09 1.01 0.33 -0.14 -0.23])
ans =
    21.8420    -2.9340    32.9260    10.7580    -4.5640    -7.4980
```

The documentation on “Examining a Function Handle” on page 11-20 explains how to see which variables are stored within a particular function handle. Another helpful resource is “Using Handles to Store Function Parameters” on page 17-35.

### **Loading a Saved Handle to a Nested Function**

If you save a function handle to a nested function and, at some later date, modify the function and then reload the handle, you may observe unexpected behavior from the restored handle. when you invoke the function from the reloaded handle.

## Applications of Function Handles

### In this section...

“Example of Passing a Function Handle” on page 11-13

“Pass a Function to Another Function” on page 11-13

“Capture Data Values For Later Use By a Function” on page 11-15

“Call Functions Outside of Their Normal Scope” on page 11-18

“Save the Handle in a MAT-File for Use in a Later MATLAB Session” on page 11-18

### Example of Passing a Function Handle

The following example creates a handle for a function supplied by MATLAB called `humps` and assigns it to the variable `h`. (The `humps` function returns a strong maxima near  $x = 0.3$  and  $x = 0.9$ ).

```
h = @humps;
```

After constructing the handle, you can pass it in the argument list of a call to some other function, as shown here. This example passes the function handle `h` that was just created as the first argument in a call to `fminbnd`. This function then minimizes over the interval `[0.3, 1]`.

```
x = fminbnd(h, 0.3, 1)
x =
    0.6370
```

Using a function handle enables you to pass different functions for `fminbnd` to use in determining its final result.

### Pass a Function to Another Function

The ability to pass variables to a function enables you to run the function on different values. In the same way, you can pass function handles as input arguments to a function, thus allowing the called function to change the operations it runs on the input data.

**Example 1 – Run integral on Varying Functions**

Run the integral function on varying input functions:

```
a = 0; b = 5;

integral(@log, a, b)
ans =
    3.0472

integral(@sin, a, b)
ans =
    0.7163

integral(@humps, a, b)
ans =
    12.3566
```

**Example 2 – Run integral on Anonymous Functions**

Run integral on a MATLAB built-in function or an anonymous function:

```
n = integral(@log, 0, 3);

n = integral(@(x)x.^2, 0, 3);
```

Change the parameters of the function you pass to `integral` with a simple modification of the anonymous function that is associated with the function handle input:

```
a = 3.7;
z = integral(@(x)x.^a, 0, 3);
```

**Example 3 – Compare integral Results on Different Functions**

Compare the integral of the cosine function over the interval `[a, b]`:

```
a = 0; b = 10;
int1 = integral(@cos,a,b)

int1 =
```

```
-0.5440
```

with the integral over the same interval of the piecewise polynomial `pp` that approximates the cosine function by interpolating the computed values `x` and `y`:

```
x = a:b;
y = cos(x);
pp = spline(x,y);
int2 = integral(@(x)ppval(pp,x), a, b)
```

```
int2 =
    -0.5485
```

## Capture Data Values For Later Use By a Function

You can do more with a function handle than just create an association to a certain function. By using anonymous functions, you can also capture certain variables and their values from the function workspace and store them in the handle. These data values are stored in the handle at the time of its construction, and are contained within the handle for as long as it exists. Whenever you then invoke the function by means of its handle, MATLAB supplies the function with all variable inputs specified in the argument list of the function call, and also any constant inputs that were stored in the function handle at the time of its construction.

Storing some or all input data in a function handle enables you to reliably use the same set of data with that function regardless of where or when you invoke the handle. You can also interrupt your use of a function and resume it with the same data at a later time simply by saving the function handle to a MAT-file.

### Example 1 – Constructing a Function Handle that Preserves Its Variables

Compare the following two ways of implementing a simple plotting function called `draw_plot`. The first case creates the function as one that you would call by name and that accepts seven inputs specifying coordinate and property information:

```
function draw_plot(x, y, lnSpec, lnWidth, mkEdge, mkFace, mkSize)
```

```
plot(x, y, lnSpec, ...
     'LineWidth', lnWidth, ...
     'MarkerEdgeColor', mkEdge, ...
     'MarkerFaceColor', mkFace, ...
     'MarkerSize', mkSize)
```

The second case implements `draw_plot` as an anonymous function to be called by a function handle, `h`. The `draw_plot` function has only two inputs now; the remaining five are specified only on a call to the handle constructor function, `get_plot_handle`:

```
function h = get_plot_handle(lnSpec, lnWidth, mkEdge, ...
                             mkFace, mkSize)
h = @draw_plot;
    function draw_plot(x, y)
        plot(x, y, lnSpec, ...
             'LineWidth', lnWidth, ...
             'MarkerEdgeColor', mkEdge, ...
             'MarkerFaceColor', mkFace, ...
             'MarkerSize', mkSize)
    end
end
```

Because these input values are required by the `draw_plot` function but are not made available in its argument list, MATLAB supplies them by storing them in the function handle for `draw_plot` at the time it is constructed. Construct the function handle `h`, also supplying the values to be stored in handle:

```
h = get_plot_handle('--rs', 2, 'k', 'g', 10);
```

Now call the function, specifying only the `x` and `y` inputs:

```
x = -pi:pi/10:pi;
y = tan(sin(x)) - sin(tan(x));
h(x, y) % Draw the plot
```

The later section on “Examining a Function Handle” on page 11-20 continues this example by showing how you can examine the contents of the function and workspace contents of this function handle.

## Example 2 – Varying Data Values Stored in a Function Handle

Values stored within a handle to a nested function do not have to remain constant. The following function constructs and returns a function handle `h` to the anonymous function `addOne`. In addition to associating the handle with `addOne`, MATLAB also stores the initial value of `x` in the function handle:

```
function h = counter
x = 0;
h = @addOne;
    function y = addOne;
        x = x + 1;
        y = x;
    end
end
```

The `addOne` function that is associated with handle `h` increments variable `x` each time you call it. This modifies the value of the variable stored in the function handle:

```
h = counter;
h()
ans =
     1
h()
ans =
     2
```

## Example 3 – You Cannot Vary Data in a Handle to an Anonymous Function

Unlike the example above, values stored within a handle to an anonymous function do remain constant. Construct a handle to an anonymous function that just returns the value of `x`, and initialize `x` to 300. The value of `x` within the function handle remains constant regardless of how you modify `x` external to the handle:

```
x = 300;
h = @( )x;

x = 50;
h()
```

```
ans =  
    300  
  
clear x  
h()  
ans =  
    300
```

## **Call Functions Outside of Their Normal Scope**

By design, only functions within a program file are permitted to access local functions defined within that file. However, if, in this same file, you were to construct a function handle for one of the internal local functions, and then pass that handle to a variable that exists outside of the file, access to that local function would be essentially unlimited. By capturing the access to the local function in a function handle, and then making that handle available to functions external to the file (or to the command line), the example extends that scope. An example of this is shown in the preceding section, “Capture Data Values For Later Use By a Function” on page 11-15.

Private functions also have specific access rules that limit their availability with the MATLAB environment. But, as with local functions, MATLAB allows you to construct a handle for a private function. Therefore, you can call it by means of that handle from any location or even from the MATLAB command line, should it be necessary.

## **Save the Handle in a MAT-File for Use in a Later MATLAB Session**

If you have one or more function handles that you would like to reuse in a later MATLAB session, you can store them in a MAT-file using the `save` function and then use `load` later on to restore them to your MATLAB workspace.



## Saving and Loading Function Handles

You can save and load function handles in a MAT-file using the MATLAB `save` and `load` functions. If you load a function handle that you saved in an earlier MATLAB session, the following conditions could cause unexpected behavior:

- Any of the files that define the function have been moved, and thus no longer exist on the path stored in the handle.
- You load the function handle into an environment different from that in which it was saved. For example, the source for the function either does not exist or is located in a different folder than on the system on which the handle was saved.

In both of these cases, the function handle is now invalid because it is no longer associated with any existing function code. Although the handle is invalid, MATLAB still performs the load successfully and without displaying a warning. Attempting to invoke the handle, however, results in an error.

### Invalid or Obsolete Function Handles

If you create a handle to a function that is not on the MATLAB path, or if you load a handle to a function that is no longer on the path, MATLAB catches the error only when the handle is invoked. You can assign an invalid handle and use it in such operations as `func2str`. MATLAB catches and reports an error only when you attempt to use it in a runtime operation.

## Advanced Operations on Function Handles

### In this section...

“Examining a Function Handle” on page 11-20

“Converting to and from a String” on page 11-21

“Comparing Function Handles” on page 11-23

### Examining a Function Handle

Use the `functions` function to examine the contents of a function handle.

---

**Caution** MATLAB provides the `functions` function for querying and debugging purposes only. Because its behavior may change in subsequent releases, you should not rely upon it for programming purposes.

---

The following example is a continuation of an example in an earlier section of the Function Handles documentation. See Example 1 in the section “Capture Data Values For Later Use By a Function” on page 11-15 for the complete example.

Construct a function handle that contains both a function association, and data required by that function to execute. The following function constructs the function handle, `h`:

```
function h = get_plot_handle(lnSpec, lnWidth, mkEdge, ...
    mkFace, mkSize)
h = @draw_plot;
    function draw_plot(x, y)
        plot(x, y, lnSpec, ...
            'LineWidth', lnWidth, ...
            'MarkerEdgeColor', mkEdge, ...
            'MarkerFaceColor', mkFace, ...
            'MarkerSize', mkSize)
    end
end
```

Use functions to examine the contents of the returned handle:

```
f = functions(h)
f =
    function: 'get_plot_handle/draw_plot'
      type: 'nested'
      file: 'D:\matlab\work\get_plot_handle.m'
 workspace: {[1x1 struct]}
```

The call to `functions` returns a structure with four fields:

- **function** — Name of the function or local function to which the handle is associated. (Function names that follow a slash character (/) are implemented in the program code as local functions.)
- **type** — Type of function (e.g., simple, nested, anonymous)
- **file** — Filename and path to the file. (For built-in functions, this is the string 'MATLAB built-in function')
- **workspace** — Variables in the function workspace at the time the handle was constructed, along with their values

Examine the workspace variables that you saved in the function handle:

```
f.workspace{:}
ans =
    h: @get_plot_handle/draw_plot
   lnSpec: '--rs'
   lnWidth: 2
  mrkrEdge: 'k'
  mrkrFace: 'g'
  mrkrSize: 10
```

## Converting to and from a String

Two functions, `str2func` and `func2str` enable you to convert between a string containing a function name and a function handle that is associated with that function name.

## Converting a String to a Function Handle

Another means of creating a function handle is to convert a string that holds a function name to a handle for the named function. You can do this using the `str2func` function:

```
handle = str2func('functionname');
```

The example below takes the name of a function as the first argument. It compares part of the name to see if this is a polynomial function, converts the function string to a function handle if it is not, and then calls the function by means of its handle:

```
function run_function(funcname, arg1, arg2)
if strcmp(funcname, 'poly', 4)
    disp 'You cannot run polynomial functions on this data.'
    return
else
    h = str2func(funcname);
    h(arg1, arg2);
end
```

---

**Note** Nested functions are not accessible to `str2func`. To construct a function handle for a nested function, you must use the function handle constructor, `@`.

---

## Converting a Function Handle to a String

You can also convert a function handle back into a string using the `func2str` function:

```
functionname = func2str(handle);
```

This example converts the function handle `h` to a string containing the function name, and then uses the function name in a message displayed to the user:

```
function call_h(h, arg1, arg2)
sprintf('Calling function %s ...\n', func2str(h))
h(arg1, arg2)
```

## Comparing Function Handles

This section describes how MATLAB determines whether or not separate function handles are equal to each other:

- “Comparing Handles Constructed from a Named Function” on page 11-23
- “Comparing Handles to Anonymous Functions” on page 11-23
- “Comparing Handles to Nested Functions” on page 11-24
- “Comparing Handles Saved to a MAT-File” on page 11-25

### Comparing Handles Constructed from a Named Function

MATLAB considers function handles that you construct from the same named function (e.g., `handle = @sin`) to be equal. The `isequal` function returns a value of `true` when comparing these types of handles:

```
func1 = @sin;  
func2 = @sin;  
isequal(func1, func2)  
ans =  
    1
```

If you save these handles to a MAT-file, and then load them back into the workspace later on, they are still equal.

### Comparing Handles to Anonymous Functions

Unlike handles to named functions, any two function handles that represent the same anonymous function (i.e., handles to anonymous functions that contain the same text) are not equal. This is because MATLAB cannot guarantee that the frozen values of non-argument variables (such as `A`, below) are the same.

```
A = 5;  
h1 = @(x)A * x.^2;  
h2 = @(x)A * x.^2;  
  
isequal(h1, h2)  
ans =  
    0
```

---

**Note** In general, MATLAB may underestimate the equality of function handles. That is, a test for equality may return `false` even when the functions happen to behave the same. But in cases where MATLAB does indicate equality, the functions are guaranteed to behave in an identical manner.

---

If you make a copy of an anonymous function handle, the copy and the original are equal:

```
h1 = @(x)A * x.^2;   h2 = h1;
isequal(h1, h2)
ans =
     1
```

### Comparing Handles to Nested Functions

MATLAB considers function handles to the same nested function to be equal only if your code constructs these handles on the same call to the function containing the nested functions. Given this function that constructs two handles to the same nested function:

```
function [h1, h2] = test_eq(a, b, c)
h1 = @findZ;
h2 = @findZ;

    function z = findZ
        z = a.^3 + b.^2 + c';
    end
end
```

function handles constructed from the same nested function and on the same call to the parent function are considered equal:

```
[h1 h2] = test_eq(4, 19, -7);

isequal(h1, h2),
ans =
     1
```

while those constructed from different calls are not considered equal:

```
[q1 q2] = test_eq(3, -1, 2);  
  
isequal(h1, q1)  
ans =  
    0
```

### Comparing Handles Saved to a MAT-File

If you save equivalent anonymous or nested function handles to separate MAT-files, and then load them back into the MATLAB workspace, they are no longer equal. This is because saving the function handle loses track of the original circumstances under which the function handle was created. Reloading it results in a function handle that compares as being unequal to the original function handle.

Create two equivalent anonymous function handles:

```
h1 = @(x) sin(x);  
h2 = h1;  
  
isequal(h1, h2)  
ans =  
    1
```

Save each to a different MAT-file:

```
save fname1 h1;  
save fname2 h2;
```

Clear the MATLAB workspace, and then load the function handles back into the workspace:

```
clear all  
load fname1  
load fname2
```

The function handles are no longer considered equal:

```
isequal(h1, h2)  
ans =
```

0

Note, however, that equal anonymous and nested function handles that you save to the same MAT-file are equal when loaded back into MATLAB.



## Functions That Operate on Function Handles

MATLAB provides the following functions for working with function handles. See the reference pages for these functions for more information.

Function	Description
<code>functions</code>	Return information describing a function handle.
<code>func2str</code>	Construct a function name string from a function handle.
<code>str2func</code>	Construct a function handle from a function name string.
<code>save</code>	Save a function handle from the current workspace to a MAT-file.
<code>load</code>	Load a function handle from a MAT-file into the current workspace.
<code>isa</code>	Determine if a variable contains a function handle.
<code>isequal</code>	Determine if two function handles are handles to the same function.



# Map Containers

---

- “Overview of the Map Data Structure” on page 12-2
- “Description of the Map Class” on page 12-4
- “Creating a Map Object” on page 12-6
- “Examining the Contents of the Map” on page 12-9
- “Reading and Writing Using a Key Index” on page 12-11
- “Modifying Keys and Values in the Map” on page 12-15
- “Mapping to Different Value Types” on page 12-18

## Overview of the Map Data Structure

A *Map* is a type of fast key lookup data structure that offers a flexible means of indexing into its individual elements. Unlike most array data structures in the MATLAB software that only allow access to the elements by means of integer indices, the indices for a Map can be nearly any scalar numeric value or a character string.

Indices into the elements of a Map are called *keys*. These keys, along with the data *values* associated with them, are stored within the Map. Each entry of a Map contains exactly one unique key and its corresponding value. Indexing into the Map of rainfall statistics shown below with a string representing the month of August yields the value internally associated with that month, 37.3.

	KEYS	VALUES	
	Jan	327.2	
	Feb	368.2	
	Mar	197.6	
	Apr	178.4	
	May	100.0	
	Jun	69.9	
	Jul	32.3	
Aug →	Aug	37.3	→ 37.3
	Sep	19.0	
	Oct	37.0	
	Nov	73.2	
	Dec	110.9	
	Annual	1551.0	

### Mean monthly rainfall statistics (mm)

Keys are not restricted to integers as they are with other arrays. Specifically, a key may be any of the following types:

- 1-by-N character array
- Scalar real double or single

- Signed or unsigned scalar integer

The values stored in a Map can be of any type. This includes arrays of numeric values, structures, cells, strings, objects, or other Maps.

---

**Note** A Map is most memory efficient when the data stored in it is a scalar number or a character array.

---

## Description of the Map Class

### In this section...

“Properties of the Map Class” on page 12-4

“Methods of the Map Class” on page 12-5

A Map is actually an object, or instance, of a MATLAB class called `Map`. It is also a handle object and, as such, it behaves like any other MATLAB handle object. This section gives a brief overview of the Map class. For more details, see the `containers.Map` reference page.

### Properties of the Map Class

All objects of the Map class have three properties. You cannot write directly to any of these properties; you can change them only by means of the methods of the Map class.

Property	Description	Default
Count	Unsigned 64-bit integer that represents the total number of key/value pairs contained in the Map object.	0
KeyType	String that indicates the type of all keys contained in the Map object. <code>KeyType</code> can be any of the following: <code>double</code> , <code>single</code> , <code>char</code> , and signed or unsigned 32-bit or 64-bit integer. If you attempt to add keys of an unsupported type, <code>int8</code> for example, MATLAB makes them <code>double</code> .	<code>char</code>
ValueType	String that indicates the type of values contained in the Map object. If the values in a Map are all scalar numbers of the same type, <code>ValueType</code> is set to that type. If the values are all character arrays, <code>ValueType</code> is <code>'char'</code> . Otherwise, <code>ValueType</code> is <code>'any'</code> .	<code>any</code>

To examine one of these properties, follow the name of the Map object with a dot and then the property name. For example, to see what type of keys are used in Map `mapObj`, use

```
mapObj.KeyType
```

A Map is a handle object. As such, if you make a copy of the object, MATLAB does not create a new Map; it creates a new handle for the existing Map that you specify. If you alter the Map's contents in reference to this new handle, MATLAB applies the changes you make to the original Map as well. You can, however, delete the new handle without affecting the original Map.

## Methods of the Map Class

The Map class implements the following methods. Their use is explained in the later sections of this documentation and also in the function reference pages.

Method	Description
<code>isKey</code>	Check if Map contains specified key
<code>keys</code>	Names of all keys in Map
<code>length</code>	Length of Map
<code>remove</code>	Remove key and its value from Map
<code>size</code>	Dimensions of Map
<code>values</code>	Values contained in Map

## Creating a Map Object

### In this section...

“Constructing an Empty Map Object” on page 12-6

“Constructing An Initialized Map Object” on page 12-7

“Combining Map Objects” on page 12-8

A Map is an object of the Map class. It is defined within a MATLAB package called `containers`. As with any class, you use its constructor function to create any new instances of it. You must include the package name when calling the constructor:

```
newMap = containers.Map(optional_keys_and_values)
```

### Constructing an Empty Map Object

When you call the Map constructor with no input arguments, MATLAB constructs an empty Map object. When you do not end the command with a semicolon, MATLAB displays the following information about the object you have constructed:

```
newMap = containers.Map()
newMap =
  containers.Map handle
  Package: containers

  Properties:
    Count: 0
    KeyType: 'char'
    ValueType: 'any'
  Methods, Events, Superclasses
```

The properties of an empty Map object are set to their default values:

- `Count = 0`
- `KeyType = 'char'`
- `ValueType = 'any'`



Once you construct the empty Map object, you can use the `keys` and `values` methods to populate it. For a summary of MATLAB functions you can use with a Map object, see “Methods of the Map Class” on page 12-5

## Constructing An Initialized Map Object

Most of the time, you will want to initialize the Map with at least some keys and values at the time you construct it. You can enter one or more sets of keys and values using the syntax shown here. The brace operators (`{}`) are not required if you enter only one key/value pair:

```
mapObj = containers.Map({key1, key2, ...}, {val1, val2, ...});
```

For those keys and values that are character strings, be sure that you specify them enclosed within single quotation marks. For example, when constructing a Map that has character string keys, use

```
mapObj = containers.Map(...
    {'keystr1', 'keystr2', ...}, {val1, val2, ...});
```

As an example of constructing an initialized Map object, create a new Map for the following key/value pairs taken from the monthly rainfall map shown earlier in this section.

KEYS	VALUES
Jan	327.2
Feb	368.2
Mar	197.6
Apr	178.4
May	100.0
Jun	69.9
Jul	32.3
Aug	37.3
Sep	19.0
Oct	37.0
Nov	73.2
Dec	110.9
Annual	1551.0

```
k = {'Jan', 'Feb', 'Mar', 'Apr', 'May', 'Jun', ...
     'Jul', 'Aug', 'Sep', 'Oct', 'Nov', 'Dec', 'Annual'};

v = {327.2, 368.2, 197.6, 178.4, 100.0, 69.9, ...
     32.3, 37.3, 19.0, 37.0, 73.2, 110.9, 1551.0};

rainfallMap = containers.Map(k, v)
rainfallMap =
  containers.Map handle
  Package: containers

Properties:
  Count: 13
  KeyType: 'char'
  ValueType: 'double'
  Methods, Events, Superclasses
```

The Count property is now set to the number of key/value pairs in the Map, 13, the KeyType is char, and the ValueType is double.

### Combining Map Objects

You can combine Map objects vertically using concatenation. However, the result is not a vector of Maps, but rather a single Map object containing all key/value pairs of the contributing Maps. Horizontal vectors of Maps are not allowed. See “Building a Map with Concatenation” on page 12-13, below.

## Examining the Contents of the Map

Each entry in a Map consists of two parts: a unique key and its corresponding value. To find all the keys in a Map, use the `keys` method. To find all of the values, use the `values` method.

Create a new Map called `tickets` that maps airline ticket numbers to the holders of those tickets. Construct the Map with four key/value pairs:

```
ticketMap = containers.Map(...
    {'2R175', 'B7398', 'A479GY', 'NZ1452'}, ...
    {'James Enright', 'Carl Haynes', 'Sarah Latham', ...
     'Bradley Reid'});
```

Use the `keys` method to display all keys in the Map. MATLAB lists keys of type `char` in alphabetical order, and keys of any numeric type in numerical order:

```
keys(ticketMap)
ans =
    '2R175'    'A479GY'    'B7398'    'NZ1452'
```

Next, display the values that are associated with those keys in the Map. The order of the values is determined by the order of the keys associated with them.

This table shows the keys listed in alphabetical order:

keys	values
2R175	James Enright
A479GY	Sarah Latham
B7398	Carl Haynes
NZ1452	Bradley Reid

The `values` method uses the same ordering of values:

```
values(ticketMap)
ans =
```

'James Enright' 'Sarah Latham' 'Carl Haynes' 'Bradley Reid'

## Reading and Writing Using a Key Index

### In this section...

“Reading From the Map” on page 12-11

“Adding Key/Value Pairs” on page 12-12

“Building a Map with Concatenation” on page 12-13

When reading from the Map, use the same keys that you have defined and associated with particular values. Writing new entries to the Map requires that you supply the values to store with a key for each one .

---

**Note** For a large Map, the keys and value methods use a lot of memory as their outputs are cell arrays.

---

### Reading From the Map

After you have constructed and populated your Map, you can begin to use it to store and retrieve data. You use a Map in the same manner that you would an array, except that you are not restricted to using integer indices. The general syntax for looking up a value (`valueN`) for a given key (`keyN`) is shown here. If the key is a character string, enclose it in single quotation marks:

```
valueN = mapObj(keyN);
```

You can find any single value by indexing into the map with the appropriate key:

```
passenger = ticketMap('2R175')
passenger =
    James Enright
```

Find the person who holds ticket A479GY:

```
sprintf('    Would passenger %s please come to the desk?\n', ...
    ticketMap('A479GY'))
ans =
    Would passenger Sarah Latham please come to the desk?
```

To access the values of multiple keys, use the `values` method, specifying the keys in a cell array:

```
values(ticketMap, {'2R175', 'B7398'})
ans =
    'James Enright'    'Carl Haynes'
```

Map containers support scalar indexing only. You cannot use the colon operator to access a range of keys as you can with other MATLAB classes. For example, the following statements throw an error:

```
ticketMap('2R175':'B7398')
ticketMap(:)
```

## Adding Key/Value Pairs

Unlike other array types, each entry in a Map consists of two items: the value and its key. When you write a new value to a Map, you must supply its key as well. This key must be consistent in type with any other keys in the Map.

Use the following syntax to insert additional elements into a Map:

```
existingMapObj(newKeyName) = newValue;
```

Add two more entries to the `ticketMap` used in the above examples, Verify that the Map now has five key/value pairs:

```
ticketMap('947F4') = 'Susan Spera';
ticketMap('417R93') = 'Patricia Hughes';
```

```
ticketMap.Count
ans =
    6
```

List all of the keys and values in Map `ticketMap`:

```
keys(ticketMap), values(ticketMap)
ans =
    '2R175'    '417R93'    '947F4'    'A479GY'    'B7398'    'NZ1452'
ans =
    Columns 1 through 3
```

```
'James Enright'   'Patricia Hughes'   'Susan Spera'
Columns 4 through 6
'Sarah Latham'   'Carl Haynes'   'Bradley Reid'
```

## Building a Map with Concatenation

You can add key/value pairs to a Map in groups using concatenation. The concatenation of Map objects is different from other classes. Instead of building a vector of s, MATLAB returns a single Map containing the key/value pairs from each of the contributing Map objects.

Rules for the concatenation of Map objects are:

- Only vertical vectors of Map objects are allowed. You cannot create an m-by-n array or a horizontal vector of s. For this reason, `vertcat` is supported for Map objects, but not `horzcat`.
- All keys in each map being concatenated must be of the same class.
- You can combine Maps with different numbers of key/value pairs. The result is a single Map object containing key/value pairs from each of the contributing maps:

```
tMap1 = containers.Map({'2R175', 'B7398', 'A479GY'}, ...
    {'James Enright', 'Carl Haynes', 'Sarah Latham'});

tMap2 = containers.Map({'417R93', 'NZ1452', '947F4'}, ...
    {'Patricia Hughes', 'Bradley Reid', 'Susan Spera'});

% Concatenate the two maps:
ticketMap = [tMap1; tMap2];
```

The result of this concatenation is the same 6-element map that was constructed in the previous section:

```
ticketMap.Count
ans =
    6

keys(ticketMap), values(ticketMap)
ans =
    '2R175'   '417R93'   '947F4'   'A479GY'   'B7398'   'NZ1452'
```

```
ans =  
  Columns 1 through 3  
    'James Enright'    'Patricia Hughes'    'Susan Spera'  
  Columns 4 through 6  
    'Sarah Latham'    'Carl Haynes'    'Bradley Reid'
```

- Concatenation does not include duplicate keys or their values in the resulting Map object.

In the following example, both objects `m1` and `m2` use a key of 8. In Map `m1`, 8 is a key to value C; in `m2`, it is a key to value X:

```
m1 = containers.Map({1, 5, 8}, {'A', 'B', 'C'});  
m2 = containers.Map({8, 9, 6}, {'X', 'Y', 'Z'});
```

Combine `m1` and `m2` to form a new Map object, `m`:

```
m = [m1; m2];
```

The resulting Map object `m` has only five key/value pairs. The value C was dropped from the concatenation because its key was not unique:

```
keys(m), values(m)  
ans =  
    [1]    [5]    [6]    [8]    [9]  
ans =  
    'A'    'B'    'Z'    'X'    'Y'
```



## Modifying Keys and Values in the Map

### In this section...

“Removing Keys and Values from the Map” on page 12-15

“Modifying Values” on page 12-15

“Modifying Keys” on page 12-16

“Modifying a Copy of the Map” on page 12-16

---

**Note** Keep in mind that if you have more than one handle to a Map, modifying the handle also makes changes to the original Map. See “Modifying a Copy of the Map” on page 12-16, below.

---

### Removing Keys and Values from the Map

Use the `remove` method to delete any entries from a Map. When calling this method, specify the Map object name and the key name to remove. MATLAB deletes the key and its associated value from the Map.

The syntax for the `remove` method is

```
remove(mapName, 'keyname');
```

Remove one entry (the specified key and its value) from the Map object:

```
remove(ticketMap, 'NZ1452');
values(ticketMap)
ans =
    Columns 1 through 3
    'James Enright'    'Patricia Hughes'    'Susan Spera'
    Columns 4 through 5
    'Sarah Latham'    'Carl Haynes'
```

### Modifying Values

You can modify any value in a Map simply by overwriting the current value. The passenger holding ticket A479GY is identified as Sarah Latham:

```
ticketMap('A479GY')
ans =
    Sarah Latham
```

Change the passenger's first name to Anna Latham by overwriting the original value for the A479GY key:

```
ticketMap('A479GY') = 'Anna Latham';
```

Verify the change:

```
ticketMap('A479GY')
ans =
    'Anna Latham';
```

## Modifying Keys

To modify an existing key while keeping the value the same, first remove both the key and its value from the Map. Then create a new entry, this time with the corrected key name.

Modify the ticket number belonging to passenger James Enright:

```
remove(ticketMap, '2R175');
ticketMap('2S185') = 'James Enright';

k = keys(ticketMap); v = values(ticketMap);
str1 = '    '%s'' has been assigned a new\n';
str2 = '    ticket number: %s.\n';

fprintf(str1, v{1})
fprintf(str2, k{1})

'James Enright' has been assigned a new
    ticket number: 2S185.
```

## Modifying a Copy of the Map

Because `ticketMap` is a handle object, you need to be careful when making copies of the Map. Keep in mind that by copying a Map object, you are really

just creating another handle to the same object. Any changes you make to this handle are also applied to the original Map.

Make a copy of Map `ticketMap`. Write to this copy, and notice that the change is applied to the original Map object itself:

```
copiedMap = ticketMap;

copiedMap('AZ12345') = 'unidentified person';
ticketMap('AZ12345')
ans =
    unidentified person
```

Clean up:

```
remove(ticketMap, 'AZ12345');
clear copiedMap;
```

## Mapping to Different Value Types

### In this section...

“Mapping to a Structure Array” on page 12-18

“Mapping to a Cell Array” on page 12-19

It is fairly common to store other classes, such as structures or cell arrays, in a Map structure. However, Maps are most memory efficient when the data stored in them belongs to one of the basic MATLAB types such as double, char, integers, and logicals.

### Mapping to a Structure Array

The following example maps airline seat numbers to structures that contain information on who occupies the seat. To start out, create the following structure array:

```
s1.ticketNum = '2S185'; s1.destination = 'Barbados';
s1.reserved = '06-May-2008'; s1.origin = 'La Guardia';
s2.ticketNum = '947F4'; s2.destination = 'St. John';
s2.reserved = '14-Apr-2008'; s2.origin = 'Oakland';
s3.ticketNum = 'A479GY'; s3.destination = 'St. Lucia';
s3.reserved = '28-Mar-2008'; s3.origin = 'JFK';
s4.ticketNum = 'B7398'; s4.destination = 'Granada';
s4.reserved = '30-Apr-2008'; s4.origin = 'JFK';
s5.ticketNum = 'NZ1452'; s5.destination = 'Aruba';
s5.reserved = '01-May-2008'; s5.origin = 'Denver';
```

Map five of the seats to one of these structures:

```
seatingMap = containers.Map( ...
    {'23F', '15C', '15B', '09C', '12D'}, ...
    {s5, s1, s3, s4, s2});
```

Using this Map object, find information about the passenger, who has reserved seat 09C:

```
seatingMap('09C')
ans =
```

```

        ticketNum: 'B7398'
    destination: 'Granada'
        reserved: '30-Apr-2008'
        origin: 'JFK'

```

```

seatingMap('15B').ticketNum
ans =
    A479GY

```

Using two Maps together, you can find out the name of the person who has reserved the seat:

```

passenger = ticketMap(seatingMap('15B').ticketNum)
passenger =
    Anna Latham

```

## Mapping to a Cell Array

As with structures, you can also map to a cell array in a Map object. Continuing with the airline example of the previous sections, some of the passengers on the flight have “frequent flyer” accounts with the airline. Map the names of these passengers to records of the number of miles they have used and the number of miles they still have available:

```

accountMap = containers.Map( ...
    {'Susan Spera', 'Carl Haynes', 'Anna Latham'}, ...
    {{247.5, 56.1}, {0, 1342.9}, {24.6, 314.7}});

```

Use the Map to retrieve account information on the passengers:

```

name = 'Carl Haynes';
acct = accountMap(name);

fprintf('%s has used %.1f miles on his/her account,\n', ...
    name, acct{1})
fprintf(' and has %.1f miles remaining.\n', acct{2})

```

```

Carl Haynes has used 0.0 miles on his/her account,
    and has 1342.9 miles remaining.

```



# Combining Unlike Classes

---

- “Valid Combinations of Unlike Classes” on page 13-2
- “Combining Unlike Integer Types” on page 13-3
- “Combining Integer and Noninteger Data” on page 13-6
- “Combining Cell Arrays with Non-Cell Arrays” on page 13-7
- “Empty Matrices” on page 13-8
- “Concatenation Examples” on page 13-9

## Valid Combinations of Unlike Classes

Matrices and arrays can be composed of elements of most any MATLAB data type as long as all elements in the matrix are of the same type. If you do include elements of unlike classes when constructing a matrix, MATLAB converts some elements so that all elements of the resulting matrix are of the same type.

Data type conversion is done with respect to a preset precedence of classes. The following table shows the five classes you can concatenate with an unlike type without generating an error (that is, with the exception of character and logical).

TYPE	character	integer	single	double	logical
character	character	character	character	character	invalid
integer	character	integer	integer	integer	integer
single	character	integer	single	single	single
double	character	integer	single	double	double
logical	invalid	integer	single	double	logical

For example, concatenating a double and single matrix always yields a matrix of type single. MATLAB converts the double element to single to accomplish this.

### Concepts

- “Combining Unlike Integer Types” on page 13-3
- “Combining Integer and Noninteger Data” on page 13-6
- “Combining Cell Arrays with Non-Cell Arrays” on page 13-7
- “Concatenation Examples” on page 13-9



## Combining Unlike Integer Types

### In this section...

“Overview” on page 13-3

“Example of Combining Unlike Integer Sizes” on page 13-4

“Example of Combining Signed with Unsigned” on page 13-4

### Overview

If you combine different integer types in a matrix (e.g., signed with unsigned, or 8-bit integers with 16-bit integers), MATLAB returns a matrix in which all elements are of one common type. MATLAB sets all elements of the resulting matrix to the data type of the left-most element in the input matrix. For example, the result of the following concatenation is a vector of three 16-bit signed integers:

```
A = [int16(450) uint8(250) int32(1000000)]
```

MATLAB also displays a warning to inform you that the result may not be what you had expected:

```
A = [int16(450) uint8(250) int32(1000000)];  
Warning: Concatenation with dominant (left-most) integer class  
may overflow other operands on conversion to return class.
```

You can disable this warning by entering the following two commands directly after the operation that caused the warning. The first command retrieves the message identifier associated with the most recent warning issued by MATLAB. The second command uses this identifier to disable any further warnings of that type from being issued:

```
[msg, intcat_msgid] = lastwarn;  
warning('off', intcat_msgid);
```

To re-enable the warning so that it will now be displayed, use

```
warning('on', intcat_msgid);
```

You can use these commands to disable or enable the display of any MATLAB warning.

### Example of Combining Unlike Integer Sizes

After disabling the integer concatenation warnings as shown above, concatenate the following two numbers once, and then switch their order. The return value depends on the order in which the integers are concatenated. The left-most type determines the data type for all elements in the vector:

```
A = [int16(5000) int8(50)]
A =
    5000     50
```

```
B = [int8(50) int16(5000)]
B =
     50    127
```

The first operation returns a vector of 16-bit integers. The second returns a vector of 8-bit integers. The element `int16(5000)` is set to 127, the maximum value for an 8-bit signed integer.

The same rules apply to vertical concatenation:

```
C = [int8(50); int16(5000)]
C =
     50
    127
```

---

**Note** You can find the maximum or minimum values for any MATLAB integer type using the `intmax` and `intmin` functions. For floating-point types, use `realmax` and `realmin`.

---

### Example of Combining Signed with Unsigned

Now do the same exercise with signed and unsigned integers. Again, the left-most element determines the data type for all elements in the resulting matrix:

```
A = [int8(-100) uint8(100)]
A =
   -100    100
```

```
B = [uint8(100) int8(-100)]
B =
    100     0
```

The element `int8(-100)` is set to zero because it is no longer signed.

MATLAB evaluates each element *prior to* concatenating them into a combined array. In other words, the following statement evaluates to an 8-bit signed integer (equal to 50) and an 8-bit unsigned integer (unsigned -50 is set to zero) before the two elements are combined. Following the concatenation, the second element retains its zero value but takes on the unsigned `int8` type:

```
A = [int8(50), uint8(-50)]
A =
    50     0
```

### Combining Integer and Noninteger Data

If you combine integers with `double`, `single`, or `logical` classes, all elements of the resulting matrix are given the data type of the left-most integer. For example, all elements of the following vector are set to `int32`:

```
A = [true pi int32(1000000) single(17.32) uint8(250)]
```

## Combining Cell Arrays with Non-Cell Arrays

Combining a number of arrays in which one or more is a cell array returns a new cell array. Each of the original arrays occupies a cell in the new array:

```
A = [100, {uint8(200), 300}, 'MATLAB'];  
whos A
```

Name	Size	Bytes	Class	Attributes
A	1x4	477	cell	

Each element of the combined array maintains its original class:

```
fprintf('Classes: %s %s %s %s\n',...  
       class(A{1}),class(A{2}),class(A{3}),class(A{4}))
```

```
Classes: double uint8 double char
```

### Empty Matrices

If you construct a matrix using empty matrix elements, the empty matrices are ignored in the resulting matrix:

```
A = [5.36; 7.01; []; 9.44]
```

```
A =
```

```
5.3600
```

```
7.0100
```

```
9.4400
```

## Concatenation Examples

### In this section...

“Combining Single and Double Types” on page 13-9  
 “Combining Integer and Double Types” on page 13-9  
 “Combining Character and Double Types” on page 13-10  
 “Combining Logical and Double Types” on page 13-10

### Combining Single and Double Types

Combining `single` values with `double` values yields a `single` matrix. Note that  $5.73 \times 10^{300}$  is too big to be stored as a `single`, thus the conversion from `double` to `single` sets it to infinity. (The `class` function used in this example returns the data type for the input value).

```
x = [single(4.5) single(-2.8) pi 5.73*10^300]
x =
    4.5000    -2.8000    3.1416    Inf

class(x)           % Display the data type of x
ans =
    single
```

### Combining Integer and Double Types

Combining integer values with `double` values yields an integer matrix. Note that the fractional part of `pi` is rounded to the nearest integer. (The `int8` function used in this example converts its numeric argument to an 8-bit integer).

```
x = [int8(21) int8(-22) int8(23) pi 45/6]
x =
    21   -22    23     3     8

class(x)
ans =
    int8
```

## Combining Character and Double Types

Combining character values with double values yields a character matrix. MATLAB converts the double elements in this example to their character equivalents:

```
x = ['A' 'B' 'C' 68 69 70]
```

```
x =  
  ABCDEF
```

```
class(x)
```

```
ans =  
  char
```

## Combining Logical and Double Types

Combining logical values with double values yields a double matrix. MATLAB converts the logical true and false elements in this example to double:

```
x = [true false false pi sqrt(7)]
```

```
x =  
  1.0000      0      0  3.1416  2.6458
```

```
class(x)
```

```
ans =  
  double
```



# Using Objects

---

- “MATLAB Objects” on page 14-2
- “General Purpose Vs. Specialized Arrays” on page 14-5
- “Key Object Concepts” on page 14-8
- “Creating Objects” on page 14-11
- “Accessing Object Data” on page 14-14
- “Calling Object Methods” on page 14-16
- “Desktop Tools Are Object Aware” on page 14-19
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## MATLAB Objects

In this section...
“Getting Oriented” on page 14-2
“What Are Objects and Why Use Them?” on page 14-2
“Working with Objects” on page 14-3
“Objects In the MATLAB Language” on page 14-3
“Other Kinds of Objects Used by MATLAB” on page 14-4

### Getting Oriented

This section provides information for people using objects. It does not provide a thorough treatment of object-oriented concepts, but instead focuses on what you need to know to use the objects provided with MATLAB.

If you are interested in object-oriented programming in the MATLAB language, see “Object-Oriented Programming”. For background information on objects, see object-oriented design.

### What Are Objects and Why Use Them?

In the simplest sense, objects are special-purpose data structures that have a specific set of operations that you can perform on the data they contain.

You do not need to know how objects implement operations or store data. This fact makes objects modular and easy to pass within application programs. It also isolates your code from changes to the object’s design and implementation.

MATLAB uses objects because they are a convenient way to package data. Working with objects in MATLAB is like working with any variables and is often more convenient because objects are optimized for specific purposes. Think of an object as a neatly packaged collection of data that includes functions that operate on the data. The documentation for any particular object describes how to use it.

Objects are organized collections of data and functions that have been designed for specific purposes.

For example, an object might contain time series data that consists of value/time-sample pairs and associated information like units, sample uniformity, and so on. This object can have a set of specific operations designed to perform analysis, such as filtering, interpolating, and plotting.

## Working with Objects

You can perform the common operations on objects like you can on any variable. For example, you can do the following things with objects:

- Create it and assign a variable name so you can reference it again
- Assign or reassign data to it (see “Accessing Object Data” on page 14-14)
- Operate on its data (see “Calling Object Methods” on page 14-16)
- Convert it to another class (if this operation is supported by the object’s class)
- Save it to a MAT-file so you can reload it later (see `save`)
- Copy it (see “Copying Objects” on page 14-27)
- Clear it from the workspace (`clear`)

Any object can have restrictions on how you create it, access its data, or what operations you can perform on it. Refer to the documentation for the particular MATLAB object for a description of what you can do with that object.

## Objects In the MATLAB Language

The MATLAB language uses many specialized objects. For example, `MException` objects capture information when errors occur, `timer` objects execute code at a certain time interval, the `serial` object enables you to communicate with devices connected to your computer’s serial port, and so on. MATLAB toolboxes often define objects to manage data and analyses performed by the toolbox.

Objects provide specific functionality that is not necessarily available from general purpose language components.

## Other Kinds of Objects Used by MATLAB

The MATLAB language enables you to use objects that are defined other in languages. The following objects are different from the MATLAB objects described in this documentation. See the individual sections referenced below for information on using these objects.

- Handle Graphics® objects create graphs and GUIs. These objects provide a `set/get` interface to property values. You cannot subclass graphics objects. See “Graphics Objects” for more information.
- Java classes enable you to access the capabilities of Java classes from MATLAB programs. See “Call Java Libraries” for more information.
- Microsoft COM objects enable you to integrate these software components into your application. See “Call COM Objects” for more information.
- Microsoft .NET objects enable you to integrate .NET assemblies into your application. See “Call .NET Libraries” for more information.
- User-defined MATLAB objects created prior to Version 7.6 used different syntax for class definition (no `classdef` block) and exhibit other differences. See “Compatibility with Previous Versions ” for more information.

## General Purpose Vs. Specialized Arrays

### In this section...

“How They Differ” on page 14-5

“Using General-Purpose Data Structures” on page 14-5

“Using Specialized Objects” on page 14-6

### How They Differ

The MATLAB language uses both general-purpose and specialized arrays. For example, numeric, `struct`, and `cell` arrays provide general-purpose data storage. You typically extract data from the array and pass this data to functions (for example, to perform mathematical analysis). Then, you store the result in general-purpose arrays.

When using a specialized object, you typically pass data to a function that creates the object. Once created, you use specially defined functions to operate on the data. These functions are unique to the object and are designed specifically for the type and structure of the data contained by the object.

### Using General-Purpose Data Structures

A commonly used general-purpose data structure references data via fieldnames. For example, these statements create a MATLAB struct (a MATLAB structure array):

```
s.Data = rand(10,1);  
s.Time = .01:.01:.1;  
s.Name = 'Data1';  
s.Units = 'seconds';
```

The structure `s` contains two arrays of numbers. However, `s` is a generic type in the sense that MATLAB does not define special functions to operate on the data in this particular structure. For example, while `s` contains two fields that would be useful to plot, `Data` and `Time`, you cannot pass `s` to the `plot` function:

```
plot(s)  
Error using plot
```

### Not enough input arguments.

While `s` has enough information to create a plot of Data versus Time, `plot` cannot access this data because structures like `s` can contain any values in its fields and the fields can have any name. Just because one field is named Data does not force you to assign data to that field.

To plot the data in `s`, you have to extract the data from the fields, pass them as numeric arrays in the desired order to the plot function, add a title, labels, and so on:

```
plot(s.Time,s.Data)
title(['Time Series Plot: ' s.Name])
xlabel(['Time ( ' s.Units ' )'])
ylabel(s.Name)
```

You could create a function to perform these steps for you. Other programs using the structure `s` would need to create their own functions or access the one you created.

## Using Specialized Objects

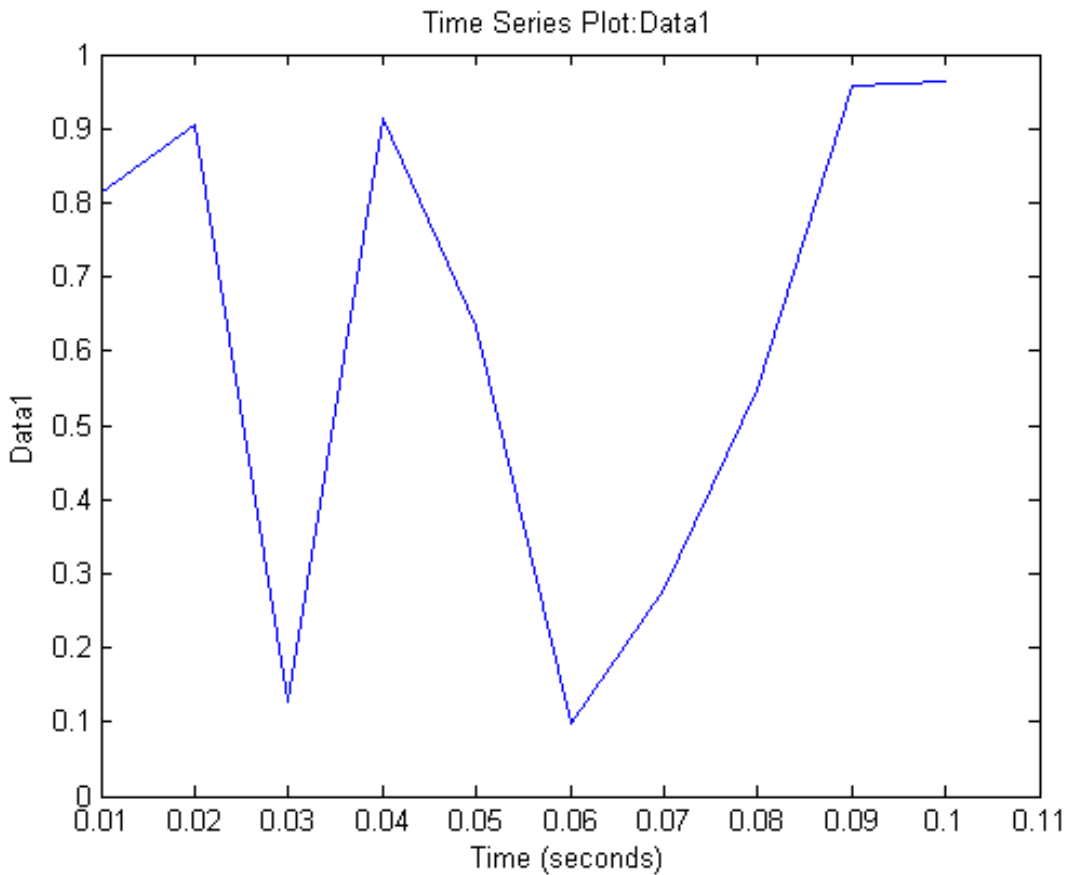
Compare the array `s` above to an object that you have designed specifically to contain and manipulate time series data. For example, the following statement creates a MATLAB® `timeseries` object. It is initialized to store the same data as the structure `s` above:

```
tsobj = timeseries(rand(10,1),.01:.01:.1,'Name','Data1');
```

The function that creates the object `tsobj`, accepts sample data, sample times, a property name/property value pair (`Name/Data1`), and uses a default value of `Units` (which is seconds).

The designer of this object created a special version of the `plot` function that works directly with this object. For example:

```
plot(tsobj)
```



Notice how the object's `plot` function creates a graph that is plotted and labeled with the data from the `tsobj` object. As a user of this object, you do not need write your own code to produce this graph. The class design specifies the standard way to present graphs of `timeseries` data and all clients of this object use the same code for plotting.

## Key Object Concepts

In this section...
“Basic Concepts” on page 14-8
“Classes Describe How to Create Objects” on page 14-8
“Properties Contain Data” on page 14-9
“Methods Implement Operations” on page 14-9
“Events are Notices Broadcast to Listening Objects” on page 14-10

### Basic Concepts

There are some basic concepts that are fundamental to objects. Objects represent something in the real world, like an error condition or the set of data you collected in a product test. Objects enable you to do something useful, like provide an error report or analyze and present the results of tests.

There are basic components that MATLAB uses to realize the design of an object. These components include:

- Classes
- Properties
- Methods
- Events

### Classes Describe How to Create Objects

A *class* defines a set of similar objects. It is a description from which MATLAB creates a particular instance of the class, and it is the instance (that is, the object) that contains actual data. Therefore, while there is a `timeseries` class, you work with `timeseries` objects.

Classes are defined in code files — either as separate `.m` files or built-in to the MATLAB executable. Objects are specific representations of a class that you access through workspace variables.



## Properties Contain Data

Objects store data in *properties*. Consider a `timeseries` object as an example. `timeseries` object properties contain time series data, corresponding time values, and related information, such as units, events, data quality, and interpolation method. MATLAB objects enable you to access property data directly (see “Accessing Object Data” on page 14-14 for information on property syntax).

Properties are sometimes called fields in other programming languages and are similar to the fields of MATLAB structures. Properties have descriptive names, such as `Data` and `DataInfo`, in the case of `timeseries` objects, and can contain any kind of MATLAB data, including other objects.

An object, then, is a container for a predefined set of data. Unlike a cell array or structure, you cannot add new properties or delete defined properties from an object. Doing so would compromise the object’s intended purpose and violate the class design.

The class design can restrict the values you can assign to a property. For example, a `Length` property might restrict possible values to positive integers or might be read only and determine its own value when queried.

## Methods Implement Operations

Class *methods* are functions designed to work with objects of a particular class. Methods enable the class designer to implement specific operations that are optimized for the data contained in the object. You do not have to extract the data from the object, modify its format, and pass it to a general-purpose MATLAB function because the class defines methods with an awareness of the object’s structure.

Methods can define operations that are unique to a particular class of object, such as adding a data sample to an existing set of time series data, or can *overload* common operations in a way that makes sense for the particular object. For example, `timeseries` objects have an `addsample` method to add a new data sample to an existing `timeseries` object. Also, `timeseries` overloads the MATLAB `plot` function to work with `timeseries` objects.

MATLAB software determines which overloaded version of a method to call based on the class of the object passed as an argument. If you execute a MATLAB statement like:

```
tsobjnew = tsobj1 + tsobj2;
```

where `tsobj1` and `tsobj2` are `timeseries` objects, MATLAB calls the `timeseries` version of the `+` operation (if defined) and returns a new `timeseries` object.

Because the `timeseries` class defines the operation, you can add a `timeseries` object to a scalar number:

```
tsobjnew = tsobj1 + 4;
```

The class definition determines what happens when you add a scalar double to a `timeseries` object (the scalar is added to each `Data` value).

Methods make working with objects convenient for the user, but also provide advantages to the class designer. Methods hide implementation details from users—you do not need to create your own functions to access and manipulate data, as you would when using general-purpose data structures like `structs` and cell arrays. This provides the flexibility to change the internal design of an object without affecting object clients (i.e., application programs that use the objects).

## **Events are Notices Broadcast to Listening Objects**

Classes can define names for specific actions and trigger the broadcast of notices when those actions occur. Listeners respond to the broadcast of an event notice by executing a predefined function.

For example, objects can listen for the change of the value of a property and execute a function when that change occurs. If an object defines an event for which you can define a listening object, the object's documentation describes that event. See "Events" for information on how class designers use events.

## Creating Objects

### In this section...

“Class Constructor” on page 14-11

“When to Use Package Names” on page 14-11

### Class Constructor

Usually, you create an object by calling a function designed for the purpose of creating that specific class of object. For example, the following code creates a `timeseries` object and assigns it to the variable `tsobj`:

```
load count.dat % Load some data
tsobj = timeseries(count(:,1),1:24, 'Name', 'Data1');
```

The `timeseries` constructor creates an object and initializes its data with the values specified as arguments. Classes that create objects define a special method whose purpose is to create objects of the class. This method has the same name as the class and is called the *class constructor*.

However, in some cases, you might create objects by calling other functions or even using a GUI. For example, a `try-catch` block can return an `MException` object that contains information about a specific error condition. In this case, you do not explicitly create the object, rather it is returned by the `catch` statement (see “Accessing Object Data” on page 14-14 for an example).

### When to Use Package Names

A package is a container that provides a logical grouping for class and function definitions. The class and function names within a given package must be unique, but can be reused in other packages. Packages are folders that begin with the `+` character.

If a package folder contains a class definition, then you must use the package name when calling the class constructor. For example, this statement creates a `Map` object, whose class definition file is in a folder in the `containers` package:

```
mapobj = containers.Map({'rose', 'bicycle'}, {'flower', 'machine'});
```

You need to use the package name to refer to:

- Class constructors (e.g., `containers.Map`), which you call to create an object
- Static methods (methods that do not require an object of the class as an argument)
- Package functions (functions defined in the package)

However, because MATLAB uses the class of an object to determine which ordinary method to call, you do not need to use the package name in conjunction with object references. For example, suppose you have the following folder structure:

```
pathfolder/+packagename/@ClassName/ClassName.m
pathfolder/+packagename/@ClassName/staticMethodName.m
pathfolder/+packagename/functionName.m
```

In the following examples, `obj` is the object you are creating.

```
% Create object of ClassName
obj = packagename.ClassName(...);

% Call methodName
obj.methodName(...);

% Set or get the value of property PropertyName
obj.PropertyName = x;
x = obj.PropertyName;

% Call static method staticMethodName
packagename.ClassName.staticMethodName(...);

% Call package function functionName
packagename.functionName(...)
```

If a package folder contains a class definition file, then consider the package name as part of the class name. Wherever you need to use the class name, include the package name. For example, `containers.Map` is the full class name of the `Map` class.

See the object's user documentation for the syntax you need to use to create objects.

See “Organizing Classes in Folders” and “Packages Create Namespaces” for more information on the use of packages.

See “Importing Classes” for information on importing packages into functions.

## Accessing Object Data

### In this section...

“Listing Public Properties” on page 14-14

“Getting Property Values” on page 14-14

“Setting Property Values” on page 14-15

### Listing Public Properties

---

**Note** Always use the correct case when referring to properties by name.

---

Display the names of all public object properties using the `properties` function with the object’s class name or with an actual object. For example:

```
>> properties('MException')
```

```
Properties for class MException:
```

```
    identifier  
    message  
    cause  
    stack
```

### Getting Property Values

After creating an object, you can access the values of its properties:

```
try  
    a = rand(4);  
    a(17) = 7;  
catch me % catch creates an MException object named me  
    disp(['Current error identifier: ' me.identifier])  
end  
Current error identifier: MATLAB:indexed_matrix_cannot_be_resized
```

Access the data in properties using dot notation:

```
object.PropertyName
```

For example, you can access the `message` property of the `MException` object, `me`, with this syntax:

```
me.message
ans =
    In an assignment A(I) = B, a matrix A cannot be resized.
```

See “Capture Information About Exceptions” on page 23-5 for more information on using `MException` objects.

## Setting Property Values

Objects often restrict what values you can assign to them. For example, the following `timeseries` object has 10 data values, each corresponding to a sample time:

```
tsobj = timeseries(rand(10,1),1:10,'Name','Random Sample');
```

Now suppose you attempt to set the `Data` property to a three-element vector:

```
tsobj.Data = [1 2 3];
Error using timeseries.utreshape (line 864)
Size of the data array is incompatible with the time vector.
...
```

The `timeseries` class design ensures that the number of data samples matches the number of time samples. This illustrates one of the advantages a specialized object has over a general purpose-data structure like a MATLAB `struct`.

## Calling Object Methods

### In this section...

“What Operations Can You Perform” on page 14-16

“Method Syntax” on page 14-16

“Class of Objects Returned by Methods” on page 14-18

### What Operations Can You Perform

Methods define an object’s behavior. Consequently, classes implement methods that an object user is unlikely to call directly. The user documentation for the object you are using describes the operations you can perform on any particular object.

You can list the methods defined by a class with the `methods` or `methodsview` functions:

```
methods('timeseries')
```

Methods for class timeseries:

<code>addevent</code>	<code>gettsbetweenevents</code>	<code>set</code>
<code>addsample</code>	<code>horzcat</code>	<code>setabstime</code>
<code>createTstoolNode</code>	<code>idealfilter</code>	<code>setinterpmethod</code>
<code>ctranspose</code>	<code>init</code>	<code>setprop</code>
<code>...</code>		

### Method Syntax

Call an object’s method using dot notation:

```
returnValue = object.methodName(args,...)
```

You also can call a method using function syntax, passing the object as the first (left-most) argument.

```
returnValue = methodName(object,args,...)
```



For example, MException objects have a `getReport` method that returns information about the error.

```
try
    surf
catch me
    disp(me.getReport)
end
```

```
Error using ==> surf at (line 50)
Not enough input arguments.
```

Dot and function notation are usually equivalent. That is, both of the following statements return the MException report:

```
rpt = getReport(me); % Call getReport using function notation
rpt = me.getReport; % Call getReport using dot notation
```

## Calling the Correct Method

It is possible for the function syntax to call an unexpected method if there is more than one object in the argument list. Suppose there are two classes, `ClassA` and `ClassB`, that define a method called `addData`. Suppose further that `ClassA` is defined as being inferior to `ClassB` in precedence (something that the class designer can do in the class definition). In this situation, given `objA` is of `ClassA` and `objB` is of `ClassB`, the following two statements call different methods:

```
addData(objA, objB) % Calls objB.addData
objA.addData(objB) % Calls objA.addData
```

If `ClassA` and `ClassB` had equal precedence, then the left-most argument determines which method MATLAB calls (i.e., `objA.addData` in both statements).

It is unlikely that you will encounter this particular scenario, however, if you are calling a method that accepts more than one object as arguments, using dot notation removes any ambiguity about which object's method MATLAB calls.

## Class of Objects Returned by Methods

While methods sometimes return objects of the same class, this is not always the case. For example, the MException object's getReport returns a character string:

```
try
  surf
catch me
  rpt = me.getReport;
end
```

```
whos
  Name          Size          Bytes  Class          Attributes

  me            1x1            1118  MException
  rpt           1x126           252   char
```

Methods can return any type of value and properties can contain any type of value. However, class constructor methods always return an object or array of objects of the same type as the class.

## Desktop Tools Are Object Aware

### In this section...

“Tab Completion Works with Objects” on page 14-19

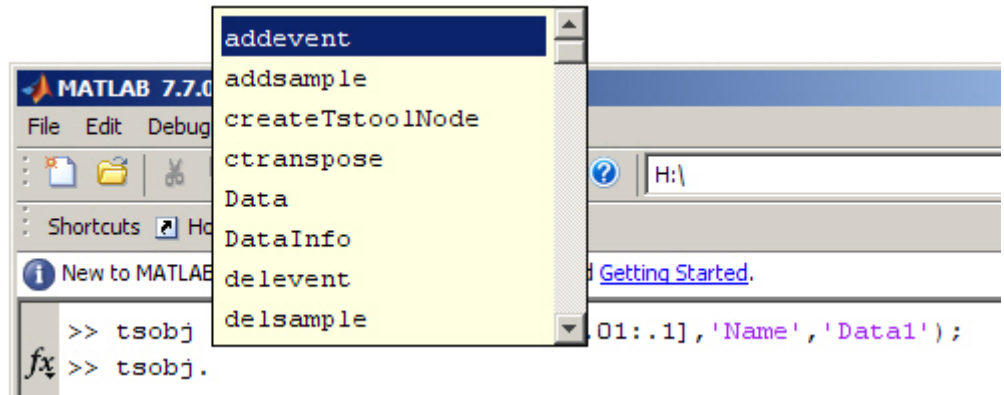
“Editing Objects with the Variables Editor” on page 14-19

### Tab Completion Works with Objects

MATLAB tab completion works with objects. For example, if you enter an object name followed by a dot:

```
tsobj.
```

and then press the tab key, MATLAB pops up a selection box with a list of properties and methods:



The more letters you complete after the dot, the more specific is the list. See “Tab Completion” for more information.

### Editing Objects with the Variables Editor

You can use the MATLAB Variables Editor to edit object properties. To open an object in the Variables Editor, you can double-click the object name in the Workspace browser or use the `openvar` command:

```
tsobj = timeseries(rand(10,1),.01:.01:.1,'Name','Data1');  
openvar tsobj
```

See “View, Edit, and Copy Variables” for more information.

## Getting Information About Objects

### In this section...

“The Class of Workspace Variables” on page 14-21

“Information About Class Members” on page 14-23

“Logical Tests for Objects” on page 14-24

“Displaying Objects” on page 14-25

“Getting Help for MATLAB Objects” on page 14-25

### The Class of Workspace Variables

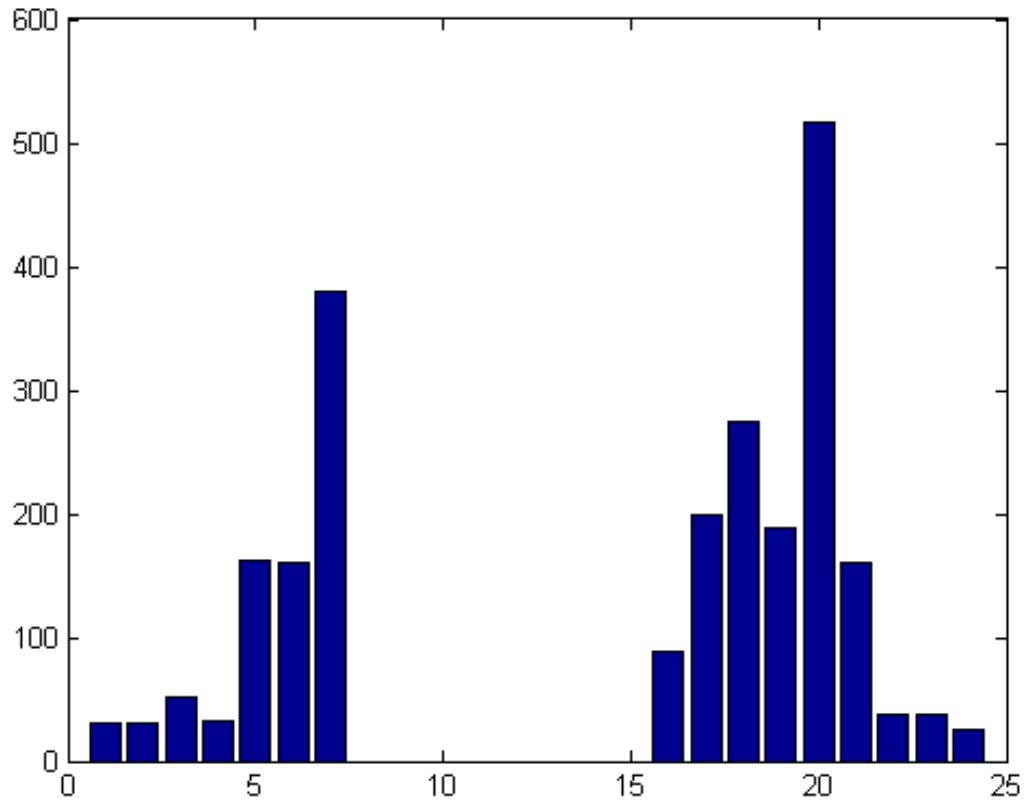
All workspace variables are of a specific class. For example, consider the following variable created in your workspace:

```
load count.dat % Load some data
tsobj = timeseries(count(:,1),1:24,'Name','Data1');
whos
```

Name	Size	Bytes	Class	Attributes
count	24x3	576	double	
tsobj	1x1	1261	timeseries	

The `whos` command lists information about your workspace variables. Notice that the variable loaded from the `count.dat` file (`count`) is an array of doubles. You know, therefore, that you can perform indexing and arithmetic operations on this array. For example:

```
newcount = sum(count,2);
newcount(8:15) = NaN;
bar(newcount)
```



Indexed assignment and the `bar` function work with inputs of class `double`.

However, the `timeseries` class does not define a `bar` method for `timeseries` objects. The `timeseries` class defines a `plot` method for graphing because the class design specified a line plot as the best way to represent time series data.

## Extracting Data From Object Properties

Suppose you have a `timeseries` object and you want to work directly with the numeric values of the `timeseries` data. You can extract data from the object properties and assign these values to an array. For example

```
load count.dat
tsoj = timeseries(sum(count,2),1:24,'Name','DataSum');
d = tsoj.Data;
t = tsoj.Time;
n = tsoj.Name;
d(8:15) = NaN;
bar(t,d); title(n)
```

## Testing for the Class of an Object

Suppose you create a function that operates on more than one class of object. If you have a `timeseries` object, you call the `timeseries` plot method, but if the object is of class `double`, you can call the `bar` function (which isn't supported by `timeseries` objects). You could use `isa` as in the following code to make this determination:

```
obj = tsoj.Data; % Define an input variable
function myPlotter(obj)
    if isa(obj,'timeseries')
        plot(obj)
    elseif isa(obj,'double')
        bar(obj)
    end
end
```

## Information About Class Members

These functions provide information about the object.

Function	Purpose
<code>class</code>	Return class of object
<code>events</code>	List of event names defined by the class
<code>methods</code>	List of methods implemented by the class

Function	Purpose
methodsview	Information on class methods in separate window
properties	List of class property names

## Logical Tests for Objects

In functions, you might need conditional statements to determine the status of an object before performing certain actions. For example, you might perform different actions based on the class of an object (see “Testing for the Class of an Object” on page 14-23). The following functions provide logical tests for objects:

Function	Purpose
isa	Determine whether argument belongs to a particular class. True for object’s class and all of object’s superclasses.
isequal	Determine if two objects are equal.
isobject	Determine whether the input is a MATLAB object.

## Testing for Object Equality

`isequal` finds two objects to be equal if all the following conditions are met:

- Both objects are of the same class
- Both objects are of the same size
- All corresponding property values are equal

`isequal` tests the value of every array element in every property and every property of every object contained in the objects being tested. As contained objects are tested for equality, MATLAB calls each object’s own version of `isequal` (if such versions exist).

If objects contain large amounts of data stored in other objects, then testing for equality can be a time-consuming process.



## Identifying MATLAB Objects

The `isobject` function returns `true` only for MATLAB objects. For Java objects, use `isjava`. For Handle Graphics objects, use `ishandle`.

---

**Note** `ishandle` returns `false` for MATLAB handle objects. See “Testing for Handle or Value Class” on page 14-32 for more information.

---

## Displaying Objects

When you issue commands that return objects and do not terminate those commands with a semicolon, or when you pass an object to the `disp` function, MATLAB displays information about the object. For example:

```
hobj = containers.Map({'Red Sox', 'Yankees'},
{'Boston', 'New York'})
hobj =
  containers.Map handle
  Package: containers

  Properties:
    Count: 2
    KeyType: 'char'
    ValueType: 'char'
  Methods, Events, Superclasses
```

This information includes links (shown in blue) to documentation on the object’s class and superclasses, and lists of methods, events, and superclasses. Properties and their current values are also listed.

Some classes (`timeseries`, for example) redefine how they display objects to provide more useful information for this particular class.

## Getting Help for MATLAB Objects

You can get documentation for MATLAB objects using the `doc` command with the class name. To see the reference pages for the objects used in this chapter, use the following commands:

```
doc timeseries
```

```
doc MException
doc containers.Map % Include the package name
```

## Copying Objects

### In this section...

“Two Copy Behaviors” on page 14-27

“Value Object Copy Behavior” on page 14-27

“Handle Object Copy Behavior” on page 14-28

“Testing for Handle or Value Class” on page 14-32

### Two Copy Behaviors

There are two fundamental kinds of MATLAB classes—handles and values.

*Value* classes create objects that behave like ordinary MATLAB variables with respect to copy operations. Copies are independent values. Operations that you perform on one object do not affect copies of that object.

*Handle* classes create objects that behave as references. This is because a handle, and all copies of this handle, refer to the same underlying object. When you create a handle object, you can copy the handle, but not the data referenced by the object’s properties. Any operations you perform on a handle object are visible from all handles that reference that object.

### Value Object Copy Behavior

MATLAB numeric variables are of value objects. For example, when you copy `a` to the variable `b`, both variables are independent of each other. Changing the value of `a` does not change the value of `b`:

```
a = 8;  
b = a;
```

Now reassign `a` and `b` is unchanged:

```
a = 6;  
b  
b =  
    8
```

Clearing a does not affect b:

```
clear a
b
b =
    8
```

## Value Object Properties

The copy behavior of values stored as properties in value objects is the same. For example, suppose vobj1 is a value object with property a:

```
vobj1.a = 8; % Property is set to a value
```

If you copy vobj1 to vobj2, and then change the value of vobj1 property a, you can see that the value of the copied object's property vobj2.a is unaffected:

```
vobj2 =vobj1;
vobj1.a = 5;

vobj2.a
ans =
    8
```

## Handle Object Copy Behavior

Here is a handle class called HdClass that defines a property called Data.

```
classdef HdClass < handle
    properties
        Data
    end
    methods
        function obj = HdClass(val)
            if nargin > 0
                obj.Data = val;
            end
        end
    end
end
```

Create an object of this class with the following statement:

```
hobj1 = HdClass(8)
```

Because this statement is not terminated with a semicolon, MATLAB displays information about the object:

```
hobj1 =
```

```
    HdClass handle
```

```
    Properties:
```

```
        Data: 8
```

```
    Methods, Events, Superclasses
```

The variable `hobj1` is a handle that references the object created. Copying `hobj1` to `hobj2` results in another handle (the variable `hobj2`) referring to the same object:

```
hobj2 = hobj1
```

```
hobj2 =
```

```
    HdClass handle
```

```
    Properties:
```

```
        Data: 8
```

```
    Methods, Events, Superclasses
```

Because handle objects reference the data contained in their properties, copying an object copies the handle to a new variable name, but the properties still refer to the same data. For example, given that `hobj1` is a handle object with property `Data`:

```
hobj1.Data
```

```
ans =
```

```
    8
```

Change the value of `hobj1`'s `Data` property and the value of the copied object's `Data` property also changes:

```
hobj1.Data = 5;
```

```
hobj2.Data
```

```
ans =
```

```
5
```

Because `hobj2` and `hobj1` are handles to the same object, changing the copy, `hobj2`, also changes the data you access through handle `hobj1`:

```
hobj2.Data = 17;
```

```
hobj1.Data
```

```
ans =
```

```
17
```

### **Copy Method for Handle Classes**

Handle classes can derive copy functionality from the `matlab.mixin.Copyable` class. Class designers can investigate the use of this class in their class design.

### **Reassigning Handle Variables**

Reassigning a handle variable produces the same result as reassigning any MATLAB variable. When you create a new object and assign it to `hobj1`:

```
hobj1 = HdClass(3.14);
```

`hobj1` references the new object, not the same object referenced previously (and still referenced by `hobj2`).

### **Clearing Handle Variables**

When you clear a handle from the workspace, MATLAB removes the variable, but does not removed the object referenced by the handle. Therefore, given `hobj1` and `hobj2`, which both reference the same object, you can clear either handle without affecting the object:

```
hobj1.Data = 2^8;
```

```
clear hobj1
hobj2
hobj2 =

    HdClass handle

Properties:
    Data: 256
```

[Methods, Events, Superclasses](#)

If you clear both `hobj1` and `hobj2`, then there are no references to the object and MATLAB deletes the object and frees the memory used by that object.

## Deleting Handle Objects

To remove an object referenced by any number of handles, use `delete`. Given `hobj1` and `hobj2`, which both reference the same object, if you delete either handle, MATLAB deletes the object:

```
hobj1 = HdClass(8);
hobj2 = hobj1;
delete(hobj1)
hobj2

hobj2 =

    deleted HdClass handle
```

[Methods, Events, Superclasses](#)

See “Destroying Objects” on page 14-34 for more information about object lifecycle.

## Modifying Objects

When you pass an object to a function, MATLAB follows *pass by value* semantics. This means that MATLAB passes a copy of the object to the function. If you modify the object in the function, MATLAB modifies only the copy of the object. The differences in copy behavior between handle and value classes are important in such cases:

- Value class — The function must return the modified copy of the object to the caller.
- Handle class — The copy refers to the same data as the original object. Therefore, the function does not need to return the modified copy.

See “Passing Objects to Functions” for more information.

### **More Information About Handle and Value Classes**

For information about handle and value classes for class designers, see “Handle Classes” in the Object-Oriented Programming documentation.

### **Testing for Handle or Value Class**

If you are writing MATLAB programs that copy objects, you might need to determine if any given object is a handle or a value. To determine if an object is a handle object, use the `isa` function:

```
isa(obj, 'handle')
```

For example, the `containers.Map` class creates a handle object:

```
hobj = containers.Map({'Red Sox', 'Yankees'}, {'Boston', 'New York'});  
isa(hobj, 'handle')
```

```
ans =
```

```
1
```

`hobj` is also a `containers.Map` object:

```
isa(hobj, 'containers.Map')
```

```
ans =
```

```
1
```

If you query the class of `hobj`, you see that it is a `containers.Map` object:

```
class(hobj)
```



```
ans =
```

```
containers.Map
```

The `class` function returns the specific class of an object, whereas `isa` returns `true` for any of the object's superclasses as well. This behavior is consistent with the object-oriented concept that an object is a member of all its superclasses. Therefore, it is true that a `containers.Map` object is a `handle` object and a `containers.Map` object.

There is no equivalent test for value classes because there is no value base class. If an object is a value object, `isa(object, 'handle')` returns `false` (i.e., logical 0).

See “Map Containers” for more information on the `containers.Map` class.

## Destroying Objects

### In this section...

“Object Lifecycle” on page 14-34

“Difference Between clear and delete” on page 14-34

### Object Lifecycle

An object’s lifecycle ends when:

- You reassign a new value to that variable.
- The object is no longer used in a function.
- Function execution ends.

MATLAB handle classes have a special method called `delete` that MATLAB calls when a handle object lifecycle ends.

Calling `delete` on an object explicitly makes all copies of a handle object invalid because it destroys the data associated with the object and frees memory used by deleted objects. MATLAB calls `delete` automatically so it is not necessary for you to do so. Classes can redefine the handle class `delete` method to perform other cleanup operations, like closing files or saving data.

Deleting a handle object renders all copies invalid:

```
hobj1 = HdClass(8);  
hobj2 = hobj1;  
delete(hobj1)  
hobj2.Data  
Invalid or deleted object.
```

### Difference Between clear and delete

The handle class `delete` method removes the handle object, but does not clear the variable name. The `clear` function removes a variable name, but does not remove the values to which the variable refers. For example, if you have two variables that refer to the same handle object, you can clear either one without affecting the actual object:

```
hobj = containers.Map({'Red Sox', 'Yankees'}, {'Boston', 'New York'});
hobj_copy = hobj;
clear hobj
city = hobj_copy('Red Sox')

city =

Boston
```

If you call `clear` on all handle variables that refer to the same handle object, then you have lost access to the object and MATLAB destroys the object. That is, when there are no references to an object, the object ceases to exist.

On value objects, you can call `clear` to remove the variable. However, MATLAB does not automatically call a value class `delete` method, if one exists, when you clear the variable.



# Defining Your Own Classes

---

All MATLAB data types are implemented as object-oriented classes. You can add data types of your own to your MATLAB environment by creating additional classes. These user-defined classes define the structure of your new data type, and the functions, or *methods*, that you write for each class define the behavior for that data type.

These methods can also define the way various MATLAB operators, including arithmetic operations, subscript referencing, and concatenation, apply to the new data types. For example, a class called `polynomial` might redefine the addition operator (+) so that it correctly performs the operation of addition on polynomials.

With MATLAB classes you can

- Create methods that overload existing MATLAB functionality
- Restrict the operations that are allowed on an object of a class
- Enforce common behavior among related classes by inheriting from the same parent class
- Significantly increase the reuse of your code

For more information, see “Classes in the MATLAB Language”.



# Scripts and Functions

---

- Chapter 16, “Scripts”
- Chapter 17, “Function Basics”
- Chapter 18, “Function Arguments”
- Chapter 19, “Debugging MATLAB Code”
- Chapter 20, “Presenting MATLAB Code”
- Chapter 21, “Coding and Productivity Tips”
- Chapter 22, “Programming Utilities”





# Scripts


---

- “Create Scripts” on page 16-2
- “Add Comments to Programs” on page 16-4
- “Run Code Sections” on page 16-6
- “Scripts vs. Functions” on page 16-16

## Create Scripts

Scripts are the simplest kind of program file because they have no input or output arguments. They are useful for automating series of MATLAB commands, such as computations that you have to perform repeatedly from the command line or series of commands you have to reference.

You can open a new script in the following ways:

- Highlight commands from the Command History, right-click, and select **Create Script**.
- Click the **New Script**  button on the **Home** tab.
- Use the `edit` function.

This code opens the file *file\_name*:


```
edit file_name
```

If *file\_name* is unspecified, MATLAB opens a new file called `Untitled`.

For example, suppose you save this code that generates random numbers between 0 and 100 as a script called `numGenerator.m`:

```
columns = 10000;  
rows = 1;  
bins = columns/100;  
  
rng(now);  
list = 100*rand(rows,columns);  
hist(list,bins)
```

You can run the code in `numGenerator.m` using either of these methods:

- Type the script name `numGenerator` on the command line and press **Enter**
- Click the **Run**  button on the **Editor** tab

When execution completes, the variables (`columns`, `rows`, `bins` and `list`) remain in the MATLAB workspace. To see a listing of variables, enter `whos` at the command prompt. Scripts share the base workspace with your interactive MATLAB session and with other scripts.

## Concepts

- “Base and Function Workspaces” on page 17-9

## Add Comments to Programs

This topic explains how and why to add comments to your program files.

When you write code, it is a good practice to add comments that describe the code. Comments allow others to understand your code, and can refresh your memory when you return to it later. Add comments to MATLAB code using the percent (%) symbol.

Comment lines can appear anywhere in a program file, and you can append comments to the end of a line of code. For example,

```
% Add up all the vector elements.  
y = sum(x)           % Use the sum function.
```

Comments are also useful for program development and testing—comment out any code that does not need to run. To comment out multiple lines of code, you can use the block comment operators, %{ and %}:

```
a = magic(3);  
%{  
sum(a)  
diag(a)  
sum(diag(a))  
%}  
sum(diag(fliplr(a)))
```


The %{ and %} operators must appear alone on the lines that immediately precede and follow the block of help text. Do not include any other text on these lines.

To comment out part of a statement that spans multiple lines, use an ellipsis (...) instead of a percent sign. For example,

```
header = ['Last Name, ', ...  
         'First Name, ', ...  
         ... 'Middle Initial, ', ...  
         'Title']
```

The MATLAB Editor includes tools and context menu items to help you add, remove, or change the format of comments for MATLAB, Java, and C/C++ code. For example, if you paste lengthy text onto a comment line, such as

```
% This is a program that has a comment that is a little more than 75 columns wide.
disp('Hello, world')
```

and then press the  button next to **Comment** on the **Editor** tab, the Editor wraps the comment:

```
% This is a program that has a comment that is a little more than 75
% columns wide.
disp('Hello, world')
```

By default, as you type comments in the Editor, the text wraps when it reaches a column width of 75. To change the column where the comment text wraps, or to disable automatic comment wrapping, adjust the **Editor/Debugger Language** preference settings labeled **Comment formatting**.

The Editor does not wrap comments with:

- Code section titles (comments that begin with %%)
- Long contiguous strings, such as URLs
- Bulleted list items (text that begins with \* or #) onto the preceding line
- “Add Help for Your Program” on page 17-5
- “Editor/Debugger Preferences”

## Related Examples

## Concepts

## Run Code Sections

### In this section...

“Divide Your File into Code Sections” on page 16-6

“Evaluate Code Sections” on page 16-7

“Navigate Among Code Sections in a File” on page 16-8

“Example of Evaluating Code Sections” on page 16-9


“Change the Appearance of Code Sections” on page 16-12


“Use Code Sections with Control Statements and Functions” on page 16-13

### Divide Your File into Code Sections

MATLAB files often consist of many commands. You typically focus efforts on a single part of your program at a time, working with the code in chunks. Similarly, when explaining your files to others, often you describe your program in chunks. To facilitate these processes, use *code sections*, also known as code cells or cell mode. A code section contains contiguous lines of code that you want to evaluate as a group in a MATLAB script, beginning with two comment characters (%%).

To define code section boundaries explicitly, insert section breaks using these methods:

- On the **Editor** tab, in the **Edit** section, in the Comment button group, click .
- Enter two percent signs (%%) at the start of the line where you want to begin the new code section.




The text on the same line as %% is called the *section title* . Including section titles is optional, however, it improves the readability of the file and appears as a heading if you publish your code.

## Evaluate Code Sections

As you develop a MATLAB file, you can use the Editor section features to evaluate the file section-by-section. This method helps you to experiment with, debug, and fine-tune your program. You can navigate among sections, and evaluate each section individually. To evaluate a section, it must contain all the values it requires, or the values must exist in the MATLAB workspace.

The section evaluation features run the section code currently highlighted in yellow. MATLAB does not automatically save your file when evaluating individual code sections. The file does not have to be on your search path.

This table provides instructions on evaluating code sections.

Operation	Instructions
Run the code in the current section.	<ul style="list-style-type: none"> <li>Place the cursor in the code section.</li> <li>On the <b>Editor</b> tab, in the <b>Run</b> section, click  <b>Run Section</b>.</li> </ul>
Run the code in the current section, and then move to the next section.	<ul style="list-style-type: none"> <li>Place the cursor in the code section.</li> <li>On the <b>Editor</b> tab, in the <b>Run</b> section, click  <b>Run and Advance</b>.</li> </ul>
Run all the code in the file.	<ul style="list-style-type: none"> <li>Type the saved script name in the Command Window.</li> <li>On the <b>Editor</b> tab, in the <b>Run</b> section, click  <b>Run</b>.</li> </ul>

---

**Note** You cannot debug when running individual code sections. MATLAB ignores any breakpoints.

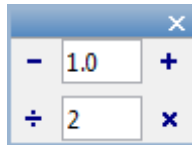
---

### Increment Values in Code Sections

You can increment numbers within a section, rerunning that section after every change. This helps you fine-tune and experiment with your code.

To increment or decrement a number in a section:

- 1 Highlight or place your cursor next to the number.
- 2 Right-click to open the context menu.
- 3 Select **Increment Value and Run Section**. A small dialog box appears.



- 4 Input appropriate values in the  $-/+$  text box or  $\div/\times$  text box.
- 5 Click the  $+$ ,  $-$ ,  $\times$ , or  $\div$  button to add to, subtract from, multiply, or divide the selected number in your section.

MATLAB runs the section after every click.

---



**Note** MATLAB software does not automatically save changes you make to the numbers in your script.

---

### Navigate Among Code Sections in a File

You can navigate among sections in a file without evaluating the code within those sections. This facilitates jumping quickly from section to section within a file. You might do this, for example, to find specific code in a large file.



Operation	Instructions
Move to the next section.	<ul style="list-style-type: none"> <li>On the <b>Editor</b> tab, in the <b>Run</b> section, click .</li> </ul>
Move to the previous section.	<ul style="list-style-type: none"> <li>Press <b>Ctrl + Up</b> arrow.</li> </ul>
Move to a specific section.	<ul style="list-style-type: none"> <li>On the <b>Editor</b> tab, in the <b>Navigate</b> section, use the  <b>Go To</b> to move the cursor to a selected section.</li> </ul>

## Example of Evaluating Code Sections

This example defines two code sections in a file called `sine_wave.m` and then increments a parameter to adjust the created plot. To open this file in your Editor, run the following command, and then save the file to a local folder:

```
edit(fullfile(matlabroot, 'help', 'techdoc', 'matlab_env', ...
'examples', 'sine_wave.m'))
```

After the file is open in your Editor:

- 1 Insert a section break and the following title on the first line of the file.


```
%% Calculate and Plot Sine Wave
```

- 2 Insert a blank line and a second section break after `plot(x,y)`. Add a section title, `Modify Plot Properties`, so that the entire file contains this code:

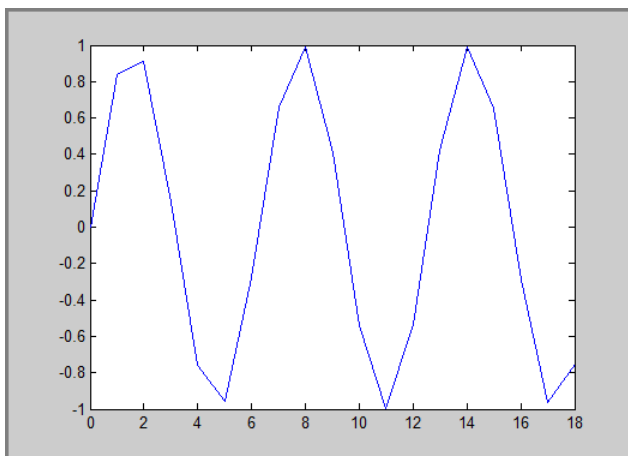
```
%% Calculate and Plot Sine Wave
% Define the range for x.
% Calculate and plot y = sin(x).
x = 0:1:6*pi;
y = sin(x);
plot(x,y)

%% Modify Plot Properties
title('Sine Wave', 'FontWeight', 'bold')
xlabel('x')
```

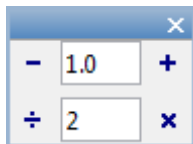
```
ylabel('sin(x)')
set(gca, 'Color', 'w')
set(gcf, 'MenuBar', 'none')
```

- 3 Save the file.
- 4 Place your cursor in the section titled Calculate and Plot Sine Wave. On the **Editor** tab, in the **Run** section, click  **Run Section**.


A figure displaying a course plot of  $\sin(x)$  appears.



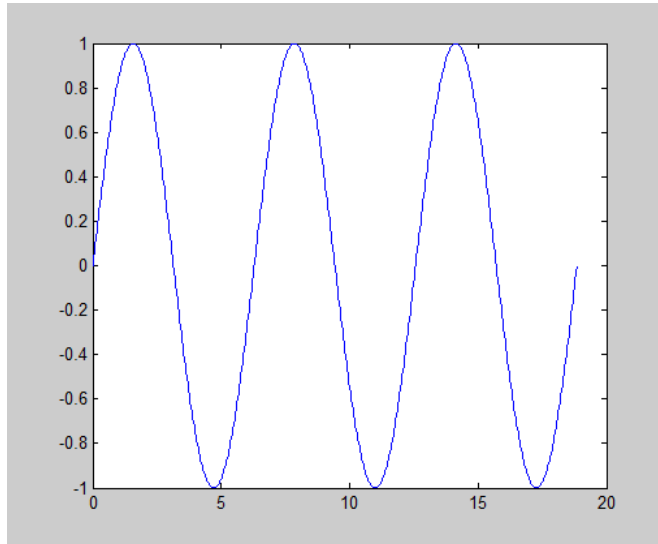
- 5 Smooth the sine plot.
  - a Highlight 1 in the statement: `x = 0:1:6*pi; .`
  - b Right-click and select **Increment Value and Run Section**. A small dialog box appears.



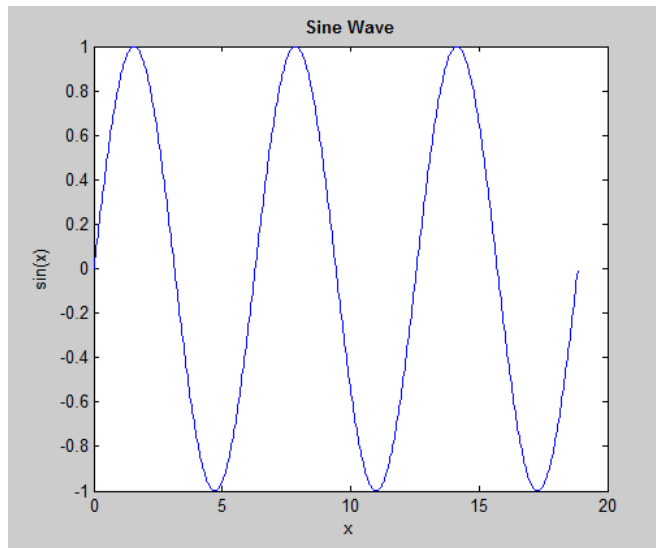
- c Type 2 in the  $\div / \times$  text box.

- d** Click the  button several times.

The sine plot becomes smoother after each subsequent click.



- e** Close the Figure and save the file.
- 6** Run the entire `sine_wave.m` file. A smooth sine plot with titles appears in a new Figure.



## Change the Appearance of Code Sections

You can change how code sections appear within the MATLAB Editor. MATLAB highlights code sections in yellow, by default, and divides them with horizontal lines. When the cursor is positioned in any line within a section, the Editor highlights the entire section.

To change how code sections appear:

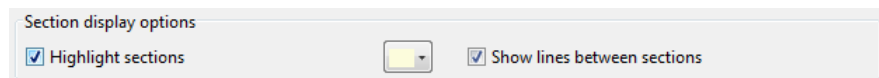
- 1 On the **Home** tab, in the **Environment** section, click  **Preferences**.

The Preference dialog box appears.

- 2 In the left pane, select **MATLAB > Colors > Programming Tools**.

3

Under **Section display options**, select the appearance of your code sections.



You can choose whether to highlight the sections, the color of the highlighting, and whether dividing lines appear between code sections.

## Use Code Sections with Control Statements and Functions

Unexpected results can appear when using code sections within control statements and functions because MATLAB automatically inserts section breaks that do not appear in the Editor unless *you* insert section breaks explicitly. This is especially true when nested code is involved. Nested code occurs wherever you place a control statement or function within the scope of another control statement or function.

MATLAB automatically defines section boundaries in a code block, according to this criteria:

- MATLAB inserts a section break at the top and bottom of a file, creating a code section that encompasses the entire file. However, the Editor does not highlight the resulting section, which encloses the entire file, unless you add one or more explicit code sections to the file.
- If you define a section break within a control flow statement (such as an `if` or `while` statement), MATLAB automatically inserts section breaks at the lines containing the start and end of the statement.
- If you define a section break within a function, MATLAB inserts section breaks at the function declaration and at the function end statement. If you do not end the function with an `end` statement, MATLAB behaves as if the end of the function occurs immediately before the start of the next function.

If an automatic break occurs on the same line as a break you insert, they collapse into one section break.

### Nested Code Section Breaks

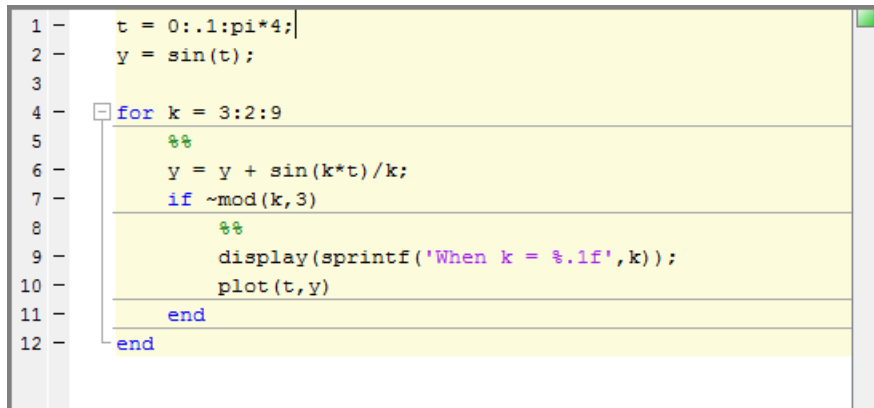
The following code illustrates the concept of nested code sections:

```
t = 0:.1:pi*4;  
y = sin(t);  
  
for k = 3:2:9  
    %%
```

```
y = y + sin(k*t)/k;
if ~mod(k,3)
    %%
    display(sprintf('When k = %.1f',k));
    plot(t,y)
end
end
```

If you copy and paste this code into a MATLAB Editor, you see that the two section breaks create three nested levels:

- **At the outermost level of nesting**, one section spans the entire file.

A screenshot of the MATLAB Editor interface. The code is displayed on a yellow background. The code is as follows:

```
1 - t = 0:.1:pi*4;
2 - y = sin(t);
3
4 - for k = 3:2:9
5     %%
6     y = y + sin(k*t)/k;
7     if ~mod(k,3)
8         %%
9         display(sprintf('When k = %.1f',k));
10        plot(t,y)
11    end
12 end
```

The code is enclosed in a section break that spans the entire file (lines 1-12). There is also a second-level section break that spans from line 4 to line 11, encompassing the for loop.

MATLAB only defines section in a code block if you specify section breaks *at the same level* within the code block. Therefore, MATLAB considers the cursor to be within the section that encompasses the entire file.

- **At the second-level of nesting**, a section exists within the for loop.

```
1 - t = 0:.1:pi*4;
2 - y = sin(t);
3
4 - for k = 3:2:9
5     %%
6     y = y + sin(k*t)/k;
7     if ~mod(k,3)
8         %%
9         display(sprintf('When k = %.1f',k));
10        plot(t,y)
11    end
12 end
```

- **At the third-level of nesting**, one section exists within the if statement.

```
1 - t = 0:.1:pi*4;
2 - y = sin(t);
3
4 - for k = 3:2:9
5     %%
6     y = y + sin(k*t)/k;
7     if ~mod(k,3)
8         %%
9         display(sprintf('When k = %.1f',k));
10        plot(t,y)
11    end
12 end
```

## Concepts

- “Scripts vs. Functions” on page 16-16

## Scripts vs. Functions

This topic discusses the differences between scripts and functions, and shows how to convert a script to a function.

Program files can be *scripts* that simply execute a series of MATLAB statements, or they can be *functions* that also accept input arguments and produce output. Both scripts and functions contain MATLAB code, and both are stored in text files with a `.m` extension. However, functions are more flexible and more easily extensible.

For example, create a script in a file named `triarea.m` that computes the area of a triangle:

```
b = 5;  
h = 3;  
a = 0.5*(b.* h)
```

After you save the file, you can call the script from the command line:

```
triarea  
  
a =  
    7.5000
```

To calculate the area of another triangle using the same script, you could update the values of `b` and `h` in the script and rerun it. Each time you run it, the script stores the result in a variable named `a` that is in the base workspace.

However, instead of manually updating the script each time, you can make your program more flexible by converting it to a function. Replace the statements that assign values to `b` and `h` with a function declaration statement. The declaration includes the `function` keyword, the names of input and output arguments, and the name of the function.

```
function a = triarea(b,h)  
a = 0.5*(b.* h);
```

After you save the file, you can call the function with different base and height values from the command line without modifying the script:



```
a1 = triarea(1,5)
a2 = triarea(2,10)
a3 = triarea(3,6)
```

```
a1 =
    2.5000
a2 =
    10
a3 =
     9
```

Functions have their own workspace, separate from the base workspace. Therefore, none of the calls to the function `triarea` overwrite the value of `a` in the base workspace. Instead, the function assigns the results to variables `a1`, `a2`, and `a3`.

## Related Examples

- “Create Scripts” on page 16-2
- “Create Functions in Files” on page 17-2

## Concepts

- “Base and Function Workspaces” on page 17-9



# Function Basics

---

- “Create Functions in Files” on page 17-2
- “Add Help for Your Program” on page 17-5
- “Run Functions in the Editor” on page 17-7
- “Base and Function Workspaces” on page 17-9
- “Share Data Between Workspaces” on page 17-10
- “Check Variable Scope in Editor” on page 17-15
- “Types of Functions” on page 17-19
- “Anonymous Functions” on page 17-23
- “Local Functions” on page 17-30
- “Nested Functions” on page 17-32
- “Variables in Nested and Anonymous Functions” on page 17-39
- “Private Functions” on page 17-41
- “Function Precedence Order” on page 17-43

## Create Functions in Files

This example shows how to create a function in a program file.

### Write a Function

Open a file in a text editor. Within the file, declare the function and add program statements:

```
function f = fact(n)
f = prod(1:n);
```

Function `fact` accepts a single input argument `n`, and returns the factorial of `n` in output argument `f`.

The definition statement is the first executable line of any function. Function definitions are not valid at the command line or within a script. Each function definition includes these elements.

function keyword (required)	Use lowercase characters for the keyword.
Output arguments (optional)	If your function returns more than one output, enclose the output names in square brackets, such as <pre>function [one,two,three] = myfunction(x)</pre> If there is no output, either omit it, <pre>function myfunction(x)</pre> or use empty square brackets: <pre>function [] = myfunction(x)</pre>

Function name (required)	<p>Valid function names follow the same rules as variable names. They must start with a letter, and can contain letters, digits, or underscores.</p> <hr/> <p><b>Note</b> To avoid confusion, use the same name for both the file and the first function within the file. MATLAB associates your program with the <i>file</i> name, not the function name.</p> <hr/>
Input arguments (optional)	<p>If your function accepts any inputs, enclose their names in parentheses after the function name. Separate inputs with commas, such as</p> <pre>function y = myfunction(one,two,three)</pre> <p>If there are no inputs, you can omit the parentheses.</p>

---

**Tip** When you define a function with multiple input or output arguments, list any required arguments first. This allows you to call your function without specifying optional arguments.

---

The body of a function can include valid MATLAB expressions, control flow statements, comments, blank lines, and nested functions. Any variables that you create within a function are stored within a workspace specific to that function, which is separate from the base workspace.

Functions end with either an end statement, the end of the file, or the definition line for another function, whichever comes first. The end statement is required only when a function in the file contains a nested function (a function completely contained within its parent).

Program files can contain multiple functions. The first function is the main function, and is the function that MATLAB associates with the file name. Subsequent functions that are not nested are called *local* functions. They are only available to other functions within the same file.

**Save the File**

Save the file (in this example, `fact.m`), either in the current folder or in a folder on the MATLAB search path. MATLAB looks for programs in these specific locations.

**Call the Function**

From the command line, call the new `fact` function to calculate  $5!$ , using the same syntax rules that apply to calling functions installed with MATLAB:

```
x = 5;  
y = fact(x);
```

The variables that you pass to the function do not need to have the same names as the arguments in the function definition line.

**See Also**

`function` | `edit` | `clear` | `what` | `which`

**Related Examples**

- “Files and Folders that MATLAB Accesses”
- “Add Help for Your Program” on page 17-5
- “Support Variable Number of Inputs” on page 18-4

**Concepts**

- “Base and Function Workspaces” on page 17-9
- “Local Functions” on page 17-30
- “Nested Functions” on page 17-32
- “Debugging Process and Features” on page 19-2

## Add Help for Your Program

This example shows how to provide help for the programs you write. Help text appears in the Command Window when you use the `help` function.

Create help text by inserting comments at the beginning of your program. If your program includes a function, position the help text immediately below the function definition line (the line with the function keyword).

For example, create a function in a file named `addme.m` that includes help text:

```
function c = addme(a,b)
% ADDME Add two values together.
% C = ADDME(A) adds A to itself.
% C = ADDME(A,B) adds A and B together.
%
% See also SUM, PLUS.

switch nargin
    case 2
        c = a + b;
    case 1
        c = a + a;
    otherwise
        c = 0;
end
```

When you type `help addme` at the command line, the help text displays in the Command Window:

```
addme Add two values together.
C = addme(A) adds A to itself.
C = addme(A,B) adds A and B together.

See also sum, plus.
```

The first help text line, often called the H1 line, typically includes the program name and a brief description. The Current Folder browser and the `help` and `lookfor` functions use the H1 line to display information about the program.

Create `See also` links by including function names at the end of your help text on a line that begins with `% See also`. If the function exists on the search path or in the current folder, the `help` command displays each of these function names as a hyperlink to its help. Otherwise, `help` prints the function names as they appear in the help text.

You can include hyperlinks (in the form of URLs) to Web sites in your help text. Create hyperlinks by including an HTML `<a></a>` anchor element. Within the anchor, use a `matlab:` statement to execute a web command. For example:

```
% For more information, see <a href="matlab:
% web('http://www.mathworks.com')">the MathWorks Web site</a>.
```

End your help text with a blank line (without a `%`). The help system ignores any comment lines that appear after the help text block.

---

**Note** When multiple programs have the same name, the `help` command determines which help text to display by applying the rules described in “Function Precedence Order” on page 17-43. However, if a program has the same name as a MathWorks function, the **Help on Selection** option in context menus always displays documentation for the MathWorks function.

---

## See Also

`help` | `lookfor`

## Related Examples

- “Add Comments to Programs” on page 16-4
- “Create Help Summary Files (Contents.m)” on page 27-13
- “Check Which Programs Have Help” on page 27-10
- “Display Custom Documentation” on page 27-16



## Run Functions in the Editor

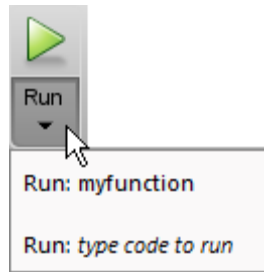
This example shows how to run a function that requires some initial setup, such as input argument values, while working in the Editor.

- 1 Create a function in a program file named `myfunction.m`.

```
function y = myfunction(x)
y = x.^2 + x;
```

This function requires input `x`.

- 2 View the commands available for running the function by clicking **Run** on the **Editor** tab. The command at the top of the list is the command that the Editor uses by default when you click the **Run** icon.



- 3 Replace the text *type code to run* with an expression that allows you to run the function.

```
y = myfunction(1:10)
```

You can enter multiple commands on the same line, such as

```
x = 1:10; y = myfunction(x)
```

For more complicated, multiline commands, create a separate script file, and then run the script.

---

**Note** Run commands use the base workspace. Any variables that you define in a run command can overwrite variables in the base workspace that have the same name.

---

- 4** Run the function by clicking **Run** or a specific run command from the drop-down list. For `myfunction.m`, and an input of `1:10`, this result appears in the Command Window:

```
y =  
    2     6    12    20    30    42    56    72    90   110
```

When you select a run command from the list, it becomes the default for the **Run** button.

To edit or delete an existing run command, select the command, right-click, and then select **Edit** or **Delete**.

## Base and Function Workspaces

This topic explains the differences between the base workspace and function workspaces, including workspaces for local functions, nested functions, and scripts.

The *base workspace* stores variables that you create at the command line. This includes any variables that scripts create, assuming that you run the script from the command line or from the Editor. Variables in the base workspace exist until you clear them or end your MATLAB session.

Functions do not use the base workspace. Every function has its own *function workspace*. Each function workspace is separate from the base workspace and all other workspaces to protect the integrity of the data. Even local functions in a common file have their own workspaces. Variables specific to a function workspace are called *local* variables. Typically, local variables do not remain in memory from one function call to the next.

When you call a script from a function, the script uses the function workspace.

Like local functions, nested functions have their own workspaces. However, these workspaces are unique in two significant ways:

- Nested functions can access and modify variables in the workspaces of the functions that contain them.
  - All of the variables in nested functions or the functions that contain them must be explicitly defined. That is, you cannot call a function or script that assigns values to variables unless those variables already exist in the function workspace.
- Related Examples**
- “Share Data Between Workspaces” on page 17-10
- Concepts**
- “Nested Functions” on page 17-32

## Share Data Between Workspaces

### In this section...

“Introduction” on page 17-10

“Best Practice: Passing Arguments” on page 17-10

“Nested Functions” on page 17-11

“Persistent Variables” on page 17-12

“Global Variables” on page 17-12

“Evaluating in Another Workspace” on page 17-13

### Introduction

This topic shows how to share variables between workspaces or allow them to persist between function executions.

In most cases, variables created within a function are *local* variables known only within that function. Local variables are not available at the command line or to any other function. However, there are several ways to share data between functions or workspaces.

### Best Practice: Passing Arguments

The most secure way to extend the scope of a function variable is to use function input and output arguments, which allow you to pass values of variables.

For example, create two functions, `update1` and `update2`, that share and modify an input value. `update2` can be a local function in the file `update1.m`, or can be a function in its own file, `update2.m`.

```
function y1 = update1(x1)
    y1 = 1 + update2(x1);
```

```
function y2 = update2(x2)
    y2 = 2 * x2;
```

Call the `update1` function from the command line and assign to variable `Y` in the base workspace:

```
X = [1,2,3];  
Y = update1(X)
```

```
Y =  
    3    5    7
```

## Nested Functions

A nested function has access to the workspaces of all functions in which it is nested. So, for example, a nested function can use a variable (in this case, `x`) that is defined in its parent function:

```
function primaryFx  
    x = 1;  
    nestedFx;  
  
    function nestedFx  
        x = x + 1;  
    end  
end
```

When parent functions do not use a given variable, the variable remains local to the nested function. For example, in this version of `primaryFx`, the two nested functions have their own versions of `x` that cannot interact with each other.

```
function primaryFx  
    nestedFx1;  
    nestedFx2;  
  
    function nestedFx1  
        x = 1;  
    end  
  
    function nestedFx2  
        x = 2;  
    end  
end
```

For more information, see “Nested Functions” on page 17-32.

## Persistent Variables

When you declare a variable within a function as persistent, the variable retains its value from one function call to the next. Other local variables retain their value only during the current execution of a function. Persistent variables are equivalent to static variables in other programming languages.

Declare variables using the `persistent` keyword before you use them. MATLAB initializes persistent variables to an empty matrix, `[]`.

For example, define a function in a file named `findSum.m` that initializes a sum to 0, and then adds to the value on each iteration.

```
function findSum(inputvalue)
persistent SUM_X

if isempty(SUM_X)
    SUM_X = 0;
end
SUM_X = SUM_X + inputvalue;
```

When you call the function, the value of `SUM_X` persists between subsequent executions.

These operations clear the persistent variables for a function:

- `clear all`
- `clear functionname`
- Editing the function file

To prevent clearing persistent variables, lock the function file using `mlock`.

## Global Variables

Global variables are variables that you can access from functions or from the command line. They have their own workspace, which is separate from the base and function workspaces.

However, global variables carry notable risks. For example:

- Any function can access and update a global variable. Other functions that use the variable might return unexpected results.
- If you unintentionally give a “new” global variable the same name as an existing global variable, one function can overwrite the values expected by another. This error is difficult to diagnose.

Use global variables sparingly, if at all.

If you use global variables, declare them using the `global` keyword before you access them within any particular location (function or command line). For example, create a function in a file called `falling.m`:

```
function h = falling(t)
    global GRAVITY
    h = 1/2*GRAVITY*t.^2;
```

Then, enter these commands at the prompt:

```
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. However, as a more robust alternative, redefine the function to accept the value as an input:

```
function h = falling(t,gravity)
    h = 1/2*gravity*t.^2;
```

Then, enter these commands at the prompt:

```
GRAVITY = 32;
y = falling((0:.1:5)',GRAVITY);
```

## Evaluating in Another Workspace

The `evalin` and `assignin` functions allow you to evaluate commands or variable names from strings and specify whether to use the current or base workspace.

Like global variables, these functions carry risks of overwriting existing data. Use them sparingly.

`evalin` and `assignin` are sometimes useful for callback functions in graphical user interfaces to evaluate against the base workspace. For example, create a list box of variable names from the base workspace:

```
function listBox
figure;
lb = uicontrol('Style','listbox','Position',[10 10 100 100],...
              'Callback',@update_listBox);
update_listBox(lb)

function update_listBox(src,~)
vars = evalin('base','who');
set(src,'String',vars)
```

For other programming applications, consider argument passing and the techniques described in “Alternatives to the `eval` Function” on page 2-69.

## Concepts

- “Base and Function Workspaces” on page 17-9



## Check Variable Scope in Editor

### In this section...

“Use Automatic Function and Variable Highlighting” on page 17-15

“Example of Using Automatic Function and Variable Highlighting” on page 17-16


Scoping issues can be the source of some coding problems. For instance, if you are unaware that nested functions share a particular variable, the results of running your code might not be as you expect. Similarly, mistakes in usage of local, global, and persistent variables can cause unexpected results.

The Code Analyzer does not always indicate scoping issues because sharing a variable across functions is not an error—it may be your intent. Use MATLAB function and variable highlighting features to identify when and where your code uses functions and variables. If you have an active Internet connection, you can watch the Variable and Function Highlighting video for an overview of the major features.

For conceptual information on nested functions and the various types of MATLAB variables, see “Sharing Variables Between Parent and Nested Functions” on page 17-33 and “Share Data Between Workspaces” on page 17-10.

### Use Automatic Function and Variable Highlighting

By default, the Editor indicates functions, local variables, and variables with shared scope in various shades of blue. Variables with shared scope include: global variables, persistent variables, and variables within nested functions. (For more information, see “Nested Functions” on page 17-11.)

To enable and disable highlighting or to change the colors, click  **Preferences** and select **MATLAB > Colors > Programming tools**.

By default, the Editor:

- Highlights all instances of a given function or local variable in sky blue when you place the cursor within a function or variable name. For instance:

`collatz`

- Displays a variable with shared scope in teal blue, regardless of the cursor location. For instance:

`x`

## Example of Using Automatic Function and Variable Highlighting

Consider the code for a function rowsum:

```
function rowTotals = rowsum
% Add the values in each row and
% store them in a new array

x = ones(2,10);
[n, m] = size(x);
rowTotals = zeros(1,n);
for i = 1:n
    rowTotals(i) = addToSum;
end

function colsum = addToSum
    colsum = 0;
    thisrow = x(i,:);
    for i = 1:m
        colsum = colsum + thisrow(i);
    end
end

end
```

When you run this code, instead of returning the sum of the values in each row and displaying:

```
ans =


    10    10
```

MATLAB displays:

ans =

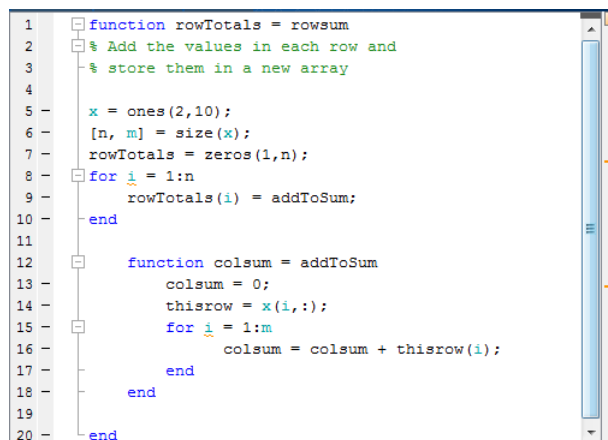
0 0 0 0 0 0 0 0 0 10

Examine the code by following these steps:

- 1 On the **Home** tab in the **Environment** section, click  **Preferences** and select **MATLAB > Colors > Programming tools**. Ensure that **Automatically highlight** and **Variables with shared scope** are selected.
- 2 Copy the rowsum code into the Editor.

Notice the variable **i** appears in teal blue, which indicates **i** is not a local variable. Both the rowTotals function and the addToSum functions set and use the variable **i**.

The variable **n**, at line 6 appears in black, indicating that it does not span multiple functions.



```

1  function rowTotals = rowsum
2  % Add the values in each row and
3  % store them in a new array
4
5  x = ones(2,10);
6  [n, m] = size(x);
7  rowTotals = zeros(1,n);
8  for i = 1:n
9      rowTotals(i) = addToSum;
10 end
11
12 function colsum = addToSum
13     colsum = 0;
14     thisrow = x(i,:);
15     for i = 1:m
16         colsum = colsum + thisrow(i);
17     end
18 end
19
20 end

```

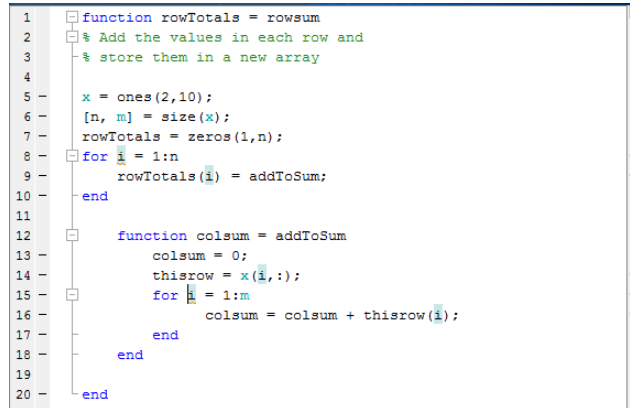
- 3 Hover the mouse pointer over an instance of variable **i**.

A tooltip appears: The scope of variable 'i' spans multiple functions.

- 4 Click the tooltip link for information about variables whose scope span multiple functions.

**5** Click an instance of `i`.

Every reference to `i` highlights in sky blue and markers appear in the indicator bar on the right side of the Editor.



```
1  function rowTotals = rowsum
2  % Add the values in each row and
3  % store them in a new array
4
5  x = ones(2,10);
6  [n, m] = size(x);
7  rowTotals = zeros(1,n);
8  for i = 1:n
9      rowTotals(i) = addToSum;
10 end
11
12     function colsum = addToSum
13     colsum = 0;
14     thisrow = x(i,:);
15     for j = 1:m
16         colsum = colsum + thisrow(j);
17     end
18 end
19
20 end
```

**6** Hover over one of the indicator bar markers.

A tooltip appears and displays the name of the function or variable and the line of code represented by the marker.

**7** Click a marker to navigate to the line indicated in tooltip for that marker.

This is particularly useful when your file contains more code than you can view at one time in the Editor.

Fix the code by changing the instance of `i` at line 15 to `y`.

You can see similar highlighting effects when you click on a function reference. For instance, click on `addToSum`.

## Types of Functions

### In this section...

“Local and Nested Functions in a File” on page 17-19

“Private Functions in a Subfolder” on page 17-20

“Anonymous Functions Without a File” on page 17-21

### Local and Nested Functions in a File

Program files can contain multiple functions: the main function and any combination of local or nested functions. Local and nested functions are useful for dividing programs into smaller tasks, making it easier to read and maintain your code.

*Local functions* are subroutines that are available to any other functions within the same file. They can appear in the file in any order after the main function in the file. Local functions are the most common way to break up programmatic tasks.

For example, create a single program file named `myfunction.m` that contains a main function, `myfunction`, and two local functions, `squareMe` and `doubleMe`:

```
function b = myfunction(a)
    b = squareMe(a) + doubleMe(a);
end
function y = squareMe(x)
    y = x.^2;
end
function y = doubleMe(x)
    y = x.*2;
end
```

You can call the main function from the command line or another program file, although the local functions are only available to `myfunction`:

```
myfunction(pi)

ans =
    16.1528
```

*Nested functions* are completely contained within another function. The primary difference between nested functions and local functions is that nested functions can use variables defined in parent functions without explicitly passing those variables as arguments.

Nested functions are useful when subroutines share data, such as GUI applications that pass data between components. For example, create a function that allows you to set a value between 0 and 1 using either a slider or an editable text box. If you use nested functions for the callbacks, the slider and text box can share the value and each other's handles without explicitly passing them:

```
function myslider
value = 0;
f = figure;
s = uicontrol(f,'Style','slider','Callback',@slider);
e = uicontrol(f,'Style','edit','Callback',@edittext,...
             'Position',[100,20,100,20]);

    function slider(obj,~)
        value = get(obj,'Value');
        set(e,'String',num2str(value));
    end
    function edittext(obj,~)
        value = str2double(get(obj,'String'));
        set(s,'Value',value);
    end
end
```

## Private Functions in a Subfolder

Like local or nested functions, private functions are accessible only to functions in a specific location. However, private functions are not in the same file as the functions that can call them. Instead, they are in a subfolder named `private`. Private functions are available only to functions in the folder immediately above the `private` folder. Use private functions to separate code into different files, or to share code between multiple, related functions.

## Anonymous Functions Without a File

Anonymous functions allow you to define a function without creating a program file, as long as the function consists of a single statement. A common application of anonymous functions is to define a mathematical expression, and then evaluate that expression over a range of values using a MATLAB® *function function*, i.e., a function that accepts a function handle as an input.

For example, this statement creates a function handle named `s` for an anonymous function:

```
s = @(x) sin(1./x);
```

This function has a single input, `x`. The `@` operator creates the function handle.

You can use the function handle to evaluate the function for particular values, such as

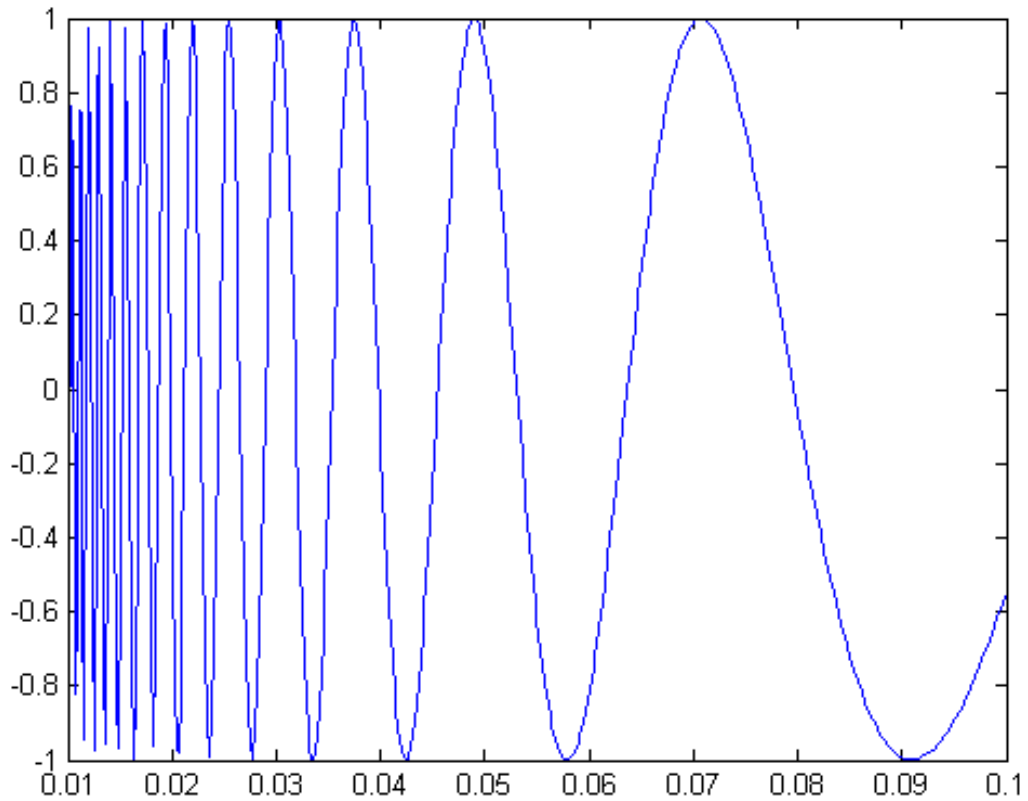
```
y = s(pi)
```

```
y =
```

```
0.3130
```

Or, you can pass the function handle to a function that evaluates over a range of values, such as `fplot`:

```
range = [0.01,0.1];  
fplot(s,range)
```

**Concepts**

- “Local Functions” on page 17-30
- “Nested Functions” on page 17-32
- “Private Functions” on page 17-41
- “Anonymous Functions” on page 17-23



## Anonymous Functions

### In this section...

“What Are Anonymous Functions?” on page 17-23

“Variables in the Expression” on page 17-24

“Multiple Anonymous Functions” on page 17-25

“Functions with No Inputs” on page 17-26

“Functions with Multiple Inputs or Outputs” on page 17-26

“Arrays of Anonymous Functions” on page 17-28

### What Are Anonymous Functions?

An anonymous function is a function that is *not* stored in a program file, but is associated with a variable whose data type is `function_handle`. Anonymous functions can accept inputs and return outputs, just as standard functions do. However, they can contain only a single executable statement.

For example, create a handle to an anonymous function that finds the square of a number:

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

Variable `sqr` is a function handle. The `@` operator creates the handle, and the parentheses `()` immediately after the `@` operator include the function input arguments. This anonymous function accepts a single input `x`, and implicitly returns a single output, an array the same size as `x` that contains the squared values.

Find the square of a particular value (5) by passing the value to the function handle, just as you would pass an input argument to a standard function.

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

```
a =  
    25
```

Many MATLAB functions accept function handles as inputs so that you can evaluate functions over a range of values. You can create handles either for anonymous functions or for functions in program files. The benefit of using anonymous functions is that you do not have to edit and maintain a file for a function that requires only a brief definition.

For example, find the integral of the `sqr` function from 0 to 1 by passing the function handle to the `integral` function:

```
q = integral(sqr,0,1);
```

You do not need to create a variable in the workspace to store an anonymous function. Instead, you can create a temporary function handle within an expression, such as this call to the `integral` function:

```
q = integral(@(x) x.^2,0,1);
```

## Variables in the Expression

Function handles can store not only an expression, but also variables that the expression requires for evaluation.

For example, create a function handle to an anonymous function that requires coefficients `a`, `b`, and `c`.

```
a = 1.3;  
b = .2;  
c = 30;  
parabola = @(x) a*x.^2 + b*x + c;
```

Because `a`, `b`, and `c` are available at the time you create `parabola`, the function handle includes those values. The values persist within the function handle even if you clear the variables:

```
clear a b c  
x = 1;  
y = parabola(x)  
  
y =  
    31.5000
```

To supply different values for the coefficients, you must create a new function handle:

```
a = -3.9;
b = 52;
c = 0;
parabola = @(x) a*x.^2 + b*x + c;

x = 1;
y = parabola(1)

y =
    48.1000
```

You can save function handles and their associated values in a MAT-file and load them in a subsequent MATLAB session using the `save` and `load` functions, such as

```
save myfile.mat parabola
```

## Multiple Anonymous Functions

The expression in an anonymous function can include another anonymous function. This is useful for passing different parameters to a function that you are evaluating over a range of values. For example, you can solve the equation

$$g(c) = \int_0^1 (x^2 + cx + 1) dx$$

for varying values of  $c$  by combining two anonymous functions:

```
g = @(c) (integral(@(x) (x.^2 + c*x + 1),0,1));
```

Here is how to derive this statement:

- 1 Write the integrand as an anonymous function,

```
@(x) (x.^2 + c*x + 1)
```

- 2 Evaluate the function from zero to one by passing the function handle to `integral`,

```
integral(@(x) (x.^2 + c*x + 1),0,1)
```

- 3** Supply the value for *c* by constructing an anonymous function for the entire equation,

```
g = @(c) (integral(@(x) (x.^2 + c*x + 1),0,1));
```

The final function allows you to solve the equation for any value of *c*. For example:

```
g(2)
```

```
ans =  
    2.3333
```

## Functions with No Inputs

If your function does not require any inputs, use empty parentheses when you define and call the anonymous function. For example:

```
t = @() datestr(now);  
d = t()
```

```
d =  
26-Jan-2012 15:11:47
```

Omitting the parentheses in the assignment statement creates another function handle, and does not execute the function:

```
d = t
```

```
d =  
    @() datestr(now)
```

## Functions with Multiple Inputs or Outputs

Anonymous functions require that you explicitly specify the input arguments as you would for a standard function, separating multiple inputs with commas. For example, this function accepts two inputs, *x* and *y*:

```
myfunction = @(x,y) (x^2 + y^2 + x*y);
```

```
x = 1;
```

```
y = 10;  
z = myfunction(x,y)
```

```
z =
```

```
111
```

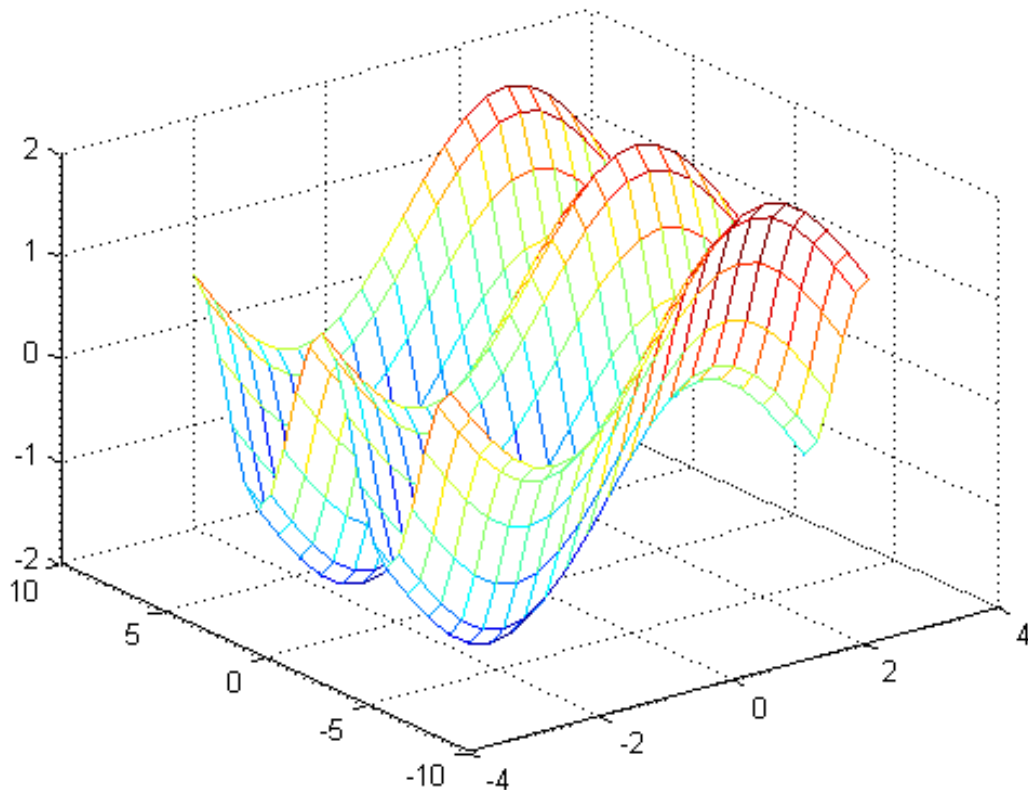
However, you do not explicitly define output arguments when you create an anonymous function. If the expression in the function returns multiple outputs, then you can request them when you call the function. Enclose multiple output variables in square brackets.

For example, the `ndgrid` function can return as many outputs as the number of input vectors. This anonymous function that calls `ndgrid` can also return multiple outputs:

```
c = 10;  
mygrid = @(x,y) ndgrid((-x:x/c:x),(-y:y/c:y));  
[x,y] = mygrid(pi,2*pi);
```

You can use the output from `mygrid` to create a mesh or surface plot:

```
z = sin(x) + cos(y);  
mesh(x,y,z)
```



## Arrays of Anonymous Functions

Although most MATLAB fundamental data types support multidimensional arrays, function handles must be scalars (single elements). However, you can store multiple function handles using a cell array or structure array. The most common approach is to use a cell array, such as

```
f = {@(x)x.^2;  
     @(y)y+10;  
     @(x,y)x.^2+y+10};
```

When you create the cell array, keep in mind that MATLAB interprets spaces as column separators. Either omit spaces from expressions, as shown in the previous code, or enclose expressions in parentheses, such as

```
f = {@(x) (x.^2);  
     @(y) (y + 10);  
     @(x,y) (x.^2 + y + 10)};
```

Access the contents of a cell using curly braces. For example, `f{1}` returns the first function handle. To execute the function, pass input values in parentheses after the curly braces:

```
x = 1;  
y = 10;  
  
f{1}(x)  
f{2}(y)  
f{3}(x,y)  
  
ans =  
    1  
  
ans =  
    20  
  
ans =  
    21
```

## Concepts

- “Creating a Function Handle” on page 11-3

## Local Functions

This topic explains the term *local function*, and shows how to create and use local functions.

MATLAB program files can contain code for more than one function. The first function in the file (the main function) is visible to functions in other files, or you can call it from the command line. Additional functions within the file are called local functions. Local functions are only visible to other functions in the same file. They are equivalent to subroutines in other programming languages, and are sometimes called subfunctions.

Local functions can occur in any order, as long as the main function appears first. Each function begins with its own function definition line.

For example, create a program file named `mystats.m` that contains a main function, `mystats`, and two local functions, `mymean` and `mymedian`.

```
function [avg, med] = mystats(x)
n = length(x);
avg = mymean(x,n);
med = mymedian(x,n);
end

function a = mymean(v,n)
% MYMEAN Example of a local function.

a = sum(v)/n;
end

function m = mymedian(v,n)
% MYMEDIAN Another example of a local function.

w = sort(v);
if rem(n,2) == 1
    m = w((n + 1)/2);
else
    m = (w(n/2) + w(n/2 + 1))/2;
end
end
```



The local functions `mymean` and `mymedian` calculate the average and median of the input list. The main function `mystats` determines the length of the list `n` and passes it to the local functions.

Although you cannot call a local function from the command line or from functions in other files, you can access its help using the `help` function. Specify names of both the main function and the local function, separating them with a `>` character:

```
help mystats>mymean
```

```
mymean Example of a local function.
```

Local functions in the current file have precedence over functions in other files. That is, when you call a function within a program file, MATLAB checks whether the function is a local function before looking for other main functions. This allows you to create an alternate version of a particular function while retaining the original in another file.

All functions, including local functions, have their own workspaces that are separate from the base workspace. Local functions cannot access variables used by other functions unless you pass them as arguments. In contrast, *nested* functions (functions completely contained within another function) can access variables used by the functions that contain them.

## See Also

`localfunctions`

## Concepts

- “Nested Functions” on page 17-32
- “Function Precedence Order” on page 17-43

## Nested Functions

### In this section...

“What Are Nested Functions?” on page 17-32

“Requirements for Nested Functions” on page 17-33

“Sharing Variables Between Parent and Nested Functions” on page 17-33

“Using Handles to Store Function Parameters” on page 17-35

“Visibility of Nested Functions” on page 17-37

### What Are Nested Functions?

A nested function is a function that is completely contained within a parent function. Any function in a program file can include a nested function.

For example, this function named `parent` contains a nested function named `nestedfx`:

```
function parent
disp('This is the parent function')
nestedfx

    function nestedfx
        disp('This is the nested function')
    end

end
```

The primary difference between nested functions and other types of functions is that they can access and modify variables that are defined in their parent functions. As a result:

- Nested functions can use variables that are not explicitly passed as input arguments.
- In a parent function, you can create a handle to a nested function that contains the data necessary to run the nested function.

## Requirements for Nested Functions

- Typically, functions do not require an end statement. However, to nest any function in a program file, *all* functions in that file must use an end statement.
- You cannot define a nested function inside any of the MATLAB program control statements, such as `if/elseif/else`, `switch/case`, `for`, `while`, or `try/catch`.
- You must call a nested function either directly by name (without using `feval`), or using a function handle that you created using the `@` operator (and not `str2func`).
- All of the variables in nested functions or the functions that contain them must be explicitly defined. That is, you cannot call a function or script that assigns values to variables unless those variables already exist in the function workspace. (For more information, see “Variables in Nested and Anonymous Functions” on page 17-39.)

## Sharing Variables Between Parent and Nested Functions

In general, variables in one function workspace are not available to other functions. However, nested functions can access and modify variables in the workspaces of the functions that contain them.

This means that both a nested function and a function that contains it can modify the same variable without passing that variable as an argument. For example, in each of these functions, `main1` and `main2`, both the main function and the nested function can access variable `x`:

```
function main1
x = 5;
nestfun1;

    function nestfun1
        x = x + 1;
    end

end

function main2
    nestfun2;

        function nestfun2
            x = 5;
        end

        x = x + 1;
    end
```

When parent functions do not use a given variable, the variable remains local to the nested function. For example, in this function named `main`, the two nested functions have their own versions of `x` that cannot interact with each other:

```
function main
    nestedfun1;
    nestedfun2;

    function nestedfun1
        x = 1;
    end

    function nestedfun2
        x = 2;
    end
end
```

Functions that return output arguments have variables for the outputs in their workspace. However, parent functions only have variables for the output of nested functions if they explicitly request them. For example, this function `parentfun` does *not* have variable `y` in its workspace:

```
function parentfun
x = 5;
nestfun;

    function y = nestfun
        y = x + 1;
```

```
    end  
  
end
```

If you modify the code as follows, variable `z` is in the workspace of `parentfun`:

```
function parentfun  
x = 5;  
z = nestfun;  
  
    function y = nestfun  
        y = x + 1;  
    end  
  
end
```

## Using Handles to Store Function Parameters

Nested functions can use variables from three sources:

- Input arguments
- Variables defined within the nested function
- Variables defined in a parent function, also called *externally scoped* variables

When you create a function handle for a nested function, that handle stores not only the name of the function, but also the values of externally scoped variables.

For example, create a function in a file named `makeParabola.m`. This function accepts several polynomial coefficients, and returns a handle to a nested function that calculates the value of that polynomial.

```
function p = makeParabola(a,b,c)  
p = @parabola;  
  
    function y = parabola(x)  
        y = a*x.^2 + b*x + c;  
    end
```

```
end
```

The `makeParabola` function returns a handle to the parabola function that includes values for coefficients `a`, `b`, and `c`.

At the command line, call the `makeParabola` function with coefficient values of 1.3, .2, and 30. Use the returned function handle `p` to evaluate the polynomial at a particular point:

```
p = makeParabola(1.3, .2, 30);
```

```
X = 25;
```

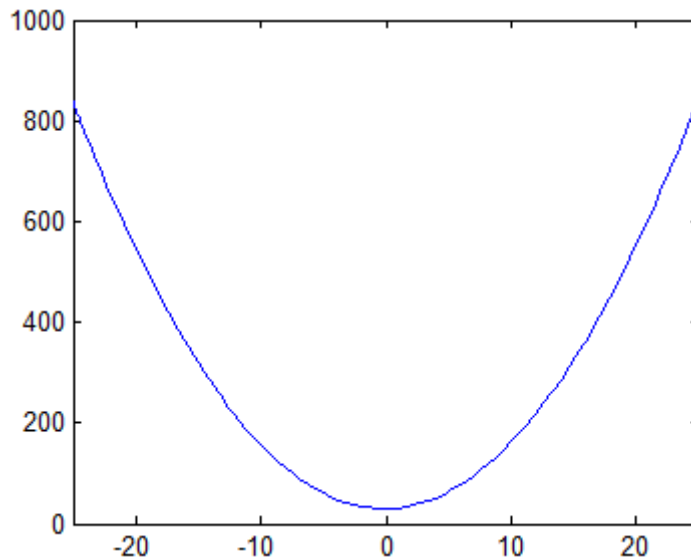
```
Y = p(X)
```

```
Y =
```

```
847.5000
```

Many MATLAB functions accept function handle inputs to evaluate functions over a range of values. For example, plot the parabolic equation from -25 to +25:

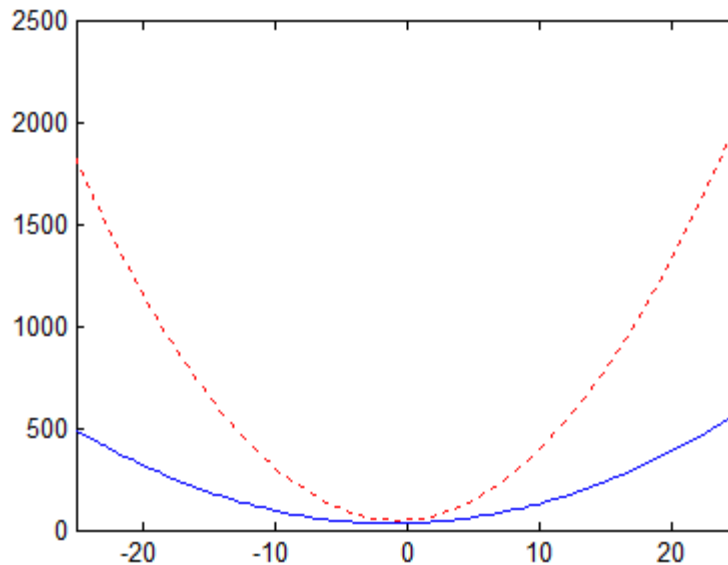
```
fplot(p, [-25, 25])
```



You can create multiple handles to the parabola function that each use different polynomial coefficients:

```
firstp = makeParabola(0.8,1.6,32);  
secondp = makeParabola(3,4,50);  
range = [-25,25];
```

```
figure  
hold on  
fplot(firstp,range)  
fplot(secondp,range,'r:')  
hold off
```



## Visibility of Nested Functions

Every function has a certain *scope*, that is, a set of other functions to which it is visible. A nested function is available:

- From the level immediately above it. (In the following code, function A can call B or D, but not C or E.)

- From a function nested at the same level within the same parent function. (Function B can call D, and D can call B.)
- From a function at any lower level. (Function C can call B or D, but not E.)

```
function A(x, y)           % Main function
B(x,y);
D(y);

    function B(x,y)       % Nested in A
C(x);
D(y);

        function C(x)    % Nested in B
D(x);
end
end

function D(x)             % Nested in A
E(x);

    function E(x)        % Nested in D
disp(x)
end
end
end
```

The easiest way to extend the scope of a nested function is to create a function handle and return it as an output argument, as shown in “Using Handles to Store Function Parameters” on page 17-35. Only functions that can call a nested function can create a handle to it.

## Concepts

- “Variables in Nested and Anonymous Functions” on page 17-39
- “Calling a Function Using Its Handle” on page 11-7
- “Argument Checking in Nested Functions” on page 18-11



# Variables in Nested and Anonymous Functions

The scoping rules for nested and anonymous functions require that all variables used within the function be present in the text of the code.

If you attempt to dynamically add a variable to the workspace of an anonymous function, a nested function, or a function that contains a nested function, then MATLAB issues an error of the form

Attempt to add *variable* to a static workspace.

This table describes typical operations that attempt dynamic assignment, and the recommended ways to avoid it.

Type of Operation	Best Practice to Avoid Dynamic Assignment
load	Specify the variable name as an input to the load function. Or, assign the output from the load function to a structure array.
eval, evalin, or assignin	If possible, avoid using these functions altogether. See “Alternatives to the eval Function” on page 2-69.
Calling a MATLAB script that creates a variable	Convert the script to a function and pass the variable using arguments. This approach also clarifies the code.
Assigning to a variable in the MATLAB debugger	Create a global variable for temporary use in debugging, such as  <pre>K&gt;&gt; global X; K&gt;&gt; X = myvalue;</pre>

Another way to avoid dynamic assignment is to explicitly declare the variable within the function. For example, suppose a script named `makeX.m` assigns a value to variable `X`. A function that calls `makeX` and explicitly declares `X` avoids the dynamic assignment error because `X` is in the function workspace. A common way to declare a variable is to initialize its value to an empty array:

```
function noerror
X = [];
nestedfx

    function nestedfx
        makeX
    end
end
```

## Concepts

- “Base and Function Workspaces” on page 17-9

## Private Functions

This topic explains the term *private function*, and shows how to create and use private functions.

Private functions are useful when you want to limit the scope of a function. You designate a function as private by storing it in a subfolder with the name `private`. Then, the function is available only to functions in the folder immediately above the `private` subfolder, or to scripts called by the functions that reside in the parent folder.

For example, within a folder that is on the MATLAB search path, create a subfolder named `private`. Do not add `private` to the path. Within the `private` folder, create a function in a file named `findme.m`:

```
function findme
% FINDME An example of a private function.

disp('You found the private function.')
```

Change to the folder that contains the `private` folder and create a file named `visible.m`.

```
function visible
findme
```

Change your current folder to any location and call the `visible` function.

```
visible

You found the private function.
```

Although you cannot call the private function from the command line or from functions outside the parent of the `private` folder, you can access its help:

```
help private/findme

    findme An example of a private function.
```

Private functions have precedence over standard functions, so MATLAB finds a private function named `test.m` before a nonprivate program file named

`test.m`. This allows you to create an alternate version of a particular function while retaining the original in another folder.

### **Concepts**

- “Function Precedence Order” on page 17-43

## Function Precedence Order

This topic explains how MATLAB determines which function to call when multiple functions in the current scope have the same name. The current scope includes the current file, an optional private subfolder relative to the currently running function, the current folder, and the MATLAB path.

MATLAB uses this precedence order:

### 1 Variables

Before assuming that a name matches a function, MATLAB checks for a variable with that name in the current workspace.

---

**Note** If you create a variable with the same name as a function, MATLAB cannot run that function until you clear the variable from memory.

---

### 2 Imported package functions

A package function is associated with a particular folder. When you import a package function using the `import` function, it has precedence over all other functions with the same name.

### 3 Nested functions within the current function

### 4 Local functions within the current file

### 5 Private functions

*Private* functions are functions in a subfolder named `private` that is immediately below the folder of the currently running file.

### 6 Object functions

An object function accepts a particular class of object in its input argument list. When there are multiple object functions with the same name, MATLAB checks the classes of the input arguments to determine which function to use.

**7** Class constructors in @ folders

MATLAB uses class constructors to create a variety of objects (such as `timeseries` or `audioplayer`), and you can define your own classes using object-oriented programming. For example, if you create a class folder `@polynom` and a constructor function `@polynom/polynom.m`, the constructor takes precedence over other functions named `polynom.m` anywhere on the path.

**8** Functions in the current folder**9** Functions elsewhere on the path, in order of appearance

When determining the precedence of functions within the same folder, MATLAB considers the file type, in this order:

**1** Built-in function**2** MEX-function**3** Simulink® model, with file types in this order:**a** SLX file**b** MDL file**4** P-file (that is, an encoded program file with a `.p` extension)**5** Program file with a `.m` extension

For example, if MATLAB finds a `.m` file and a P-file with the same name in the same folder, it uses the P-file. Because P-files are not automatically regenerated, make sure that you regenerate the P-file whenever you edit the program file.

To determine the function MATLAB calls for a particular input, include the function name and the input in a call to the `which` function. For example, determine the location of the `max` function that MATLAB calls for `double` and `int8` values:

```
testval = 10;  
which max(testval)
```

```
% double method
built-in (matlabroot\toolbox\matlab\datafun\@double\max)

testval = int8(10);
which max(testval)

% int8 method
built-in (matlabroot\toolbox\matlab\datafun\@int8\max)
```

For more information, see:

- “Search Path Basics”
- Variables
- “Types of Functions” on page 17-19
- “Class Precedence and MATLAB Path”





# Function Arguments

---

- “Find Number of Function Arguments” on page 18-2
- “Support Variable Number of Inputs” on page 18-4
- “Support Variable Number of Outputs” on page 18-6
- “Validate Number of Function Arguments” on page 18-8
- “Argument Checking in Nested Functions” on page 18-11
- “Ignore Function Inputs” on page 18-13
- “Check Function Inputs with `validateattributes`” on page 18-14
- “Parse Function Inputs” on page 18-17
- “Input Parser Validation Functions” on page 18-22

## Find Number of Function Arguments

This example shows how to determine how many input or output arguments your function receives using `nargin` and `nargout`.

### Input Arguments

Create a function in a file named `addme.m` that accepts up to two inputs. Identify the number of inputs with `nargin`.

```
function c = addme(a,b)

switch nargin
    case 2
        c = a + b;
    case 1
        c = a + a;
    otherwise
        c = 0;
end
```

Call `addme` with one, two, or zero input arguments.

```
addme(42)
```

```
ans =
    84
```

```
addme(2,4000)
```

```
ans =
    4002
```

```
addme
```

```
ans =
     0
```

### Output Arguments

Create a new function in a file named `addme2.m` that can return one or two outputs (a result and its absolute value). Identify the number of requested outputs with `nargout`.

```
function [result,absResult] = addme2(a,b)

switch nargin
    case 2
        result = a + b;
    case 1
        result = a + a;
    otherwise
        result = 0;
end

if nargin > 1
    absResult = abs(result);
end
```

Call `addme2` with one or two output arguments.

```
value = addme2(11,-22)
```

```
value =
    -11
```

```
[value,absValue] = addme2(11,-22)
```

```
value =
    -11
```

```
absValue =
     11
```

Functions return outputs in the order they are declared in the function definition.

## See Also

`nargin` | `narginchk` | `nargout` | `nargoutchk`

## Support Variable Number of Inputs

This example shows how to define a function that accepts a variable number of input arguments using `varargin`. The `varargin` argument is a cell array that contains the function inputs, where each input is in its own cell.

Create a function in a file named `plotWithTitle.m` that accepts a variable number of paired  $(x,y)$  inputs for the `plot` function and an optional title. If the function receives an odd number of inputs, it assumes that the last input is a title.

```
function plotWithTitle(varargin)
if rem(nargin,2) ~= 0
    myTitle = varargin{nargin};
    numPlotInputs = nargin - 1;
else
    myTitle = 'Default Title';
    numPlotInputs = nargin;
end

plot(varargin{1:numPlotInputs})
title(myTitle)
```

Because `varargin` is a cell array, you access the contents of each cell using curly braces, `{}`. The syntax `varargin{1:numPlotInputs}` creates a comma-separated list of inputs to the `plot` function.

Call `plotWithTitle` with two sets of  $(x,y)$  inputs and a title.

```
x = [1:.1:10]; y1 = sin(x); y2 = cos(x);
plotWithTitle(x,y1,x,y2,'Sine and Cosine')
```

You can use `varargin` alone in an input argument list, or at the end of the list of inputs, such as

```
function myfunction(a,b,varargin)
```

In this case, `varargin{1}` corresponds to the third input passed to the function, and `nargin` returns `length(varargin) + 2`.

### See Also

`nargin` | `varargin`

**Related Examples**

- “Access Data in a Cell Array” on page 10-5

**Concepts**

- “Argument Checking in Nested Functions” on page 18-11
- “Comma-Separated Lists” on page 2-61

## Support Variable Number of Outputs

This example shows how to define a function that returns a variable number of output arguments using `varargout`. Output `varargout` is a cell array that contains the function outputs, where each output is in its own cell.

Create a function in a file named `magicfill.m` that assigns a magic square to each requested output.

```
function varargout = magicfill
    nOutputs = nargin;
    varargout = cell(1,nOutputs);

    for k = 1:nOutputs;
        varargout{k} = magic(k);
    end
```

Indexing with curly braces `{}` updates the contents of a cell.

Call `magicfill` and request three outputs.

```
[first,second,third] = magicfill
```

```
first =
     1

second =
     1     3
     4     2

third =
     8     1     6
     3     5     7
     4     9     2
```

MATLAB assigns values to the outputs according to their order in the `varargout` array. For example, `first == varargout{1}`.

You can use `varargout` alone in an output argument list, or at the end of the list of outputs, such as

```
function [x,y,varargout] = myfunction(a,b)
```

In this case, `varargout{1}` corresponds to the third output that the function returns, and `nargout` returns `length(varargout) + 2`.

**See Also**

`nargout` | `varargout`

**Related Examples**

- “Access Data in a Cell Array” on page 10-5

**Concepts**

- “Argument Checking in Nested Functions” on page 18-11

## Validate Number of Function Arguments

This example shows how to check whether your custom function receives a valid number of input or output arguments. MATLAB performs some argument checks automatically. For other cases, you can use `narginchk` or `nargoutchk`.

### Automatic Argument Checks

MATLAB checks whether your function receives more arguments than expected when it can determine the number from the function definition. For example, this function accepts up to two outputs and three inputs:

```
function [x,y] = myFunction(a,b,c)
```

If you pass too many inputs to `myFunction`, MATLAB issues an error. You do not need to call `narginchk` to check for this case.

```
[X,Y] = myFunction(1,2,3,4)
```

```
Error using myFunction
Too many input arguments.
```

Use the `narginchk` and `nargoutchk` functions to verify that your function receives:

- A minimum number of required arguments.
- No more than a maximum number of arguments, when your function uses `varargin` or `varargout`.

### Input Checks with `narginchk`

Define a function in a file named `testValues.m` that requires at least two inputs. The first input is a threshold value to compare against the other inputs.

```
function testValues(threshold,varargin)
minInputs = 2;
maxInputs = Inf;
narginchk(minInputs,maxInputs)
```



```

for k = 1:(nargin-1)
    if (varargin{k} > threshold)
        fprintf('Test value %d exceeds %d\n',k,threshold);
    end
end

```

Call `testValues` with too few inputs.

```
testValues(10)
```

```

Error using testValues (line 4)
Not enough input arguments.

```

Call `testValues` with enough inputs.

```
testValues(10,1,11,111)
```

```

Test value 2 exceeds 10
Test value 3 exceeds 10

```

### Output Checks with `nargoutchk`

Define a function in a file named `mysize.m` that returns the dimensions of the input array in a vector (from the `size` function), and optionally returns scalar values corresponding to the sizes of each dimension. Use `nargoutchk` to verify that the number of requested individual sizes does not exceed the number of available dimensions.

```

function [sizeVector,varargout] = mysize(x)
minOutputs = 0;
maxOutputs = ndims(x) + 1;
nargoutchk(minOutputs,maxOutputs)

sizeVector = size(x);

varargout = cell(1,nargout-1);
for k = 1:length(varargout)
    varargout{k} = sizeVector(k);
end

```

Call `mysize` with a valid number of outputs.

```
A = rand(3,4,2);  
[fullsize,nrows,ncols,npages] = mysize(A)
```

```
fullsize =  
    3     4     2
```

```
nrows =  
    3
```

```
ncols =  
    4
```

```
npages =  
    2
```

Call `mysize` with too many outputs.

```
A = 1;  
[fullsize,nrows,ncols,npages] = mysize(A)
```

```
Error using mysize (line 4)  
Too many output arguments.
```

### See Also

`narginchk` | `nargoutchk`

### Related Examples

- “Support Variable Number of Inputs” on page 18-4
- “Support Variable Number of Outputs” on page 18-6

## Argument Checking in Nested Functions

This topic explains special considerations for using `varargin`, `varargout`, `nargin`, and `nargout` with nested functions.

`varargin` and `varargout` allow you to create functions that accept variable numbers of input or output arguments. Although `varargin` and `varargout` look like function names, they refer to variables, not functions. This is significant because nested functions share the workspaces of the functions that contain them.

If you do not use `varargin` or `varargout` in the declaration of a nested function, then `varargin` or `varargout` within the nested function refers to the arguments of an outer function.

For example, create a function in a file named `showArgs.m` that uses `varargin` and has two nested functions, one that uses `varargin` and one that does not.

```
function showArgs(varargin)
    nested1(3,4)
    nested2(5,6,7)

    function nested1(a,b)
        disp('nested1: Contents of varargin{1}')
        disp(varargin{1})
    end

    function nested2(varargin)
        disp('nested2: Contents of varargin{1}')
        disp(varargin{1})
    end

end
```

Call the function and compare the contents of `varargin{1}` in the two nested functions.

```
showArgs(0,1,2)

nested1: Contents of varargin{1}
```

```
0
```

```
nested2: Contents of varargin{1}
5
```

On the other hand, `nargin` and `nargout` are functions. Within any function, including nested functions, calls to `nargin` or `nargout` return the number of arguments for that function. If a nested function requires the value of `nargin` or `nargout` from an outer function, pass the value to the nested function.

For example, create a function in a file named `showNumArgs.m` that passes the number of input arguments from the primary (parent) function to a nested function.

```
function showNumArgs(varargin)

disp(['Number of inputs to showNumArgs: ',int2str(nargin)]);
nestedFx(nargin,2,3,4)

    function nestedFx(n,varargin)
        disp(['Number of inputs to nestedFx: ',int2str(nargin)]);
        disp(['Number of inputs to its parent: ',int2str(n)]);
    end

end
```

Call `showNumArgs` and compare the output of `nargin` in the parent and nested functions.

```
showNumArgs(0,1)
```

```
Number of inputs to showNumArgs: 2
Number of inputs to nestedFx: 4
Number of inputs to its parent: 2
```

**See Also**

`nargin` | `nargout` | `varargin` | `varargout`

## Ignore Function Inputs

This example shows how to ignore inputs in your function definition using the tilde (~) operator.

Use this operator when your function must accept a predefined set of inputs, but your function does not use all of the inputs. Common applications include defining callback functions, as shown here, or deriving a class from a superclass.

Define a callback for a push button in a file named `colorButton.m` that does not use the `eventdata` input. Ignore the input with a tilde.

```
function colorButton
figure;
uicontrol('Style','pushbutton','String','Click me','Callback',@btnCallback)

function btnCallback(h,~)
set(h,'BackgroundColor',rand(3,1))
```

The function declaration for `btnCallback` is essentially the same as

```
function btnCallback(h,eventdata)
```

However, using the tilde prevents the addition of `eventdata` to the function workspace and makes it clearer that the function does not use `eventdata`.

You can ignore any number of function inputs, in any position in the argument list. Separate consecutive tildes with a comma, such as

```
myfunction(myinput,~,~)
```

## Check Function Inputs with `validateattributes`

This example shows how to verify that the inputs to your function conform to a set of requirements using the `validateattributes` function.

`validateattributes` requires that you pass the variable to check and the supported data types for that variable. Optionally, pass a set of attributes that describe the valid dimensions or values.

### Check Data Type and Other Attributes

Define a function in a file named `checkme.m` that accepts up to three inputs: `a`, `b`, and `c`. Check whether:

- `a` is a two-dimensional array of positive double-precision values.
- `b` contains 100 numeric values in an array with 10 columns.
- `c` is a nonempty character string or cell array.

```
function checkme(a,b,c)

validateattributes(a,{'double'},{'positive','2d'})
validateattributes(b,{'numeric'},{'numel',100,'ncols',10})
validateattributes(c,{'char','cell'},{'nonempty'})

disp('All inputs are ok.')
```

The curly braces `{}` indicate that the set of data types and the set of additional attributes are in cell arrays. Cell arrays allow you to store combinations of text and numeric data, or text strings of different lengths, in a single variable.

Call `checkme` with valid inputs.

```
checkme(pi,rand(5,10,2),'text')
```

```
All inputs are ok.
```

The scalar value `pi` is two-dimensional because `size(pi) = [1,1]`.

Call `checkme` with invalid inputs. The `validateattributes` function issues an error for the first input that fails validation, and `checkme` stops processing.

```
checkme(-4)
```

```
Error using checkme (line 3)  
Expected input to be positive.
```

```
checkme(pi,rand(3,4,2))
```

```
Error using checkme (line 4)  
Expected input to be an array with number of elements equal to 100.
```

```
checkme(pi,rand(5,10,2),struct)
```

```
Error using checkme (line 5)  
Expected input to be one of these types:
```

```
char, cell
```

```
Instead its type was struct.
```

The default error messages use the generic term `input` to refer to the argument that failed validation. When you use the default error message, the only way to determine which input failed is to view the specified line of code in `checkme`.

### **Add Input Name and Position to Errors**

Define a function in a file named `checkdetails.m` that performs the same validation as `checkme`, but adds details about the input name and position to the error messages.

```
function checkdetails(a,b,c)  
  
validateattributes(a,{'double'},{'positive','2d'},'', 'First',1)  
validateattributes(b,{'numeric'},{'numel',100,'ncols',10},'', 'Second',2)  
validateattributes(c,{'char'},{'nonempty'},'', 'Third',3)  
  
disp('All inputs are ok.')
```

The empty string '' for the fourth input to `validateattributes` is a placeholder for an optional function name string. You do not need to specify a function name because it already appears in the error message. Specify the function name when you want to include it in the error identifier for additional error handling.

Call `checkdetails` with invalid inputs.

```
checkdetails(-4)
```

```
Error using checkdetails (line 3)  
Expected input number 1, First, to be positive.
```

```
checkdetails(pi,rand(3,4,2))
```

```
Error using checkdetails (line 4)  
Expected input number 2, Second, to be an array with  
number of elements equal to 100.
```

**See Also**

`validateattributes` | `validatestring`



## Parse Function Inputs

This example shows how to define required and optional inputs, assign defaults to optional inputs, and validate all inputs to a custom function using the Input Parser.

The Input Parser provides a consistent way to validate and assign defaults to inputs, improving the robustness and maintainability of your code. To validate the inputs, you can take advantage of existing MATLAB functions or write your own validation routines.

### Step 1. Define your function.

Create a function in a file named `printPhoto.m`. The `printPhoto` function has one required input for the file name, and optional inputs for the finish (glossy or matte), color space (RGB or CMYK), width, and height.

```
function printPhoto(filename,varargin)
```

In your function declaration statement, specify required inputs first. Use `varargin` to support optional inputs.

### Step 2. Create an InputParser object.

Within your function, call `inputParser` to create a parser object.

```
p = inputParser;
```

### Step 3. Add inputs to the scheme.

Add inputs to the parsing scheme in your function using `addRequired`, `addOptional`, or `addParameter`. For optional inputs, specify default values.

For each input, you can specify a handle to a validation function that checks the input and returns a scalar logical (`true` or `false`) or errors. The validation function can be an existing MATLAB function (such as `ischar` or `isnumeric`) or a function that you create (such as an anonymous function or a local function).

In the `printPhoto` function, `filename` is a required input. Define `finish` and `color` as optional input strings, and `width` and `height` as optional parameter value pairs.

```
defaultFinish = 'glossy';
validFinishes = {'glossy','matte'};
checkFinish = @(x) any(validatestring(x,validFinishes));

defaultColor = 'RGB';
validColors = {'RGB','CMYK'};
checkColor = @(x) any(validatestring(x,validColors));

defaultWidth = 6;
defaultHeight = 4;

addRequired(p,'filename',@ischar);
addOptional(p,'finish',defaultFinish,checkFinish);
addOptional(p,'color',defaultColor,checkColor);
addParameter(p,'width',defaultWidth,@isnumeric);
addParameter(p,'height',defaultHeight,@isnumeric);
```

Inputs that you add with `addRequired` or `addOptional` are *positional* arguments. When you call a function with positional inputs, specify those values in the order they are added to the parsing scheme.

Inputs added with `addParameter` are not positional, so you can pass values for `height` before or after values for `width`. However, parameter value inputs require that you pass the input name ('`height`' or '`width`') along with the value of the input.

If your function accepts optional input strings and parameter name and value pairs, specify validation functions for the optional input strings. Otherwise, the Input Parser interprets the optional strings as parameter names. For example, the `checkFinish` validation function ensures that `printPhoto` interprets 'glossy' as a value for `finish` and not as an invalid parameter name.

**Step 4. Set properties to adjust parsing (optional).**

By default, the Input Parser makes assumptions about case sensitivity, function names, structure array inputs, and whether to allow additional parameter names and values that are not in the scheme. Properties allow you to explicitly define the behavior. Set properties using dot notation, similar to assigning values to a structure array.

Allow `printPhoto` to accept additional parameter value inputs that do not match the input scheme by setting the `KeepUnmatched` property of the Input Parser.

```
p.KeepUnmatched = true;
```

If `KeepUnmatched` is `false` (default), the Input Parser issues an error when inputs do not match the scheme.

#### **Step 5. Parse the inputs.**

Within your function, call the `parse` method. Pass the values of all of the function inputs.

```
parse(p,filename,varargin{:});
```

#### **Step 6. Use the inputs in your function.**

Access parsed inputs using these properties of the `inputParser` object:

- `Results` — Structure array with names and values of all inputs in the scheme.
- `Unmatched` — Structure array with parameter names and values that are passed to the function, but are not in the scheme (when `KeepUnmatched` is `true`).
- `UsingDefaults` — Cell array with names of optional inputs that are assigned their default values because they are not passed to the function.

Within the `printPhoto` function, display the values for some of the inputs:

```
disp(['File name: ',p.Results.filename])  
disp(['Finish: ', p.Results.finish])  
  
if ~isempty(fieldnames(p.Unmatched))
```

```
        disp('Extra inputs:')
        disp(p.Unmatched)
    end
    if ~isempty(p.UsingDefaults)
        disp('Using defaults: ')
        disp(p.UsingDefaults)
    end
end
```

**Step 7. Call your function.**

The Input Parser expects to receive inputs as follows:

- Required inputs first, in the order they are added to the parsing scheme with `addRequired`.
- Optional positional inputs in the order they are added to the scheme with `addOptional`.
- Positional inputs before parameter name and value pair inputs.
- Parameter names and values in the form `Name1,Value1,...,NameN,ValueN`.

Pass several combinations of inputs to `printPhoto`, some valid and some invalid:

```
printPhoto('myfile.jpg')

File name: myfile.jpg
Finish: glossy
Using defaults:
    'finish'    'color'    'width'    'height'

printPhoto(100)

Error using printPhoto (line 23)
Argument 'filename' failed validation ischar.

printPhoto('myfile.jpg','satin')

Error using printPhoto (line 23)
Argument 'finish' failed validation with error:
Expected input to match one of these strings:
```

```
glossy, matte
```

The input, 'satin', did not match any of the valid strings.

```
printPhoto('myfile.jpg','height',10,'width',8)
```

```
File name: myfile.jpg
Finish: glossy
Using defaults:
    'finish'    'color'
```

To pass a value for the  $n$ th positional input, either specify values for the previous  $(n - 1)$  inputs or pass the input as a parameter name and value pair. For example, these function calls assign the same values to `finish` (default 'glossy') and `color`:

```
printPhoto('myfile.gif','glossy','CMYK'); % positional
```

```
printPhoto('myfile.gif','color','CMYK'); % name and value
```

## See Also

`inputParser` | `varargin`

## Concepts

- “Input Parser Validation Functions” on page 18-22

## Input Parser Validation Functions

This topic shows ways to define validation functions that you pass to the Input Parser to check custom function inputs.

The Input Parser methods `addRequired`, `addOptional`, and `addParameter` each accept an optional handle to a validation function. Designate function handles with an at (`@`) symbol.

Validation functions must accept a single input argument, and they must either return a scalar logical value (`true` or `false`) or error. If the validation function returns `false`, the Input Parser issues an error and your function stops processing.

There are several ways to define validation functions:

- Use an existing MATLAB function such as `ischar` or `isnumeric`. For example, check that a required input named `num` is numeric:

```
p = inputParser;  
checknum = @isnumeric;  
addRequired(p, 'num', checknum);  
  
parse(p, 'text');
```

```
Argument 'num' failed validation isnumeric.
```

- Create an anonymous function. For example, check that input `num` is a numeric scalar greater than zero:

```
p = inputParser;  
checknum = @(x) isnumeric(x) && isscalar(x) && (x > 0);  
addRequired(p, 'num', checknum);  
  
parse(p, rand(3));
```

```
Argument 'num' failed validation @(x)isnumeric(x)&&isscalar(x)&&(x>0).
```

- Define your own function, typically a local function in the same file as your primary function. For example, in a file named `usenum.m`, define a local

function named `checknum` that issues custom error messages when the input `num` to `usenum` is not a numeric scalar greater than zero:

```
function usenum(num)
    p = inputParser;
    addRequired(p, 'num', @checknum);
    parse(p, num);

function TF = checknum(x)
    TF = false;
    if ~isscalar(x)
        error('Input is not scalar');
    elseif ~isnumeric(x)
        error('Input is not numeric');
    elseif (x <= 0)
        error('Input must be > 0');
    else
        TF = true;
    end
```

Call the function with an invalid input:

```
usenum(-1)
```

```
Error using usenum (line 4)
Argument 'num' failed validation with error:
Input must be > 0
```

## See Also

[inputParser](#) | [function\\_handle](#) | [is\\*](#) | [validateattributes](#)

## Related Examples

- “Parse Function Inputs” on page 18-17

## Concepts

- “Anonymous Functions” on page 17-23





# Debugging MATLAB Code

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## Debugging Process and Features

### In this section...

- “Ways to Debug MATLAB Files” on page 19-2
- “Preparing for Debugging” on page 19-2
- “Set Breakpoints” on page 19-5
- “Run a File with Breakpoints” on page 19-8
- “Step Through a File” on page 19-10
- “Examine Values” on page 19-11
- “Correct Problems and End Debugging” on page 19-17
- “Conditional Breakpoints” on page 19-24
- “Breakpoints in Anonymous Functions” on page 19-26
- “Breakpoints in Methods That Overload Functions” on page 19-27
- “Error Breakpoints” on page 19-28

### Ways to Debug MATLAB Files

You can debug MATLAB files using the Editor, which is a graphical user interface, as well as by using debugging functions from the Command Window. You can use both methods interchangeably. These topics and the example describe both methods.

### Preparing for Debugging

Do the following to prepare for debugging:

- 1** Open the file — To use the Editor for debugging, open it with the file to run.
- 2** Save changes — If you are editing the file, save the changes before you begin debugging. If you try to run a file with unsaved changes from within the Editor, the file is automatically saved before it runs. If you run a file with unsaved changes from the Command Window, MATLAB software runs the saved version of the file. Therefore, you do not see the results of your changes.

- 3 Add the files to a folder on the search path or put them in the current folder. Be sure the file you run and any files it calls are in folders that are on the search path. If all required files are in the same folder, you can instead make that folder the current folder.

### Debugging Example – The Collatz Problem

The debugging process and features are best described using an example. To prepare to use the example, create two files, `collatz.m` and `collatzplot.m`, that produce data for the Collatz problem.

For any given positive integer,  $n$ , the Collatz algorithm produces a sequence of integers. If  $n$  equals 1, the sequence is complete. Otherwise, if  $n$  is odd, multiply it by 3 and add 1 to get the next integer in the sequence. Otherwise, if  $n$  is even, divide it by 2 to get the next integer in the sequence. Repeat the process until the sequence terminates with 1. The number of integers in the sequence varies depending on the starting value,  $n$ .

The Collatz conjecture is that the sequence always terminates within a finite number of steps. The files for this example are useful for studying the behavior of the Collatz algorithm. The file `collatz.m` generates the Collatz sequence of integers for any given  $n$ . The file `collatzplot.m` plots the length of the sequence against the starting value for all starting values from 1 through a given value  $m$ . The plot shows patterns that you can study further.

Following are the results when  $n$  is 1, 2, or 3.

<b>n</b>	<b>Sequence</b>	<b>Number of Integers in the Sequence</b>
1	1	1
2	2 1	2
3	3 10 5 16 8 4 2 1	8

**Files for the Collatz Problem.** Following are the two files you use for the debugging example. To create these files on your system, open two new files. Select and copy the following code from the Help browser and paste it into the files. Save and name the files `collatz.m` and `collatzplot.m`. Save them to your current folder or add the folder where you save them to the search path. One of the files has an embedded error to illustrate the debugging features.

Open the files by issuing the following commands, and then saving each file to a local folder:

```
open(fullfile(matlabroot, 'help', 'techdoc', 'matlab_env', ...  
    'examples', 'collatz.m'))
```

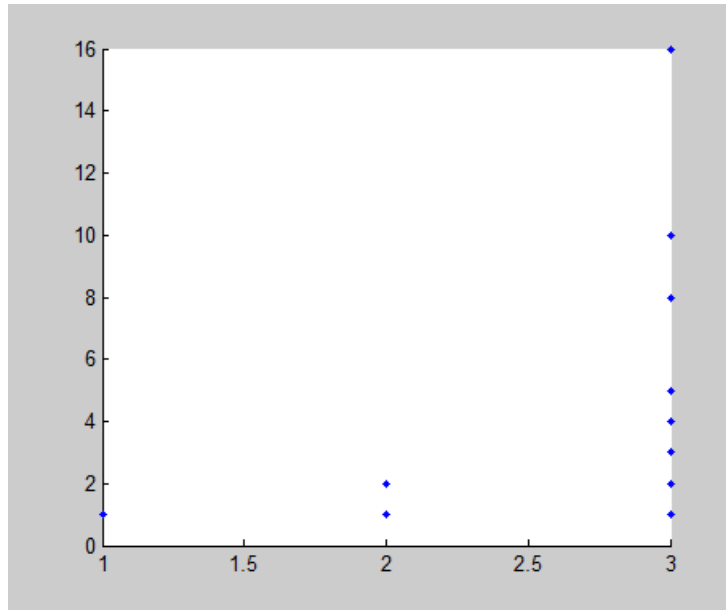
```
open(fullfile(matlabroot, 'help', 'techdoc', 'matlab_env', ...  
    'examples', 'collatzplot.m'))
```

**Trial Run for the Example.** Open the file `collatzplot.m`. Make sure that the current folder is the folder in which you saved `collatzplot`.

Try out `collatzplot` to see if it works correctly. Use a simple input value, for example, 3, and compare the results to those shown in the preceding table. Typing

```
collatzplot(3)
```

produces the plot shown in the following figure.



The plot for  $n = 1$  appears to be correct—for 1, the Collatz series is 1, and contains one integer. But for  $n = 2$  and  $n = 3$ , it is wrong. There should be only one value plotted for each integer, the number of integers in the sequence, which the preceding table shows to be 2 (for  $n = 2$ ) and 8 (for  $n = 3$ ). Instead, multiple values are plotted. Use MATLAB debugging features to isolate the problem.

## Set Breakpoints

Set breakpoints to pause execution of the MATLAB file so you can examine values where you think the problem can be. You can set breakpoints using the Editor, using functions in the Command Window, or both.

There are three basic types of breakpoints you can set in MATLAB files:

- A standard breakpoint, which stops at a specified line in a file. For details, see “Set Standard Breakpoints” on page 19-7.
- A conditional breakpoint, which stops at a specified line in a file only under specified conditions. For details, see “Conditional Breakpoints” on page 19-24.
- An error breakpoint that stops in any file when it produces the specified type of warning, error, or NaN or infinite value. For details, see “Error Breakpoints” on page 19-28.

You can disable standard and conditional breakpoints so that MATLAB temporarily ignores them, or you can remove them. For details, see “Disable and Clear Breakpoints” on page 19-18. Breakpoints do not persist after you exit the MATLAB session.

You can only set valid standard and conditional breakpoints at executable lines in saved files that are in the current folder or in folders on the search path. When you add or remove a breakpoint in a file that is not in a folder on the search path or in the current folder, a dialog box appears. This dialog box presents options that allow you to add or remove the breakpoint. You can either change the current folder to the folder containing the file, or you can add the folder containing the file to the search path.

Do not set a breakpoint at a `for` statement if you want to examine values at increments in the loop. For example, in


```
for n = 1:10
    m = n+1;
end
```

MATLAB executes the `for` statement only once, which is efficient. Therefore, when you set a breakpoint at the `for` statement and step through the file, you only stop at the `for` statement once. Instead place the breakpoint at the next line, `m=n+1` to stop at each pass through the loop.

You cannot set breakpoints while MATLAB is busy, for example, running a file, unless that file is paused at a breakpoint.

## Set Standard Breakpoints

To set a standard breakpoint using the Editor:

- 1 If you have changed the file, save it.
- 2 Either:
  - Click in the breakpoint alley at an executable line where you want to set the breakpoint. The *breakpoint alley* is the narrow column on the left side of the Editor, to the right of the line number.
  - Position the cursor in an executable line. On the **Editor** tab, in the **Breakpoints** section, click  **Breakpoints**, and then select **Set/Clear**.

Executable lines are preceded by a - (dash). If you attempt to set breakpoints at lines that are not executable, such as comments or blank lines, MATLAB sets it at the next executable line.

**Set Breakpoints for the Example.** It is unclear whether the problem in the example is in `collatzplot` or `collatz`. To start, follow these steps:

- 1 In `collatzplot.m`, click the dash in the breakpoint alley at line 9 to set a breakpoint.

This breakpoint enables you to step into `collatz` to see if the problem is there.

- 2 Set additional breakpoints at lines 10 and 11.

These breakpoints stop the program so you can examine the interim results.

```

1  function collatzplot(m)
2  % Plot length of sequence for Collatz problem
3  % Prepare figure
4  -  clf
5  -  set(gca,'XScale','linear')
6  -  %
7  % Determine and plot sequence and sequence length
8  -  for N = 1:m
9  ●  plot_seq = collatz(N);
10 ●  seq_length(N) = length(plot_seq);
11 ●  line(N,plot_seq,'Marker','.','MarkerSize',9,'Color','b')
12 -  drawnow
13 -  end
14 % This M-file has an intentional error at line 10 to demonstrate
15 % The plot_seq variable should be seq_length(N).

```

**Valid (Red) and Invalid (Gray) Breakpoints.** Red breakpoints indicate valid standard breakpoints.

Breakpoints are gray for either of these reasons:

- There are unsaved changes in the file. Save the file to make breakpoints valid. The gray breakpoints become red, indicating they are now valid. Any gray breakpoints that you entered at invalid breakpoint lines automatically move to the next valid breakpoint line with a successful file save.
- There is a syntax error in the file. When you set a breakpoint, an error message appears indicating where the syntax error is. Fix the syntax error and save the file to make breakpoints valid.

### Function Alternative for Setting Breakpoints

To set a breakpoint using the debugging functions, use `dbstop`. For the example, type:

```

dbstop in collatzplot at 9
dbstop in collatzplot at 10
dbstop in collatzplot at 11

```

### Run a File with Breakpoints

After setting breakpoints, run the file from the Command Window or the Editor.



## Run the Example

For the example, run `collatzplot` for the simple input value, 3, by typing the following in the Command Window:

```
collatzplot(3)
```

The example, `collatzplot`, requires an input argument and therefore runs only from the Command Window or from the input value(s) specified on the **Run** ▾ drop-down list on the **Editor** tab.

## Results of Running a File Containing Breakpoints



Running the file results in the following:

- The prompt in the Command Window changes to

```
K>>
```

indicating that MATLAB is in debug mode.

- The program pauses at the first breakpoint. This means that line will be executed when you continue. The pause is indicated in the Editor by the green arrow just to the right of the breakpoint. In the example, the pause is at line 9 of `collatzplot`, as shown here:

```
9   | | plot_seq = collatz(N);
```

The line at which you are paused displays in the Command Window. For the example:

```
9 plot_seq = collatz(N);
```

- The function the **Function Call Stack** field displays on the **Editor** tab changes to reflect the current function (sometimes referred to as the caller or calling workspace). The call stack includes local functions as well as called functions. If you use debugging functions from the Command Window, use `dbstack` to view the current call stack.
- If the file you are running is not in the current folder or a folder on the search path, you are prompted to either add the folder to the path or change the current folder.




In debug mode, you can set breakpoints, step through programs, examine variables, and run other functions.

MATLAB software could become nonresponsive if it stops at a breakpoint while displaying a modal dialog box or figure that your file creates. In that event, press **Ctrl+C** to go to the MATLAB prompt.





## Step Through a File



While debugging, you can step through a MATLAB file, pausing at points where you want to examine values.

Use any of the following methods:


- Click  **Step**,  **Step In**,  **Step Out** in **Editor** tab.
- Use the `dbstep` or `dbcont` function

Details about these debugging buttons appear in the following table.


Toolbar Button	Debug Menu Item	Description	Function Alternative
	<b>Run to Cursor</b>	Continue execution of file until the line where the cursor is positioned. Also available on the context menu.	None
	<b>Step</b>	Execute the current line of the file.	<code>dbstep</code>
	<b>Step In</b>	Execute the current line of the file and, if the line is a call to another function, step into that function.	<code>dbstep in</code>
	<b>Continue</b>	Resume execution of file until completion or until another breakpoint is encountered.	<code>dbcont</code>


Toolbar Button	Debug Menu Item	Description	Function Alternative
	Step Out	After stepping in, run the rest of the called function or local function, leave the called function, and pause.	dbstep out
	Quit Debugging	Exit debug mode.	dbquit out

### Continue Running in the Example

In the example, `collatzplot` is paused at line 9. Because the problem results are correct for  $N/n = 1$ , continue running until  $N/n = 2$ . Click  **Continue** three times to move through the breakpoints at lines 9, 10, and 11. Now the program is again paused at the breakpoint at line 9.

### Step into the Called Function in the Example

Now that `collatzplot` is paused at line 9 during the second iteration, click  **Step In** or type `dbstep in` in the Command Window to step into `collatz` and walk through that file. Stepping into line 9 of `collatzplot` goes to line 9 of `collatz`. If `collatz` is not open in the Editor, it automatically opens if you have selected **Automatically open files when MATLAB reaches a breakpoint** in the Preference dialog box.

The pause indicator at line 9 of `collatzplot` changes to a hollow arrow , indicating that MATLAB control is now in a local function called from the main program. The call stack shows that the current function is now `collatz`.

In the called function, `collatz` in the example, you can do the same things you can do in the main (calling) function—set breakpoints, run, step through, and examine values.

### Examine Values

While the program is paused, you can view the value of any variable currently in the workspace. Examine values when you want to see whether a line of code has produced the expected result or not. If the result is as expected,

continue running or step to the next line. If the result is not as you expect, then that line, or a previous line, contains an error. Use the following methods to examine values:

- “Select the Workspace” on page 19-12
- “View Values as Data Tips in the Editor” on page 19-13
- “View Values in the Command Window” on page 19-13
- “View Values in the Workspace Browser and Variables Editor” on page 19-14
- “Evaluate a Selection” on page 19-15
- “Examine Values in the Example” on page 19-15
- “Problems Viewing Variable Values from the Parent Workspace” on page 19-16

Many of these methods are used in “Examine Values in the Example” on page 19-15.

### Select the Workspace

Variables assigned through the Command Window and created using scripts are considered to be in the base workspace. Variables created in a function belong to their own function workspace. To examine a variable, you must first select its workspace. When you run a program, the current workspace is shown in the **Function Call Stack** field. To examine values that are part of another workspace for a currently running function or for the base workspace, first select that workspace from the list in the **Function Call Stack** field.


If you use debugging functions from the Command Window:

- To display the call stack, use `dbstack`.
- To change to a different workspace, use `dbup` and `dbdown`.
- To list the variables in the current workspace, use `who` or `whos`.

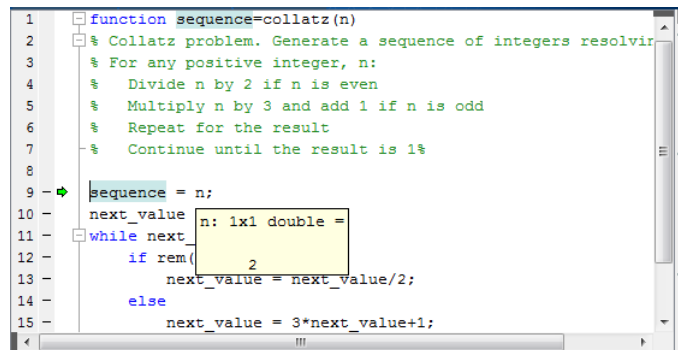
**Workspace in the Example.** At line 9 of `collatzplot`, you stepped in, and the current line is 9 in `collatz`. The **Function Call Stack** field shows that `collatz` is the current workspace.

## View Values as Data Tips in the Editor

To view the current value of a variable in the Editor, first enable datatips, then use the mouse to display a datatip:

- 1 On the **Home** tab, in the **Environment** section, click  **Preferences**, and select **MATLAB > Editor/Debugger > Display**.
- 2 Select **Enable datatips in edit mode** under **General display options**.
- 3 In the Editor, position the mouse pointer to the left of a variable.

The variable's current value appears in a data tip. The data tip stays in view until you move the pointer. If you have trouble getting the data tip to appear, click in the line containing the variable, and then move the pointer next to the variable.



```

1  function sequence=collatz(n)
2  % Collatz problem. Generate a sequence of integers resolving
3  % For any positive integer, n:
4  %   Divide n by 2 if n is even
5  %   Multiply n by 3 and add 1 if n is odd
6  %   Repeat for the result
7  %   Continue until the result is 1%
8
9  sequence = n;
10 next_value = n;
11 while next_value > 1
12     if rem(next_value, 2) == 0
13         next_value = next_value/2;
14     else
15         next_value = 3*next_value+1;

```

## View Values in the Command Window

You can examine values while in debug mode at the `K>>` prompt. To see the variables currently in the workspace, use `who`. Type a variable name in the Command Window and it displays the variable's current value. For the example, to see the value of `n`, type

```
n
```

The Command Window displays the expected result

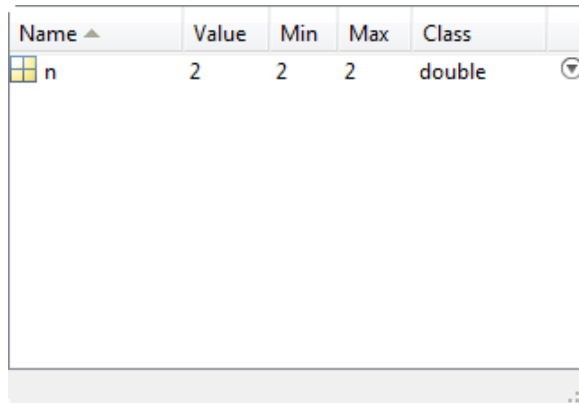
```
n =
```


2

and displays the debug prompt, `K>>`.

### View Values in the Workspace Browser and Variables Editor

You can view the value of variables in the **Value** column of the Workspace browser. The Workspace browser displays all variables in the current workspace. To change to another workspace and view its variables, use **Function Call Stack** drop-down list on the **Editor** tab, in the **Debug** section.



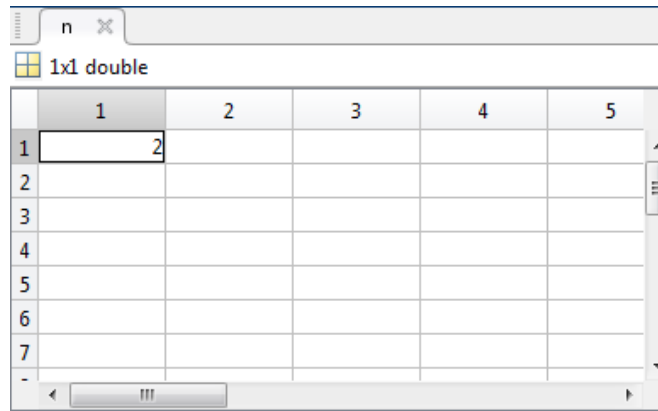
Name ▲	Value	Min	Max	Class	
 n	2	2	2	double	▼

The **Value** column does not show all details for all variables. To see details, double-click a variable in the Workspace browser. The Variables Editor opens, displaying the content for that variable. You can open the Variables Editor directly for a variable using `openvar`.

To see the value of `n` in the Variables Editor for the example, type

```
openvar n
```

and the Variables Editor opens, showing that `n = 1` as expected.



The image shows a MATLAB Command Window with a single variable 'n' of type 'double' and size '1x1'. The value of 'n' is 2. The window is displayed as a grid with 5 columns and 7 rows. The first row contains the values 1, 2, 3, 4, and 5. The second row contains the value 2 in the first column, and the rest of the cells are empty. The rest of the grid is empty.

	1	2	3	4	5
1	2				
2					
3					
4					
5					
6					
7					

## Evaluate a Selection

Select a variable or equation in a MATLAB file in the Editor. Right-click and select **Evaluate Selection** from the context menu (for a single-button mouse, press **Ctrl+click**). The Command Window displays the value of the variable or equation. You cannot evaluate a selection while MATLAB is busy, for example, running a file.

## Examine Values in the Example

Step from line 9 through line 13 in `collatz`. Step again, and the pause indicator jumps to line 17, just after the `if` loop, as expected. Step again, to line 18, check the value of `sequence` in line 17 and see that the array is

```
2 1
```

as expected for  $n = 2$ . Step again, which moves the pause indicator from line 18 to line 11. At line 11, step again. Because `next_value` is now 1, the `while` loop ends. The pause indicator is at line 11 and appears as a green down arrow  $\blacktriangledown$ . This indicates that processing in the called function is complete and program control will return to the calling program. Step again from line 11 in `collatz` and execution is now paused at line 9 in `collatzplot`.

Note that instead of stepping through `collatz`, the called function, as was just done in this example, you can step out from a called function back to the calling function, which automatically runs the rest of the called function and

returns to the next line in the calling function. To step out, use the Step Out button or type `dbstep out` in the Command Window.

In `collatzplot`, step again to advance to line 10, and then to line 11. The variable `seq_length` in line 10 is a vector with the elements:

```
1 2
```

which is correct.

Finally, step again to advance to line 12. Examining the values in line 11, `N = 2` as expected, but the second variable, `plot_seq`, has two values, where only one value is expected. While the value for `plot_seq` is as expected:

```
2 1
```

it is the incorrect variable for plotting. Instead, `seq_length(N)` should be plotted.

### Problems Viewing Variable Values from the Parent Workspace

*Sometimes*, if you set a breakpoint in a function, and then attempt to view the value of a variable in the parent workspace using the `dbup` command, the value of the variable is currently under construction. Therefore, the value is not available. This is true whether you view the value by specifying the `dbup` command in the Command Window or by using the **Function Call Stack** field on the **Editor** tab.

In such cases, MATLAB returns the following message, where *x* is the variable for which you are trying to examine the value:

```
K>> x  
Reference to a called function result under construction x.
```

For example, suppose you have code such as the following:

```
x = collatz(x);
```

MATLAB detects that the evaluation of `collatz(x)` replaces the input variable, *x*. To optimize memory use, MATLAB overwrites the memory that *x* currently occupies to hold a new value for *x*. When you request the value



of  $x$ , and it is under construction, its value is not available, and MATLAB displays the error message.

## Correct Problems and End Debugging

The following are some of the ways to correct problems and end the debugging session:

- “Change Values and Check Results” on page 19-17
- “End Debugging” on page 19-17
- “Disable and Clear Breakpoints” on page 19-18
- “Save Breakpoints” on page 19-20
- “Correct Problems in a MATLAB File” on page 19-20
- “Complete the Example” on page 19-21
- “Run Parts in MATLAB Files That Have Unsaved Changes” on page 19-23

“Complete the Example” on page 19-21 uses many of these features.

## Change Values and Check Results

While debugging, you can change the value of a variable in the current workspace to see if the new value produces expected results. While the program is paused, assign a new value to the variable in the Command Window, Workspace browser, or Variables Editor. Then continue running or stepping through the program. If the new value does not produce the expected results, the program has a different problem.

## End Debugging


After identifying a problem, end the debugging session. You must end a debugging session if you want to change and save a file to correct a problem, or if you want to run other functions in MATLAB.

---

**Note** Quit debug mode before editing a file. If you edit a file while in debug mode, you can get unexpected results when you run the file. If you do edit a file while in debug mode, breakpoints turn gray, indicating that results might not be reliable. See “Valid (Red) and Invalid (Gray) Breakpoints” on page 19-8 for details.

If you attempt to save an edited file while in debug mode, a dialog box opens allowing you to exit debug mode and save the file.

---

To end debugging, click  **Quit Debugging**, or use the function `dbquit`.


After quitting debugging, pause indicators in the Editor display no longer appear, and the normal prompt `>>` appears in the Command Window instead of the debugging prompt, `K>>`. You can no longer access the call stack.

## Disable and Clear Breakpoints


Disable a breakpoint to ignore it temporarily. Clear a breakpoint to remove it.

**Disable and Enable Breakpoints.** You can disable selected breakpoints so the program temporarily ignores them and runs uninterrupted, for example, after you think you identified and corrected a problem. This is especially useful for conditional breakpoints—see “Conditional Breakpoints” on page 19-24.

To disable a breakpoint, do one of the following:

- Right-click the breakpoint icon, and select **Disable Breakpoint** from the context menu.
- Place your cursor anywhere in a breakpoint line. Click  **Breakpoints**, and select **Enable/Disable** from the drop-down list.

To disable a conditional breakpoint, use either of the methods in the preceding list. An **X** appears through the breakpoint icon as shown here.


```
9  plot_seq = collatz(N);
```

When you run `dbstatus`, the resulting message for a disabled breakpoint is

```
Breakpoint on line 9 has conditional expression 'false'.
```

After disabling a breakpoint, you can re-enable it to make it active again or you can clear it.


To re-enable a breakpoint, do either of the following:

- Right-click the breakpoint icon and select **Enable Breakpoint** from the context menu.
- Place your cursor anywhere in a breakpoint line. Click  **Breakpoints**, and select **Enable/Disable** from the drop-down list.

The X no longer appears on the breakpoint icon and program execution will pause at that line.


**Clear (Remove) Breakpoints.** All breakpoints remain in a file until you clear (remove) them or until they are cleared automatically. Clear a breakpoint after determining that a line of code is not causing a problem.

To clear a breakpoint in the Editor:

- Right-click the breakpoint icon and select **Clear Breakpoint** from the context menu.
- Place your cursor anywhere in a breakpoint line. Click  **Breakpoints**, and select **Set/Clear** from the drop-down list.
- Use the `dbclear in file at lineno` command in the Command Window. For the example, clear the breakpoint at line 9 in `collatzplot` by typing:

```
dbclear in collatzplot at 9
```

To clear all breakpoints in all files:

- Place your cursor anywhere in a breakpoint line. Click  **Breakpoints**, and select **Clear All** from the drop-down list.
- Use `dbclear all` in the Command Window.

For the example, clear all of the breakpoints in `collatzplot` by typing:

```
dbclear all in collatzplot
```

Breakpoints clear automatically when you:

- End the MATLAB session.
- Clear the file using `clear name` or `clear all`.

---

**Note** When `clear name` or `clear all` is in a statement in a file that you are debugging, it clears the breakpoints.

---

### Save Breakpoints

You can use the `s=dbstatus` syntax and then save `s` to save the current breakpoints to a MAT-file. At a later time, you can load `s` and restore the breakpoints using `dbstop(s)`. For more information, including an example, see the `dbstatus` reference page.

### Correct Problems in a MATLAB File

To correct a problem in a MATLAB file:

- 1 Quit debugging.


Do not modify a file while MATLAB is in debug mode. If you do, breakpoints turn gray, indicating that results might not be reliable. See “Valid (Red) and Invalid (Gray) Breakpoints” on page 19-8 for details.

- 2 Modify the file.
- 3 Save the file.

- 4 Set, disable, or clear breakpoints, as appropriate.
- 5 Run the file again to be sure that it produces the expected results.

### Complete the Example

To correct the problem in the example:

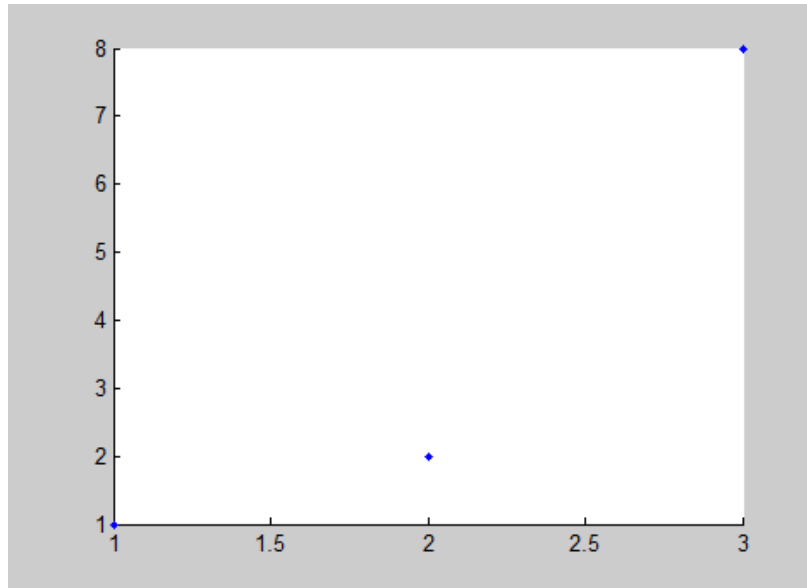
- 1 End the debugging session. One way to do this is to click  **Quit Debugging**
- 2 In `collatzplot.m` line 11, change the string `plot_seq` to `seq_length(N)` and save the file.
- 3 Clear the breakpoints in `collatzplot.m`. One way to do this is by typing  

```
dbclear all in collatzplot
```

  
in the Command Window.
- 4 Run `collatzplot` for `m = 3` by typing  

```
collatzplot(3)
```

  
in the Command Window.
- 5 Verify the result. The figure shows that the length of the Collatz series is 1 when  $n = 1$ , 2 when  $n = 2$ , and 8 when  $n = 3$ , as expected.



- 6 Test the function for a slightly larger value of  $m$ , such as 6, to be sure that the results are still accurate. To make it easier to verify `collatzplot` for  $m = 6$  as well as the results for `collatz`, add this line at the end of `collatz.m`

```
sequence
```

which displays the series in the Command Window. The results for when  $n = 6$  are

```
sequence =
```

```
6     3    10     5    16     8     4     2     1
```

Then run `collatzplot` for  $m = 6$  by typing

```
collatzplot(6)
```

- 7 To make debugging easier, you ran `collatzplot` for a small value of  $m$ . Now that you know it works correctly, run `collatzplot` for a larger value to produce more interesting results. Before doing so, you consider disabling

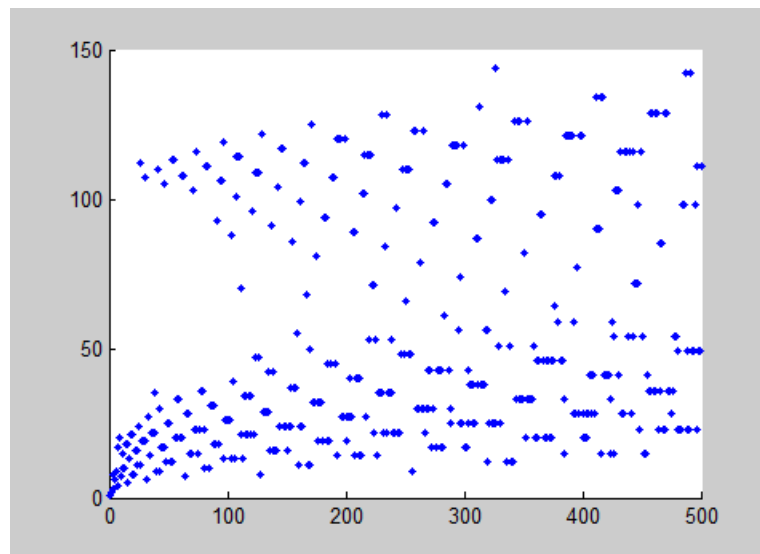
output for the line you just added in step 6, line 19 of `collatz.m`, by adding a semicolon to the end of the line so it appears as

```
sequence;
```

Then run

```
collatzplot(500)
```

The following figure shows the lengths of the Collatz series for  $n = 1$  through  $n = 500$ .



### Run Parts in MATLAB Files That Have Unsaved Changes

It is a good practice to modify a MATLAB file after you quit debugging, and then save the modification and run the file. Otherwise, you might get unexpected results. However, there are situations where you want to experiment during debugging. Perhaps you want to modify a part of the file that has not yet run, and then run the remainder of the file without saving the change. Follow these steps:

- 1 While stopped at a breakpoint, modify a part of the file that has not yet run.

Breakpoints turn gray, indicating they are invalid.

- 2 Select all of the code after the breakpoint, right-click, and then select **Evaluate Selection** from the context menu.

You can also use code sections to do this.


## Conditional Breakpoints

Set conditional breakpoints to cause MATLAB to stop at a specified line in a file only when the specified condition is met. One particularly good use for conditional breakpoints is when you want to examine results after a certain number of iterations in a loop. For example, set a breakpoint at line 10 in `collatzplot`, specifying that MATLAB stop only if `N` is greater than or equal to 2. This section covers the following topics:

- “Set Conditional Breakpoints” on page 19-24
- “Modify, Disable, or Clear Conditional Breakpoints” on page 19-25
- “Function Alternatives for Manipulating Conditional Breakpoints” on page 19-25

### Set Conditional Breakpoints

To set a conditional breakpoint:

- 1 Click in the line where you want to set the conditional breakpoint.
- 2 Click  **Breakpoints** on the **Editor** tab, and select **Set Condition**. If a standard breakpoint exists at that line, use this same method to make it conditional.

The MATLAB Editor conditional breakpoint dialog box opens.

- 3 Type a condition in the dialog box, where a condition is any valid MATLAB expression that returns a logical scalar value. Click **OK**. As noted in the dialog box, the condition is evaluated before running the line. For the example, at line 9 in `collatzplot`, enter the following as the condition:

```
N>=2
```



A yellow breakpoint icon (indicating the breakpoint is conditional) appears in the breakpoint alley at that line.

When you run the file, MATLAB software enters debug mode and pauses at the line only when the condition is met. In the `collatzplot` example, MATLAB runs through the `for` loop once and pauses on the second iteration at line 9 when `N` is 2. If you continue executing, MATLAB pauses again at line 9 on the third iteration when `N` is 3.

### Modify, Disable, or Clear Conditional Breakpoints

The following table describes how to adjust conditional breakpoints.

To	Do This
Modify a condition for a breakpoint in the current line.	Right-click the conditional breakpoint icon, and then from the context menu, select <b>Set/Modify Condition</b> .
Disable a conditional breakpoint.	Click the associated conditional breakpoint icon.
Clear a conditional breakpoint.	Double-click the associated conditional breakpoint icon.

### Function Alternatives for Manipulating Conditional Breakpoints

The following table lists the functions available for adjusting conditional breakpoints from the Command Window.

To	Use This Function
Set a conditional breakpoint.	<code>dbstop</code>
Clear a conditional breakpoint.	<code>dbclear</code>
View a list of currently set breakpoints, including the conditional expression for each conditional breakpoint.	<code>dbstatus</code>

## Breakpoints in Anonymous Functions

You can set multiple breakpoints in a line of MATLAB code that contains anonymous functions. You can do both of the following:

- Set a breakpoint for the line itself (MATLAB software pauses at the start of the line).
- Set a breakpoint for each anonymous function in that line.

When you add a breakpoint to a line containing an anonymous function, the Editor asks where in the line you want to add the breakpoint. If there is more than one breakpoint in a line, the breakpoint icon is blue, regardless of the status of any of the breakpoints on the line.

To display information in a tooltip about all breakpoints on a line, position the pointer on the blue icon.

To perform a breakpoint action for a line that can contain multiple breakpoints, such as **Clear Breakpoint**, right-click the breakpoint alley at that line, and then select the action.

When you set a breakpoint in an anonymous function, MATLAB pauses when the anonymous function is called.

The following illustration shows the Editor when you set a breakpoint in the anonymous function `sqr` in line 2, and then run the file. When you run the file, MATLAB pauses each time that the anonymous function `sqr` executes. The green arrow shows where the code defines `sqr`. The white arrow, on line 5, indicates where the code calls `sqr`.

```

1 function c = pythag(a,b)
2   |   sqr = @(x) x.^2;
3   |   disp(a)
4   |   disp(b)
5   |   c = sqrt(sqr(a) + sqr(b));
6   |   end

```

pythag.m x

Ln 2 Col 1 OVR

## Breakpoints in Methods That Overload Functions

MATLAB functions often call other MATLAB functions and methods to perform their operations. If you set a breakpoint in a class method, and then run a MATLAB function that results in calling that method, execution stops at the breakpoint. This behavior can be confusing if you are unaware that the MATLAB function calls the method containing the breakpoint.

For instance, suppose you do the following:

- 1 Define a class named `MyClass` that overloads the MATLAB `size` function.
- 2 Create an instance of `MyClass`.
- 3 Insert breakpoints within the `MyClass` `size` method.
- 4 Call `whos`.

When you call the `whos` function, it calls the `size` function to obtain size information about the variables in the workspace. Under the preceding circumstances, because `MyClass` overloads the `size` function, `whos` calls the `MyClass` `size` method instead of the default `size` function to determine the size of the `MyClass` object. Execution stops at the breakpoint you set in the `size` method. You can enable the MATLAB function to execute to completion by either stepping or continuing through the method. To prevent this behavior from recurring, remove the breakpoints.


## Error Breakpoints

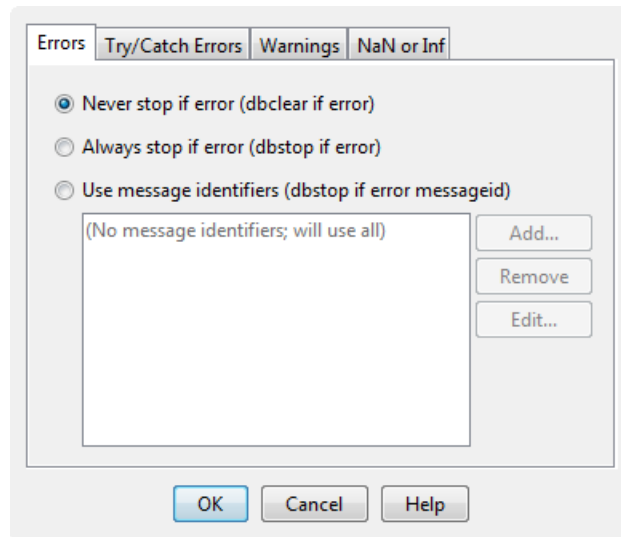
Set error breakpoints to stop program execution and enter debug mode when MATLAB encounters a problem. Unlike standard and conditional breakpoints, you do not set these breakpoints at a specific line in a specific file. Rather, once set, MATLAB stops at any line in any file when the error condition specified by using the error breakpoint occurs. MATLAB then enters debug mode and opens the file containing the error, with the pause indicator at the line containing the error. Files open only when you select **Automatically open file when MATLAB reaches a breakpoint** under **MATLAB > Editor/Debugger** in the Preferences dialog box. Error breakpoints remain in effect until you clear them or until you end the MATLAB session. This section covers the following topics:

- “Set and Clear Error Breakpoints” on page 19-28
- “Error Breakpoint Types and Options” on page 19-29
- “Examples of Setting Warning and Error Breakpoints” on page 19-30
- “Function Alternative for Manipulating Error Breakpoints” on page 19-32

## Set and Clear Error Breakpoints

To set error breakpoints:

- 1 On the Editor tab, in the Breakpoints section, click  **Breakpoints**.
- 2 Select:
  - **Stop on Errors** to stop on all errors.
  - **Stop on Warnings** to stop on all warnings.
  - **More Error and Warning Handling Options** for additional options. This opens the Stop if Errors/Warnings for All Files dialog box



To clear error breakpoints, select the **Never stop if ...** option for all appropriate tabs, and then click **OK**.

## Error Breakpoint Types and Options

As the tabs in the Stop if Errors/Warnings for All Files dialog box suggest, there are four basic types of error breakpoints you can set:

- **Errors**

When an error occurs, execution stops, unless the error is in a `try...catch` block. MATLAB enters debug mode and opens the file to the line in the `try` portion of the block that produced the error. You cannot resume execution.

- **Try/Catch Errors**

When an error occurs in a `try...catch` block, execution pauses. MATLAB enters debug mode and opens the file to the line that produced the error. You can resume execution or use debugging features.

- **Warnings**

When a warning occurs, MATLAB pauses, enters debug mode, and opens the file, paused at the line that produced the warning. You can resume execution or use debugging features.

- **NaN or Inf**

When an operator, function call, or scalar assignment produces a NaN (not-a-number) or Inf (infinite) value, MATLAB pauses, enters debug mode, and opens the file. MATLAB pauses immediately after the line that encountered the value. You can resume execution or use debugging features.

Select options for these error breakpoints:

- Click **Never stop...** on a tab to clear that type of breakpoint.
- Click **Always stop...** on a tab to set that type of breakpoint.
- Select **Use message identifiers...** on a tab to limit each type of error breakpoint (except NaN or Inf). Execution stops only for the error you specify by the corresponding message identifier.

This option is not available for the **NaN or Inf** type of error breakpoint. You can add multiple message identifiers, and edit or remove them.

## **Examples of Setting Warning and Error Breakpoints**

**Pausing Executing for Warnings.** To pause execution when MATLAB produces a warning:

- 1** Click the **Warnings** tab.
- 2** Click **Always stop if warning**, and then click **OK**.

Now, when you run a file and MATLAB produces a warning, execution pauses and MATLAB enters debug mode. The file opens in the Editor at the line that produced the warning.

**Set Breakpoints for a Specific Error.** To stop execution for a specific error add a message identifier:

- 1 Click the **Errors, Try/Catch Errors, or Warnings** tab.
- 2 Click **Use Message Identifiers**.
- 3 Click **Add**.
- 4 In the resulting Add Message Identifier dialog box, type the message identifier of the error for which you want to stop. The identifier is of the form `component:message` (for example, `MATLAB:narginchk:notEnoughInputs`). Then click **OK**.

The message identifier you specified appears in the Stop if Errors/Warnings for All Files dialog box.

- 5 Click **OK**.

**Obtain Error Message Identifiers.** To obtain an error message identifier generated by a MATLAB function, run the function to produce the error, and then call `MException.last`. For example:

```
surf
MException.last
```

The Command Window displays the `MException` object, including the error message identifier in the `identifier` field. For this example, it displays:

```
ans =

MException

Properties:
  identifier: 'MATLAB:narginchk:notEnoughInputs'
  message: 'Not enough input arguments.'
  cause: {}
  stack: [1x1 struct]
```

Methods

**Obtain Warning Message Identifiers.** To obtain a warning message identifier generated by a MATLAB function, run the function to produce the warning. Then, run:

```
[m,id] = lastwarn
```

MATLAB returns the last warning identifier to `id`. An example of a warning message identifier is `MATLAB:concatenation:integerInteraction`.

### **Function Alternative for Manipulating Error Breakpoints**

The function equivalent for each option in the Stop if Errors/Warnings for All Files dialog box, appears to the right of each option. For example, the function equivalent for **Always stop if error** is `dbstop if error`. Use these functions in the Command Window as listed in the following table.

<b>To</b>	<b>Use This Function</b>
Set error breakpoints.	<code>dbstop</code>
Clear error breakpoints.	<code>dbc clear</code>
View a list of currently set breakpoints, including the condition and message identifier for each error breakpoint.	<code>dbstatus</code>



# Presenting MATLAB Code

---

MATLAB software enables you to present your MATLAB code in various ways. You can share your code and results with others, even if they do not have MATLAB software. You can save MATLAB output in various formats, including HTML, XML, and LaTeX. If Microsoft Word or Microsoft PowerPoint® applications are on your Microsoft Windows system, you can publish to their formats as well.

- “Options for Presenting Your Code” on page 20-2
- “Document and Share Code Using Examples” on page 20-4
- “Publishing MATLAB Code” on page 20-6
- “Publishing Markup” on page 20-8
- “Output Preferences for Publishing” on page 20-29
- “Create a MATLAB Notebook with Microsoft Word” on page 20-45

## Options for Presenting Your Code

MATLAB provides options for presenting your code to others.

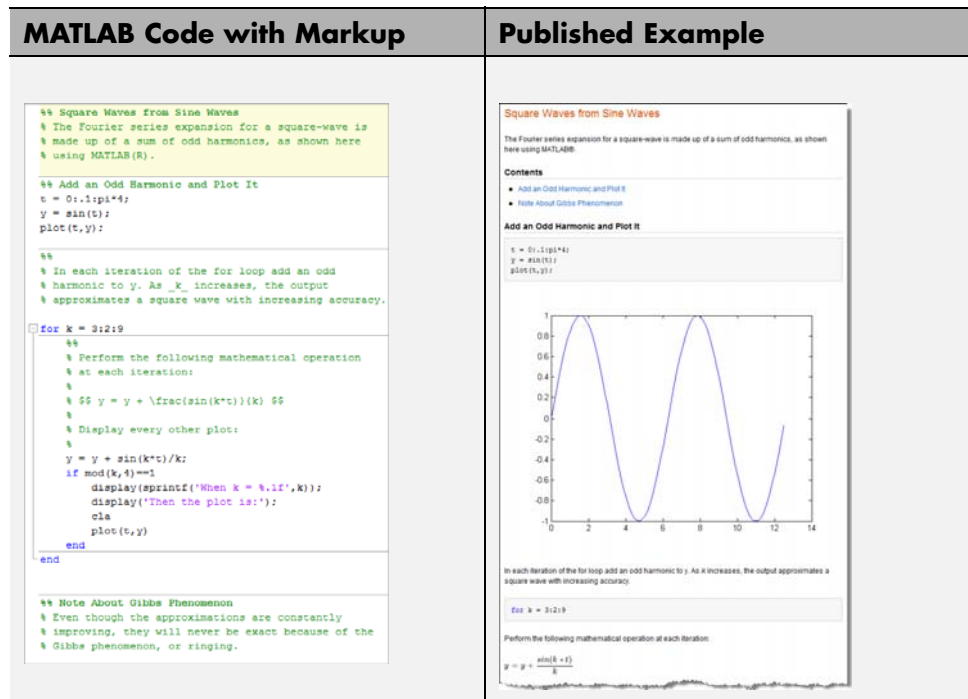
Method	Description	Output Formats	Details
Command line help	Use comments at the start of a MATLAB file to display help comments when you type <code>help file_name</code> in the Command Window.	<ul style="list-style-type: none"> <li>• ASCII text</li> </ul>	“Add Help for Your Program” on page 17-5
Publish	Use comments with basic markup to publish a document that includes text, bulleted or numbered lists, MATLAB code, and code results.	<ul style="list-style-type: none"> <li>• XML</li> <li>• HTML</li> <li>• LaTeX</li> <li>• Microsoft Word (.doc/.docx)</li> <li>• Microsoft PowerPoint (ppt)</li> <li>• PDF</li> </ul>	“Publishing MATLAB Code” on page 20-6  Publishing MATLAB Code from the Editor video
Help Browser Topics	Create HTML and XML files to provide your own MATLAB help topics for viewing from the MATLAB Help browser or the Web.	<ul style="list-style-type: none"> <li>• HTML</li> </ul>	“Display Custom Documentation” on page 27-16
Notebook	Use Microsoft Word to create electronic or printed records of MATLAB sessions for class notes, textbooks or technical reports.	<ul style="list-style-type: none"> <li>• Microsoft Word (.doc/.docx)</li> </ul>	“Create a MATLAB Notebook with Microsoft Word” on page 20-45

Method	Description	Output Formats	Details
	You must have Microsoft Word software installed.		
MATLAB Report Generator™	Use MATLAB Report Generator to build complex reports. You must have MATLAB Report Generator software installed.	<ul style="list-style-type: none"><li>• RTF</li><li>• PDF</li><li>• Word</li><li>• HTML</li><li>• XML</li></ul>	MATLAB Report Generator

## Document and Share Code Using Examples

An *example* is a readable version of a MATLAB code file that shows how to solve a particular problem. MATLAB and all MATLAB toolboxes include examples. You also can create your own examples from your source code files. Creating an example enables you to clearly document the steps of a task, because examples combine comments, code, and output together in a formatted document.

For instance, the code in the following figure demonstrates the Fourier series expansion for a square wave. When published, the example includes the explanatory text, code, and output.



To create an example:

- 1 Create a MATLAB script or function. Divide the code into steps or sections by inserting two percent signs (%%) at the beginning of each section.

- 2** Document the code by adding explanatory comments at the beginning of the file and within each section.

Within the comments at the top of each section, you can add markup that enhances the readability of the output. For example, the code in the preceding table includes the following markup.

Titles	%% Square Waves from Sine Waves %% Add an Odd Harmonic and Plot It %% Note About Gibbs Phenomenon
Variable name in italics	% As <i>_k_</i> increases, ...
LaTeX equation	% $y = y + \frac{\sin(k*t)}{k}$

- 3** Publish the code. On the **Publish** tab, click **Publish**.

By default, MATLAB creates a subfolder named `html`, which contains an HTML file and files for each graphic that your code creates. The HTML file includes the code, formatted comments, and output. Alternatively, you can publish to other formats, such as PDF files or Microsoft PowerPoint presentations.

To share published examples with others in the MATLAB community, submit them to the File Exchange. Include the original `.m` file and the `html` subfolder.

## See Also

`publish`

## Concepts

- “MATLAB Code Examples”
- “Publishing Markup” on page 20-8
- “Output Preferences for Publishing” on page 20-29

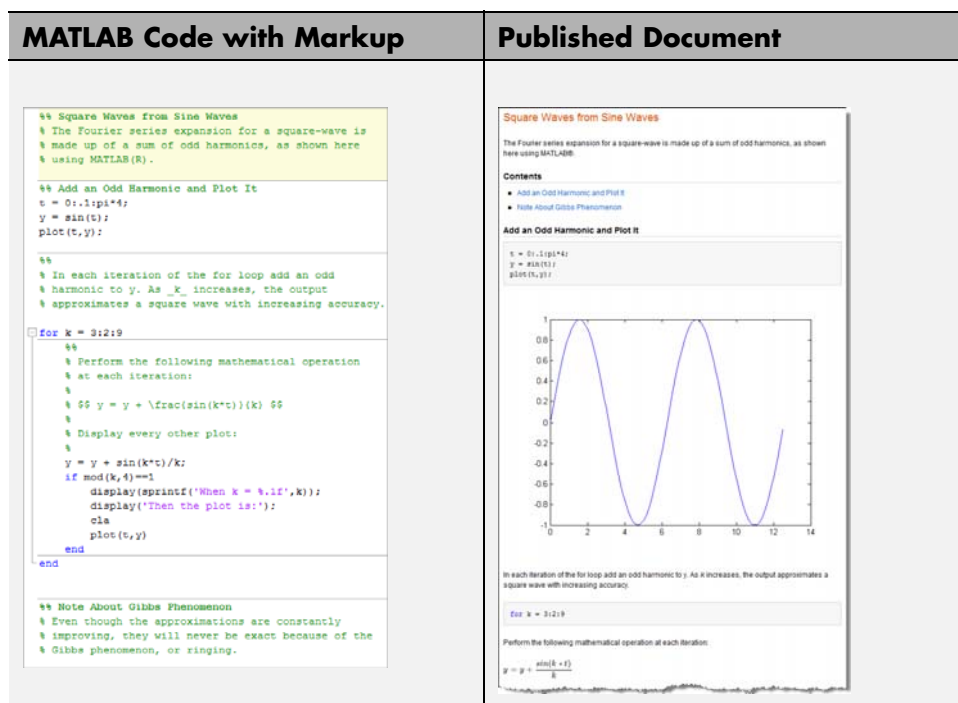
## External Web Sites

- File Exchange

## Publishing MATLAB Code

*Publishing* creates a formatted document that includes your code, comments, and output. Common reasons to publish code are to share the documents with others for teaching or demonstration, or to generate readable, external documentation of your code.

For instance, the code in the following figure demonstrates the Fourier series expansion for a square wave.



To publish your code:

- 1 Create a MATLAB script or function. Divide the code into steps or sections by inserting two percent signs (%%) at the beginning of each section.
- 2 Document the code by adding explanatory comments at the beginning of the file and within each section.

Within the comments at the top of each section, you can add markup that enhances the readability of the output. For example, the code in the preceding table includes the following markup.

Titles	%% Square Waves from Sine Waves %% Add an Odd Harmonic and Plot It %% Note About Gibbs Phenomenon
Variable name in italics	% As <i>_k_</i> increases, ...
LaTeX equation	% \$\$ y = y + \frac{\sin(k*t)}{k} \$\$

**3** Publish the code. On the **Publish** tab, click **Publish**.

By default, MATLAB creates a subfolder named `html`, which contains an HTML file and files for each graphic that your code creates. The HTML file includes the code, formatted comments, and output. Alternatively, you can publish to other formats, such as PDF files or Microsoft PowerPoint presentations.

The sample code that appears in the previous figure is part of the installed documentation. You can view the code in the Editor by running this command:

```
edit(fullfile(matlabroot, 'help', 'techdoc', 'matlab_env', ...
              'examples', 'fourier_demo2.m'))
```

## See Also

`publish`

## Concepts

- “Publishing Markup” on page 20-8
- “Output Preferences for Publishing” on page 20-29

## Publishing Markup

In this section...
“Markup Overview” on page 20-8
“Sections and Section Titles” on page 20-11
“Text Formatting” on page 20-13
“Bulleted and Numbered Lists” on page 20-14
“Text and Code Blocks” on page 20-15
“External Graphics” on page 20-16
“Image Snapshot” on page 20-19
“LaTeX Equations” on page 20-20
“Hyperlinks” on page 20-22
“HTML Markup” on page 20-25
“LaTeX Markup” on page 20-26

### Markup Overview

This section describes how to mark up your MATLAB files so that the code appears polished when publishing. You can single-source your MATLAB code with documentation that describes its purpose.

You insert markup three different ways:

- Use the formatting buttons and drop-down menus on the **Publish** tab to format the file. This method automatically inserts the text markup for you.
- Select markup from the **Insert Text Markup** list in the right click menu.
- Type the markup directly in the comments.

The following table provides a summary of the text markup options. Refer to this table if you are not using the MATLAB Editor, or if you do not want to use the **Publish** tab to apply the markup.



---

**Note** When working with markup:

- Spaces following the comment symbols (%) often determine the format of the texts that follows.
  - Starting new markup often requires preceding blank comment lines, as shown in examples.
  - Markup only works in comments that immediately follow a section break.
- 

Result in Output	Example of Corresponding File Markup
“Sections and Section Titles” on page 20-11	<pre> %% SECTION TITLE % DESCRIPTIVE TEXT  %%% SECTION TITLE WITHOUT SECTION BREAK % DESCRIPTIVE TEXT </pre>
“Text Formatting” on page 20-13	<pre> % _ITALIC TEXT_  % *BOLD TEXT*  %  MONOSPACED TEXT   % Trademarks: % TEXT(TM)  % TEXT(R) </pre>

<b>Result in Output</b>	<b>Example of Corresponding File Markup</b>
<p>“Bulleted and Numbered Lists” on page 20-14</p>	<pre>%% Bulleted List % % * BULLETED ITEM 1 % * BULLETED ITEM 2 %  %% Numbered List % % # NUMBERED ITEM 1 % # NUMBERED ITEM 2 %</pre>
<p>“Text and Code Blocks” on page 20-15</p>	<pre>%% % %   PREFORMATTED %   TEXT %  %% MATLAB(R) Code % %   for i = 1:10 %       disp x %   end %</pre>
<p>“External Graphics” on page 20-16</p>	<pre>% % &lt;&lt;FILENAME.PNG&gt;&gt; %</pre>
<p>“Image Snapshot” on page 20-19</p>	<pre>snapnow;</pre>

Result in Output	Example of Corresponding File Markup
“LaTeX Equations” on page 20-20	<pre>%% Inline Expression % \$x^2+e^{\pi i}\$  %% Block Equation % \$\$e^{\pi i} + 1 = 0\$\$</pre>
“Hyperlinks” on page 20-22	<pre>% &lt;http://www.mathworks.com MathWorks&gt;  % &lt;matlab:FUNCTION DISPLAYED_TEXT&gt;</pre>
“HTML Markup” on page 20-25	<pre>% % &lt;html&gt; % &lt;table border=1&gt;&lt;tr&gt; % &lt;td&gt;one&lt;/td&gt; % &lt;td&gt;two&lt;/td&gt;&lt;/tr&gt;&lt;/table&gt; % &lt;/html&gt; %</pre>
“LaTeX Markup” on page 20-26	<pre>%% LaTeX Markup Example % &lt;latex&gt; % \begin{tabular}{ r r } % \hline \$n\$&amp;\$n!\$\\ % \hline 1&amp;1\\ 2&amp;2\\ 3&amp;6\\ % \hline % \end{tabular} % &lt;/latex&gt; %</pre>

## Sections and Section Titles

Code sections allow you to organize, add comments, and execute portions of your code. Code sections begin with double percent signs (%) followed by an optional section title. The section title displays as a top-level heading (h1 in HTML), using a larger, bold font.

---

**Note** You can add comments in the lines immediately following the title. However, if you want an overall document title, you cannot add any MATLAB code before the start of the next section (a line starting with %%).

---

For instance, the following code produces a polished result when published.

```
%% Vector Operations
% You can perform a number of binary operations on vectors.
%%
A = 1:3;
B = 4:6;
%% Dot Product
% A dot product of two vectors yields a scalar.
% MATLAB has a simple command for dot products.
s = dot(A,B);
%% Cross Product
% A cross product of two vectors yields a third
% vector perpendicular to both original vectors.
% Again, MATLAB has a simple command for cross products.
v = cross(A,B);
```

By saving the code in an Editor and clicking the **Publish** button on the **Publish** tab, MATLAB produces the output as shown in the following figure. Notice that MATLAB automatically inserts a Contents menu from the section titles in the MATLAB file.

## Vector Operations

You can perform a number of binary operations on vectors.

### Contents

- [Dot Product](#)
- [Cross Product](#)

```
A = 1:3;
B = 4:6;
```

### Dot Product

A dot product of two vectors yields a scalar. MATLAB has a simple command for dot products.

```
s = dot(A,B);
```

### Cross Product

A cross product of two vectors yields a third vector perpendicular to both original vectors. Again, MATLAB has a simple command for cross products.

```
v = cross(A,B);
```

## Text Formatting

You can mark selected strings in the MATLAB comments so that they display in italic, bold, or monospaced text when you publish the file. Simply surround the text with `_`, `*`, or `|` for italic, bold, or monospaced text, respectively.

For instance, the following lines display each of the text formatting syntaxes if published.

```
%% Calculate and Plot Sine Wave
% _Define_ the *range* for |x|
```

Calculate and Plot Sine Wave

*Define the range for x*

## Trademark Symbols

If the comments in your MATLAB file include trademarked terms, you can include text to produce a trademark symbol (™) or registered trademark symbol (®) in the output.

For example, suppose you enter lines in a file as shown below.

```
%% Basic Matrix Operations in MATLAB(R)
% This is a demonstration of some aspects of MATLAB(R)
% software and the Neural Network Toolbox(TM) software.
```

If you publish the file to HTML, it appears in the MATLAB Web browser.



## Bulleted and Numbered Lists

MATLAB allows bulleted and numbered lists in the comments. You can use the following syntax to produce bulleted and numbered lists.

```
%% Two Lists
%
% * ITEM1
% * ITEM2
%
% # ITEM1
% # ITEM2
%
```

Publishing the example code produces the following output.

### Two Lists

- ITEM1
  - ITEM2
1. ITEM1
  2. ITEM2

## Text and Code Blocks

### Preformatted Text

Preformatted text appears in monospace font, maintains white space, and does not wrap long lines. Two spaces must appear between the comment symbol and the text of the first line of the preformatted text.

Publishing the following code produces a preformatted paragraph.

```
%%  
% Many people find monospaced texts easier to read:  
%  
% A dot product of two vectors yields a scalar.  
% MATLAB has a simple command for dot products.
```

```
Many people find monospaced texts easier to read:
```

```
A dot product of two vectors yields a scalar.  
MATLAB has a simple command for dot products.
```

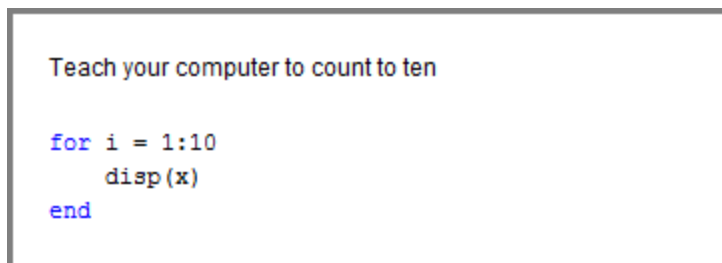
## Syntax Highlighted Sample Code

Executable code appears with syntax highlighting in published documents. You can also highlight *sample code*. Sample code is code that appears within comments.

To indicate sample code, you must put three spaces between the comment symbol and the start of the first line of code. For example, clicking the **Code** button on the **Publish** tab puts the following code in your Editor.

```
%%  
% Teach your computer to count to ten.  
%  
%   for i = 1:10  
%       disp(x)  
%   end
```

Publishing this code to HTML produces output in the MATLAB Web browser.



## External Graphics

You can insert text markup to publish an image that the MATLAB code does not generate. By default, MATLAB already includes code-generated graphics.

You can insert a generic image called `FILENAME.PNG` into your published output:

```
%%  
%  
% <<FILENAME.PNG>>  
%
```



MATLAB requires `FILENAME.PNG` be a relative path from the output location to your external image or a fully qualified URL. It is a good practice to save your image in the same folder that MATLAB publishes its output. For example, MATLAB publishes HTML documents to a subfolder `html`. Save your image file in the same subfolder. You can change the output folder by changing the publish configuration settings.

### **External Graphics Example Using `surf(peaks)`**

This example shows how to insert `surfpeaks.jpg` into a MATLAB file for publishing.

To create the `surfpeaks.jpg`, run the following code in the Command Window.

```
saveas(surf(peaks), 'surfpeaks.jpg');
```

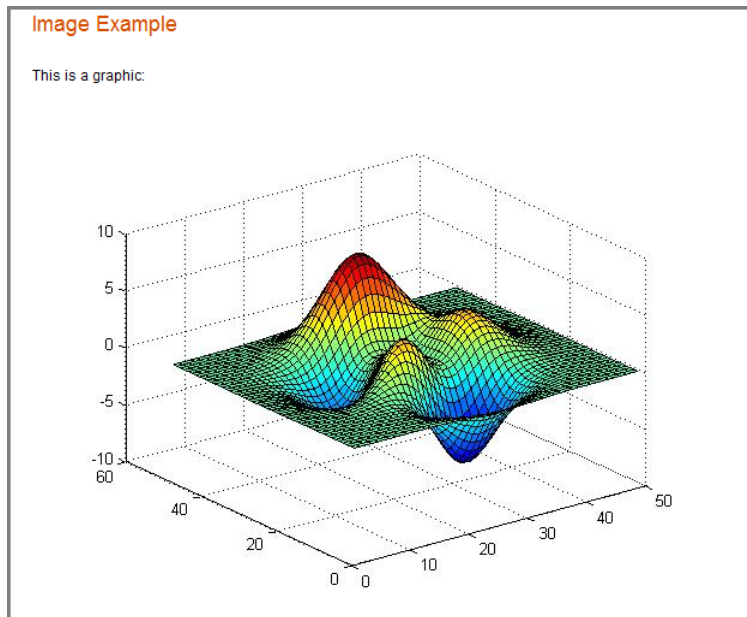
To produce an HTML file containing `surfpeaks.jpg` from a MATLAB file:

- 1** Create a subfolder called `html` in your current folder.
- 2** Create `surfpeaks.jpg` by running this code in the Command Window.

```
saveas(surf(peaks), 'html/surfpeaks.jpg');
```

- 3** Publish this MATLAB code to HTML.

```
%% Image Example
% This is a graphic:
%
% <<surfpeaks.jpg>>
%
```



### Valid Image Types for Output File Formats

The type of images you can include when you publish depends on the output type of that document as indicated in this table. For greatest compatibility, MathWorks recommends using the default image format for each output type.

Output File Format	Default Image Format	Types of Images You Can Include
doc	png	Any format that your installed version of Microsoft Office supports.
html	png	All formats publish successfully. Ensure that the tools you use to view and process the output files can display the output format you specify.

Output File Format	Default Image Format	Types of Images You Can Include
latex	png or epsc2	All formats publish successfully. Ensure that the tools you use to view and process the output files can display the output format you specify.
pdf	bmp	bmp and jpg.
ppt	png	Any format that your installed version of Microsoft Office supports.
xml	png	All formats publish successfully. Ensure that the tools you use to view and process the output files can display the output format you specify.

## Image Snapshot

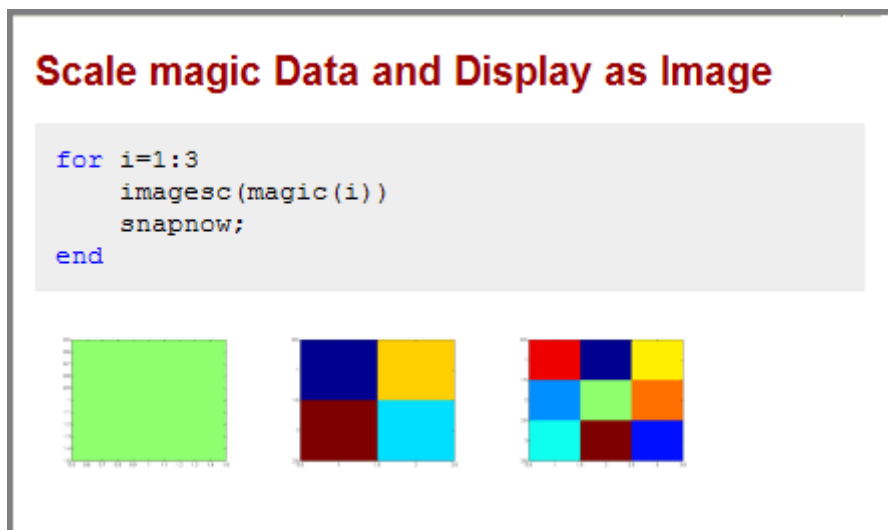
You can insert code that captures a snapshot of your MATLAB output. This is useful, for example, if you have a `for` loop that modifies a figure that you want to capture after each iteration.

For example, the following code runs a `for` loop three times and produces output after every iteration. The `snapnow` command captures all three images produced by the code.

```
%% Scale magic Data and Display as Image

for i=1:3
    imagesc(magic(i))
    snapnow;
end
```

If you publish the file to HTML, it resembles the following figure. By default, the images in the HTML are larger than shown in the figure. To resize images generated by MATLAB code, use the **Max image width** and **Max image height** fields in the **Publish settings** pane, as described in “Output Preferences for Publishing” on page 20-29.



## LaTeX Equations

### Inline LaTeX Expression

MATLAB allows you to include an inline LaTeX expression in any code that you intend to publish. To insert an inline expression, surround your LaTeX markup with dollar sign characters (\$).

---

**Note** All publishing output types support LaTeX expressions, except Microsoft PowerPoint.

---

This code contains a LaTeX expression:

```

%% LaTeX Inline Expression Example
%
% This is an equation:  $x^2+e^{\pi i}$ . It is
% inline with the text.

```

If you publish the sample text markup to HTML, the output appears:

### LaTeX Inline Expression Example

This is an equation:  $x^2 + e^{\pi i}$ . It is inline with the text.

### LaTeX Display Equation

MATLAB allows you to insert LaTeX symbols in blocks offset from the main comment text. Two dollar sign characters (\$\$) on each side of your equation denotes a block LaTeX equation.

This code is a sample text markup.

```
%% LaTeX Equation Example
%
% This is an equation:
%
% $$e^{\pi i} + 1 = 0$$
%
% It is not in line with the text.
```

If you publish to HTML, the expression appears as shown here.

### LaTeX Equation Example

This is an equation:

$$e^{\pi i} + 1 = 0$$

It is not in line with the text.

## Hyperlinks

### Static Hyperlinks

You can insert static hyperlinks within a MATLAB comment, and then publish the file to HTML, XML or Microsoft Word. When specifying a static hyperlink to a Web location, you must include a complete URL within the code. This is useful when you want to point the reader to a Web location. You can display or hide the URL in the published text. Consider excluding the URL, when you are confident that readers are viewing your output online and can click the hyperlink.

Enclose URLs and any replacement text in angled brackets.

```
%%  
% For more information, see our Web site:  
% <http://www.mathworks.com MathWorks>
```

Publishing the code to HTML produces the following output.

For more information, see our Web site: [MathWorks](http://www.mathworks.com)

Eliminating the text `MathWorks` after the URL produces the following modified output.

For more information, see our Web site: <http://www.mathworks.com>

---

**Note** If your code produces hyperlinked text in the MATLAB Command Window, the output shows the HTML code rather than the hyperlink.

---

## Dynamic Hyperlinks

You can insert dynamic hyperlinks, which MATLAB evaluates at the time a reader clicks that link. Dynamic hyperlinks allow you to point the reader to MATLAB code or documentation, or allow the reader to run code. You implement these links using `matlab:` syntax. If the code that follows the `matlab:` declaration has spaces in it, replace them with `%20`.

---

**Note** Dynamic links only work when viewing HTML in the MATLAB Web browser.

---

Diverse uses of dynamic links include:

- “Dynamic Link to Run Code” on page 20-23
- “Dynamic Link to a File” on page 20-24
- “Dynamic Link to a MATLAB Function Reference Page” on page 20-25

**Dynamic Link to Run Code.** You can specify a dynamic hyperlink to run code when a user clicks the hyperlink. For example, the following `matlab:` syntax creates hyperlinks in the output, which when clicked either enable or disable recycling:

```
%% Recycling Preference
% Click the preference you want:
%
% <matlab:recycle('off') Disable recycling>
%
% <matlab:recycle('on') Enable recycling>
```

When you publish the file to HTML, the results resemble the following.

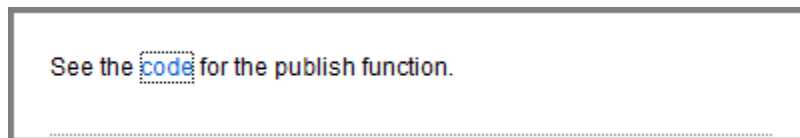


When you click one of the hyperlinks, MATLAB sets the `recycle` command accordingly. After clicking a hyperlink, run `recycle` in the Command Window to confirm the setting is as you expect.

**Dynamic Link to a File.** You can specify a link to a file that you know is in your readers' `matlabroot`. You do not need to know where each reader installed MATLAB. For example, link to the function code for `publish`.

```
%%
% See the
% <matlab:edit(fullfile(matlabroot,'toolbox','matlab','codetools','publish.m')) code>
% for the publish function.
```

Next, publish the file to HTML.



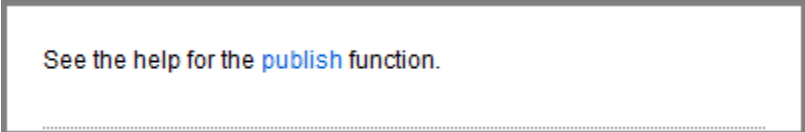
When you click the `code` link, the MATLAB Editor opens and displays the code for the `publish` function. On the reader's system, MATLAB issues the command (although the command does not appear in the reader's Command Window).



**Dynamic Link to a MATLAB Function Reference Page.** You can specify a link to a MATLAB function reference page using `matlab:` syntax. For example, suppose your readers have MATLAB installed and running. Provide a link to the `publish` reference page:

```
%%  
% See the help for the <matlab:doc('publish') publish> function.
```

Publish the file to HTML.



See the help for the [publish](#) function.

When you click the `publish` hyperlink, the MATLAB help browser opens and displays the reference page for the `publish` function. On the reader's system, MATLAB issues the command, although the command does not appear in their Command Window.

## HTML Markup

You can insert HTML markup into your MATLAB file. You must type HTML markup; no button on the **Publish** tab generates it.

---

**Note** When you insert text markup for HTML code, the HTML code publishes only when the specified output file format is HTML.

---

The following code includes HTML tagging.

```
%% HTML Markup Example  
% This is a table:  
%  
% <html>  
% <table border=1><tr><td>one</td><td>two</td></tr>  
% <tr><td>three</td><td>four</td></tr></table>  
% </html>  
%
```

If you publish the code to HTML, MATLAB creates a single-row table with two columns. The table contains the values one, two, three, and four.

### HTML Markup Example

This is a table:

one	two
three	four

If a section produces command-window output that starts with `<html>` and ends with `</html>`, MATLAB includes the source HTML in the published output. For example, MATLAB displays the `disp` command and makes a table from the HTML code if you publish this code:

```
disp('<html><table><tr><td>1</td><td>2</td></tr></table></html>')
```

```
disp('<html><table><tr><td>1</td><td>2</td></tr></table></html>')
```

1	2
---	---

## LaTeX Markup

You can insert LaTeX markup into your MATLAB file. Any LaTeX markup must be typed; no button on the **Publish** tab generates it.

---

**Note** When you insert text markup for LaTeX code, that code publishes only when the specified output file format is LaTeX.

---

The following code is an example of LaTeX markup.

```
%% LaTeX Markup Example
% This is a table:
%
% <latex>
% \begin{tabular}{|c|c|} \hline
% $n$ & $n!$ \\ \hline
% 1 & 1 \\
% 2 & 2 \\
% 3 & 6 \\ \hline
% \end{tabular}
% </latex>
```

If you publish the file to LaTeX, then the Editor opens a new .tex file containing the LaTeX markup.

```
% This LaTeX was auto-generated from MATLAB code.
% To make changes, update the MATLAB code and republish this document.
```

```
\documentclass{article}
\usepackage{graphicx}
\usepackage{color}

\sloppy
\definecolor{lightgray}{gray}{0.5}
\setlength{\parindent}{0pt}

\begin{document}
```

```
\section*{LaTeX Markup Example}
```

```
\begin{par}
This is a table:
\end{par} \vspace{1em}
\begin{par}

\begin{tabular}{|c|c|} \hline
$n$ & $n!$ \\ \hline
1 & 1 \\
2 & 2 \\
3 & 6 \\ \hline
\end{tabular}

\end{par} \vspace{1em}

\end{document}
```

MATLAB includes any additional markup necessary to compile this file with a LaTeX program.

**Concepts**

- “Publishing MATLAB Code” on page 20-6
- “Output Preferences for Publishing” on page 20-29

## Output Preferences for Publishing

### In this section...

“How to Edit Publishing Options” on page 20-29

“Specify Output File” on page 20-30

“Run Code During Publishing” on page 20-31

“Manipulate Graphics in Publishing Output” on page 20-34

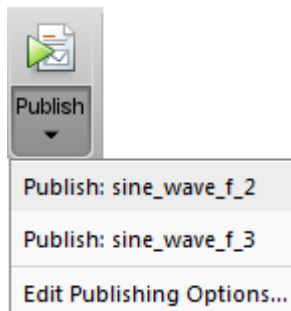
“Save a Publish Setting” on page 20-39

“Manage a Publish Configuration” on page 20-41

### How to Edit Publishing Options

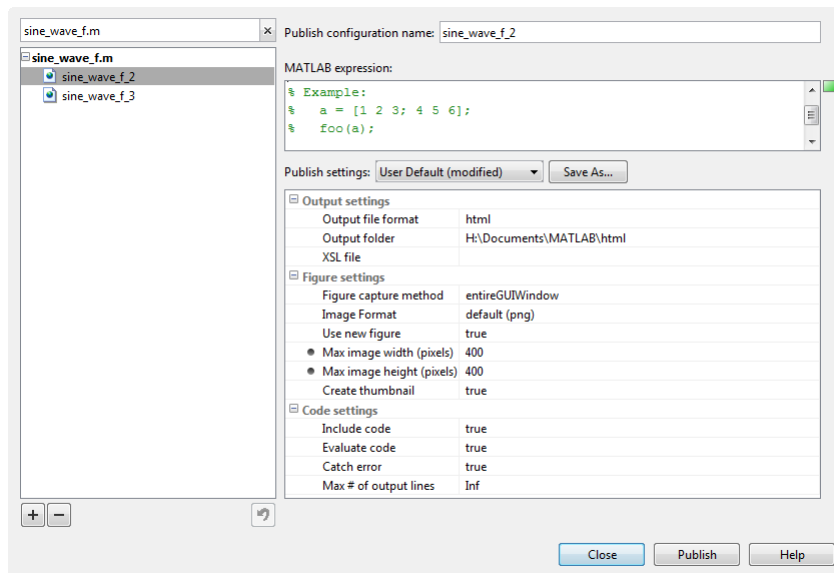
Use the default publishing preferences if your code requires no input arguments and you want to publish to HTML. However, if your code requires input arguments, or if you want to specify output settings, code execution, or figure formats, then specify a custom configuration.

- 1 Locate the **Publish** tab and click the **Publish** button arrow ↕.



- 2 Select **Edit Publishing Options**.

The Edit Configurations dialog box opens. Specify output preferences.



The **MATLAB expression** pane specifies the code that executes during publishing. The **Publish settings** pane contains output, figure, and code execution options. Together, they make what MATLAB refers to as a *publish configuration*. MATLAB associates each publish configuration with an `.m` file. The name of the publish configuration appears in the top left pane.

## Specify Output File

You specify the output format and location on the **Publish settings** pane.

MATLAB publishes to these formats.

Format	Notes
html	Publishes to an HTML document. You can use an Extensible Stylesheet Language (XSL) file.
xml	Publishes to XML document. You can use an Extensible Stylesheet Language (XSL) file.

Format	Notes
latex	Publishes to LaTeX document. Does <i>not</i> preserve syntax highlighting. You can use an Extensible Stylesheet Language (XSL) file.
doc	Publishes to a Microsoft Word document, if your system is a PC. Does <i>not</i> preserve syntax highlighting.
ppt	Publishes to a Microsoft PowerPoint document, if your system is a PC. Does <i>not</i> preserve syntax highlighting.
pdf	Publishes to a PDF document.

---

**Note** XSL files allow you more control over the appearance of the output document. For more details, see <http://docbook.sourceforge.net/release/xsl/current/doc/>.

---

## Run Code During Publishing

- “Specifying Code” on page 20-31
- “Evaluating Code” on page 20-32
- “Including Code” on page 20-33
- “Catching Errors” on page 20-33
- “Limiting the Amount of Output” on page 20-33

### Specifying Code

By default, MATLAB executes the `.m` file that you are publishing. However, you can specify any valid MATLAB code in the **MATLAB expression** pane. For example, if you want to publish a function that requires input, then you should run the command `function(input)`. Additional code, whose output you want to publish, should appear after the functions call. If you clear the **MATLAB expression** area, then MATLAB publishes the file without evaluating any code.

---

**Note** Publish configurations use the base MATLAB workspace. Therefore, a variable in the **MATLAB expression** pane overwrites the value for an existing variable in the base workspace.

---

## Evaluating Code

Another way to affect what MATLAB executes during publishing is to set the **Evaluate code** option in the **Publish setting** pane. This option indicates whether MATLAB evaluates the code in the `.m` file that is publishing. If set to `true`, MATLAB executes the code and includes the results in the output document.

Because MATLAB does not evaluate the code nor include code results when you set the **Evaluate code** option to `false`, there can be invalid code in the file. Therefore, consider first running the file with this option set to `true`.

For example, suppose you include comment text, `Label the plot`, in a file, but forget to preface it with the comment character. If you publish the document to HTML, and set the **Evaluate code** option to `true`, the output includes an error.

```
Modify Plot Properties

Label the plot
title('Sine Wave', 'FontWeight','bold')
xlabel('x')
ylabel('sin(x)')
set(gca, 'Color', 'w')
set(gcf, 'MenuBar', 'none')

??? Undefined function or method 'Label' for input arguments of type 'char'.
Error in ==> sine_wave2 at 12
Label the plot
```

Use the `false` option to publish the file that contains the publish function. Otherwise, MATLAB attempts to publish the file recursively.



## Including Code

You can specify whether to display MATLAB code in the final output. If you set the **Include code** option to true, then MATLAB includes the code in the published output document. If set to false, MATLAB excludes the code from all output file formats, except HTML.

If the output file format is HTML, MATLAB inserts the code as an HTML comment that is not visible in the Web browser. If you want to extract the code from the output HTML file, use the MATLAB `grabcode` function.

For example, suppose you publish

`H:/my_matlabfiles/my_mfiles/sine_wave.m` to HTML using a publish configuration with the **Include code** option set to false. If you share the output with colleagues, they can view it in a Web browser. To see the MATLAB code that generated the output, they can issue the following command from the folder containing `sine_wave.html`:

```
grabcode('sine_wave.html')
```

MATLAB opens the file that created `sine_wave.html` in the Editor.

## Catching Errors

You can catch and publish any errors that occur during publishing. Setting the **Catch error** option to true includes any error messages in the output document. If you set **Catch error** to false, MATLAB terminates the publish operation if an error occurs during code evaluation. However, this option has no effect if you set the **Evaluate code** property to false.

## Limiting the Amount of Output

You can limit the number of lines of code output that is included in the output document by specifying the **Max # of output lines** option in the **Publish settings** pane. Setting this option is useful if a smaller, representative sample of the code output suffices.

For example, the following loop generates 100 lines in a published output unless **Max # of output lines** is set to a lower value.

```
for n = 1:100
    disp(x)
```

```
end;
```

## Manipulate Graphics in Publishing Output

- “Choosing an Image Format” on page 20-34
- “Setting an Image Size” on page 20-35
- “Capturing Figures” on page 20-35
- “Specifying a Custom Figure Window” on page 20-36
- “Creating a Thumbnail” on page 20-39

### Choosing an Image Format

When publishing, you can choose the image format that MATLAB uses to store any graphics generated during code execution. The available image formats in the drop-down list depend on the setting of the **Figure capture method** option. For greatest compatibility, select the default as specified in this table.

Output File Format	Default Image Format	Types of Images You Can Include
doc	png	Any format that your installed version of Microsoft Office supports.
html	png	All formats publish successfully. Ensure that the tools you use to view and process the output files can display the output format you specify.
latex	png or epsc2	All formats publish successfully. Ensure that the tools you use to view and process the output files can display the output format you specify.
pdf	bmp	bmp and jpg.

Output File Format	Default Image Format	Types of Images You Can Include
ppt	png	Any format that your installed version of Microsoft Office supports.
xml	png	All formats publish successfully. Ensure that the tools you use to view and process the output files can display the output format you specify.

### Setting an Image Size

You set the size of MATLAB generated images in the **Publish settings** pane on the Edit Configurations dialog window. You specify the image size in pixels to restrict the width and height of images in the output. The pixel values act as a maximum size value because MATLAB maintains an image's aspect ratio. MATLAB ignores the size setting for the following cases:

- When working with external graphics as described in “External Graphics” on page 20-16
- When using vector formats, such as `.eps`
- When publishing to `.pdf`

### Capturing Figures

You can capture different aspects of the Figure window by setting the **Figure capture method** option. This option determines the window decorations (title bar, toolbar, menu bar, and window border) and plot backgrounds for the Figure window.

This table summarizes the effects of the various Figure capture methods.

Use This Figure Capture Method	To Get Figure Captures with These Appearance Details	
	Window Decorations	Plot Backgrounds
<code>entireGUIWindow</code>	Included for dialog boxes; Excluded for figures	Set to white for figures; matches the screen for dialog boxes
<code>print</code>	Excluded for dialog boxes and figures	Set to white
<code>getframe</code>	Excluded for dialog boxes and figures	Matches the screen plot background
<code>entireFigureWindow</code>	Included for dialog boxes and figures	Matches the screen plot background

---

**Note** Typically, MATLAB figures have the `HandleVisibility` property set to on. Dialog boxes are figures with the `HandleVisibility` property set to off or callback. If your results are different from the results listed in the preceding table, the `HandleVisibility` property of your figures or dialog boxes might be atypical. For more information, see “HandleVisibility Property”.

---

### Specifying a Custom Figure Window

MATLAB allows you to specify custom appearance for figures it creates. If the **Use new figure** option in the **Publish settings** pane is set to true, then in the published output, MATLAB uses a Figure window at the default size and with a white background. If the **Use new figure** option is set to false, then MATLAB uses the properties from an open Figure window to determine the appearance of code-generated figures. This preference does not apply to figures included using the syntax in “External Graphics” on page 20-16.

Use the following code as a template to produce Figure windows that meet your needs.

```
% Create figure
figure1 = figure('Name', 'purple_background', ...
'Color', [0.4784 0.06275 0.8941]);
```

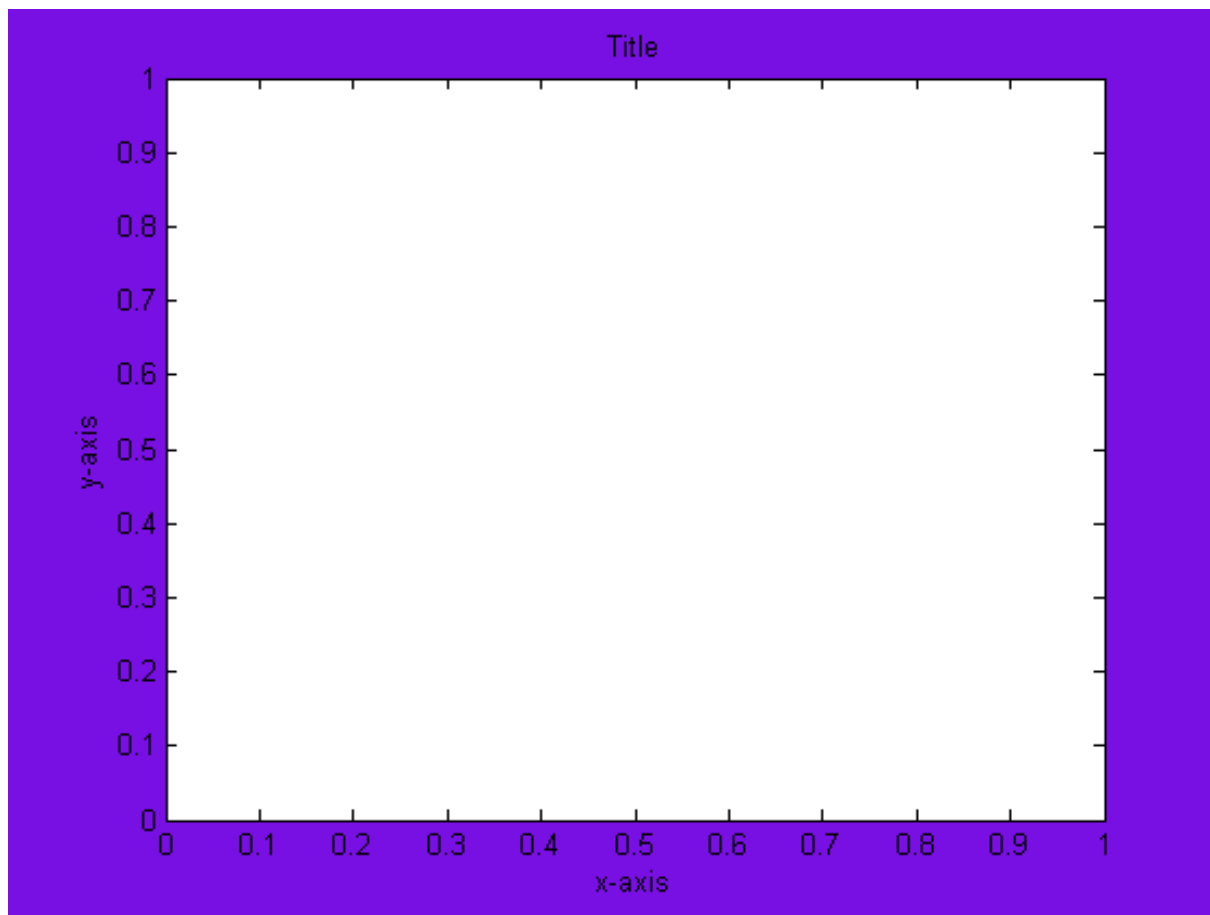
```
colormap('hsv');

% Create subplot
subplot(1,1,1, 'Parent', figure1);
box('on');

% Create axis labels
xlabel('x-axis');
ylabel({'y-axis'})

% Create title
title({'Title'});

% Enable printed output to match colors on screen
set(figure1, 'InvertHardcopy', 'off')
```



By publishing your file with this window open and the **Use new figure** option set to `false`, any code-generated figure takes the properties of the open Figure window.

---

**Note** You must set the **Figure capture method** option to `entireFigureWindow` for the final published figure to display all the properties of the open Figure window.

---

## Creating a Thumbnail

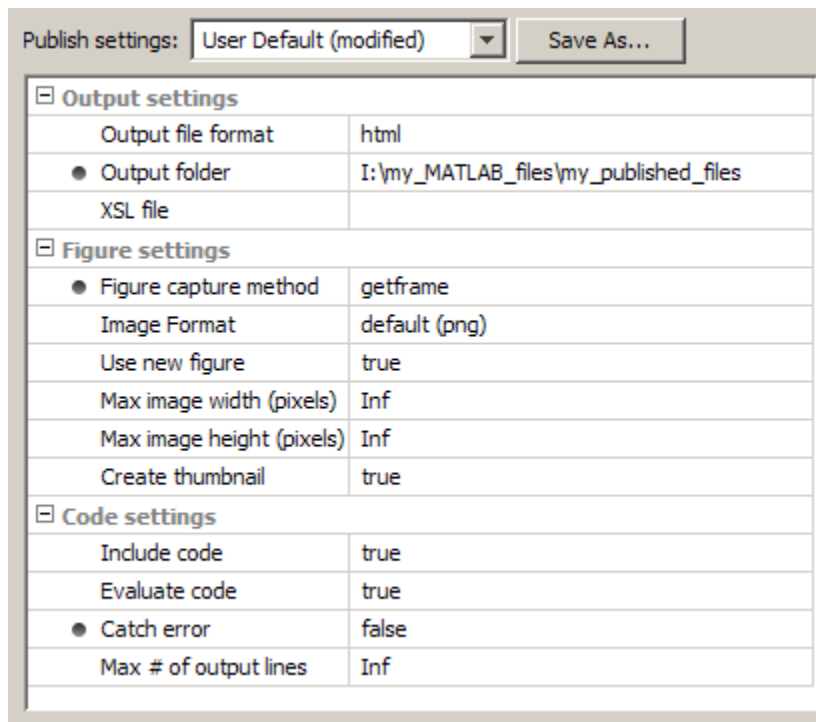
You can save the first code-generated graphic as a thumbnail image. You can use this thumbnail to represent your file on HTML pages. To create a thumbnail, follow these steps:

- 1** On the **Publish** tab, click the Publish button drop-down arrow ▾ and select **Edit Publishing Options**. The Edit Configurations dialog box opens.
- 2** Set the **Image Format** option to a bitmap format, such as .png or .jpg. MATLAB creates thumbnail images in bitmap formats.
- 3** Set the **Create thumbnail** option to true.

MATLAB saves the thumbnail image in the folder specified by the **Output folder** option in the **Publish settings** pane.

## Save a Publish Setting

You can save your publish settings, which allows you to easily reproduce output. It can be useful to save your commonly used publish settings.



When the **Publish settings** options are set, you can follow these steps to save the settings:

- 1 Click **Save As** when the options are set in the manner you want.

The **Save Publish Settings As** dialog box opens and displays the names of all the currently defined publish settings. By default the following publish settings install with MATLAB:

- Factory Default

You cannot overwrite the Factory Default and can restore them by selecting Factory Default from the **Publish settings** list.

- User Default

Initially, User Default settings are identical to the Factory Default settings. You can overwrite the User Default settings.



- 2 In the **Settings Name** field, enter a meaningful name for the settings. Then click **Save**.

You can now use the publish settings with other MATLAB files.

You also can overwrite the publishing properties saved under an existing name. Select the name from the **Publish settings** list, and then click **Overwrite**.

## Manage a Publish Configuration

- “Running an Existing Publish Configuration” on page 20-41
- “Creating Multiple Publish Configurations for a File” on page 20-42
- “Reassociating and Renaming Publish Configurations” on page 20-43
- “Using Publish Configurations across Different Systems” on page 20-43

Together, the code in the **MATLAB expression** pane and the settings in the **Publish settings** pane make a publish configuration that is associated with one file. These configurations provide a simple way to refer to publish preferences for individual files.

To create a publish configuration, click the **Publish** button drop-down arrow ▾ on the **Publish** tab, and select **Edit Publishing Options**. The Edit Configurations dialog box opens, containing the default publish preferences. In the **Publish configuration name** field, type a name for the publish configuration, or accept the default name. The publish configuration saves automatically.

## Running an Existing Publish Configuration

After saving a publish configuration, you can run it without opening the Edit Configurations dialog box:

- 1 Click the **Publish** button drop-down arrow ▾. If you position your mouse pointer on a publish configuration name, MATLAB displays a tooltip showing the MATLAB expression associated with the specific configuration.

- 2 Select a configuration name to use for the publish configuration. MATLAB publishes the file using the code and publish settings associated with the configuration.

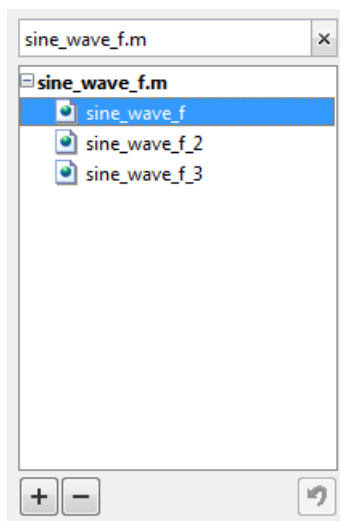
### Creating Multiple Publish Configurations for a File

You can create multiple publish configurations for a given file. You might do this to publish the file with different values for input arguments, with different publish setting property values, or both. Create a named configuration for each purpose, all associated with the same file. Later you can run whichever particular publish configuration you want.

Use the following steps as a guide to create new publish configurations.

- 1 Open a file in your Editor.
- 2 Click on the **Publish** button drop-down arrow, and select **Edit Publishing Options**. The Edit Configurations dialog box opens.
- 3 Click the **Add** button **+** located on the left pane.

A new name appears on the configurations list, *filename\_n*, where the value of *n* depends on the existing configuration names.




- 4 If you modify settings in the **MATLAB expression** or **Publish setting** pane, MATLAB automatically saves the changes.

### Reassociating and Renaming Publish Configurations

Each publish configuration is associated with a specific file. If you move or rename a file, redefine its association. If you delete a file, consider deleting the associated configurations, or associating them with a different file.

When MATLAB cannot associate a configuration with a file, the Edit Configurations dialog box displays the file name in red and a **File Not Found** message. To reassociate a configuration with another file, perform the following steps.

- 1 Click the Clear search button  on the left pane of the Edit Configurations dialog box.
- 2 Select the file for which you want to reassociate publish configurations.
- 3 In the right pane of the Edit Configurations dialog box, click **Choose...** In the Open dialog box, navigate to and select the file with which you want to reassociate the configurations.

You can rename the configurations at any time by selecting a configuration from the list in the left pane. In the right pane, edit the value for the **Publish configuration name**.

---

**Note** To run correctly after a file name change, you might need to change the code statements in the **MATLAB expression** pane. For example, change a function call to reflect the new file name for that function.

---

### Using Publish Configurations across Different Systems

Each time you create or save a publish configurations using the Edit Configurations dialog box, the Editor updates the `publish_configurations.m` file in your preferences folder. (This is the folder that MATLAB returns when you run the MATLAB `prefdir` function.)

Although you can port this file from the preferences folder on one system to another, only one `publish_configurations.m` file can exist on a system. Therefore, only move the file to another system if you have not created any publish configurations on the second system. In addition, because the `publish_configurations.m` file might contain references to file paths, be sure that the specified files and paths exist on the second system.

MathWorks recommends that you not update `publish_configurations.m` in the MATLAB Editor or a text editor. Changes that you make using tools other than the Edit Configurations dialog box might be overwritten later.

## Concepts

- “Publishing MATLAB Code” on page 20-6
- “Publishing Markup” on page 20-8

## Create a MATLAB Notebook with Microsoft Word

### In this section...

“Getting Started with MATLAB Notebooks” on page 20-45

“Creating and Evaluating Cells in a MATLAB Notebook” on page 20-47

“Formatting a MATLAB Notebook” on page 20-53

“Tips for Using MATLAB Notebooks” on page 20-56

“Configuring the MATLAB Notebook Software” on page 20-57

### Getting Started with MATLAB Notebooks

You can use the `notebook` function to open Microsoft Word and record MATLAB sessions to supplement class notes, textbooks, or technical reports. After executing the `notebook` function, you run MATLAB commands directly from Word itself. This Word document is known as a MATLAB Notebook. As an alternative, consider using the `MATLAB publish` function.

Using the `notebook` command, you create a Microsoft Word document. You then can type text, input cells (MATLAB commands), and output cells (results of MATLAB commands) directly into this document. You can format the input in the same manner as any Microsoft Word document. You can think of this document as a record of an interactive MATLAB session annotated with text, or as a document embedded with live MATLAB commands and output.

---

**Note** The `notebook` command is available only on Windows systems that have Microsoft Word installed.

---

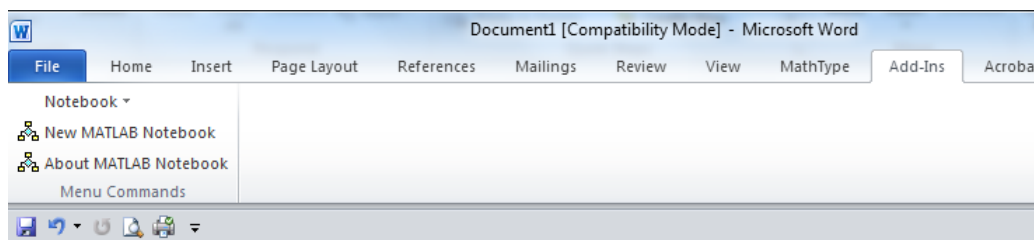
### Creating or Opening a MATLAB Notebook

If you are running the `notebook` command for the first time since you installed a new version of MATLAB, follow the instructions in “Configuring the MATLAB Notebook Software” on page 20-57. Otherwise, you can create a new or open an existing notebook:

- To open a new notebook, execute the `notebook` function in the MATLAB Command Window.

The `notebook` command starts Microsoft Word on your system and creates a MATLAB Notebook, called Document1. If a dialog box appears asking you to enable or disable macros, choose to enable macros.


Word adds the **Notebook** menu to the Word **Add-Ins** tab, as shown in the following figure.



Microsoft product screen shot reprinted with permission from Microsoft Corporation.

- To open an existing notebook, execute `notebook file_name` in the MATLAB Command Window, where `file_name` is the name of an existing MATLAB notebook.

**Converting a Word Document to a MATLAB Notebook.** To convert a Microsoft Word document to a MATLAB Notebook, insert the document into a notebook file:

- 1 Create a MATLAB Notebook.
- 2 From the **Insert** tab, in the **Text** group, click the arrow next to  **Object**.
- 3 Select **Text from File**. The Insert File dialog box opens.
- 4 Navigate and select the Word file that you want to convert in the Insert File dialog box.

### Running Commands in a MATLAB Notebook

You enter MATLAB commands in a notebook the same way you enter text in any other Word document. For example, you can enter the following text

in a Word document. The example uses text in Courier Font, but you can use any font:

Here is a sample MATLAB Notebook.

```
a = magic(3)
```

Execute a single command by pressing **Ctrl+Enter** on the line containing the MATLAB command. Execute a series of MATLAB commands using these steps:

- 1** Highlight the commands you want to execute.
- 2** Click the Notebook drop-down list on the **Add-Ins** tab.
- 3** Select **Evaluate Cell**.

MATLAB displays the results in the Word document below the original command or series of commands.

---

**Note** A good way to experiment with MATLAB Notebook is to open a sample notebook, *Readme.doc*. You can find this file in the *matlabroot/notebook/pc* folder.

---

## Creating and Evaluating Cells in a MATLAB Notebook

- “Creating Input Cells” on page 20-47
- “Evaluating Input Cells” on page 20-49
- “Undefining Cells” on page 20-51
- “Defining Calc Zones” on page 20-52

### Creating Input Cells

Input cells allow you to break up your code into manageable pieces and execute them independently. To define a MATLAB command in a Word document as an input cell:

- 1 Type the command into the MATLAB Notebook as text. For example,

This is a sample MATLAB Notebook.

```
a = magic(3)
```

- 2 Position the cursor anywhere in the command, and then select **Define Input Cell** from the Notebook drop-down list. If the command is embedded in a line of text, use the mouse to select it. The characters appear within *cell markers* ([ ]). Cell markers are bold, gray brackets. They differ from the brackets used to enclose matrices by their size and weight.

```
[a = magic(3)]
```

**Creating Autoinit Input Cells.** Autoinit cells are identical to input cells with additional characteristics:

- Autoinit cells evaluate when MATLAB Notebook opens.
- Commands in autoinit cells display in dark blue characters.

To create an autoinit cell, highlight the text, and then select **Define AutoInit Cell** from the Notebook drop-down list.

**Creating Cell Groups.** You can collect several input cells into a single input cell, called a *cell group*. All the output from a cell group appears in a single output cell immediately after the group. Cell groups are useful when you need several MATLAB commands to execute in sequence. For instance, defining labels and tick marks in a plot requires multiple commands:

```
x = -pi:0.1:pi;
plot(x,cos(x))
title('Sample Plot')
xlabel('x')
ylabel('cos(x)')
set(gca,'XTick',-pi:pi:pi)
set(gca,'XTickLabel',{'-pi','0','pi'})
```

To create a cell group:

- 1 Use the mouse to select the input cells that are to make up the group.



## 2 Select **Group Cells** from the Notebook drop-down list.

A single pair of cell markers now surrounds the new cell group.

```
[x = -pi:0.1:pi;  
plot(x,cos(x))  
title('Sample Plot')  
xlabel('x')  
ylabel('cos(x)')  
set(gca,'XTick',-pi:pi:pi)  
set(gca,'XTickLabel',{'-pi','0','pi'})]
```

When working with cell groups, you should note several behaviors:

- A cell group cannot contain output cells. If the selection includes output cells, they are deleted.
- A cell group cannot contain text. If the selection includes text, the text appears after the cell group, unless it precedes the first input cell in the selection.
- If you select part or all of an output cell, the cell group includes the respective input cell.
- If the first line of a cell group is an autoinit cell, then the entire group is an autoinit cell.

### **Evaluating Input Cells**

After you define a MATLAB command as an input cell, you can evaluate it in your MATLAB Notebook using these steps:

- 1 Highlight or place your cursor in the input cell you want to evaluate.
- 2 Select **Evaluate Cell** in the Notebook drop-down list, or press **Ctrl+Enter**.

The notebook evaluates and displays the results in an output cell immediately following the input cell. If there is already an output cell, its contents update wherever the output cell appears in the notebook. For example:

This is a sample MATLAB Notebook.

```
[a = magic(3) ]
```

```
[a =  
    8     1     6  
    3     5     7  
    4     9     2 ]
```

To evaluate more than one MATLAB command contained in different, but contiguous input cells:

- 1 Select a range of cells that includes the input cells you want to evaluate. You can include text that surrounds input cells in your selection.
- 2 Select **Evaluate Cell** in the Notebook drop-down list or press **Ctrl+Enter**.

---

**Note** Text or numeric output always displays first, regardless of the order of the commands in the group.

---

When each input cell evaluates, new output cells appear or existing ones are replaced. Any error messages appear in red, by default.

**Evaluating Cell Groups.** Evaluate a cell group the same way you evaluate an input cell (because a cell group is an input cell):

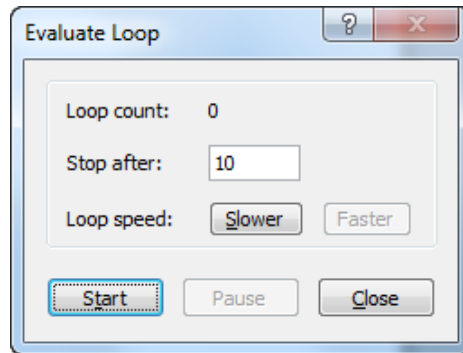
- 1 Position the cursor anywhere in the cell or in its output cell.
- 2 Select **Evaluate Cell** in the Notebook drop-down list or press **Ctrl+Enter**.

When MATLAB evaluates a cell group, the output for all commands in the group appears in a single output cell. By default, the output cell appears immediately after the cell group the first time the cell group is evaluated. If you evaluate a cell group that has an existing output cell, the results appear in that output cell, wherever it is located in the MATLAB Notebook.

**Using a Loop to Evaluate Input Cells Repeatedly.** MATLAB allows you to evaluate a sequence of MATLAB commands repeatedly, using these steps:

- 1 Highlight the input cells, including any text or output cells located between them.

- 2 Select **Evaluate Loop** in the Notebook drop-down list. The **Evaluate Loop** dialog box appears.



Microsoft product screen shot reprinted with permission from Microsoft Corporation.

- 3 Enter the number of times you want to evaluate the selected commands in the **Stop After** field, then click **Start**. The button changes to **Stop**. Command evaluation begins, and the number of completed iterations appears in the **Loop Count** field.

You can increase or decrease the delay at the end of each iteration by clicking **Slower** or **Faster**.

**Evaluating an Entire MATLAB Notebook.** To evaluate an entire MATLAB Notebook, select **Evaluate MATLAB Notebook** in the Notebook drop-down list. Evaluation begins at the top of the notebook, regardless of the cursor position and includes each input cell in the file. As it evaluates the file, Word inserts new output cells or replaces existing output cells.

If you want to stop evaluation if an error occurs, set the **Stop evaluating on error** check box on the Notebook Options dialog box.

## Undefining Cells

You can always convert cells back to normal text. To convert a cell (input, output, or a cell group) to text:

- 1 Highlight the input cell or position the cursor in the input cell.
- 2 Select **Undefine Cells** from the Notebook drop-down list.

When the cell converts to text, the cell contents reformat according to the Microsoft Word Normal style.

---

**Note**

- Converting input cells to text also converts their output cells.
  - If the output cell is graphical, the cell markers disappear and the graphic dissociates from its input cell, but the contents of the graphic remain.
- 

**Defining Calc Zones**

You can partition a MATLAB Notebook into self-contained sections, called *calc zones*. A calc zone is a contiguous block of text, input cells, and output cells. Section breaks appear before and after the section, defining the calc zone. The section break indicators include bold, gray brackets to distinguish them from standard Word section breaks.

You can use calc zones to prepare problem sets, making each problem a calc zone that you can test separately. A notebook can contain any number of calc zones.

---

**Note** Calc zones do not affect the scope of the variables in a notebook. Variables defined in one calc zone are accessible to all calc zones.

---

**Creating a Calc Zone.**

- 1 Select the input cells and text you want to include in the calc zone.
- 2 Select **Define Calc Zone** under the Notebook drop-down list.

A calc zone cannot begin or end in a cell.

## Evaluating a Calc Zone.

- 1 Position the cursor anywhere in the calc zone.
- 2 Select **Evaluate Calc Zone** from the Notebook drop-down list or press **Alt+Enter**.

By default, the output cell appears immediately after the calc zone the first time you evaluate the calc zone. If you evaluate a calc zone with an existing output cell, the results appear in the output cell wherever it is located in the MATLAB Notebook.

## Formatting a MATLAB Notebook

- “Modifying Styles in the MATLAB Notebook Template” on page 20-53
- “Controlling the Format of Numeric Output” on page 20-54
- “Controlling Graphic Output” on page 20-54

## Modifying Styles in the MATLAB Notebook Template

You can control the appearance of the text in your MATLAB Notebook by modifying the predefined styles in the notebook template, `m-book.dot`. These styles control the appearance of text and cells.

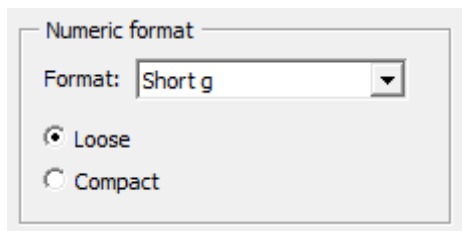
This table describes MATLAB Notebook default styles. For general information about using styles in Microsoft Word documents, see the Microsoft Word documentation.

Style	Font	Size	Weight	Color
Normal	Times New Roman®	10 points	N/A	Black
AutoInit	Courier New	10 points	Bold	Dark blue
Error	Courier New	10 points	Bold	Red
Input	Courier New	10 points	Bold	Dark green
Output	Courier New	10 points	N/A	Blue

When you change a style, Word applies the change to all characters in the notebook that use that style and gives you the option to change the template. Be cautious about changing the template. If you choose to apply the changes to the template, you affect all new notebooks that you create using the template. See the Word documentation for more information.

### Controlling the Format of Numeric Output

To change how numeric output displays, select **Notebook Options** from the Notebook drop-down list. The Notebook Options dialog box opens, containing the **Numeric format** pane.



Microsoft product screen shot reprinted with permission from Microsoft Corporation.

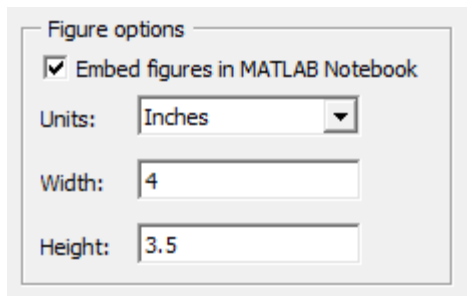
You can select a format from the **Format** list. Format choices correspond to the same options available with the MATLAB format command

The **Loose** and **Compact** settings control whether a blank line appears between the input and output cells. To suppress this blank line select **Compact**.

### Controlling Graphic Output

MATLAB allows you to embed graphics, suppress graphic output and adjust the graphic size.

By default, MATLAB embeds graphic output in a Notebook. To display graphic output in a separate figure window, click **Notebook Options** from the Notebook drop-down list. The Notebook Options dialog box opens, containing the **Figure options** pane.



Microsoft product screen shot reprinted with permission from Microsoft Corporation.

From this pane, you can choose whether to embed figures in the MATLAB Notebook. You can adjust the height and width of the figure in inches, centimeters, or points.

---

**Note** Embedded figures do not include Handle Graphics objects generated by the `uicontrol` and `uimenu` functions.

---

To prevent an input cell from producing a figure, select **Toggle Graph Output for Cell** from the Notebook drop-down list. The string (no graph) appears after the input cell and the input cell does not produce a graph if evaluated. To undo the figure suppression, select **Toggle Graph Output for Cell** again or delete the text (no graph).

---

**Note** **Toggle Graph Output for Cell** overrides the **Embed figures in MATLAB Notebook** option, if that option is set.

---

## Tips for Using MATLAB Notebooks

### Protecting the Integrity of Your Workspace in MATLAB Notebooks

If you work on more than one MATLAB Notebook in a single word-processing session, notice that

- Each notebook uses the same MATLAB executable.
- All notebooks share the same workspace. If you use the same variable names in more than one notebook, data used in one notebook can be affected by another notebook.

---

**Note** You can protect the integrity of your workspace by specifying the `clear` command as the first autoinit cell in the notebook.

---

### Ensuring Data Consistency in MATLAB Notebooks

You can think of a MATLAB Notebook as a sequential record of a MATLAB session. When executed in sequential order, the notebook accurately reflects the relationships among the commands.

If, however, you edit input cells or output cells as you refine your notebook, it can contain inconsistent data. Input cells that depend on the contents or the results of other cells do not automatically recalculate when you make a change.

When working in a notebook, consider selecting **Evaluate MATLAB Notebook** periodically to ensure that your notebook data is consistent. You can also use calc zones to isolate related commands in a section of the notebook, and then use **Evaluate Calc Zone** to execute only those input cells contained in the calc zone.

### Debugging and MATLAB Notebooks

Do not use debugging functions or the Editor while evaluating cells within a MATLAB Notebook. Instead, use this procedure:



- 1 Complete debugging files from within MATLAB.
- 2 Clear all the breakpoints.
- 3 Access the file using notebook.

If you debug while evaluating a notebook, you can experience problems with MATLAB.

## Configuring the MATLAB Notebook Software

After you install MATLAB Notebook software, but before you begin using it, specify that Word can use macros, and then configure the `notebook` command. The `notebook` function installs as part of the MATLAB installation process on Microsoft Windows platforms. For more information, see the MATLAB installation documentation.

---

**Note** Word explicitly asks whether you want to enable macros. If it does not, refer to the Word help. You can search topics relating to macros, such as “enable or disable macros”.

---

To configure MATLAB Notebook software, type the following in the MATLAB Command Window:

```
notebook -setup
```

MATLAB configures the Notebook software and issues these messages in the Command Window:

```
Welcome to the utility for setting up the MATLAB Notebook  
for interfacing MATLAB to Microsoft Word
```

```
Setup complete
```

When MATLAB configures the software, it:

- 1 Accesses the Microsoft Windows system registry to locate Microsoft Word and the Word templates folder. It also identifies the version of Word.

**2** Copies the `m-book.dot` template to the Word templates folder.

The MATLAB Notebook software supports Word versions 2002, 2003, 2007, and 2010.

After you configure the software, typing `notebook` in the MATLAB Command Window starts Microsoft Word and creates a new MATLAB Notebook.

If you suspect a problem with the current configuration, you can explicitly reconfigure the software by typing:

```
notebook -setup
```

## Concepts

- “Options for Presenting Your Code” on page 20-2
- “Publishing MATLAB Code” on page 20-6

# Coding and Productivity Tips

---


- “Open and Save Files” on page 21-2
- “Check Code for Errors and Warnings” on page 21-7
- “Improve Code Readability” on page 21-23
- “Find and Replace Text in Files” on page 21-30
- “Go To Location in File” on page 21-35
- “Display Two Parts of a File Simultaneously” on page 21-42
- “Add Reminders to Files” on page 21-45
- “Colors in the MATLAB Editor” on page 21-49
- “Code Contains %#ok — What Does That Mean?” on page 21-51
- “MATLAB Code Analyzer Report” on page 21-52
- “Change Default Editor” on page 21-56



## Open and Save Files

In this section...
“Open Existing Files” on page 21-2
“Save Files” on page 21-4

### Open Existing Files

To open an existing file or files in the Editor, choose the option that achieves your goals, as described in this table.

Goal	Steps	Additional Information
<p><b>Open with associated tool</b></p> <p>Open a file using the appropriate MATLAB tool for the file type.</p>	<p>On the <b>Editor</b> (or <b>Home</b>) tab, in the <b>File</b> section, click </p>	<p>For example, this option opens a file with a <code>.m</code> extension in the Editor and loads a MAT-file into the Workspace browser.</p>
<p><b>Open as text file</b></p> <p>Open a file in the Editor as a text file, even if the file type is associated with another application or tool.</p>	<p>On the <b>Editor</b> tab, in the <b>File</b> section, click <b>Open</b> ▾, and select <b>Open as Text</b>.</p>	<p>This is useful, for example, if you have imported a tab-delimited data file (<code>.dat</code>) into the workspace and you find you want to add a data point. Open the file as text in the Editor, make your addition, and then save the file.</p>

Goal	Steps	Additional Information
<p><b>Open function from within file</b></p> <p>Open a local function or function file from within a file in the Editor.</p>	<p>Position the cursor on the name within the open file, and then right-click and select <b>Open <i>file-name</i></b> from the context menu.</p>	<p>You also can use this method to open a variable or Simulink model.</p> <p>For details, see “Open a File or Variable from Within a File” on page 21-40.</p>
<p><b>Reopen file</b></p> <p>Reopen a recently used file.</p>	<p>At the bottom of the <b>Open ▾</b> drop-down list, select a file under <b>Recent Files</b>.</p>	<p>To change the number of files on the list, click  <b>Preferences</b>, and then select <b>MATLAB and Editor/Debugger</b>. Under <b>Most recently used file list</b>, change the value for <b>Number of entries</b>.</p>
<p><b>Reopen files at startup</b></p> <p>At startup, automatically open the files that were open when the previous MATLAB session ended.</p>	<p>On the <b>Home</b> tab, in the <b>Environment</b> section, click  <b>Preferences</b> and select <b>MATLAB and Editor/Debugger</b>. Then, select <b>On restart reopen files from previous MATLAB session</b>.</p>	<p>None.</p>
<p><b>Open file displaying in another tool</b></p> <p>Open a file name displaying in another MATLAB desktop tool or Microsoft tool.</p>	<p>Drag the file from the other tool into the Editor.</p>	<p>For example, drag files from the Current Folder browser or from Windows Explorer.</p>
<p><b>Open file using a function</b></p>	<p>Use the edit or open function.</p>	<p>For example, type the following to open <code>collatz.m</code>:</p> <pre>edit collatz.m</pre> <p>If <code>collatz.m</code> is not on the search path or in the current</p>


Goal	Steps	Additional Information
		folder, use the relative or absolute path for the file.

For special considerations on the Macintosh platform, see “Navigating Within the MATLAB Root Folder on Macintosh Platforms”.

## Save Files

After you modify a file in the Editor, an asterisk (\*) follows the file name. This asterisk indicates that there are unsaved changes to the file.

You can perform four different types of save operations, which have various effects, as described in this table.

Save Option	Steps
Save file to disk and keep file open in the Editor.	On the <b>Editor</b> tab, in the <b>File</b> section, click  .
Rename file, save it to disk, and make it the active Editor document. Original file remains unchanged on disk.	<ol style="list-style-type: none"> <li><b>1</b> On the <b>Editor</b> tab, in the <b>File</b> section, click <b>Save ▾</b> and select <b>Save As</b>.</li> <li><b>2</b> Specify a new name, type, or both for the file, and then click <b>Save</b>.</li> </ol>
Save file to disk under new name. Original file remains open and unsaved.	<ol style="list-style-type: none"> <li><b>1</b> On the <b>Editor</b> tab, in the <b>File</b> section, click <b>Save ▾</b> and select <b>Save Copy As</b>.  MATLAB opens the Select File for Backup dialog box.</li> <li><b>2</b> Specify a name and type for the backup file, and then click <b>Save</b>.</li> </ol>

Save Option	Steps
<p>Save changes to all open files using current file names.</p> <p>All files remain open.</p>	<ol style="list-style-type: none"> <li data-bbox="847 331 1328 423"><b>1</b> On the <b>Editor</b> tab, in the <b>File</b> section, click <b>Save</b> ▾ and select <b>Save All</b>.</li>   <li data-bbox="847 453 1328 545">MATLAB opens the Select File for Save As dialog box for the first unnamed file.</li>   <li data-bbox="847 574 1328 638"><b>2</b> Specify a name and type for any unnamed file, and then click <b>Save</b>.</li>   <li data-bbox="847 668 1328 732"><b>3</b> Repeat step 2 until all unnamed files are saved.</li> </ol>

## Recommendations on Saving Files

MathWorks recommends that you save files you create and files from MathWorks that you edit to a folder that is not in the *matlabroot*/toolbox folder tree, where *matlabroot* is the folder returned when you type *matlabroot* in the Command Window. If you keep your files in *matlabroot*/toolbox folders, they can be overwritten when you install a new version of MATLAB software.


At the beginning of each MATLAB session, MATLAB loads and caches in memory the locations of files in the *matlabroot*/toolbox folder tree. Therefore, if you:

- Save files to *matlabroot*/toolbox folders using an external editor, run `rehash toolbox` before you use the files in the current session.
- Add or remove files from *matlabroot*/toolbox folders using file system operations, run `rehash toolbox` before you use the files in the current session.
- Modify existing files in *matlabroot*/toolbox folders using an external editor, run `clear function-name` before you use these files in the current session.

For more information, see rehash or “Toolbox Path Caching in MATLAB”.

### **Autosaving Files**

When you modify a file in the Editor, the Editor saves a copy of the file using the same file name but with an `.asv` extension every 5 minutes. The autosave version is useful if you have system problems and lose changes you made to your file. In that event, you can open the autosave version, `filename.asv`, and then save it as `filename.m` to use the last good version of `filename`.

To select preferences, click  **Preferences**, and then select **MATLAB > Editor/Debugger > Autosave** on the **Home** tab, in the **Environment** section. You can then:

- Turn the autosave feature on or off.
- Automatically delete autosave files when you close the corresponding source file.

By default, MATLAB automatically deletes autosave files when you close the Editor. It is best to keep autosave-to-file relationships clear and current. Therefore, when you rename or remove a file, consider deleting or renaming the corresponding autosave file.

- Specify the number of minutes between automatic saves.
- Specify the file extension for autosave files.
- Specify a location for autosave files

If you edit a file in a read-only folder and the autosave **Location** preference is **Source file directories**, then the Editor does not create an autosave copy of the file.



## Check Code for Errors and Warnings

MATLAB Code Analyzer can automatically check your code for coding problems, as described in the following sections:

### In this section...

“Automatically Check Code in the Editor — Code Analyzer” on page 21-7

“Create a Code Analyzer Message Report” on page 21-12

“Adjust Code Analyzer Message Indicators and Messages” on page 21-13

“Understand Code Containing Suppressed Messages” on page 21-17


“Understand the Limitations of Code Analysis” on page 21-18

“Enable MATLAB Compiler Deployment Messages” on page 21-22

### Automatically Check Code in the Editor — Code Analyzer

You can view warning and error messages about your code, and modify your file based on the messages. The messages update automatically and continuously so you can see if your changes addressed the issues noted in the messages. Some messages offer additional information, automatic code correction, or both.

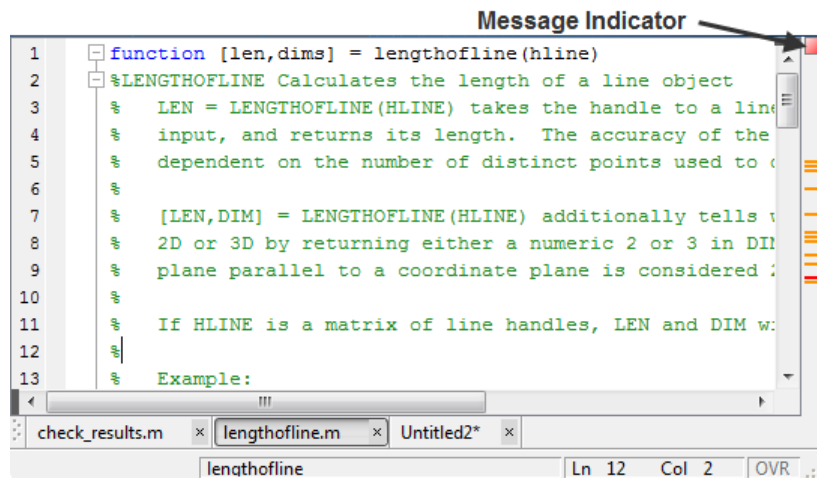
To use continuous code checking in a MATLAB code file in the Editor:

- 1** On the **Home** tab, in the **Environment** section, click  **Preferences**.
- 2** Select **MATLAB > Code Analyzer**, and then select the **Enable integrated warning and error messages** check box.
- 3** Set the **Underlining** option to **Underline warnings and errors**, and then click **OK**.
- 4** Open a MATLAB code file in the Editor. This example uses the sample file `lengthofline.m` that ships with the MATLAB software:
  - a** Open the example file:

```
open(fullfile(matlabroot,'help','techdoc','matlab_env',...
    'examples','lengthofline.m'))
```

- b Save the example file to a folder to which you have write access. For the example, `lengthofline.m` is saved to `C:\my_MATLAB_files`.
- 5 Examine the message indicator at the top of the message bar to see the Code Analyzer messages reported for the file:
    - **Red** indicates syntax errors were detected. Another way to detect some of these errors is using syntax highlighting to identify unterminated strings, and delimiter matching to identify unmatched keywords, parentheses, braces, and brackets.
    - **Orange** indicates warnings or opportunities for improvement, but no errors, were detected.
    - **Green** indicates no errors, warnings, or opportunities for improvement were detected.

In this example, the indicator is red, meaning that there is at least one error in the file.



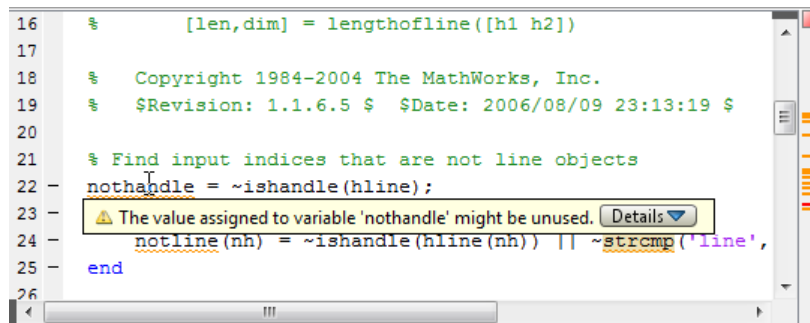
- 6 Click the message indicator to go to the next code fragment containing a message. The next code fragment is relative to the current cursor position, viewable in the status bar.

In the `lengthofline` example, the first message is at line 22. The cursor moves to the beginning of line 22.

The code fragment for which there is a message is underlined in either red for errors or orange for warnings and improvement opportunities.

- 7 View the message by moving the mouse pointer within the underlined code fragment.

The message opens in a tooltip and contains a **Details** button that provides access to additional information by extending the message. Not all messages have additional information.



```

16 % [len,dim] = lengthofline([h1 h2])
17
18 % Copyright 1984-2004 The MathWorks, Inc.
19 % $Revision: 1.1.6.5 $ $Date: 2006/08/09 23:13:19 $
20
21 % Find input indices that are not line objects
22 - nothandle = ~ishandle(hline);
23 -
24 - notline(nh) = ~ishandle(hline(nh)) || ~strcmp('line',
25 - end
26

```

The screenshot shows a MATLAB code editor window. A warning message tooltip is displayed over the underlined code on line 22: `nothandle = ~ishandle(hline);`. The tooltip text reads: "The value assigned to variable 'nothandle' might be unused." and includes a "Details" button. The code on line 24, `notline(nh) = ~ishandle(hline(nh)) || ~strcmp('line',`, is also underlined in orange.

- 8 Click the **Details** button.

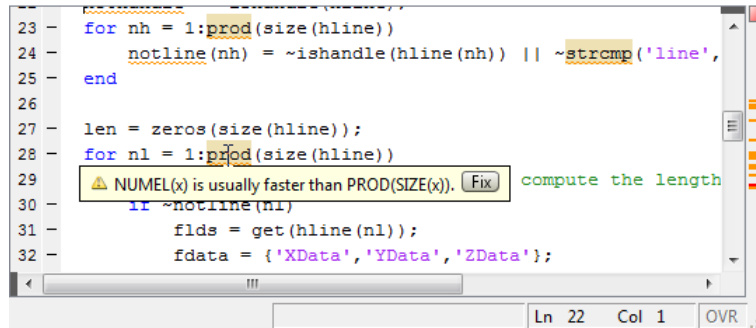
The window expands to display an explanation and user action.

- 9 Modify your code, if needed.

The message indicator and underlining automatically update to reflect changes you make, even if you do not save the file.

- 10 On line 28, hover over `prod`.

The code is underlined because there is a warning message, and it is highlighted because an automatic fix is available. When you view the message, it provides a button to apply the automatic fix.



```
23 - for nh = 1:prod(size(hline))
24 -     notline(nh) = ~ishandle(hline(nh)) || ~strcmp('line',
25 - end
26
27 - len = zeros(size(hline));
28 - for nl = 1:prod(size(hline))
29 -     NUMEL(x) is usually faster than PROD(SIZE(x)). [Fix] compute the length
30 -     if ~notline(nl)
31 -         flds = get(hline(nl));
32 -         fdata = {'XData', 'YData', 'ZData'};
```

The screenshot shows a MATLAB code editor window. The code is as follows:

```
23 - for nh = 1:prod(size(hline))
24 -     notline(nh) = ~ishandle(hline(nh)) || ~strcmp('line',
25 - end
26
27 - len = zeros(size(hline));
28 - for nl = 1:prod(size(hline))
29 -     NUMEL(x) is usually faster than PROD(SIZE(x)). [Fix] compute the length
30 -     if ~notline(nl)
31 -         flds = get(hline(nl));
32 -         fdata = {'XData', 'YData', 'ZData'};
```

A warning message is displayed over line 29: "NUMEL(x) is usually faster than PROD(SIZE(x)). [Fix] compute the length". The "Fix" button is highlighted. The status bar at the bottom right shows "Ln 22 Col 1 OVR".

### 11 Fix the problem by doing one of the following:

- If you know what the fix is (from previous experience), click **Fix**.
- If you are unfamiliar with the fix, view, and then apply it as follows:
  - a Right-click the highlighted code (for a single-button mouse, press **Ctrl**+ click), and then view the first item in the context menu.
  - b Click the fix.

MATLAB automatically corrects the code.

In this example, MATLAB replaces `prod(size(hline))` with `numel(hline)`.

### 12 Go to a different message by doing one of the following:

- To go to the next message, click the message indicator or the next underlined code fragment.
- To go to a line that a marker represents, click a red or orange line in the indicator bar .

To see the first error in `lengthofline`, click the first red marker in the message bar. The cursor moves to the first suspect code fragment in line 48. The **Details** and **Fix** buttons are dimmed, indicating that there is no more information about this message and there is no automatic fix.

```

22 - nothandle = ~ishandle(hline);
23 - for nh = 1:prod(size(hline))
24 -     notline(nh) = ~ishandle(hline(nh)) || ~strcmp('line',
25 - end
26
27 -
28 -
29 -
30 -
31 -     flds = get(hline(nl));
32 -     fdata = {'XData', 'YData', 'ZData'};

```

Line 48: Invalid syntax at ':'. Possibly, a ), }, or ] is missing. Details Fix

Line 48: Invalid syntax at ')'. Possibly, a ), }, or ] is missing. Details Fix

Line 48: Parse error at ']': usage might be invalid MATLAB syntax. Details Fix

lengthoffline Ln 28 Col 15 OVR

Multiple messages can represent a single problem or multiple problems. Addressing one might address all of them, or after addressing one, the other messages might change or what you need to do might become clearer.

- 13** Modify the code to address the problem noted in the message—the message indicators update automatically.

The message suggests a delimiter imbalance on line 48. You can investigate that as follows:

- a** On the **Home** tab, in the **Environment** section, click **Preferences**.
- b** Select **MATLAB > Keyboard**.
- c** Under **Delimiter Matching**, select **Match on arrow key**, and then click **OK**.
- d** In the Editor, move the arrow key over each of the delimiters to see if MATLAB indicates a mismatch.

In the example, it might appear that there are no mismatched delimiters. However, code analysis detects the semicolon in parentheses: `data{3} (;)`, and interprets it as the end of a statement. The message reports that the two statements on line 48 each have a delimiter imbalance.

- e** In line 48, change `data{3} (;)` to `data{3} (:)`.

Now, the underline no longer appears in line 48. The single change addresses the issues in both of the messages for line 48.

Because the change removed the only error in the file, the message indicator at the top of the bar changes from red to orange, indicating that only warnings and potential improvements remain.


After modifying the code to address all the messages, or disabling designated messages, the message indicator becomes green. The example file with all messages addressed has been saved as `lengthofline2.m`. Open the corrected example file with the command:

```
open(fullfile(matlabroot, 'help', 'techdoc', ...  
             'matlab_env', 'examples', 'lengthofline2.m'))
```

## Create a Code Analyzer Message Report

You can create a report of messages for an individual file, or for all files in a folder, using one of these methods:

- Run a report for an individual MATLAB code file:

- 1** On the Editor window, click .

- 2** Select **Show Code Analyzer Report**.

A Code Analyzer Report appears in the MATLAB Web Browser.

- 3** Modify your file based on the messages in the report.

- 4** Save the file.

- 5** Rerun the report to see if your changes addressed the issues noted in the messages.

- Run a report for all files in a folder:

- 1** On the Current Folder browser, click .

- 2** Select **Reports > Code Analyzer Report**.

- 3** Modify your files based on the messages in the report.

For details, see “MATLAB Code Analyzer Report” on page 21-52.

- 4** Save the modified file(s).

- 5** Rerun the report to see if your changes addressed the issues noted in the messages.

## Adjust Code Analyzer Message Indicators and Messages

Depending on the stage at which you are in completing a MATLAB file, you might want to restrict the code underlining. You can do this by using the Code Analyzer preference referred to in step 1, in “Check Code for Errors and Warnings” on page 21-7. For example, when first coding, you might prefer to underline only errors because warnings would be distracting.

Code analysis does not provide perfect information about every situation and in some cases, you might not want to change the code based on a message. If you do not want to change the code, and you do not want to see the indicator and message for that line, suppress them. For the `lengthofline` example, in line 49, the first message is `Terminate statement with semicolon to suppress output (in functions)`. Adding a semicolon to the end of a statement suppresses output and is a common practice. Code analysis alerts you to lines that produce output, but lack the terminating semicolon. If you want to view output from line 49, do not add the semicolon as the message suggests.

There are a few different ways to suppress (turn off) the indicators for warning and error messages:

- “Suppress an Instance of a Message in the Current File” on page 21-13
- “Suppress All Instances of a Message in the Current File” on page 21-14
- “Suppress All Instances of a Message in All Files” on page 21-15
- “Save and Reuse Code Analyzer Message Settings” on page 21-15

You cannot suppress error messages such as syntax errors. Therefore, instructions on suppressing messages do not apply to those types of messages.

### Suppress an Instance of a Message in the Current File

You can suppress a specific instance of a Code Analyzer message in the current file. For example, using the code presented in “Check Code for Errors and Warnings” on page 21-7, follow these steps:

- 1 In line 49, right-click at the first underline (for a single-button mouse, press **Ctrl**+click).

- 2** From the context menu, select **Suppress 'Terminate statement with semicolon...' > On This Line**.

The comment  `%#ok<NOPRT>` appears at the end of the line, which instructs MATLAB not to check for a terminating semicolon at that line. The underline and mark in the indicator bar for that message disappear.

- 3** If there are two messages on a line that you do not want to display, right-click separately at each underline and select the appropriate entry from the context menu.

The  `%#ok` syntax expands. For the example, in the code presented in “Check Code for Errors and Warnings” on page 21-7, ignoring both messages for line 49 adds  `%#ok<NBRAK, NOPRT>`.

Even if Code Analyzer preferences are set to enable this message, the specific instance of the message suppressed in this way does not appear because the  `%#ok` takes precedence over the preference setting. If you later decide you want to check for a terminating semicolon at that line, delete the  `%#ok<NOPRT>` string from the line.

### **Suppress All Instances of a Message in the Current File**

You can suppress all instances of a specific Code Analyzer message in the current file. For example, using the code presented in “Check Code for Errors and Warnings” on page 21-7, follow these steps:

- 1** In line 49, right-click at the first underline (for a single-button mouse, press **Ctrl+click**).
- 2** From the context menu, select **Suppress 'Terminate statement with semicolon...' > In This File**.

The comment  `%#ok<*NOPRT>` appears at the end of the line, which instructs MATLAB to not check for a terminating semicolon throughout the file. All underlines, as well as marks in the message indicator bar that correspond to this message disappear.

If there are two messages on a line that you do not want to display anywhere in the current file, right-click separately at each underline, and then select the appropriate entry from the context menu. The  `%#ok` syntax expands. For



the example, in the code presented in “Check Code for Errors and Warnings” on page 21-7, ignoring both messages for line 49 adds  `%#ok<*NBRAK, *NOPRT>`.

Even if Code Analyzer preferences are set to enable this message, the message does not appear because the  `%#ok` takes precedence over the preference setting. If you later decide you want to check for a terminating semicolon in the file, delete the  `%#ok<*NOPRT>` string from the line.


### Suppress All Instances of a Message in All Files

You can disable all instances of a Code Analyzer message in all files. For example, using the code presented in “Check Code for Errors and Warnings” on page 21-7, follow these steps:

- 1 In line 49, right-click at the first underline (for a single-button mouse, press **Ctrl**+click).
- 2 From the context menu, select **Suppress 'Terminate statement with semicolon...' > In All Files**.

This modifies the Code Analyzer preference setting.

If you know which message or messages you want to suppress, you can disable them directly using Code Analyzer preferences, as follows:


- 1 On the **Home** tab, in the **Environment** section, click  **Preferences**.
- 2 Select **MATLAB > Code Analyzer**.
- 3 Search the messages to find the ones you want to suppress.
- 4 Clear the check box associated with each message you want to suppress in all files.
- 5 Click **OK**.

### Save and Reuse Code Analyzer Message Settings

You can specify that you want certain Code Analyzer messages enabled or disabled, and then save those settings to a file. When you want to use a settings file with a particular file, you select it from the Code Analyzer

preferences pane. That setting file remains in effect until you select another settings file. Typically, you change the settings file when you have a subset of files for which you want to use a particular settings file.


Follow these steps:

- 1 On the **Home** tab, in the **Environment** section, click  **Preferences**.

The Preferences dialog box opens.

- 2 Select **MATLAB > Code Analyzer**.

- 3 Enable or disable specific messages, or categories of messages.

- 4 Click the Actions button , select **Save as**, and then save the settings to a txt file.

- 5 Click **OK**.

You can reuse these settings for any MATLAB file, or provide the settings file to another user.

To use the saved settings:

- 1 On the **Home** tab, in the **Environment** section, click  **Preferences**.

The Preferences dialog box opens.

- 2 Select **MATLAB > Code Analyzer**.

- 3 Use the Active Settings drop-down list to select **Browse...**

The Open dialog box appears.

- 4 Choose from any of your settings files.


The settings you choose are in effect for all MATLAB files until you select another set of Code Analyzer settings.

## Understand Code Containing Suppressed Messages

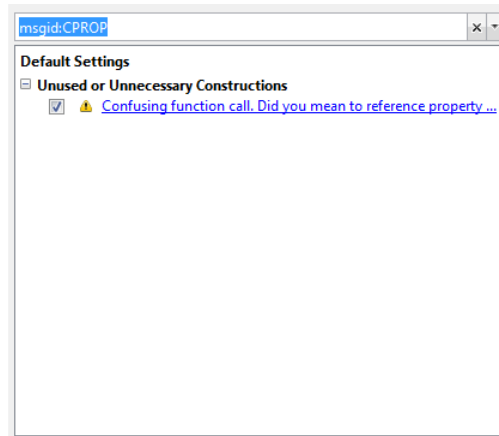
If you receive code that contains suppressed messages, you might want to review those messages without the need to unsuppress them first. A message might be in a suppressed state for any of the following reasons:

- One or more  `%#ok<message-ID>` directives are on a line of code that elicits a message specified by `<message-ID>`.
- One or more  `%#ok<*message-ID>` directives are in a file that elicits a message specified by `<message-ID>`.
- It is cleared in the Code Analyzer preferences pane.
- It is disabled by default.

To determine the reasons why some messages are suppressed:

- 1** Search the file for the  `%#ok` directive and create a list of all the message IDs associated with that directive.
- 2** On the **Home** tab, in the **Environment** section, click  **Preferences**.  
The Preferences dialog box opens.
- 3** Select **MATLAB > Code Analyzer**.
- 4** In the search field, type `msgid:` followed by one of the message IDs, if any, you found in step 1.

The message list now contains only the message that corresponds to that ID. If the message is a hyperlink, click it to see an explanation and suggested action for the message. This can provide insight into why the message is suppressed or disabled. The following image shows how the Preferences dialog box appears when you enter `msgid:CPROP` in the search field.



- 5 Click the  button to clear the search field, and then repeat step 4 for each message ID you found in step 1.
- 6 Display messages that are disabled by default and disabled in the Preferences pane by clicking the down arrow to the right of the search field. Then, click **Show Disabled Messages**.
- 7 Review the message associated with each message ID to understand why it is suppressed in the code or disabled in Preferences.

## Understand the Limitations of Code Analysis

Code analysis is a valuable tool, but there are some limitations:

- Sometimes, it fails to produce Code Analyzer messages where you expect them.

By design, code analysis attempts to minimize the number of incorrect messages it returns, even if this behavior allows some issues to go undetected.

- Sometimes, it produces messages that do not apply to your situation.

When provided with message, click the **Detail** button for additional information, which can help you to make this determination. Error messages are almost always problems. However, many warnings are

suggestions to look at something in the code that is unusual and therefore suspect, but might be correct in your case.

Suppress a warning message if you are certain that the message does not apply to your situation. If your reason for suppressing a message is subtle or obscure, include a comment giving the rationale. That way, those who read your code are aware of the situation.

For details, see “Adjust Code Analyzer Message Indicators and Messages” on page 21-13.

These sections describe code analysis limitations with respect to the following:

- “Distinguish Function Names from Variable Names” on page 21-19
- “Distinguish Structures from Handle Objects” on page 21-20
- “Distinguish Built-In Functions from Overloaded Functions” on page 21-21
- “Determine the Size or Shape of Variables” on page 21-21
- “Analyze Class Definitions with Superclasses” on page 21-21
- “Analyze Class Methods” on page 21-21

## **Distinguish Function Names from Variable Names**

Code analysis cannot always distinguish function names from variable names. For the following code, if the Code Analyzer message is enabled, code analysis returns the message, Code Analyzer cannot determine whether xyz is a variable or a function, and assumes it is a function. Code analysis cannot make a determination because xyz has no obvious value assigned to it. However, the program might have placed the value in the workspace in a way that code analysis cannot detect.

```
function y=foo(x)
    .
    .
    .
    y = xyz(x);
end
```

For example, in the following code, `xyz` can be a function, or can be a variable loaded from the MAT-file. Code analysis has no way of making a determination.

```
function y=foo(x)
    load abc.mat
    y = xyz(x);
end
```

Variables might also be undetected by code analysis when you use the `eval`, `evalc`, `evalin`, or `assignin` functions.

If code analysis mistakes a variable for a function, do one of the following:

- Initialize the variable so that code analysis does not treat it as a function.
- For the `load` function, specify the variable name explicitly in the `load` command line. For example:

```
function y=foo(x)
    load abc.mat xyz
    y = xyz(x);
end
```

### **Distinguish Structures from Handle Objects**

Code analysis cannot always distinguish structures from handle objects. In the following code, if `x` is a structure, you might expect a Code Analyzer message indicating that the code never uses the updated value of the structure. If `x` is a handle object, however, then this code can be correct.

```
function foo(x)
    x.a = 3;
end
```

Code analysis cannot determine whether `x` is a structure or a handle object. To minimize the number of incorrect messages, code analysis returns no message for the previous code, even though it might contain a subtle and serious bug.

## **Distinguish Built-In Functions from Overloaded Functions**

Code analysis does not use the MATLAB path information because it can be different, depending on whether you are editing or running the program. If some built-in functions are overloaded in a class or on the path, Code Analyzer messages might apply to the built-in function, but not to the overloaded function you are calling. In this case, suppress the message on the line where it appears or suppress it for the entire file.

For information on suppressing messages, see “Adjust Code Analyzer Message Indicators and Messages” on page 21-13.

## **Determine the Size or Shape of Variables**

Code analysis has a limited ability to determine the type of variables and the shape of matrices. Code analysis might produce messages that are appropriate for the most common case, such as for vectors. However, these messages might be inappropriate for less common cases, such as for matrices.

## **Analyze Class Definitions with Superclasses**

Because code analysis looks at one file at a time and does not use the path, it has no way to analyze superclasses. Therefore, the amount of checking that code analysis can provide for a class definition with superclasses is limited. In general, code analysis cannot always tell whether the class is a handle class. It makes an educated guess, but often cannot get enough information, to make a determination for certain.


## **Analyze Class Methods**

Most class methods must contain at least one argument that is an object of the same class as the method. But it does not always have to be the first argument. When it is, code analysis can determine that an argument is an object of the class you are defining, and it can do various checks. For example, it can check that the property and method names exist and are spelled correctly. However, when code analysis cannot determine that an object is an argument of the class you are defining, then it cannot provide these checks.

## Enable MATLAB Compiler Deployment Messages

You can switch between showing or hiding Compiler deployment messages when you work on a file. Change the Code Analyzer preference for this message category. Your choice likely depends on whether you are working on a file to be deployed. When you change the preference, it also changes the setting in the Editor. The converse is also true—when you change the setting from the Editor, it effectively changes this preference. However, if the dialog box is open at the time you modify the setting in the Editor, you will not see the changes reflected in the Preferences dialog box. Whether you change the setting from the Editor or from the Preferences dialog box, it applies to the Editor and to the Code Analyzer Report.

To enable MATLAB Compiler™ deployment messages:

- 1** On the **Home** tab, in the **Environment** section, click  **Preferences**.  
The Preferences dialog box opens.
- 2** Select **MATLAB > Code Analyzer**.
- 3** Click the down arrow next to the search field, and then select **Show Messages in Category > MATLAB Compiler (Deployment) Messages**.
- 4** Click the **Enable Category** button.
- 5** Clear individual messages that you do not want to display for your code (if any).
- 6** Decide if you want to save these settings, so you can reuse them next time you work on a file to be deployed.

The settings.txt file, which you can create as described in “Save and Reuse Code Analyzer Message Settings” on page 21-15, includes the status of this setting.



# Improve Code Readability

## In this section...

“Indenting Code” on page 21-23

“Right-Side Text Limit Indicator” on page 21-25

“Code Folding — Expand and Collapse Code Constructs” on page 21-25

## Indenting Code

Indenting code makes reading statements such as `while` loops easier. To set and apply indenting preferences to code in the Editor:

- 1 On the **Home** tab, in the **Environment** section, click  **Preferences**.

The Preferences dialog box opens.

- 2 Select **MATLAB > Editor/Debugger > Language**.

- 3 Choose a computer language from the Language drop-down list.

- 4 In the **Indenting** section, select or clear **Apply smart indenting while typing**, depending on whether you want indenting applied automatically, as you type.

If you clear this option, you can manually apply indenting by selecting the lines in the Editor to indent, right-clicking, and then selecting **Smart Indent** from the context menu.

- 5 Do one of the following:

- If you chose any language other than **MATLAB** in step 2, click **OK**.
- If you chose **MATLAB** in step 2, select a **Function indenting format**, and then click **OK**. Function indent formats are:
  - **Classic** — The Editor aligns the function code with the function declaration.
  - **Indent nested functions** — The Editor indents the function code within a nested function.

- Indent all functions — The Editor indents the function code for both main and nested functions.

The following image illustrates the function indenting formats.




```
1  % Indenting Preferences
2
3  % Classic
4  function classic_one
5 - disp('Main function code')
6      function classic_two
7 -     disp('Nested function code')
8 -     end
9 - end
10
11 % Indent Nested Functions
12 function nested_one
13 - disp('Main function code')
14     function nested_two
15 -     disp('Nested function code')
16 -     end
17 - end
18
19 % Indent All Functions
20 function all_one
21 -     disp('Main function code')
22     function all_two
23 -     disp('Nested function code')
24 -     end
25 - end
26 |
```

---

**Note** Indenting preferences are not available for TLC, VHDL, or Verilog.

---

Regardless of whether you apply indenting automatically or manually, you can move selected lines further to the left or right, by doing one of the following:

- On the **Editor** tab, in the **Edit** section, click , , or .
- Pressing the **Tab** key or the **Shift+Tab** key, respectively.


This works differently if you select the Editor/Debugger **Tab** preference for **Emacs-style Tab key smart indenting**—when you position the cursor in

any line or select a group of lines and press **Tab**, the lines indent according to smart indenting practices.

## Right-Side Text Limit Indicator

By default, a light gray vertical line (rule) appears at column 75 in the Editor, indicating where a line exceeds 75 characters. You can set this text limit indicator to another value, which is useful, for example, if you want to view the code in another text editor that has a different line width limit.

To hide, or change the appearance of the vertical line:

- 1 On the **Home** tab, in the **Environment** section, click  **Preferences**.

The Preferences dialog box opens.

- 2 Select **MATLAB > Editor/Debugger > Display**.

- 3 Adjust the settings in the **Right-hand text limit** section.

---

**Note** This limit is a visual cue only and does not prevent text from exceeding the limit. To wrap comment text at a specified column number automatically, adjust the settings in the **Comment formatting** section under **MATLAB > Editor/Debugger > Language** in the Preferences dialog box.

---

## Code Folding – Expand and Collapse Code Constructs

Code folding is the ability to expand and collapse certain MATLAB programming constructs. This improves readability when a file contains numerous functions or other blocks of code that you want to hide when you are not currently working with that part of the file. MATLAB programming constructs include:

- Code sections for running and publishing code
- Class code
- For and parfor blocks
- Function and class help

- Function code

To see the entire list of constructs, select **Editor/Debugger > Code Folding** in the Preferences dialog box.

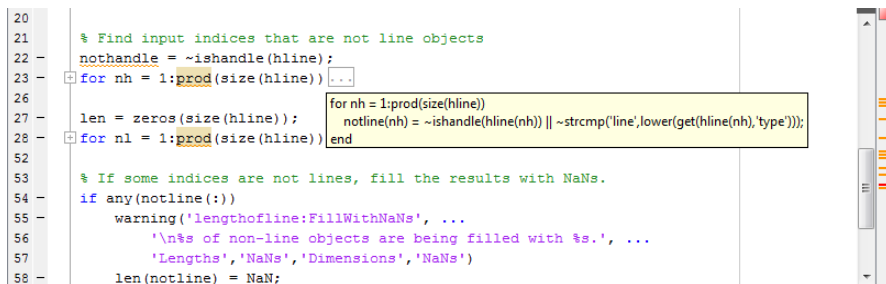
To expand or collapse code, click the plus  $\oplus$  or minus sign  $\ominus$  that appears to the left of the construct in the Editor.

To expand or collapse all of the code in a file, place your cursor anywhere within the file, right-click, and then select **Code Folding > Expand All** or **Code Folding > Fold All** from the context menu.

### View Folded Code in a Tooltip

You can view code that is currently folded by positioning the pointer over its ellipsis  $\dots$ . The code appears in a tooltip.

The following image shows the tooltip that appears when you place the pointer over the ellipsis on line 23 of `lengthofline.m` when a `for` loop is folded.



```

20
21 % Find input indices that are not line objects
22 - nothandle = ~ishandle(hline);
23 - for nh = 1:prod(size(hline)) ...
26
27 - len = zeros(size(hline));
28 - for nl = 1:prod(size(hline))
52
53 % If some indices are not lines, fill the results with NaNs.
54 - if any(notline(:))
55 -     warning('lengthofline:FillWithNaNs', ...
56 -         '\n%s of non-line objects are being filled with %s.', ...
57 -         'Lengths', 'NaNs', 'Dimensions', 'NaNs')
58 -     len(notline) = NaN;
  
```

The tooltip displays the code for the folded `for` loop on line 23:

```

for nh = 1:prod(size(hline))
    notline(nh) = ~ishandle(hline(nh)) || ~strcmp('line', lower(get(hline(nh), 'type')));
end
  
```

### Print Files with Collapsed Code

If you print a file with one or more collapsed constructs, those constructs are expanded in the printed version of the file.

### Code Folding Behavior for Functions that Have No Explicit End Statement

If you enable code folding for functions and a function in your code does not end with an explicit `end` statement, you see the following behavior:

- If a line containing only comments appears at the end of such a function, then the Editor does not include that line when folding the function. MATLAB does not include trailing white space and comments in a function definition that has no explicit end statement.

Code Folding Enabled for Function Code Only on page 21-27 illustrates this behavior. Line 13 is excluded from the fold for the `foo` function.

- If a fold for a code section overlaps the function code, then the Editor does not show the fold for the overlapping section.

The three figures that follow illustrate this behavior. The first two figures, Code Folding Enabled for Function Code Only on page 21-27 and Code Folding Enabled for Cells Only on page 21-28 illustrate how the code folding appears when you enable it for function code only and then section only, respectively. The last figure, Code Folding Enabled for Both Functions and Cells on page 21-29, illustrates the effects when code folding is enabled for both. Because the fold for section 3 (lines 11–13) overlaps the fold for function `foo` (lines 4–12), the Editor does not display the fold for section 3.

```

1  [ ] function main
2     disp function main | % end of function main
3
4  [ ] function foo
5     %% section 1
6     disp section 1
7     % end of cell 1
8     %% section 2
9     disp section2
10    % end of cell 2
11    %% section 3
12    disp section 3      % end of function foo
13    % end of cell 3
14
15 [ ] function bar
16    disp 'function bar' % end of function bar
17

```

**Code Folding Enabled for Function Code Only**

```
1  function main
2  disp function main % end of function main
3
4  function foo
5  %% section 1
6  disp section 1
7  % end of cell 1
8  %% section 2
9  disp section2
10 % end of cell 2
11 %% section 3
12 disp section 3 % end of function foo
13 % end of cell 3
14
15 function bar
16 disp 'function bar' % end of function bar
17
```

**Code Folding Enabled for Cells Only**


```
1  function main
2  disp function main % end of function main
3
4  function foo
5  %% section 1
6  disp section 1
7  % end of cell 1
8  %% section 2
9  disp section2
10 % end of cell 2
11 %% section 3
12 disp section 3 % end of function foo
13 % end of cell 3
14
15 function bar
16 disp 'function bar' % end of function bar
17
```

**Code Folding Enabled for Both Functions and Cells**

## Find and Replace Text in Files

In this section...
“Find Any Text in the Current File” on page 21-30
“Find and Replace Functions or Variables in the Current File” on page 21-30
“Automatically Rename All Functions or Variables in a File” on page 21-32
“Find and Replace Any Text” on page 21-34
“Find Text in Multiple File Names or Files” on page 21-34
“Function Alternative for Finding Text” on page 21-34
“Perform an Incremental Search in the Editor” on page 21-34

### Find Any Text in the Current File

- 1 Within the current file, select the text you want to find.
- 2 On the **Editor** tab, in the **Navigate** section, click  Find ↕, and then select **Find...**

A Find & Replace dialog box opens.

- 3 Click **Find Next** to continue finding more occurrences of the text.

To find the previous occurrence of selected text (find backwards) in the current file, click **Find Previous** on the Find & Replace dialog box.

### Find and Replace Functions or Variables in the Current File

To search for references to a particular function or variable, use the automatic highlighting feature for variables and functions. This feature is more efficient than using the text finding tools. Function and variable highlighting indicates only references to a particular function or variable, not other occurrences. For instance, it does not find instances of the function or variable name in comments. Furthermore, variable highlighting only includes references to



the *same* variable. That is, if two variables use the same name, but are in different scopes, highlighting one does not cause the other to highlight.

- 1 On the **Home** tab, in the **Environment** section, click  **Preferences**.

The Preferences dialog box opens.

- 2 Select **MATLAB > Colors > Programming Tools**.

- 3 Under **Variable and function colors**, select **Automatically highlight**, deselect **Variables with shared scope**, and then click **Apply**.

- 4 In a file open in the Editor, click an instance of the variable you want to find throughout the file.

MATLAB indicates all occurrences of that variable within the file by:

- Highlighting them in teal blue (by default) throughout the file
- Adding a marker for each in the indicator bar

If a code analyzer indicator and a variable indicator appear on the same line in a file, the marker for the variable takes precedence.

- 5 Hover over a marker in the indicator bar to see the line it represents.

- 6 Click a marker in the indicator bar to navigate to that occurrence of the variable.

Replace an instance of a function or variable by editing the occurrence at a line to which you have navigated.

The following image shows an example of how the Editor looks with variable highlighting enabled. In this image, the variable `i` appears highlighted in sky blue, and the indicator bar contains three variable markers.

```

1  function rowTotals = rowsum
2  % Add the values in each row and
3  % store them in a new array.
4
5  x = ones(2,10);
6  [n, m] = size(x);
7  rowTotals = zeros(1,n);
8  for i = 1:n
9      rowTotals(i) = addToSum;
10 end
11
12 function colsum = addToSum
13     colsum = 0;
14     thisrow = x(i,:);
15     for i = 1:m
16         colsum = colsum + thisrow(i);
17     end
18 end
19
20 end

```

## Automatically Rename All Functions or Variables in a File

To help prevent typographical errors, MATLAB provides a feature that helps rename multiple references to a function or variable within a file when you manually change any of the following:

Function or Variable Renamed	Example
Function name in a function declaration	Rename foo in: function foo(m)
Input or output variable name in a function declaration	Rename y or m in: function y = foo(m)
Variable name on the left side of assignment statement	Rename y in: y = 1

As you rename such a function or variable, a tooltip opens if there is more than one reference to that variable or function in the file. The tooltip indicates

that MATLAB will rename all instances of the function or variable in the file when you press **Shift + Enter**.

```

1  function rowTotals = rowsum
2  % Add the values in each row and
3  % store them in a new array.
4
5  x = ones(2,10);
6  [n, m] = size(x);
7  rowTotals = zeros(1,n);
8  for j = 1:n
9
10     end
11
12     function colsum = addToSum
13         colsum = 0;
14         thisrow = x(i,:);
15         for i = 1:m
16             colsum = colsum + thisrow(i);
17         end
18     end
19
20 end

```


Press Shift+Enter to rename 5 instances of "i" to "j"

Typically, multiple references to a function appear when you use nested functions or local functions.


---

**Note** MATLAB does *not* prompt you when you change:

- The name of a global variable.
  - The function input and output arguments, `varargin` and `varargout`.
- 

To undo automatic name changes, click  once.


By default, this feature is enabled. To disable it:

- 1 On the **Home** tab, in the **Environment** section, click  **Preferences**.


The Preferences dialog box opens.

- 2 Select **MATLAB > Editor/Debugger > Language**.
- 3 In the **Language** field, select **MATLAB**.
- 4 Clear **Enable automatic variable and function renaming**.

### Find and Replace Any Text

You can search for, and optionally replace specified text within a file. On the **Editor** tab, in the **Navigate** section, click  **Find** to open and use the Find & Replace dialog box.

### Find Text in Multiple File Names or Files

You can find folders and file names that include specified text, or whose contents contain specified text. On the **Editor** tab, in the **File** section, click  **Find Files** to open the Find Files dialog box. For details, see “Find Files and Folders”.

### Function Alternative for Finding Text

Use `lookfor` to search for the specified text in the first line of help for all files with the `.m` extension on the search path.

### Perform an Incremental Search in the Editor



When you perform an incremental search, the cursor moves to the next or previous occurrence of the specified text in the current file. It is similar to the Emacs search feature. In the Editor, incremental search uses the same controls as incremental search in the Command Window. For details, see “Incremental Search Using Keyboard Shortcuts”.



## Go To Location in File




In this section...
“Navigate to a Specific Location” on page 21-35
“Set Bookmarks” on page 21-39
“Navigate Backward and Forward in Files” on page 21-39
“Open a File or Variable from Within a File” on page 21-40






### Navigate to a Specific Location

This table summarizes the steps for navigating to a specific location within a file open in the Editor. In some cases, different sets of steps are available for navigating to a particular location. Choose the set that works best with your workflow.

Go To	Steps	Notes
<b>Line Number</b>	<ol style="list-style-type: none"> <li>1 On the <b>Editor</b> tab, in the <b>Navigate</b> section, click  <b>Go To</b></li> <li>2 Select <b>Go to Line...</b></li> <li>3 Specify the line to which you want to navigate.</li> </ol>	None
<b>Function definition</b>	<ol style="list-style-type: none"> <li>1 On the <b>Editor</b> tab, in the <b>Navigate</b> section, click  <b>Go To</b></li> <li>2 Under the heading <b>Function</b>, select the local function or nested function to which you want to navigate.</li> </ol>	<p>Includes local functions and nested functions</p> <p>For both class and function files, the functions list in alphabetical order—except that in function files, the name of the main function always appears at the top of the list.</p>

Go To	Steps	Notes
	<ol style="list-style-type: none"><li data-bbox="397 331 836 427">1 In the Current Folder browser, click the name of the file open in the Editor.</li><li data-bbox="397 453 836 548">2 Click the up arrow  at the bottom of Current Folder browser to open the detail panel.</li><li data-bbox="397 574 836 739">3 In the detail panel, double-click the function icon  corresponding to the title of the function or local function to which you want to navigate.</li></ol>	Functions list in order of appearance within your file.

Go To	Steps	Notes
<b>Function reference</b>	<ol style="list-style-type: none"> <li><b>1</b> Click in any instance of the function name.</li> <li><b>2</b> Press <b>Alt+Up</b> or <b>Alt+Down</b> to go to the next or previous function reference, respectively.</li> </ol>	<p><b>Alt+Up</b> and <b>Alt+Down</b> are the default keyboard shortcuts for the actions <b>Go to Previous Underline or Highlight</b> or <b>Go to Next Underline or Highlight</b>, respectively.</p> <p>For more information, see “Define Keyboard Shortcuts”.</p>
<b>Variable reference</b>	<ol style="list-style-type: none"> <li><b>1</b> Click in any instance of the variable name.</li> <li><b>2</b> Press <b>Alt+Up</b> or <b>Alt+Down</b> to go to the next or previous variable reference, respectively.</li> </ol>	
<b>Code Analyzer Message</b>	Press <b>Alt+Up</b> or <b>Alt+Down</b> to go to the next or previous code analyzer message, respectively.	
<b>Code Section</b>	<ol style="list-style-type: none"> <li><b>1</b> On the <b>Editor</b> tab, in the <b>Navigate</b> section, click  <b>Go To</b></li> <li><b>2</b> Under <b>Sections</b>, select the title of the code section to which you want to navigate.</li> </ol>	<p>For more information, see “Divide Your File into Code Sections” on page 16-6</p>
	<ol style="list-style-type: none"> <li><b>1</b> In the Current Folder browser, click the name of the file that is open in the Editor.</li> <li><b>2</b> Click the up arrow  at the bottom of Current Folder browser to open the detail panel.</li> <li><b>3</b> In the detail panel, double-click the section icon  corresponding</li> </ol>	


Go To	Steps	Notes
	to the title of the section to which you want to navigate.	
<b>Property</b>	<ol style="list-style-type: none"> <li><b>1</b> In the Current Folder browser, click the name of the file that is open in the Editor.</li> <li><b>2</b> Click the up arrow  at the bottom of Current Folder browser to open the detail panel.</li> <li><b>3</b> On the detail panel, double-click the property icon  corresponding to the name of the property to which you want to navigate.</li> </ol>	For more information, see “How to Use Properties”
<b>Method</b>	<ol style="list-style-type: none"> <li><b>1</b> In the Current Folder browser, click the name of the file that is open in the Editor.</li> <li><b>2</b> Click the up arrow  at the bottom of Current Folder browser to open the detail panel.</li> <li><b>3</b> In the detail panel, double-click the icon  corresponding to the name of the method to which you want to navigate.</li> </ol>	For more information, see “How to Use Methods”
<b>Bookmark</b>	<ol style="list-style-type: none"> <li><b>1</b> On the <b>Editor</b> tab, in the <b>Navigate</b> section, click  <b>Go To</b>.</li> <li><b>2</b> Under <b>Bookmarks</b>, select the bookmark to which you want to navigate.</li> </ol>	For information on setting and clearing bookmarks, see “Set Bookmarks” on page 21-39.




## Set Bookmarks

You can set a bookmark at any line in a file in the Editor so you can quickly navigate to the bookmarked line. This is particularly useful in long files. For example, suppose while working on a line, you want to look at another part of the file, and then return. Set a bookmark at the current line, go to the other part of the file, and then use the bookmark to return.

To set a bookmark:



- 1 Position the cursor anywhere on the line.
- 2 On the **Editor** tab, in the **Navigate** section, click  **Go To ▾**.
- 3 Under **Bookmarks**, select **Set/Clear**

A bookmark icon  appears to the left of the line.

To clear a bookmark, position the cursor anywhere on the line. Click  **Go To ▾** and select **Set/Clear** under **Bookmarks**.



MATLAB does not maintain bookmarks after you close a file.

## Navigate Backward and Forward in Files

To access lines in a file in the same sequence that you previously navigated or edited them, use  and .

### Interrupting the Sequence of Go Back and Go Forward




The back and forward sequence is interrupted if you:



- 1 Click .
- 2 Click .
- 3 Edit a line or navigate to another line using the list of features described in “Navigate to a Specific Location” on page 21-35.

You can still go to the lines preceding the interruption point in the sequence, but you cannot go to any lines after that point. Any lines you edit or navigate

to after interrupting the sequence are added to the sequence after the interruption point.

For example:

- 1 Open a file.
- 2 Edit line 2, line 4, and line 6.
- 3 Click  to return to line 4, and then to return to line 2.
- 4 Click  to return to lines 4 and 6.
- 5 Click  to return to line 1.
- 6 Edit at 3.

This interrupts the sequence. You can no longer use  to return to lines 4 and 6. You can, however, click  to return to line 1.

## Open a File or Variable from Within a File

You can open a function, file, variable, or Simulink model from within a file in the Editor. Position the cursor on the name, and then right-click and select **Open selection** from the context menu. Based on what the selection is, the Editor performs a different action, as described in this table.

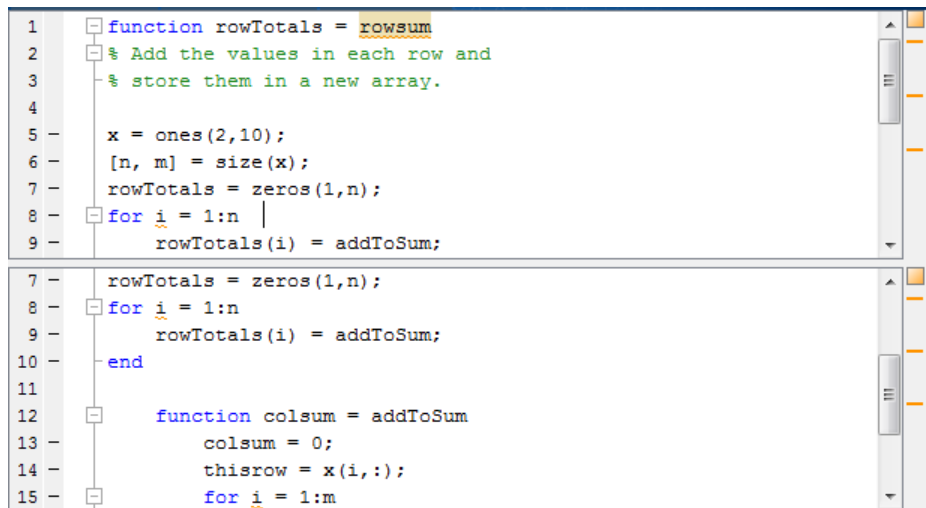
Item	Action
Local function	Navigates to the local function within the current file, if that file is a MATLAB code file. If no function by that name exists in the current file, the Editor runs the <code>open</code> function on the selection, which opens the selection in the appropriate tool.
Text file	Opens in the Editor.
Figure file (.fig)	Opens in a figure window.

<b>Item</b>	<b>Action</b>
MATLAB variable that is in the current workspace	Opens in the Variables Editor.
Model	Opens in Simulink.
Other	If the selection is some other type, <b>Open selection</b> looks for a matching file in a private folder in the current folder and performs the appropriate action.

## Display Two Parts of a File Simultaneously

You can simultaneously display two different parts of a file in the Editor by splitting the screen display, as shown in the image that follows. This feature makes it easy to compare different lines in a file or to copy and paste from one part of a file to another.

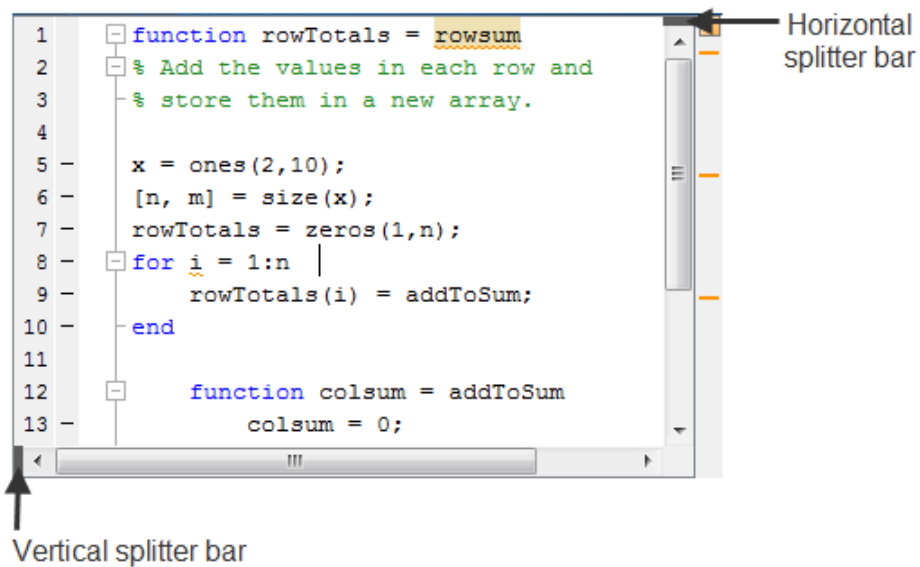
See also “Document Layout” for instructions on displaying multiple documents simultaneously.



```
1  function rowTotals = rowsum
2  % Add the values in each row and
3  % store them in a new array.
4
5  x = ones(2,10);
6  [n, m] = size(x);
7  rowTotals = zeros(1,n);
8  for i = 1:n
9      rowTotals(i) = addToSum;
7  rowTotals = zeros(1,n);
8  for i = 1:n
9      rowTotals(i) = addToSum;
10 end
11
12 function colsum = addToSum
13     colsum = 0;
14     thisrow = x(i,:);
15     for i = 1:m
```

The following table describes the various ways you can split the Editor and manipulate the split-screen views. When you open a document, it opens unsplit, regardless of its split status it had when you closed it.

<b>Operation</b>	<b>Instructions</b>
Split the screen horizontally.	<p>Do either of the following:</p> <ul style="list-style-type: none"> <li>• Right-click and, select <b>Split Screen &gt; Top/Bottom</b> from the Context Menu.</li> <li>• If there is a vertical scroll bar, as shown in the illustration that follows, drag the splitter bar down.</li> </ul>
Split the screen vertically.	<p>Do either of the following:</p> <ul style="list-style-type: none"> <li>• From the Context Menu, select <b>Split Screen &gt; Left/Right</b>.</li> <li>• If there is a horizontal scroll bar, as shown in the illustration that follows, drag the splitter bar from the left of the scroll bar.</li> </ul>
Specify the active view.	<p>Do either of the following:</p> <ul style="list-style-type: none"> <li>• From the Context Menu, select <b>Split Screen &gt; Switch Focus</b>.</li> <li>• Click in the view you want to make active.</li> </ul> <p>Updates you make to the document in the active view are also visible in the other view.</p>
Remove the splitter	<p>Do one of the following:</p> <ul style="list-style-type: none"> <li>• Double-click the splitter.</li> <li>• From the Context Menu, <b>Split Screen &gt; Off</b>.</li> </ul>



## Add Reminders to Files

Annotating a file makes it easier to find areas of your code that you intend to improve, complete, or update later.

To annotate a file, add comments with the text TODO, FIXME, or a string of your choosing.

After you annotate several files, run the TODO/FIXME Report, to identify all the MATLAB code files within a given folder that you have annotated.

This sample TODO/FIXME Report shows files containing the strings TODO, FIXME, and NOTE. The search is case insensitive.

**TODO/FIXME Report**

The TODO/FIXME Report shows MATLAB files that contain the text strings selected below ([Learn More](#)).

TODO  FIXME

Report for folder H:\Documents\MATLAB debugging

**MATLAB File List**

<a href="#">collatz</a>	<p>2 Collatz problem. Generate a sequence of integers resolving to 1</p> <p>3 For any positive integer, n:</p> <p>4 Divide n by 2 if n is even</p> <p>5 Multiply n by 3 and add 1 if n is odd</p> <p>6 Repeat for the result</p> <p>7 Continue until the result is 1%</p>
<a href="#">collatzplot</a>	<p>2 Plot length of sequence for Collatz problem</p> <p>3 Prepare figure</p> <p>6</p> <p>7 Determine and plot sequence and sequence length</p> <p>14 This M-file has an intentional error at line 10 to demonstrate debugging.</p> <p>15 The plot_seq variable should be seq_length(N).</p>

## Working with TODO/FIXME Reports

- 1 Use the Current Folder browser to navigate to the folder containing the files for which you want to produce a TODO/FIXME report.

---

**Note** You cannot run reports when the path is a UNC (Universal Naming Convention) path; that is, a path that starts with \\\. Instead, use an actual hard drive on your system, or a mapped network drive.

---

- 2** On the Current Folder browser, click , and then select **Reports > TODO/FIXME Report**.

The TODO/FIXME Report opens in the MATLAB Web Browser.

- 3** In the TODO/FIXME Report window, select one or more of the following to specify the lines that you want the report to include:
  - TODO
  - FIXME
  - The text field check box

You can then enter any text string in this field, including a regular expression. For example, you can enter NOTE, tbd, or re.\*check.

- 4** Run the report on the files in the current folder, by clicking **Rerun This Report**.

The window refreshes and lists all lines in the MATLAB files within the specified folder that contain the strings you selected in step 1. Matches are not case sensitive.

If you want to run the report on a folder other than the one currently specified in the report window, change the current folder. Then, click **Run Report on Current Folder**.

To open a file in the Editor at a specific line, click the line number in the report. Then you can change the file, as needed.

Suppose you have a file, `area.m`, in the current folder. The code for `area.m` appears in the image that follows.



```

1  function [output] = area(flag,radius)
2  % This function calculates the area of the entity
3  % flag = 1 for calculating the area of a
4  % flag = 2 for calculating the surface area of a sphere
5  % radius = radius of the entity
6
7  switch flag
8      % Modify the function to include the area of square
9      % and rectangle. (todo)
10
11     case 1
12         output = pi * radius^2;
13
14     case 2
15         output = 4 * pi * radius^2;
16         % Fixme: is the area of hemisphere as below?
17         % case 3
18         % output = 2 * pi * radius^2;
19         % fixME
20
21     otherwise
22         disp('Incorrect flag');
23         output = NaN;
24         % NOTE: Find out from manager if we need to include
25         % the area of a cone
26
27 end

```

When you run the TODO/FIXME report on the folder containing `area.m`, with the TODO and FIXME strings selected and the string NOTE specified and selected, the report lists:

```

9 and rectangle. (todo)
14 Fixme: Is the area of hemisphere as below?
17 fixME
21 NOTE: Find out from the manager if we need to include

```

<pre> <u>area</u> </pre>	<pre> <u>9</u> and rectangle. (todo) <u>14</u> Fixme: Is the area of hemisphere as below? <u>17</u> fixME <u>21</u> NOTE: Find out from the manager if we need to include </pre>
--------------------------	--

Notice the report includes the following:

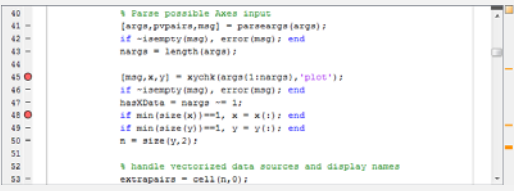

- Line 9 as a match for the TODO string. The report includes lines that have a selected string regardless of its placement within a comment.
- Lines 14 and 17 as a match for the FIXME string. The report matches selected strings in the file regardless of their casing.

- Line 21 as a match for the NOTE string. The report includes lines that have a string specified in the text field, assuming that you select the text field.

## Colors in the MATLAB Editor

Colors in the Editor help you to read code, identify code elements, and evaluate sections of code. To find out why certain portions of your code appear in color, how to change the color, or learn more about the features highlighted in color, see the table that follows.

Sample (Using Default Colors)	What the Color Indicates
<pre data-bbox="140 564 615 720"> %create a file for output ! touch testFile.txt fid = fopen('testFile.txt', 'w'); for i = 1:10     fprintf(fid, '%6.2f \n', i); end </pre>	<p>Different types of language elements, such as keywords, comments, and strings appear in different colors. This is called <i>syntax highlighting</i>.</p> <p>See also, “Syntax Highlighting”</p>
<pre data-bbox="140 789 675 1058"> function test(input) persistent multifactor; multifactor = multifactor +1;  a_var = nestedfunction(multifactor) unused_var = a_var; function out = nestedfunction(factor)     out=input*factor; end end </pre>	<p>Teal blue characters indicate variables with shared scope</p> <p>Sky blue shading indicates function or variable names that match the name in which the cursor is currently placed.</p> <p>See also, “Check Variable Scope in Editor” on page 17-15.</p>
<pre data-bbox="140 1128 690 1380"> if isempty(data{3}) ...     (length(unique(data{1}(:)))==1) ...     (length(unique(data{2}(:)))==1) ...     (length(unique(data{3}(:)))==1) ...     data{3} = zeros(size(data{1}));     dim(n1) = 2; else     dime(n1) = 3; end </pre>	<p>Orange and red wavy underlines indicate warning and error conditions, respectively.</p> <p>Orange shading indicates coding issues that MATLAB can correct for you.</p> <p>See also, “Check Code for Errors and Warnings” on page 21-7</p>

Sample (Using Default Colors)	What the Color Indicates
<pre> %% Plot Sine Wave % Calculate and plot a sine wave. %% Calculate and Plot Sine Wave % Define the range for x. % % \$\$\$00&lt;= x &lt;= pi\$\$ % % Calculate and plot y = sin(x). x = 0:0.125:6*pi; y = sin(x); plot(x,y) %% Modify Plot Properties % Add labels and set colors. </pre>	<p>Yellow highlighting indicates code sections, which:</p> <ul style="list-style-type: none"> <li>• Help you visually identify subsections of code</li> <li>• Enable you to publish and run subsections of code.</li> </ul> <p>See also, “Divide Your File into Code Sections” on page 16-6</p>
 <pre> 40 % Pass possible Axes input 41 [args,propairs,mgp] = parseargs(args); 42 if ~isempty(mgp), error(mgp); end 43 nargs = length(args); 44 45 [mgp,x,y] = xyzmk(args(1:nargs),'plot'); 46 if ~isempty(mgp), error(mgp); end 47 baseNData = nargs - 1; 48 if min(size(x))==1, x = x(:); end 49 if min(size(y))==1, y = y(:); end 50 n = size(y,2); 51 52 % handle vectorized data sources and display names 53 extrapairs = cell(n,0); </pre>	<p>Red dots represent breakpoints, which you use in debugging.</p> <p>If you attempt to run your code, MATLAB stops at the first breakpoint it encounters.</p> <p>See also, “Debugging Process and Features” on page 19-2</p>
	<p>A gray vertical line indicates the location of a particular column in the Editor that you can use to limit line widths.</p> <p>The Editor does not enforce the limit.</p> <p>See also, “Right-Side Text Limit Indicator” on page 21-25</p>

## **Code Contains %#ok – What Does That Mean?**

If code contains the string %#ok at the end of a line of code, it indicates that one or more Code Analyzer messages is suppressed. For more information, see “Understand Code Containing Suppressed Messages” on page 21-17.

## MATLAB Code Analyzer Report

### In this section...

“Running the Code Analyzer Report” on page 21-52

“Changing Code Based on Code Analyzer Messages” on page 21-54

“Other Ways to Access Code Analyzer Messages” on page 21-55


### Running the Code Analyzer Report

The Code Analyzer Report displays potential errors and problems, as well as opportunities for improvement in your code through messages. For example, a common message indicates that a variable `foo` might be unused.

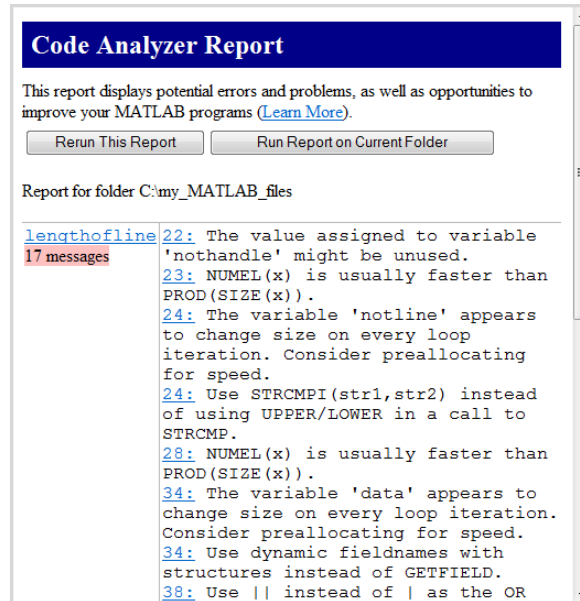
To run the Code Analyzer Report:

- 1 In the Current Folder browser, navigate to the folder that contains the files you want to check. To use the example shown in this documentation, `lengthoffline.m`, you can change the current folder by running


```
cd(fullfile(matlabroot,'help','techdoc','matlab_env','examples'))
```

- 2 If you plan to modify the example, save the file to a folder for which you have write access. Then, make that folder the current MATLAB folder. This example saves the file in `C:\my_MATLAB_files`.
- 3 In the Current Folder browser, click , and then select **Reports > Code Analyzer Report**.

The report displays in the MATLAB Web Browser, showing those files identified as having potential problems or opportunities for improvement.



- 4** For each message in the report, review the suggestion and your code. Click the line number to open the file in the Editor at that line, and change the file based on the message. Use the following general advice:
- If you are unsure what a message means or what to change in the code, click the link in the message if one appears. For details, see “Check Code for Errors and Warnings” on page 21-7.
  - If the message does not contain a link, and you are unsure what a message means or what to do, search for related topics in the Help browser. For examples of messages and what to do about them, including specific changes to make for the example, `lengthofline.m`, see “Changing Code Based on Code Analyzer Messages” on page 21-54.
  - The messages do not provide perfect information about every situation and in some cases, you might not want to change anything based on the message. For details, see “Understand the Limitations of Code Analysis” on page 21-18.
  - If there are certain messages or types of messages you do not want to see, you can suppress them. For details, see “Adjust Code Analyzer Message Indicators and Messages” on page 21-13.

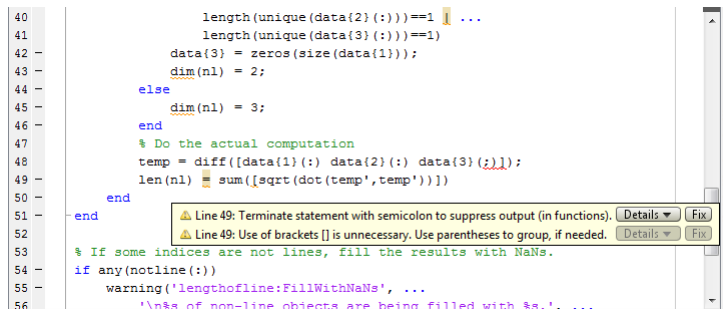
- 5 After modifying it, save the file. Consider saving the file to a different name if you made significant changes that might introduce errors. Then you can refer to the original file, if needed, to resolve problems with the updated file. Use the  **Compare** button on the **Editor** tab to help you identify the changes you made to the file. For more information, see “Comparing Text Files”.
- 6 Run and debug the file or files again to be sure that you have not introduced any inadvertent errors.
- 7 If the report is displaying, click **Rerun This Report** to update the report based on the changes you made to the file. Ensure that the messages are gone, based on the changes you made to the files.

## Changing Code Based on Code Analyzer Messages

For information on how to correct the potential problems presented in Code Analyzer messages, use the following resources:

- Open the file in the Editor and click the **Details** button in the tooltip, as shown in the image following this list. An extended message opens. However, not all messages have extended messages.
- Use the Help browser **Search** pane to find documentation about terms presented in the messages.

The following image shows a tooltip with a **Details** button. The orange *line* under the equals (=) sign indicates a tooltip displays if you hover over the equals sign. The orange *highlighting* indicates that an automatic fix is available.



```

40     length(unique(data(2) (:))) == 1 ...
41     length(unique(data(3) (:))) == 1)
42     data(3) = zeros(size(data(1)));
43     dim(nl) = 2;
44     else
45         dim(nl) = 3;
46     end
47     % Do the actual computation
48     temp = diff([data(1) (:); data(2) (:); data(3) (:)]);
49     len(nl) = sum (sqrt(dot(temp', temp)))
50 end
51 -end
52
53 % If some indices are not lines, fill the results with NaNs.
54 if any(notline(:))
55     warning('lengthofline:FillWithNaNs', ...
56         '\n%s of non-line objects are being filled with %s.', ...

```



## Other Ways to Access Code Analyzer Messages

You can get Code Analyzer messages using any of the following methods. Each provides the same messages, but in a different format:

- Access the Code Analyzer Report for a file from the Profiler detail report.
- Run the `checkcode` function, which analyzes the specified file and displays messages in the Command Window.
- Run the `mlintrpt` function, which runs `checkcode` and displays the messages in the Web Browser.
- Use automatic code checking while you work on a file in the Editor. See “Automatically Check Code in the Editor — Code Analyzer” on page 21-7.

## Change Default Editor


### In this section...

“Set Default Editor” on page 21-56

“Set Default Editor in '-nodisplay' mode” on page 21-56

### Set Default Editor

To specify the default editor for MATLAB:

- 1 On the **Home** tab, in the **Environment** section, click  **Preferences**. The Preferences dialog box opens.
- 2 Select the **MATLAB > Editor/Debugger** node on the left pane.
- 3 In the **Editor** pane, click **Text editor** and specify a default text editor.

### Set Default Editor in '-nodisplay' mode

If you invoke the `edit` command while running MATLAB with the `-nodisplay` option, choose an appropriate text-based editor instead of the default editor specified in the Preferences dialog box. This is done differently depending on your platform.

#### Mac Platforms

When running MATLAB with the `-nodisplay` startup option, `edit` opens the editor specified in the `EDITOR` environment variable.

To display the current value of `$EDITOR` in MATLAB, execute the command:

```
!printenv EDITOR
```

#### UNIX Platforms

When running MATLAB with the `-nodisplay` option (or without the `DISPLAY` environment variable set) on UNIX platforms, you can find the default editor defined for your system in `matlabroot/X11/app-defaults/Matlab`.

You can specify the default editor or editor options by adding the following line to your own `.Xdefaults` file, located in `~home`:

```
matlab*externalEditorCommand: $EDITOR -option $FILE
```

where

- `$EDITOR` is the name of your default editor, for example, `emacs`. Leaving the environment variable `EDITOR` as `$EDITOR` instruct MATLAB to use your default system editor.
- `-option` is a valid option flag you can include for the specified editor.
- `$FILE` means the file name you type with the `edit` command opens in the specified editor.

After adding the line to your `.Xdefaults` file, run the following before starting MATLAB:

```
xrdb -merge -home/.Xdefaults
```

For example, this code opens `foo` in the `emacs` editor:

```
emacs foo
```



# Programming Utilities

---

- “Identify Program Dependencies” on page 22-2
- “Protect Your Source Code” on page 22-9
- “Create Hyperlinks that Run Functions” on page 22-12

## Identify Program Dependencies

If you need to know what other functions and scripts your program is dependent upon, use one of the techniques described below.

In this section...
“Simple Display of Program File Dependencies” on page 22-2
“Detailed Display of Program File Dependencies” on page 22-2
“Dependencies Within a Folder” on page 22-3

### Simple Display of Program File Dependencies

For a simple display of all program files referenced by a particular function, follow these steps:

- 1 Type `clear functions` to clear all functions from memory (see Note below).

---

**Note** `clear functions` does not clear functions locked by `mlock`. If you have locked functions (which you can check using `inmem`) unlock them with `munlock`, and then repeat step 1.

---

- 2 Execute the function you want to check. Note that the function arguments you choose to use in this step are important, because you can get different results when calling the same function with different arguments.
- 3 Type `inmem` to display all program files that were used when the function ran. If you want to see what MEX-files were used as well, specify an additional output:

```
[mfiles, mexfiles] = inmem
```

### Detailed Display of Program File Dependencies

For a more detailed display of dependent function information, use the `matlab.codetools.requiredFilesAndProducts` function. In addition to program files, `matlab.codetools.requiredFilesAndProducts` shows which

MathWorks products a particular function depends on. If you have a function, `myFun`, that calls to the `edge` function in the Image Processing Toolbox™:

```
[fList,pList] = matlab.codetools.requiredFilesAndProducts('myFun.m');  
fList
```

```
fList =
```

```
    'C:\work\myFun.m'
```

The only required program file, is the function file itself, `myFun`.

```
{pList.Name}'
```

```
ans =
```

```
    'MATLAB'
```

```
    'Image Processing Toolbox'
```

The file, `myFun.m`, requires both MATLAB and the Image Processing Toolbox.

## Dependencies Within a Folder

The Dependency Report shows dependencies among MATLAB code files in a folder. Use this report to determine:

- Which files in the folder are required by other files in the folder
- If any files in the current folder will fail if you delete a file
- If any called files are missing from the current folder

The report does not list:

- Files in the `toolbox/matlab` folder because every MATLAB user has those files.

Therefore, if you use a function file that shadows a built-in function file, MATLAB excludes both files from the list.

- Files called from anonymous functions.
- The superclass for a class file.

- Files called from `eval`, `evalc`, `run`, `load`, function handles, and callbacks.

MATLAB does not resolve these files until run time, and therefore the Dependency Report cannot discover them.

- Some method files.

The Dependency Report finds class constructors that you call in a MATLAB file. However, any methods you execute on the resulting object are unknown to the report. These methods can exist in the `classdef` file, as separate method files, or files belonging to superclass or superclasses of a method file.

To provide meaningful results, the Dependency Report requires the following:

- The search path when you run the report is the same as when you run the files in the folder. (That is, the current folder is at the top of the search path.)
- The files in the folder for which you are running the report do not change the search path or otherwise manipulate it.
- The files in the folder do not load variables, or otherwise create name clashes that result in different program elements with the same name.

---

**Note** Do not use the Dependency Report to determine which MATLAB code files someone else needs to run a particular file. Instead use the `matlab.codetools.requiredFilesAndProducts` function.

---

## Creating Dependency Reports

- 1 Use the Current Folder pane to navigate to the folder containing the files for which you want to produce a Dependency Report.

---

**Note** You cannot run reports when the path is a UNC (Universal Naming Convention) path; that is, a path that starts with `\\`. Instead, use an actual hard drive on your system, or a mapped network drive.

---



- 2 On the Current Folder pane, click , and then select **Reports > Dependency Report**.

The Dependency Report opens in the MATLAB Web Browser.

- 3 If you want, select one or more options within the report, as follows:
  - To see a list of all MATLAB code files (children) called by each file in the folder (parent), select **Show child functions**.

The report indicates where each child function resides, for example, in a specified toolbox. If the report specifies that the location of a child function is unknown, it can be because:

- The child function is not on the search path.
  - The child function is not in the current folder.
  - The file was moved or deleted.
- To list the files that call each MATLAB code file, select **Show parent functions**.

The report limits the parent (calling) functions to functions in the current folder.

- To include local functions in the report, select **Show subfunctions**. The report lists local functions directly after the main function and highlights them in gray.

- 4 Click **Run Report on Current Folder**.

## Reading and Working with Dependency Reports

The following image shows a Dependency Report. It indicates that `chirpy.m` calls two files in Signal Processing Toolbox™ and one in Image Processing Toolbox. It also shows that `go.m` calls `mobius.m`, which is in the current folder.

### Dependency Report

The Dependency Report shows dependencies among MATLAB files in a folder ([Learn More](#)).

Show child functions
  Show parent functions (current folder only)
   
 Show subfunctions

Built-in functions and files in toolbox/matlab are not shown

Report for Folder I:\my\_MATLAB\_files

MATLAB File List	Children (called functions)
<a href="#">chirpy</a>	toolbox : <a href="#">\images\images\erode.m</a> toolbox : <a href="#">\shared\siglib\chirp.m</a> toolbox : <a href="#">\signal\signal\specgram.m</a>
<a href="#">collatz</a>	
<a href="#">collatzall</a>	subfunction : <a href="#">collatzplot new</a>
<a href="#">collatzplot</a>	current dir : <a href="#">collatz</a>
<a href="#">collatzplot new</a>	current dir : <a href="#">collatz</a>
<a href="#">go</a>	current dir : <a href="#">mobius</a>
<a href="#">mobius</a>	

The Dependency Report includes the following:

- MATLAB File List

The list of files in the folder on which you ran the Dependency Report. Click a link in this column to open the file in the Editor.

- Children

The function or functions called by the MATLAB file.

Click a link in this column to open the MATLAB file listed in the same row, and go to the first reference to the called function. For instance, suppose your Dependency Report appears as shown in the previous image. Clicking `\images\images\erode.m` opens `chirpy.m` and places the cursor at the first line that references `erode`. In other words, it does not open `erode.m`.

- Multiple class methods


Because the report is a static analysis, it cannot determine run-time data types and, therefore, cannot identify the particular class methods required by a file. If multiple class methods match a referenced method, the Dependency Report inserts a question mark link next to the file name. The question mark appears in the following image.

<a href="#">rational differential</a>	toolbox	:	<a href="#">\rf\rf\s2sdd.m</a>
	toolbox	:	<a href="#">\rf\rf\@rfckt\smith.m</a>
	toolbox	:	<a href="#">\rf\rf\s2tf.m</a>
	toolbox	:	<a href="#">\rf\rf\rationalfit.m</a>
	toolbox	:	? <a href="#">Multiple class methods match freqresp.m</a>
	toolbox	:	<a href="#">\rf\rf\@rfmodel\timeresp.m</a>
	toolbox	:	<a href="#">\rf\rf\@rfckt\analyze.m</a>
	toolbox	:	<a href="#">\signal\signal\fftfilt.m</a>

Click the question mark link to list the class methods with the specified name that MATLAB might use. MATLAB lists *almost all* the method files on the search path that match the specified method file (in this case, `freqresp.m`). Do not be concerned if the list includes methods of classes and MATLAB built-in functions that are unfamiliar to you.

It is not necessary for you to determine which file MATLAB will use. MATLAB determines which method to use depending on the object that the program calls at run time.

The following image shows the contents of the right side of the Web Browser after you click the question mark link.

```
toolbox : \rf\rf\s2sdd.m
toolbox : \rf\rf\@rfckt\smith.m
toolbox : \rf\rf\s2tf.m
toolbox : \rf\rf\rationalfit.m
toolbox :  Multiple class methods match freqresp.m

Unable to determine which of the following files will run: (Learn More)
\control\ctrlobsolete\freqresp.m
W:\bat\Akernel\perfect\matlab\toolbox\control\control\@lti\freqresp.m
W:\bat\Akernel\perfect\matlab\toolbox\ident\ident\@idproc\freqresp.m
W:\bat\Akernel\perfect\matlab\toolbox\ident\ident\@idpoly\freqresp.m
W:\bat\Akernel\perfect\matlab\toolbox\ident\ident\@idmodel\freqresp.m
W:\bat\Akernel\perfect\matlab\toolbox\ident\ident\@idfrd\freqresp.m
W:\bat\Akernel\perfect\matlab\toolbox\rf\rf\@rfmodel\freqresp.m
```

## Protect Your Source Code

Although MATLAB source (.m) code is executable by itself, the contents of MATLAB source files are easily accessed, revealing design and implementation details. If you do not want to distribute your proprietary application code in this format, you can use one of these options instead:

- Deploy as P-code — Convert some or all of your source code files to a content-obscured form called a *P-code* file (from its .p file extension), and distribute your application code in this format. When MATLAB P-codes a file, the file is *obfuscated* not *encrypted*. While the content in a .p file is difficult to understand, it should not be considered secure. It is not recommended that you P-code files to protect your intellectual property.
- Compile into binary format — Compile your source code files using the MATLAB Compiler to produce a standalone application. Distribute the latter to end users of your application.

### Building a Content Obscured Format with P-Code

A P-code file behaves the same as the MATLAB source from which it was produced. The P-code file also runs at the same speed as the source file. P-code files are purposely obfuscated. They are not encrypted. While the content in a .p file is difficult to understand, it should not be considered secure. It is not recommended that you P-code files to protect your intellectual property.

---

**Note** Because users of P-code files cannot view the MATLAB code, consider providing diagnostics to enable a user to proceed in the event of an error.

---

### Building the P-Code File

To generate a P-code file, enter the following command in the MATLAB Command Window:

```
pcode file1 file2, ...
```

The command produces the files, `file1.p`, `file2.p`, and so on. To convert *all* .m source files residing in your current folder to P-code files, use the command:

```
pcode *.m
```

See the `pcode` function reference page for a description of all syntaxes for generating P-code files.

### **Invoking the P-Code File**

You invoke the resulting P-code file in the same way you invoke the MATLAB `.m` source file from which it was derived. For example, to invoke file `myfun.p`, type

```
[out, out2, ...] = myfun(in1, in2, ...);
```

To invoke script `myscript.p`, type

```
myscript;
```

When you call a P-code file, MATLAB gives it execution precedence over its corresponding `.m` source file. This is true even if you happen to change the source code at some point after generating the P-code file. Remember to remove the `.m` source file before distributing your code.

### **Running Older P-Code Files on Later Versions of MATLAB**

P-code files are designed to be independent of the release under which they were created and the release in which they are used (backward and forward compatibility). New and deprecated MATLAB features can be a problem, but it is the same problem that would exist if you used the original MATLAB input file. To fix errors of this kind in a P-code file, fix the corresponding MATLAB input file and create a new P-code file.

P-code files built using MATLAB Version 7.4 and earlier have a different format than those built with more recent versions of MATLAB. You still can use these older P-code files when you run MATLAB 7.4 and later, but this capability could be removed in a future release. MathWorks recommends that you rebuild any P-code files that were built with MATLAB 7.4 or earlier using a more recent version of MATLAB, and then redistribute them as necessary.

## **Building a Standalone Executable**

Another way to protect your source code is to build it into a standalone executable and distribute the executable, along with any other necessary files, to external customers. You must have the MATLAB Compiler and a supported C or C++ compiler installed to prepare files for deployment. The end user, however, does not need MATLAB.

To build a standalone application for your MATLAB application, develop and debug your application following the usual procedure for MATLAB program files. Then, generate the executable file or files following the instructions in “Steps by the Developer to Deploy to End Users” in the MATLAB Compiler documentation.

## Create Hyperlinks that Run Functions

The special keyword `matlab:` lets you embed commands in other functions. Most commonly, the functions that contain it display hyperlinks, which execute the commands when you click the hyperlink text. Functions that support `matlab:` syntax include `disp`, `error`, `fprintf`, `help`, and `warning`.

Use `matlab:` syntax to create a hyperlink in the Command Window that runs one or more functions. For example, you can use `disp` to display the word Hypotenuse as an executable hyperlink as follows:

```
disp(' <a href="matlab:a=3; b=4;c=hypot(a,b)">Hypotenuse</a> ')
```

Clicking the hyperlink executes the three commands following `matlab:`, resulting in

```
c =  
    5
```

Executing the link creates or redefines the variables `a`, `b`, and `c` in the base workspace.

The argument to `disp` is an `<a href>` HTML hyperlink. Include the full hypertext string, from `'<a href=` to `</a>'` within a single line, that is, do not continue a long string on a new line. No spaces are allowed after the opening `<` and before the closing `>`. A single space is required between `a` and `href`.

You cannot directly execute `matlab:` syntax. That is, if you type

```
matlab:a=3; b=4;c=hypot(a,b)
```

you receive an error, because MATLAB interprets the colon as an array operator in an illegal context:

```
??? matlab:a=3; b=4;c=hypot(a,b)
```

```
      |  
Error: The expression to the left of the equals sign  
      is not a valid target for an assignment.
```



You do not need to use `matlab:` to display a live hyperlink to the Web. For example, if you want to link to an external Web page, you can use `disp`, as follows:

```
disp(' <a href="http://en.wikipedia.org/wiki/Hypotenuse">Hypotenuse</a> ')
```

The result in the Command Window looks the same as the previous example, but instead opens a page at `en.wikipedia.org`:

Hypotenuse

Using `matlab:`, you can:

- “Run a Single Function” on page 22-13
- “Run Multiple Functions” on page 22-13
- “Provide Command Options” on page 22-14
- “Include Special Characters” on page 22-14

## Run a Single Function

Use `matlab:` to run a specified statement when you click a hyperlink in the Command Window. For example, run this command:

```
disp(' <a href="matlab:magic(4)">Generate magic square</a> ')
```

It displays this link in the Command Window:

[Generate magic square](#)

When you click the link, MATLAB runs `magic(4)`.

## Run Multiple Functions

You can run multiple functions with a single link. For example, run this command:

```
disp(' <a href="matlab: x=0:1:8;y=sin(x);plot(x,y)">Plot x,y</a> ')
```

It displays this link in the Command Window:

### [Plot x,y](#)

When you click the link, MATLAB runs this code:

```
x = 0:1:8;  
y = sin(x);  
plot(x,y)
```

Redefine x in the base workspace:

```
x = -2*pi:pi/16:2*pi;
```

Click the hyperlink, `Plot x,y` again and it changes the current value of `x` back to `0:1:8`. The code that `matlab:` runs when you click the `Plot x,y` defines `x` in the base workspace.

## Provide Command Options

Use multiple `matlab:` statements in a file to present options, such as

```
disp('<a href = "matlab:state = 0">Disable feature</a>')  
disp('<a href = "matlab:state = 1">Enable feature</a>')
```

The Command Window displays the links that follow. Depending on which link you click, MATLAB sets `state` to 0 or 1.

[Disable feature](#)  
[Enable feature](#)

## Include Special Characters

MATLAB correctly interprets most strings that include special characters, such as a greater than symbol (>). For example, the following statement includes a greater than symbol (>).

```
disp('<a href="matlab:str = ''Value > 0''">Positive</a>')
```

and generates the following hyperlink.

[Positive](#)

Some symbols might not be interpreted correctly and you might need to use the ASCII value for the symbol. For example, an alternative way to run the previous statement is to use ASCII 62 instead of the greater than symbol:

```
disp('<a href="matlab:str=['Value ' char(62) ' 0']">Positive</a>')
```



# Software Development

---

- Chapter 23, “Error Handling”
- Chapter 24, “Program Scheduling”
- Chapter 25, “Performance”
- Chapter 26, “Memory Usage”
- Chapter 27, “Custom Help and Documentation”
- Chapter 28, “Source Control Interface”
- Chapter 29, “Unit Testing”



# Error Handling

---

- “Exception Handling in a MATLAB Application” on page 23-2
- “Capture Information About Exceptions” on page 23-5
- “Throw an Exception” on page 23-16
- “Respond to an Exception” on page 23-18
- “Clean Up When Functions Complete” on page 23-23
- “Issue Warnings and Errors” on page 23-30
- “Suppress Warnings” on page 23-34
- “Restore Warnings” on page 23-37
- “Change How Warnings Display” on page 23-40
- “Use try/catch to Handle Errors” on page 23-42

## Exception Handling in a MATLAB Application

In this section...
“Overview” on page 23-2
“Getting an Exception at the Command Line” on page 23-2
“Getting an Exception in Your Program Code” on page 23-3
“Generating a New Exception” on page 23-4

### Overview

No matter how carefully you plan and test the programs you write, they may not always run as smoothly as expected when executed under different conditions. It is always a good idea to include error checking in programs to ensure reliable operation under all conditions.

In the MATLAB software, you can decide how your programs respond to different types of errors. You may want to prompt the user for more input, display extended error or warning information, or perhaps repeat a calculation using default values. The error-handling capabilities in MATLAB help your programs check for particular error conditions and execute the appropriate code depending on the situation.

When MATLAB detects a severe fault in the command or program it is running, it collects information about what was happening at the time of the error, displays a message to help the user understand what went wrong, and terminates the command or program. This is called *throwing an exception*. You can get an exception while entering commands at the MATLAB command prompt or while executing your program code.

### Getting an Exception at the Command Line

If you get an exception at the MATLAB prompt, you have several options on how to deal with it as described below.

#### Determine the Fault from the Error Message

Evaluate the error message MATLAB has displayed. Most error messages attempt to explain at least the immediate cause of the program failure. There



is often sufficient information to determine the cause and what you need to do to remedy the situation.

### Review the Failing Code

If the function in which the error occurred is implemented as a MATLAB program file, the error message should include a line that looks something like this:

```
surf
```

```
Error using surf (line 50)  
Not enough input arguments.
```

The text includes the name of the function that threw the error (`surf`, in this case) and shows the failing line number within that function's program file. Click the line number; MATLAB opens the file and positions the cursor at the location in the file where the error originated. You may be able to determine the cause of the error by examining this line and the code that precedes it.

### Step Through the Code in the Debugger

You can use the MATLAB Debugger to step through the failing code. Click the underlined error text to open the file in the MATLAB Editor at or near the point of the error. Next, click the hyphen at the beginning of that line to set a breakpoint at that location. When you rerun your program, MATLAB pauses execution at the breakpoint and enables you to step through the program code. The command `dbstop on error` is also helpful in finding the point of error.

See the documentation on “Debugging Process and Features” on page 19-2 for more information.

### Getting an Exception in Your Program Code

When you are writing your own program in a program file, you can *catch* exceptions and attempt to handle or resolve them instead of allowing your program to terminate. When you catch an exception, you interrupt the normal termination process and enter a block of code that deals with the faulty situation. This block of code is called a *catch block*.

Some of the things you might want to do in the catch block are:

- Examine information that has been captured about the error.
- Gather further information to report to the user.
- Try to accomplish the task at hand in some other way.
- Clean up any unwanted side effects of the error.

When you reach the end of the catch block, you can either continue executing the program, if possible, or terminate it.

The documentation on “Capture Information About Exceptions” on page 23-5 describes how to acquire information about what caused the error, and “Respond to an Exception” on page 23-18 presents some ideas on how to respond to it.

## **Generating a New Exception**

When your program code detects a condition that will either make the program fail or yield unacceptable results, it should throw an exception. This procedure

- Saves information about what went wrong and what code was executing at the time of the error.
- Gathers any other pertinent information about the error.
- Instructs MATLAB to throw the exception.

The documentation on “Capture Information About Exceptions” on page 23-5 describes how to use an `MException` object to capture information about the error, and “Throw an Exception” on page 23-16 explains how to initiate the exception process.

## Capture Information About Exceptions

### In this section...

“Overview” on page 23-5

“The MException Class” on page 23-5

“Properties of the MException Class” on page 23-7

“Methods of the MException Class” on page 23-14

### Overview

When the MATLAB software throws an exception, it captures information about what caused the error in a data structure called an MException object. This object is an instance of the MATLAB MException class. You can obtain access to the MException object by *catching* the exception before your program aborts and accessing the object constructed for this particular error via the catch command. When throwing an exception in response to an error in your own code, you will have to create a new MException object and store information about the error in that object.

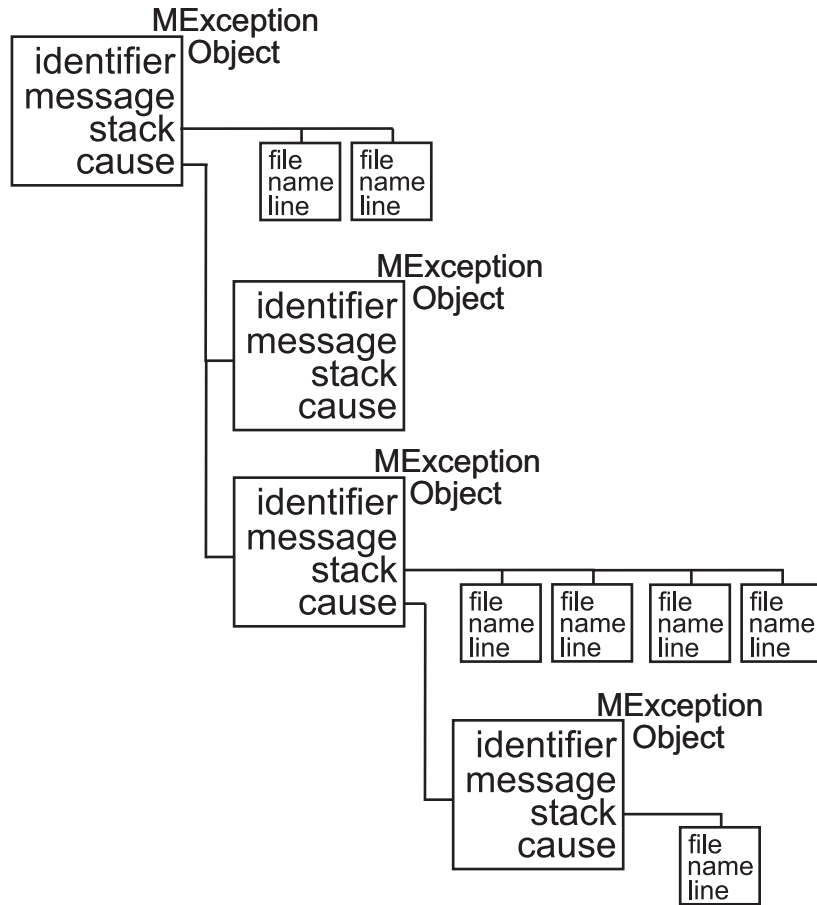
This section describes the MException class and objects constructed from that class:

Information on how to use this class is presented in later sections on “Respond to an Exception” on page 23-18 and “Throw an Exception” on page 23-16.

### The MException Class

The figure shown below illustrates one possible configuration of an object of the MException class. The object has four properties: `identifier`, `message`, `stack`, and `cause`. Each of these properties is implemented as a field of the structure that represents the MException object. The `stack` field is an N-by-1 array of additional structures, each one identifying a function, and line number from the call stack. The `cause` field is an M-by-1 cell array of MException objects, each representing an exception that is related to the current one.

See “Properties of the MException Class” on page 23-7 for a full description of these properties.



**Object Constructor**

Any code that detects an error and throws an exception must also construct an MException object in which to record and transfer information about the error. The syntax of the MException constructor is

```
ME = MException(identifier, message)
```

where `identifier` is a MATLAB message identifier of the form

```
component:mnemonic
```

that is enclosed in single quotes, and `message` is a text string, also enclosed in single quotes, that describes the error. The output `ME` is the resulting `MException` object.

If you are responding to an exception rather than throwing one, you do not have to construct an `MException` object. The object has already been constructed and populated by the code that originally detected the error.

## Properties of the `MException` Class

The `MException` class has four properties. Each of these properties is implemented as a field of the structure that represents the `MException` object. Each of these properties is described in the sections below and referenced in the sections on “Respond to an Exception” on page 23-18 and “Throw an Exception” on page 23-16. All are read-only; their values cannot be changed.

The `MException` properties are:

- `identifier`
- `message`
- `stack`
- `cause`

Repeating the `surf` example shown above, but this time catching the exception, you can see the four properties of the `MException` object structure. (This example uses `try/catch` in an atypical fashion. See the section on “The `try/catch` Statement” on page 23-18 for more information on using `try/catch`).

```
try
    surf
catch ME
    ME
end
```

Run this at the command line and MATLAB returns the contents of the MException object:

```
ME =  
MException object with properties:  
  
    identifier: 'MATLAB:narginchk:notEnoughInputs'  
    message: 'Not enough input arguments.'  
    stack: [1x1 struct]  
    cause: {}
```

The `stack` field shows the filename, function, and line number where the exception was thrown:

```
ME.stack  
ans =  
    file: 'matlabroot\toolbox\matlab\graph3d\surf.m'  
    name: 'surf'  
    line: 54
```

The `cause` field is empty in this case. Each field is described in more detail in the sections that follow.

## Message Identifiers

A message identifier is a tag that you attach to an error or warning statement that makes that error or warning uniquely recognizable by MATLAB. You can use message identifiers with error reporting to better identify the source of an error, or with warnings to control any selected subset of the warnings in your programs.

The message identifier is a read-only character string that specifies a *component* and a *mnemonic* label for an error or warning. The format of a simple identifier is

```
component:mnemonic
```

A colon separates the two parts of the identifier: `component` and `mnemonic`. If the identifier uses more than one `component`, then additional colons are required to separate them. A message identifier must always contain at least one colon.

Some examples of message identifiers are

```
MATLAB:rmpath:DirNotFound
MATLAB:odearguments:InconsistentDataType
Simulink:actionNotTaken
TechCorp:OpenFile:notFoundInPath
```

Both the component and mnemonic fields must adhere to the following syntax rules:

- No white space (space or tab characters) is allowed anywhere in the identifier.
- The first character must be alphabetic, either uppercase or lowercase.
- The remaining characters can be alphanumeric or an underscore.

There is no length limitation to either the component or mnemonic. The identifier can also be an empty string.

**Component Field.** The component field specifies a broad category under which various errors and warnings can be generated. Common components are a particular product or toolbox name, such as `MATLAB` or `Control`, or perhaps the name of your company, such as `TechCorp` in the preceding example.

You can also use this field to specify a multilevel component. The following statement has a three-level component followed by a mnemonic label:

```
TechCorp:TestEquipDiv:Waveform:obsoleteSyntax
```

The component field enables you to guarantee the uniqueness of each identifier. Thus, while the internal MATLAB code might use a certain warning identifier like `MATLAB:InconsistentDataType`, that does not preclude you from using the same mnemonic, as long as you precede it with a unique component. For example,

```
warning('TechCorp:InconsistentDataType', ...
    'Value %s is inconsistent with existing properties.' ...
    sprocketDiam)
```

**Mnemonic Field.** The mnemonic field is a string normally used as a tag relating to the particular message. For example, when reporting an error resulting from the use of ambiguous syntax, a simple component and mnemonic such as the following might be appropriate:

```
MATLAB:ambiguousSyntax
```

**Message Identifiers in an MException Object.** When throwing an exception, create an appropriate identifier and save it to the MException object at the time you construct the object using the syntax

```
ME = MException(identifier, string)
```

For example,

```
ME = MException('AcctError:NoClient', ...  
               'Client name not recognized.');
```

```
ME.identifier  
ans =  
    AcctError:NoClient
```

When responding to an exception, you can extract the message identifier from the MException object as shown here. Using the surf example again,

```
try  
    surf  
catch ME  
    id = ME.identifier  
end  
  
id =  
    MATLAB:narginchk:notEnoughInputs
```

### **Text of the Error Message**

An error message in MATLAB is a read-only character string issued by the program code and returned in the MException object. This message can assist the user in determining the cause, and possibly the remedy, of the failure.



When throwing an exception, compose an appropriate error message and save it to the `MException` object at the time you construct the object using the syntax

```
ME = MException(identifier, string)
```

If your message string requires formatting specifications, like those available with the `sprintf` function, use this syntax for the `MException` constructor:

```
ME = MException(identifier, formatstring, arg1, arg2, ...)
```

For example,

```
S = 'Accounts'; f1 = 'ClientName';  
ME = MException('AcctError:Incomplete', ...  
    'Field ''%.%s'' is not defined.', S, f1);
```

```
ME.message  
ans =  
    Field 'Accounts.ClientName' is not defined.
```

When responding to an exception, you can extract the error message from the `MException` object as follows:

```
try  
    surf  
catch ME  
    msg = ME.message  
end  
  
msg =  
    Not enough input arguments.
```

## The Call Stack

The `stack` field of the `MException` object identifies the line number, function, and filename where the error was detected. If the error occurs in a called function, as in the following example, the `stack` field contains the line number, function name, and filename not only for the location of the immediate error, but also for each of the calling functions. In this case, `stack`

is an N-by-1 array, where N represents the depth of the call stack. That is, the stack field displays the function name and line number where the exception occurred, the name and line number of the caller, the caller's caller, etc., until the top-most function is reached.

When throwing an exception, MATLAB stores call stack information in the stack field. You cannot write to this field; access is read-only.

For example, suppose you have three functions that reside in two separate files:

```
mfileA.m
=====
      .
      .
42 function A1(x, y)
43 B1(x, y);
```

```
mfileB.m
=====
      .
      .
 8 function B1(x, y)
 9 B2(x, y)
      .
      .
26 function B2(x, y)
27      .
28      .
29      .
30      .
31 % Throw exception here
```

Catch the exception in variable ME and then examine the stack field:

```
for k=1:length(ME.stack)
    ME.stack(k)
end
```

```
ans =  
    file: 'C:\matlab\test\mfileB.m'  
    name: 'B2'  
    line: 31  
ans =  
    file: 'C:\matlab\test\mfileB.m'  
    name: 'B1'  
    line: 9  
ans =  
    file: 'C:\matlab\test\mfileA.m'  
    name: 'A1'  
    line: 43
```

## The Cause Array

In some situations, it can be important to record information about not only the one command that caused execution to stop, but also other exceptions that your code caught. You can save these additional `MException` objects in the `cause` field of the primary exception.

The `cause` field of an `MException` is an optional cell array of related `MException` objects. You must use the following syntax when adding objects to the `cause` cell array:

```
primaryException = addCause(primaryException, secondaryException)
```

This example attempts to assign an array `D` to variable `X`. If the `D` array does not exist, the code attempts to load it from a MAT-file and then retries assigning it to `X`. If the load fails, a new `MException` object (`ME3`) is constructed to store the cause of the first two errors (`ME1` and `ME2`):

```
try  
    X = D(1:25)  
catch ME1  
    try  
        filename = 'test200';  
        load(filename);  
        X = D(1:25)  
    catch ME2  
        ME3 = MException('MATLAB:LoadErr', ...
```

```
        'Unable to load from file %s', filename);
    ME3 = addCause(ME3, ME1);
    ME3 = addCause(ME3, ME2);
end
end
```

There are two exceptions in the cause field of ME3:

```
ME3.cause
ans =
    [1x1 MException]
    [1x1 MException]
```

Examine the cause field of ME3 to see the related errors:

```
ME3.cause{:}
ans =

MException object with properties:

    identifier: 'MATLAB:UndefinedFunction'
    message: 'Undefined function or method 'D' for input
arguments of type 'double'.'
    stack: [0x1 struct]
    cause: {}
ans =

MException object with properties:

    identifier: 'MATLAB:load:couldNotReadFile'
    message: 'Unable to read file test204: No such file or
directory.'
    stack: [0x1 struct]
    cause: {}
```

## Methods of the MException Class

There are ten methods that you can use with the MException class. The names of these methods are case-sensitive. See the MATLAB function reference pages for more information.

<b>Method Name</b>	<b>Description</b>
<code>addCause</code>	Append an <code>MException</code> to the <code>cause</code> field of another <code>MException</code> .
<code>disp</code>	Display an <code>MException</code> object.
<code>eq</code>	Compare <code>MException</code> objects for equality.
<code>getReport</code>	Return a formatted message based on the current exception.
<code>isequal</code>	Compare <code>MException</code> objects for equality.
<code>last</code>	Return the last uncaught exception. This is a static method.
<code>ne</code>	Compare <code>MException</code> objects for inequality.
<code>rethrow</code>	Reissue an exception that has previously been caught.
<code>throw</code>	Issue an exception.
<code>throwAsCaller</code>	Issue an exception, but omit the current stack frame from the <code>stack</code> field.

## Throw an Exception

When your program detects a fault that will keep it from completing as expected or will generate erroneous results, you should halt further execution and report the error by throwing an exception. The basic steps to take are

- 1** Detect the error. This is often done with some type of conditional statement, such as an `if` statement that checks the output of the current operation.
- 2** Construct an `MException` object to represent the error. Add a message identifier string and error message string to the object when calling the constructor.
- 3** If there are other exceptions that may have contributed to the current error, you can store the `MException` object for each in the `cause` field of a single `MException` that you intend to throw. Use the `addCause` method for this.
- 4** Use the `throw` or `throwAsCaller` function to have the MATLAB software issue the exception. At this point, MATLAB stores call stack information in the `stack` field of the `MException`, exits the currently running function, and returns control to either the keyboard or an enclosing catch block in a calling function.

This example illustrates throwing an exception using the steps just described:

```
function check_results(resultsArr, dataFile)
minValue = 0.09;    maxValue = 2.14;

% 1) Detect the error.
if any(resultsArr < minValue) || any(resultsArr > maxValue)

    % 2) Construct an MException object to represent the error.
    err = MException('ResultChk:OutOfRange', ...
        'Resulting value is outside expected range');
    fileInfo = dir(dataFile);

    % 3) Store any information contributing to the error.
    if datenum(fileInfo.date) < datenum('Oct09','mmyy')
        errCause = MException('ResultChk:BadInput', ...
            'Input file %s is out of date.', dataFile);
```

```
        err = addCause(err, errCause);
    end

    % 4) Throw the exception to stop execution and display
        an error message.
    throw(err)
end
```

If the program detects the `OutOfRange` condition, the `throw(err)` statement throws an exception at the end. If the `BadInput` condition is also detected, the program also displays this as the cause:

```
resultsArr = [1.63, 2.05, 0.91, 2.16, 1.5, 2.11 0.72];
check_results(resultsArr, 'run33.dat')
```

```
Error using check_results (line 20)
Resulting value is outside expected range
```

Caused by:

```
Input file run33.dat is out of date.
```

## Respond to an Exception

In this section...
“Overview” on page 23-18
“The try/catch Statement” on page 23-18
“Suggestions on How to Handle an Exception” on page 23-20

### Overview

As stated earlier, the MATLAB software, by default, terminates the currently running program when an exception is thrown. If you catch the exception in your program, however, you can capture information about what went wrong, and deal with the situation in a way that is appropriate for the particular condition. This requires a try/catch statement.

This section covers the following topics:

### The try/catch Statement

When you have statements in your code that could generate undesirable results, put those statements into a try/catch block that catches any errors and handles them appropriately.

A try/catch statement looks something like the following pseudocode. It consists of two parts:

- A try block that includes all lines between the try and catch statements.
- A catch block that includes all lines of code between the catch and end statements.

```
try
    Perform one ...
        or more operations
A catch ME
    Examine error info in exception object ME
    Attempt to figure out what went wrong
    Either attempt to recover, or clean up and abort
```



```
end
```

## B Program continues

The program executes the statements in the `try` block. If it encounters an error, it skips any remaining statements in the `try` block and jumps to the start of the `catch` block (shown here as point A). If all operations in the `try` block succeed, then execution skips the `catch` block entirely and goes to the first line following the `end` statement (point B).

Specifying the `try`, `catch`, and `end` commands and also the code of the `try` and `catch` blocks on separate lines is recommended. If you combine any of these components on the same line, separate them with commas:

```
try, surf, catch ME, ME.stack, end
ans =
    file: 'matlabroot\toolbox\matlab\graph3d\surf.m'
    name: 'surf'
    line: 54
```

---

**Note** You cannot define nested functions within a `try` or `catch` block.

---

## The Try Block

On execution, your code enters the `try` block and executes each statement as if it were part of the regular program. If no errors are encountered, MATLAB skips the `catch` block entirely and continues execution following the `end` statement. If any of the `try` statements fail, MATLAB immediately exits the `try` block, leaving any remaining statements in that block unexecuted, and enters the `catch` block.

## The Catch Block

The `catch` command marks the start of a `catch` block and provides access to a data structure that contains information about what caused the exception. This is shown as the variable `ME` in the preceding pseudocode. This data structure is an object of the MATLAB `MException` class. When an exception occurs, MATLAB constructs an instance of this class and returns it in the `catch` statement that handles that error.

You are not required to specify any argument with the `catch` statement. If you do not need any of the information or methods provided by the `MException` object, just specify the `catch` keyword alone.

The `MException` object is constructed by internal code in the program that fails. The object has properties that contain information about the error that can be useful in determining what happened and how to proceed. The `MException` object also provides access to methods that enable you to respond to the exception. See the section on “The `MException` Class” on page 23-5 to find out more about the `MException` class.

Having entered the `catch` block, MATLAB executes the statements in sequence. These statements can attempt to

- Attempt to resolve the error.
- Capture more information about the error.
- Switch on information found in the `MException` object and respond appropriately.
- Clean up the environment that was left by the failing code.

The `catch` block often ends with a `rethrow` command. The `rethrow` causes MATLAB to exit the current function, keeping the call stack information as it was when the exception was first thrown. If this function is at the highest level, that is, it was not called by another function, the program terminates. If the failing function was called by another function, it returns to that function. Program execution continues to return to higher level functions, unless any of these calls were made within a higher-level `try` block, in which case the program executes the respective `catch` block.

More information about the `MException` class is provided in the section “Capture Information About Exceptions” on page 23-5.

## **Suggestions on How to Handle an Exception**

The following example reads the contents of an image file. The `try` block attempts to open and read the file. If either the `open` or `read` fails, the program catches the resulting exception and saves the `MException` object in the variable `ME1`.

The catch block in the example checks to see if the specified file could not be found. If so, the program allows for the possibility that a common variation of the filename extension (e.g., jpeg instead of jpg) was used by retrying the operation with a modified extension. This is done using a try/catch statement nested within the original try/catch.

```
function d_in = read_image(filename)
[path name ext] = fileparts(filename);
try
    fid = fopen(filename, 'r');
    d_in = fread(fid);
catch ME1
    % Get last segment of the error message identifier.
    idSegLast = regexp(ME1.identifier, '(?<=:\)\w+$', 'match');

    % Did the read fail because the file could not be found?
    if strcmp(idSegLast, 'InvalidFid') && ...
        ~exist(filename, 'file')

        % Yes. Try modifying the filename extension.
        switch ext
        case '.jpg'      % Change jpg to jpeg
            filename = strrep(filename, '.jpg', '.jpeg')
        case '.jpeg'    % Change jpeg to jpg
            filename = strrep(filename, '.jpeg', '.jpg')
        case '.tif'     % Change tif to tiff
            filename = strrep(filename, '.tif', '.tiff')
        case '.tiff'    % Change tiff to tif
            filename = strrep(filename, '.tiff', '.tif')
        otherwise
            fprintf('File %s not found\n', filename);
            rethrow(ME1);
        end

        % Try again, with modified filenames.
        try
            fid = fopen(filename, 'r');
            d_in = fread(fid);
        catch ME2
            fprintf('Unable to access file %s\n', filename);
```

```
        ME2 = addCause(ME2, ME1);  
        rethrow(ME2)  
    end  
end  
end
```

This example illustrates some of the actions that you can take in response to an exception:

- Compare the `identifier` field of the `MException` object against possible causes of the error.
- Use a nested `try/catch` statement to retry the open and read operations using a known variation of the filename extension.
- Display an appropriate message in the case that the file truly does not exist and then rethrow the exception.
- Add the first `MException` object to the `cause` field of the second.
- Rethrow the exception. This stops program execution and displays the error message.

Cleaning up any unwanted results of the error is also advisable. For example, your program may have allocated a significant amount of memory that it no longer needs.

# Clean Up When Functions Complete

## In this section...

“Overview” on page 23-23

“Examples of Cleaning Up a Program Upon Exit” on page 23-25

“Retrieving Information About the Cleanup Routine” on page 23-27

“Using onCleanup Versus try/catch” on page 23-28

“onCleanup in Scripts” on page 23-28

## Overview

A good programming practice is to make sure that you leave your program environment in a clean state that does not interfere with any other program code. For example, you might want to

- Close any files that you opened for import or export.
- Restore the MATLAB path.
- Lock or unlock memory to prevent or allow erasing MATLAB function or MEX-files.
- Set your working folder back to its default if you have changed it.
- Make sure global and persistent variables are in the correct state.

MATLAB provides the `onCleanup` function for this purpose. This function, when used within any program, establishes a cleanup routine for that function. When the function terminates, whether normally or in the event of an error or **Ctrl+C**, MATLAB automatically executes the cleanup routine.

The following statement establishes a cleanup routine `cleanupFun` for the currently running program:

```
cleanupObj = onCleanup(@cleanupFun);
```

When your program exits, MATLAB finds any instances of the `onCleanup` class and executes the associated function handles. The process of generating and activating function cleanup involves the following steps:

- 1** Write one or more cleanup routines for the program under development. Assume for now that it takes only one such routine.
- 2** Create a function handle for the cleanup routine.
- 3** At some point, generally early in your program code, insert a call to the `onCleanup` function, passing the function handle.
- 4** When the program is run, the call to `onCleanup` constructs a cleanup object that contains a handle to the cleanup routine created in step 1.
- 5** When the program ends, MATLAB implicitly clears all objects that are local variables. This invokes the destructor method for each local object in your program, including the cleanup object constructed in step 4.
- 6** The destructor method for this object invokes this routine if it exists. This perform the tasks needed to restore your programming environment.

You can declare any number of cleanup routines for a program file. Each call to `onCleanup` establishes a separate cleanup routine for each cleanup object returned.

If, for some reason, the object returned by `onCleanup` persists beyond the life of your program, then the cleanup routine associated with that object is not run when your function terminates. Instead, it will run whenever the object is destroyed (e.g., by clearing the object variable).

Your cleanup routine should never rely on variables that are defined outside of that routine. For example, the nested function shown here on the left executes with no error, whereas the very similar one on the right fails with the error, `Undefined function or variable 'k'`. This results from the cleanup routine's reliance on variable `k` which is defined outside of the nested cleanup routine:

```
function testCleanup
k = 3;
myFun
    function myFun
        fprintf('k is %d\n', k)
    end
end
```

```
function testCleanup
k = 3;
obj = onCleanup(@myFun);
function myFun
    fprintf('k is %d\n', k)
end
end
```

## Examples of Cleaning Up a Program Upon Exit

### Example 1 – Close Open Files on Exit

MATLAB closes the file with identifier `fid` when function `openFileSafely` terminates:

```
function openFileSafely(fileName)
    fid = fopen(fileName, 'r');
    c = onCleanup(@()fclose(fid));

    s = fread(fid);
        .
        .
        .
end
```

### Example 2 – Maintain the Selected Folder

This example preserves the current folder whether function `functionThatMayError` returns an error or not:

```
function changeFolderSafely(fileName)
    currentFolder = pwd;
    c = onCleanup(@()cd(currentFolder));

    functionThatMayError;
end % c executes cd(currentFolder) here.
```

### Example 3 – Close Figure and Restore MATLAB Path

This example extends the MATLAB path to include files in the toolbox\images folders, and then displays a figure from one of these folders. After the figure displays, the cleanup routine `restore_env` closes the figure and restores the path to its original state:

```
function showImageOutsidePath(imageFile)
    fig1 = figure;
    imgpath = genpath([matlabroot '\toolbox\images']);
```

```
% Define the cleanup routine.
cleanupObj = onCleanup(@()restore_env(fig1, imgpath));

% Modify the path to gain access to the image file,
% and display the image.
addpath(imgpath);
rgb = imread(imageFile);
fprintf('\n  Opening the figure %s\n', imageFile);
image(rgb);
pause(2);

% This is the cleanup routine.
function restore_env(fighandle, newpath)
    disp '  Closing the figure'
    close(fighandle);
    pause(2)

    disp '  Restoring the path'
    rmpath(newpath);
end
end
```

Run the function as shown here. You can verify that the path has been restored by comparing the length of the path before and after running the function:

```
origLen = length(path);

showImageOutsidePath('greens.jpg')
    Opening the figure greens.jpg
    Closing the figure
    Restoring the path

currLen = length(path);
currLen == origLen
ans =
    1
```



## Retrieving Information About the Cleanup Routine

In Example 3 shown above, the cleanup routine and data needed to call it are contained in a handle to an anonymous function:

```
@()restore_env(fig1, imgpath)
```

The details of that handle are then contained within the object returned by the `onCleanup` function:

```
cleanupObj = onCleanup(@()restore_env(fig1, imgpath));
```

You can access these details using the `task` property of the cleanup object as shown here. (Modify the `showImageOutsidePath` function by adding the following code just before the comment line that says, “% This is the cleanup routine.”)

```
disp '   Displaying information from the function handle:'
task = cleanupObj.task;
fun = functions(task)
wsp = fun.workspace{2,1}
fprintf('\n');
pause(2);
```

Run the modified function to see the output of the `functions` command and the contents of one of the workspace cells:

```
showImageOutsidePath('greens.jpg')
```

Opening the figure `greens.jpg`

Displaying information from the function handle:

```
fun =
    function: '@()restore_env(fig1,imgpath)'
    type: 'anonymous'
    file: 'c:\work\g6.m'
workspace: {2x1 cell}
wsp =
    imageFile: 'greens.jpg'
    fig1: 1
    imgpath: [1x3957 char]
    cleanupObj: [1x1 onCleanup]
    rgb: [300x500x3 uint8]
```

```
task: @()restore_env(fig1,imgpath)
```

Closing the figure  
Restoring the path

## Using onCleanup Versus try/catch

Another way to run a cleanup routine when a function terminates unexpectedly is to use a `try, catch` statement. There are limitations to using this technique however. If the user ends the program by typing **Ctrl+C**, MATLAB immediately exits the `try` block, and the cleanup routine never executes. The cleanup routine also does not run when you exit the function normally.

The following program cleans up if an error occurs, but not in response to **Ctrl+C**:

```
function cleanupByCatch
try
    pause(10);
catch
    disp('    Collecting information about the error')
    disp('    Executing cleanup tasks')
end
```

Unlike the `try/catch` statement, the `onCleanup` function responds not only to a normal exit from your program and any error that might be thrown, but also to **Ctrl+C**. This next example replaces the `try/catch` with `onCleanup`:

```
function cleanupByFunc
obj = onCleanup(@()...
    disp('    Executing cleanup tasks'));
pause(10);
```

## onCleanup in Scripts

`onCleanup` does not work in scripts as it does in functions. In functions, the cleanup object is stored in the function workspace. When the function exits, this workspace is cleared thus executing the associated cleanup routine. In scripts, the cleanup object is stored in the base workspace (that is, the workspace used in interactive work done at the command prompt). Because exiting a script has no effect on the base workspace, the cleanup object is

not cleared and the routine associated with that object does not execute. To use this type of cleanup mechanism in a script, you would have to explicitly clear the object from the command line or another script when the first script terminates.

## Issue Warnings and Errors

### In this section...

“Issue Warnings” on page 23-30

“Throw Errors” on page 23-30

“Add Run-Time Parameters to Your Warnings and Errors” on page 23-31

“Add Identifiers to Warnings and Errors” on page 23-32

### Issue Warnings

You can issue a warning to flag unexpected conditions detected when running a program. The warning function prints a warning message to the command line. Warnings differ from errors in two significant ways:

- Warnings do not halt the execution of the program.
- You can suppress any unhelpful MATLAB warnings.

Use the warning function in your code to generate a warning message during execution. Specify the message string as the input argument to the warning function:

```
warning('Input must be a string')
```

For example, you can insert a warning in your code to verify the software version:

```
function warningExample1
    if ~strncmp(version, '7', 1)
        warning('You are using a version other than v7')
    end
```

### Throw Errors

You can throw an error to flag fatal problems within the program. Use the error function to print error messages to the command line. After displaying the message, MATLAB stops the execution of the current program.

For example, suppose you construct a function that returns the number of combinations of  $k$  elements from  $n$  elements. Such a function is nonsensical if  $k > n$ ; you cannot choose 8 elements if you start with just 4. You must incorporate this fact into the function to let anyone using combinations know of the problem:

```
function com = combinations(n,k)
    if k > n
        error('Cannot calculate with given values')
    end
    com = factorial(n)/(factorial(k)*factorial(n-k));
end
```

If the combinations function receives invalid input, MATLAB stops execution immediately after throwing the error message:

```
combinations(4,8)
```

```
Error using combinations (line 3)
Cannot calculate with given values
```

## Add Run-Time Parameters to Your Warnings and Errors

To make your warning or error messages more specific, insert components of the message string at the time of execution. The warning function uses *conversion characters* that are the same as those used by the `sprintf` function. Conversion characters act as placeholders for substrings or values, unknown until the code executes.

For example, this warning uses `%s` and `%d` to mark where to insert the values of variables `arrayname` and `arraydims`:

```
warning('Array %s has %d dimensions.',arrayname,arraydims)
```

If you execute this command with `arrayname = 'A'` and `arraydims = 3`, MATLAB responds:

```
Warning: Array A has 3 dimensions.
```

Adding run-time parameters to your warnings and errors can clarify the problems within a program. Consider the function combinations from

“Throw Errors” on page 23-30. You can throw a much more informative error using run-time parameters:

```
function com = combinations(n,k)
    if k > n
        error('Cannot choose %i from %i elements',k,n)
    end
    com = factorial(n)/(factorial(k)*factorial(n-k));
end
```

If this function receives invalid arguments, MATLAB throws an error message and stops the program:

```
combinations(6,9)
```

```
Error using combinations (line 3)
Cannot choose 9 from 6 elements
```

## Add Identifiers to Warnings and Errors

A message identifier provides a way to uniquely reference a warning or an error.

Enable or disable warnings with identifiers. Use an identifying string argument with the `warning` function to attach a unique tag to a message:

```
warning(identifier_string,message_string)
```

For example, you can add an identifier tag to the previous MATLAB warning about which version of software is running:

```
minver = '7';
if ~strncmp(version,minver,1)
    warning('MYTEST:VERCHK','Running a version other than v%s',minver)
end
```

Adding an identifier to an error message allows for negative testing. However, adding and recovering more information from errors often requires working with `MException` objects.

### See Also

warning | lastwarn | warndlg | MException

**Related Examples**

- “Suppress Warnings” on page 23-34
- “Restore Warnings” on page 23-37
- “Capture Information About Exceptions” on page 23-5
- “Exception Handling in a MATLAB Application” on page 23-2

**Concepts**

- “Message Identifiers” on page 23-8

## Suppress Warnings

Your program might issue warnings that do not always adversely affect execution. To avoid confusion, you can hide warning messages during execution by changing their states from 'on' to 'off'.

To suppress specific warning messages, you must first find the warning identifier. Each warning message has a unique identifier. To find the identifier associated with a MATLAB warning, reproduce the warning. For example, this code reproduces a warning thrown if MATLAB attempts to remove a nonexistent folder:

```
rmpath('folderthatisnotonpath');
```

```
Warning: "folderthatisnotonpath" not found in path.
```

---

**Note** If this statement does not produce a warning message, use the following code to temporarily enable the display of all warnings, and then restore the original warning state:

```
w = warning('on','all');  
rmpath('folderthatisnotonpath');  
warning(w);
```

---

To obtain information about the most recently issued warning, use the `warning` or `lastwarn` functions. This code uses the `query` state to return a data structure containing the message identifier and the current state of the last warning:

```
w = warning('query','last')  
  
w =  
  
    identifier: 'MATLAB:rmpath:DirNotFound'  
    state: 'on'
```

You can save the identifier field in the variable, `id`:

```
id = w.identifier;
```



---

**Note** `warning('query','last')` returns the last displayed warning. MATLAB only displays warning messages that have state: `'on'`.

---

Using the `lastwarn` function, you can retrieve the last-*displayed* warning message:

```
lastwarn
```

```
ans =
```

```
"folderthatisnotonpath" not found in path.
```

## Turn Warnings On and Off

After you obtain the identifier from the query state, use this information to disable or enable the warning associated with that identifier.

Continuing the example from the previous section, turn the warning `'MATLAB:rmpath:DirNotFound'` off, and repeat the operation.

```
warning('off',id)
rmpath('folderthatisnotonpath');
```

MATLAB displays no warning.

Turn the warning on, and try to remove a nonexistent path:

```
warning('on',id)
rmpath('folderthatisnotonpath');
```

```
Warning: "folderthatisnotonpath" not found in path.
```

MATLAB now issues a warning.

---

**Tip** Turn off the most recently invoked warning with `warning('off','last')`.

---

## Controlling All Warnings

The term **all** refers *only* to those warnings that have been issued or modified during your current MATLAB session. Modified warning states persist only through the current session. Starting a new session restores the default settings.

Use the identifier 'all' to represent the group of all warnings. View the state of all warnings with either syntax:

```
warning('query','all')
```

```
warning
```

To enable all warnings and verify the state:

```
warning('on','all');  
warning('query','all');
```

All warnings have the state 'on'.

To disable all warnings and verify the state, use this syntax:

```
warning('off','all');  
warning;
```

All warnings have the state 'off'.

## Related Examples

- “Restore Warnings” on page 23-37
- “Change How Warnings Display” on page 23-40

## Restore Warnings

MATLAB allows you to save the on-off warning states, modify warning states, and restore the original warning states. This is useful if you need to temporarily turn off some warnings and later reinstate the original settings.

The following statement saves the current state of all warnings in the structure array called `orig_state`:

```
orig_state = warning;
```

To restore the original state after any warning modifications, use this syntax:

```
warning(orig_state);
```

You also can save the current state and toggle warnings in a single command. For example, the statement, `orig_state = warning('off', 'all');` is equivalent to the commands:

```
orig_state = warning;  
warning('off', 'all');
```

### Disable and Restore a Particular Warning

This example shows you how to restore the state of a particular warning.

- 1 Query the `Control:parameterNotSymmetric` warning:

```
warning('query', 'Control:parameterNotSymmetric')
```

The state of warning `'Control:parameterNotSymmetric'` is `'on'`.

- 2 Turn off the `Control:parameterNotSymmetric` warning:

```
orig_state = warning('off', 'Control:parameterNotSymmetric')
```

```
orig_state =
```

```
    identifier: 'Control:parameterNotSymmetric'  
         state: 'on'
```

```
orig_state contains the warning state before MATLAB turns
Control:parameterNotSymmetric off.
```

**3** Query all warning states:

```
warning
```

```
The default warning state is 'on'. Warnings not set to the default are
```

```
State Warning Identifier
```

```
off Control:parameterNotSymmetric
```

```
MATLAB indicates that Control:parameterNotSymmetric is 'off'.
```

**4** Restore the original state:

```
warning(orig_state)
warning('query','Control:parameterNotSymmetric')
```

```
The state of warning 'Control:parameterNotSymmetric' is 'on'.
```

## Disable and Restore Multiple Warnings

This example shows you how to save and restore multiple warning states.

**1** Disable three warnings, and query all the warnings:

```
w(1) = warning('off','MATLAB:rmpath:DirNotFound');
w(2) = warning('off','MATLAB:singularMatrix');
w(3) = warning('off','Control:parameterNotSymmetric');
warning
```

```
The default warning state is 'on'. Warnings not set to the default are
```

```
State Warning Identifier
```

```
off Control:parameterNotSymmetric
off MATLAB:rmpath:DirNotFound
off MATLAB:singularMatrix
```

**2** Restore the three warnings to their the original state, and query all warnings:

```
warning(w)  
warning
```

All warnings have the state 'on'.

You do not need to store information about the previous warning states in an array, but doing so allows you to restore warnings with one command.

---

**Note** When temporarily disabling multiple warnings, using methods related to `onCleanup` might be advantageous.

---

Alternatively, you can save and restore all warnings.

- 1 Enable all warnings, and save the original warning state:

```
orig_state = warning('on', 'all');
```

- 2 Restore your warnings to the previous state:

```
warning(orig_state)
```

```
warning | onCleanup
```

## See Also

## Related Examples

- “Suppress Warnings” on page 23-34
- “Clean Up When Functions Complete” on page 23-23

## Change How Warnings Display

You can control how warnings appear in MATLAB by modifying two warning *modes*, `verbose` and `backtrace`.

Mode	Description	Default
<code>verbose</code>	Display a message on how to suppress the warning.	<code>off</code> ( <code>terse</code> )
<code>backtrace</code>	Display a stack trace after a warning is invoked.	<code>on</code> ( <code>enabled</code> )

---

**Note** The `verbose` and `backtrace` modes present some limitations:

- `prev_state` does not contain information about the `backtrace` or `verbose` modes in the statement, `prev_state = warning('query','all')`.
  - A mode change affects all enabled warnings.
- 

### Enable Verbose Warnings

When you enable verbose warnings, MATLAB displays an extra line of information with each warning that tells you how to suppress it.

For example, you can turn on all warnings, disable `backtrace`, and enable verbose warnings:

```
warning on all
warning off backtrace
warning on verbose
```

Running a command that produces an error displays an extended message:

```
rmrpath('folderthatisnotonpath');
```

```
Warning: "folderthatisnotonpath" not found in path.
(Type "warning off MATLAB:rmrpath:DirNotFound" to suppress this warning.)
```

## Display a Stack Trace on a Specific Warning

It can be difficult to locate the source of a warning when it is generated from code buried in several levels of function calls. When you enable the backtrace mode, MATLAB displays the file name and line number where the warning occurred. For example, you can enable backtrace and disable verbose:

```
warning on backtrace  
warning off verbose
```

Running a command that produces an error displays a hyperlink with a line number:

```
Warning: "folderthatisnotonpath" not found in path.  
> In rmpath at 58
```

Clicking the hyperlink takes you to the location of the warning.

## Use try/catch to Handle Errors

You can use a `try/catch` statement to execute code after your program encounters an error. `try/catch` statements can be useful if you:

- Want to finish the program in another way that avoids errors
- Need to clean up unwanted side effects of the error
- Have many problematic input parameters or commands

Arrange `try/catch` statements into blocks of code, similar to this pseudocode:

```
try
    try block...
catch
    catch block...
end
```

If an error occurs within the `try block`, MATLAB skips any remaining commands in the `try block` and executes the commands in the `catch block`. If no error occurs within `try block`, MATLAB skips the entire `catch block`.

For example, a `try/catch` statement can prevent the need to throw errors. Consider the `combinations` function that returns the number of combinations of  $k$  elements from  $n$  elements:

```
function com = combinations(n,k)
    com = factorial(n)/(factorial(k)*factorial(n-k));
end
```

MATLAB throws an error whenever  $k > n$ . You cannot construct a set with more elements,  $k$ , than elements you possess,  $n$ . Using a `try/catch` statement, you can avoid the error and execute this function regardless of the order of inputs:

```
function com = robust_combine(n,k)
    try
        com = factorial(n)/(factorial(k)*factorial(n-k));
    catch
        com = factorial(k)/(factorial(n)*factorial(k-n));
    end
```



```
end
```

`robust_combine` treats any order of integers as valid inputs:

```
C1 = robust_combine(8,4)
C2 = robust_combine(4,8)
```

```
C1 =
    70
```

```
C2 =
    70
```

MATLAB might give you a code analyzer message: Line 4: Best practice is for CATCH to be followed by an identifier that gets the error information. This message indicates that you can capture more information about errors if a variable follows your catch statement:

```
catch MExc
```

`MExc` is an `MException` class object that contains more information about the thrown error. To learn more about accessing information from `MException` objects, see “Exception Handling in a MATLAB Application” on page 23-2.

## See Also

`MException` | `onCleanup`



# Program Scheduling

---

- “Use a MATLAB Timer Object” on page 24-2
- “Timer Callback Functions” on page 24-5
- “Handling Timer Queuing Conflicts” on page 24-10

## Use a MATLAB Timer Object

In this section...
“Overview” on page 24-2
“Example: Displaying a Message” on page 24-3

### Overview

The MATLAB software includes a timer object that you can use to schedule the execution of MATLAB commands. This section describes how you can create timer objects, start a timer running, and specify the processing that you want performed when a timer fires. A timer is said to *fire* when the amount of time specified by the timer object elapses and the timer object executes the commands you specify.

To use a timer, perform these steps:

- 1 Create a timer object.

You use the `timer` function to create a timer object.

- 2 Specify which MATLAB commands you want executed when the timer fires and control other aspects of timer object behavior.

You use timer object properties to specify this information. To learn about all the properties supported by the timer object, see `timer` and `set`. You can also set timer object properties when you create them, in step 1.

- 3 Start the timer object.

After you create the timer object, you must start it, using either the `start` or `startat` function.

- 4 Delete the timer object when you are done with it.

After you are finished using a timer object, you should delete it from memory. See `delete` for more information.

---

**Note** The specified execution time and the actual execution of a timer can vary because timer objects work in the MATLAB single-threaded execution environment. The length of this time lag is dependent on what other processing MATLAB is performing. To force the execution of the callback functions in the event queue, include a call to the `drawnow` function in your code. The `drawnow` function flushes the event queue.

---

## Example: Displaying a Message

The following example sets up a timer object that executes a MATLAB command string after 10 seconds elapse. The example creates a timer object, specifying the values of two timer object properties, `TimerFcn` and `StartDelay`. `TimerFcn` specifies the timer callback function. This is the MATLAB command string or program file that you want to execute when the timer fires. In the example, the timer callback function sets the value of the MATLAB workspace variable `stat` and executes the MATLAB `disp` command. The `StartDelay` property specifies how much time elapses before the timer fires.

After creating the timer object, the example uses the `start` function to start the timer object. (The additional commands in this example are included to illustrate the timer but are not required for timer operation.)

```
t = timer('TimerFcn', 'stat=false; disp(''Timer!'')',...
         'StartDelay',10);
start(t)

stat=true;
while(stat==true)
    disp('.')
    pause(1)
end
```

When you execute this code, it produces this output:

```
.
.
.
.
```

.  
. .  
. .  
. .  
. .

Timer!

delete(t) % Always delete timer objects after using them.

### Concepts

- “Timer Callback Functions” on page 24-5

## Timer Callback Functions

In this section...
“Associating Commands with Timer Object Events” on page 24-5
“Creating Callback Functions” on page 24-6
“Specifying the Value of Callback Function Properties” on page 24-8

---

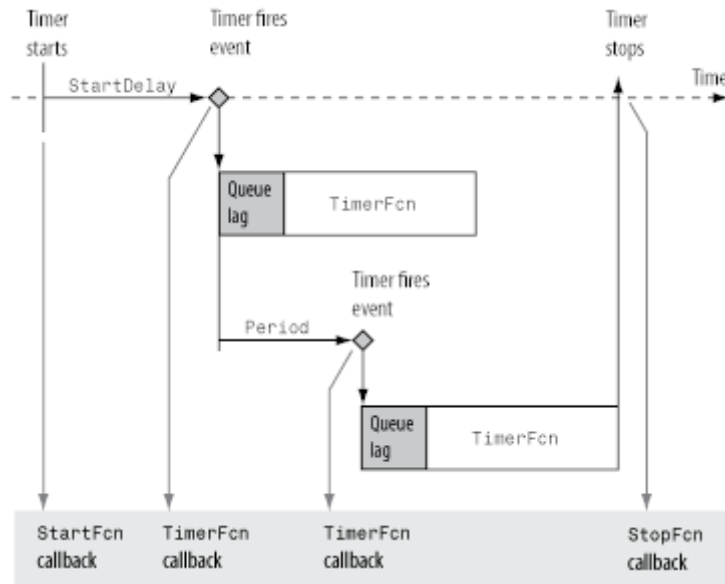
**Note** Callback function execution might be delayed if the callback involves a CPU-intensive task such as updating a figure.

---

### Associating Commands with Timer Object Events

The timer object supports properties that let you specify the MATLAB commands that execute when a timer fires, and for other timer object events, such as starting, stopping, or when an error occurs. These are called *callbacks*. To associate MATLAB commands with a timer object event, set the value of the associated timer object callback property.

The following diagram shows when the events occur during execution of a timer object and give the names of the timer object properties associated with each event. For example, to associate MATLAB commands with a start event, assign a value to the `StartFcn` callback property. Error callbacks can occur at any time.



### Timer Object Events and Related Callback Function

## Creating Callback Functions

When the time period specified by a timer object elapses, the timer object executes one or more MATLAB functions of your choosing. You can specify the functions directly as the value of the callback property. You can also put the commands in a function file and specify the function as the value of the callback property.

### Specifying Callback Functions Directly

This example creates a timer object that displays a greeting after 5 seconds. The example specifies the value of the `TimerFcn` callback property directly, putting the commands in a text string.

```
t = timer('TimerFcn',@(x,y)disp('Hello World!'),'StartDelay',5);
```



---

**Note** When you specify the callback commands directly as the value of the callback function property, the commands are evaluated in the MATLAB workspace.

---

## Putting Commands in a Callback Function

Instead of specifying MATLAB commands directly as the value of a callback property, you can put the commands in a MATLAB program file and specify the file as the value of the callback property.

When you create a callback function, the first two arguments must be a handle to the timer object and an event structure. An event structure contains two fields: `Type` and `Data`. The `Type` field contains a text string that identifies the type of event that caused the callback. The value of this field can be any of the following strings: `'StartFcn'`, `'StopFcn'`, `'TimerFcn'`, or `'ErrorFcn'`. The `Data` field contains the time the event occurred.

In addition to these two required input arguments, your callback function can accept application-specific arguments. To receive these input arguments, you must use a cell array when specifying the name of the function as the value of a callback property. For more information, see “Specifying the Value of Callback Function Properties” on page 24-8.

## Example: Writing a Callback Function

This example implements a simple callback function that displays the type of event that triggered the callback and the time the callback occurred. To illustrate passing application-specific arguments, the example callback function accepts as an additional argument a text string and includes this text string in the display output. To see this function used with a callback property, see “Specifying the Value of Callback Function Properties” on page 24-8.

```
function my_callback_fcn(obj, event, string_arg)

txt1 = ' event occurred at ';
txt2 = string_arg;

event_type = event.Type;
```

```

event_time = datestr(event.Data.time);

msg = [event_type txt1 event_time];
disp(msg)
disp(txt2)

```

## Specifying the Value of Callback Function Properties

You associate a callback function with a specific event by setting the value of the appropriate callback property. You can specify the callback function as a cell array or function handle. If your callback function accepts additional arguments, you must use a cell array.

The following table shows the syntax for several sample callback functions and describes how you call them.

Callback Function Syntax	How to Specify as a Property Value for Object t
function myfile(obj, event)	t.StartFcn = @myfile
function myfile	t.StartFcn = @(~,~)myfile
function myfile(obj, event, arg1, arg2)	t.StartFcn = {@myfile, 5, 6}

This example illustrates several ways you can specify the value of timer object callback function properties, some with arguments and some without. To see the code of the callback function, `my_callback_fcn`, see “Example: Writing a Callback Function” on page 24-7:

- 1 Create a timer object.

```

t = timer('StartDelay', 4, 'Period', 4, 'TasksToExecute', 2, ...
         'ExecutionMode', 'fixedRate');

```

- 2 Specify the value of the `StartFcn` callback. Note that the example specifies the value in a cell array because the callback function needs to access arguments passed to it:

```

t.StartFcn = {@my_callback_fcn, 'My start message'};

```

- 3 Specify the value of the `StopFcn` callback. Again, the value is specified in a cell array because the callback function needs to access the arguments passed to it:

```
t.StopFcn = { @my_callback_fcn, 'My stop message' };
```

- 4 Specify the value of the `TimerFcn` callback. The example specifies the MATLAB commands in a text string:

```
t.TimerFcn = @(x,y)disp('Hello World!');
```

- 5 Start the timer object:

```
start(t)
```

The example outputs the following.

```
StartFcn event occurred at 10-Mar-2004 17:16:59
My start message
Hello World!
Hello World!
StopFcn event occurred at 10-Mar-2004 17:16:59
My stop message
```

- 6 Delete the timer object after you are finished with it.

```
delete(t)
```

**See Also** `timer`

## Handling Timer Queuing Conflicts

At busy times, in multiple-execution scenarios, the timer may need to add the timer callback function (TimerFcn) to the MATLAB execution queue before the previously queued execution of the callback function has completed. You can determine how the timer object handles this scenario by setting the `BusyMode` property to use one of these modes:

In this section...
“Drop Mode (Default)” on page 24-10
“Error Mode” on page 24-12
“Queue Mode” on page 24-13

### Drop Mode (Default)

If you specify 'drop' as the value of the `BusyMode` property, the timer object adds the timer callback function to the execution queue only when the queue is empty. If the execution queue is not empty, the timer object skips the execution of the callback.

For example, suppose you create a timer with a period of 1 second, but a callback that requires at least 1.6 seconds, as shown here for `mytimer.m`.

```
function mytimer()
    t = timer;

    t.Period          = 1;
    t.ExecutionMode   = 'fixedRate';
    t.TimerFcn        = @mytimer_cb;
    t.BusyMode        = 'drop';
    t.TasksToExecute  = 5;
    t.UserData        = tic;

    start(t)
end

function mytimer_cb(h,~)
```

```

    timeStart = toc(h.UserData)
    pause(1.6);
    timeEnd = toc(h.UserData)
end

```

This table describes how the timer manages the execution queue.

<b>Approximate Elapsed Time (Seconds)</b>	<b>Action</b>
0	Start the first execution of the callback.
1	Attempt to start the second execution of the callback. The first execution is not complete, but the execution queue is empty. The timer adds the callback to the queue.
1.6	Finish the first callback execution, and start the second. This action clears the execution queue.
2	Attempt to start the third callback execution. The second execution is not complete, but the queue is empty. The timer adds the callback to the queue.
3	Attempt to start the fourth callback execution. The third callback is in the execution queue, so the timer drops this execution of the function.
3.2	Finish the second callback and start the third, clearing the execution queue.
4	Attempt to start another callback execution. Because the queue is empty, the timer adds the callback to the queue. This is the fifth attempt, but only the fourth instance that will run.
4.8	Finish the third execution and start the fourth instance, clearing the queue.
5	Attempt to start another callback. An instance is running, but the execution queue is empty, so the timer adds it to the queue. This is the fifth instance that will run.

Approximate Elapsed Time (Seconds)	Action
6	Do nothing: the value of the <code>TasksToExecute</code> property is 5, and the fifth instance to run is in the queue.
6.4	Finish the fourth callback execution and start the fifth.
8	Finish the fifth callback execution.

## Error Mode

The 'error' mode for the `BusyMode` property is similar to the 'drop' mode: In both modes, the timer allows only one instance of the callback in the execution queue. However, in 'error' mode, when the queue is nonempty, the timer calls the function that you specify using the `ErrorFcn` property, and then stops processing. The currently running callback function completes, but the callback in the queue does not execute.

For example, modify `mytimer.m` (described in the previous section) so that it includes an error handling function and sets `BusyMode` to 'error'.

```
function mytimer()
    t = timer;

    t.Period          = 1;
    t.ExecutionMode   = 'fixedRate';
    t.TimerFcn        = @mytimer_cb;
    t.ErrorFcn         = @myerror;
    t.BusyMode        = 'error';
    t.TasksToExecute  = 5;
    t.UserData        = tic;

    start(t)
end

function mytimer_cb(h,~)
    timeStart = toc(h.UserData)
```

```

    pause(1.6);
    timeEnd = toc(h.UserData)
end

function myerror(h,~)
    disp('Reached the error function')
end

```

This table describes how the timer manages the execution queue.

<b>Approximate Elapsed Time (Seconds)</b>	<b>Action</b>
0	Start the first execution of the callback.
1	Attempt to start the second execution of the callback. The first execution is not complete, but the execution queue is empty. The timer adds the callback to the queue.
1.6	Finish the first callback execution, and start the second. This action clears the execution queue.
2	Attempt to start the third callback execution. The second execution is not complete, but the queue is empty. The timer adds the callback to the queue.
3	Attempt to start the fourth callback execution. The third callback is in the execution queue. The timer does not execute the third callback, but instead calls the error handling function.
3.2	Finish the second callback and start the error handling function.

## Queue Mode

If you specify 'queue', the timer object waits until the currently executing callback function finishes before queuing the next execution of the timer callback function.

In 'queue' mode, the timer object tries to make the average time between executions equal the amount of time specified in the `Period` property. If the timer object has to wait longer than the time specified in the `Period` property between executions of the timer function callback, it shortens the time period for subsequent executions to make up the time.

**See Also** `timer`



# Performance

---

- “Analyzing Your Program’s Performance” on page 25-2
- “Profiling for Improving Performance” on page 25-4
- “Determining Profiler Coverage” on page 25-27
- “Techniques for Improving Performance” on page 25-29
- “Vectorization” on page 25-33

## Analyzing Your Program's Performance

### In this section...

“Overview of Performance Timing Functions” on page 25-2

“Time Functions” on page 25-2

“Time Portions of Code” on page 25-2

“The cputime Function vs. tic/toc and timeit” on page 25-3

### Overview of Performance Timing Functions

The MATLAB Profiler, the stopwatch timer functions `tic` and `toc` and the `timeit` function enable you to get information on how your program is performing and help you identify areas that need improvement. The Profiler is useful for measuring relative execution time and identifying specific performance bottlenecks in code. The `timeit` function provides a robust measurement of the time required for function execution. Since the function provides a more vigorous estimate, use it instead of the stopwatch timer functions. Use `tic` and `toc` to estimate time for smaller portions of code that are not complete functions.

### Time Functions

To measure the time required to run a function, use the `timeit` function. The `timeit` function takes a handle to the function to be measured and returns the typical execution time, in seconds. Suppose you have defined a function, `computeFunction`, that takes two inputs, `x` and `y`, that are defined in your workspace. You can compute the time to execute the function using `timeit`.

```
f = @() computeFunction(x,y); % handle to function
timeit(f)
```

### Time Portions of Code

If you need to estimate how long a portion of your program takes to run or compare the speed of different implementations of portions of your program, you can use the stopwatch timer functions, `tic` and `toc`. Invoking `tic` starts the timer, and the next `toc` reads the elapsed time.

Use `tic` and `toc` as shown here:

```
tic
-- The program section to time. --
toc
```

Keep in mind that `tic` and `toc` measure overall elapsed time. Make sure that no other applications are running in the background on your system that could affect the timing of your MATLAB programs.

### Time Smaller Sections of Code

Shorter programs sometimes run too fast for `tic` and `toc` to provide useful data. In this case, try measuring the program running repeatedly in a loop, and then average to find the time for a single run.

```
tic
  for k = 1:100
    -- The program section to time. --
  end
toc
```

### The `cputime` Function vs. `tic/toc` and `timeit`

Although you can measure performance using the `cputime` function, the `timeit` or `tic` and `toc` functions are better for this purpose. Generally for CPU-intensive calculations run on Microsoft Windows machines, the elapsed time using `cputime` and using `tic` and `toc` are close in value, ignoring any first-time costs. There are cases, however, that show a significant difference between these methods. For example, in the case of a Pentium 4 with hyperthreading running Windows, there can be a significant difference between the values returned by `cputime` versus `tic` and `toc`.

Like `tic` and `toc`, `timeit` provides more reliable results than `cputime`. However, the `timeit` function additionally takes first-time costs into account.

### See Also

`timeit` | `tic` | `toc`

### Related Examples

- “Profiling for Improving Performance” on page 25-4

## Profiling for Improving Performance

### In this section...

“What Is Profiling?” on page 25-4

“Profiling Process and Guidelines” on page 25-5

“Using the Profiler” on page 25-6

“Profile Summary Report” on page 25-12

“Profile Detail Report” on page 25-14

“The profile Function” on page 25-20

### What Is Profiling?

*Profiling* is a way to measure where a program spends time. To assist you in profiling, MATLAB software provides a graphical user interface, called the Profiler, which is based on the results returned by the `profile` function. Once you identify which functions are consuming the most time, you can determine why you are calling them. Then, look for ways to minimize their use and thus improve performance. It is often helpful to decide whether the number of times the code calls a particular function is reasonable. Because programs often have several layers, your code might not explicitly call the most time-consuming functions. Rather, functions within your code might be calling other time-consuming functions that can be several layers down in the code. In this case it is important to determine which of your functions are responsible for such calls.

Profiling helps to uncover performance problems that you can solve by:

- Avoiding unnecessary computation, which can arise from oversight
- Changing your algorithm to avoid costly functions
- Avoiding recomputation by storing results for future use

When profiling spends most of its time on calls to a few built-in functions, you have probably optimized the code as much as you can.

---

**Note** When using the Parallel Computing Toolbox™ software, you can use the parallel profiler to profile parallel jobs. For details, see “Profiling Parallel Code”.

---

## Profiling Process and Guidelines

Here is a general process you can follow to use the Profiler to improve performance in your code. This section includes the following topics:

- Using Profiling as a Debugging Tool
- “Using Profiling to Understand an Unfamiliar File” on page 25-6

---

**Tip** Premature optimization can increase code complexity unnecessarily without providing a real gain in performance. Your first implementation should be as simple as possible. Then, if speed is an issue, use profiling to identify bottlenecks.

---

- 1** In the summary report produced by the Profiler, look for functions that used a significant amount of time or are called most frequently. See “Profile Summary Report” on page 25-12 for more information.
- 2** View the detail report produced by the Profiler for those functions and look for the lines that use the most time or are called most often. See “Profile Detail Report” on page 25-14 for more information.

Consider keeping a copy of your first detail report as a basis for comparison. After you change the function file, run the Profiler again and compare the reports.

- 3** Determine whether there are changes you can make to the lines most called or the most time-consuming lines to improve performance.

For example, if you have a `load` statement within a loop, `load` is called every time the loop is called. You might be able to save time by moving the `load` statement so it is before the loop and therefore is called only once.

- 4 Click the links to the files and make the changes you identified for potential performance improvement. Save the files and run `clear all`. Run the Profiler again and compare the results to the original report. Note that there are inherent time fluctuations that are not dependent on your code. If you profile the identical code twice, you can get slightly different results each time.
- 5 Repeat this process to continue improving the performance.

### **Using Profiling as a Debugging Tool**

The Profiler is a useful tool for isolating problems in your code.

For example, if a particular section of a file did not run, you can look at the detail reports to see what lines did run. The detail report might point you to the problem.

You can also view the lines that did not run to help you develop test cases that exercise that code.

If you get an error in the file when profiling, the Profiler provides partial results in the reports. You can see what ran and what did not to help you isolate the problem. Similarly, you can do this if you stop the execution using **Ctrl+C**. Using **Ctrl+C** can be useful when a file is taking much more time to run than expected.

### **Using Profiling to Understand an Unfamiliar File**

For a lengthy MATLAB code file that you did not create, or with which you are unfamiliar, use the Profiler to see how the file actually works. Use the Profiler detail reports to see the lines called.

If there is an existing GUI tool (or file) like one that you want to create, start profiling, use the tool, then stop profiling. Look through the Profiler detail reports to see what functions and lines ran. This helps you determine the lines of code in the file that are most like the code you want to create.

### **Using the Profiler**

Use the Profiler to help you determine where you can modify your code to make performance improvements. The Profiler is a tool that shows you where a file is spending its time. This section covers:



- “Running the Profiler” on page 25-7
- “Profiling a Graphical User Interface” on page 25-8
- “Profiling Statements from the Command Window” on page 25-9
- “Changing Fonts for the Profiler” on page 25-9
- “Troubleshooting” on page 25-9

For information about the reports generated by the Profiler, see “Profile Summary Report” on page 25-12 and “Profile Detail Report” on page 25-14.

## Running the Profiler

To profile a MATLAB code file or a line of code:

### 1 Launch the Profiler using one of the following methods:

- On the **Editor** tab, in the **Run** section, click  **Run and Time**. If you use this method, the Profiler automatically profiles the code in the current Editor tab, so skip to step 5.
- On the **Home** tab, in the **Code** section, click  **Run and Time**.
- In the Command Window, type `profile viewer`.

### 2 Do one of the following in the Profiler:

- For a statement you have not profiled in the current MATLAB session:

In the **Run this code** field, type the statement you want to run.

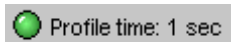
For example, you can run the Lotka-Volterra example, which is provided with MATLAB examples (`lotkademo`):

```
[t,y] = ode23('lotka',[0 2],[20;20])
```

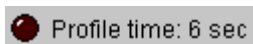
- For a statement you previously profiled in the current MATLAB session:
  - 1 Select the statement from the list box—MATLAB automatically starts profiling the code.
  - 2 Skip to step 5.

### 3 Click **Start Profiling**.

While the Profiler is running, the **Profile time** indicator is green and the number of seconds it reports increases. The **Profile time** indicator appears at the top right of the Profiler window.



When the Profiler finishes, the **Profile time** indicator becomes dark red and shows the length of time the Profiler ran. The statements you profiled display as having been executed in the Command Window.



This time is not the actual time that your statements took to run. It is the wall clock (or tic/toc) time elapsed from when you clicked **Start Profiling** until profiling stops. If the time reported is very different from what you expected (for example, hundreds of seconds for a simple statement), you might have had profiling on longer than you realize. This time also does not match the time reported in Profiler Summary report statistics, which is based on cpu time by default, not wall clock time. To view profile statistics based on wall clock time, use the `profile` function with the `-timer real` option as shown in “Using the profile Function to Change the Time Type Used by the Profiler” on page 25-25.

- 4 When profiling is complete, the Profile Summary report appears in the Profiler window. For more information about this report, see “Profile Summary Report” on page 25-12.

### **Profiling a Graphical User Interface**

You can run the Profiler for a graphical user interface, such as the Filter Design and Analysis tool included with Signal Processing Toolbox. You can also run the Profiler for an interface you created, such as one built using GUIDE.

To profile a graphical user interface:

- 1 In the Profiler, click **Start Profiling**. Make sure that no code appears in the **Run this code** field.



- 2 Start the graphical user interface. (If you do not want to include its startup process in the profile, do not click **Stop Profiling**, step 1, until after you start the graphical interface.)
- 3 Use the graphical interface. When you finish, click **Stop Profiling** in the Profiler.

The Profile Summary report appears in the Profiler.

### **Profiling Statements from the Command Window**


To profile more than one statement:

- 1 In the Profiler, clear the **Run this code** field and click **Start Profiling**.
- 2 In the Command Window, enter and run the statements you want to profile.
- 3 After running all the statements, click **Stop Profiling** in the Profiler.

The Profile Summary report appears in the Profiler.

### **Changing Fonts for the Profiler**

To change the fonts used in the Profiler:

- 1 On the **Home** tab, in the **Environment** section, click **Preferences** .
- 2 Select **Fonts > Custom** in the left pane.
- 3 Under **Desktop tools**, select **Profiler and Comparison Tool**.
- 4 Under **Font to use**, select the font. For more information, click the **Help** button in the dialog box.
- 5 Click **Apply** or **OK**. The Profiler font reflects the changes.

### **Troubleshooting**

If your profiling results are not what you expect, and your system has multiple cores and/or processors consider restricting the active number of CPUs to one. See one of the following for details:

- “Multi-Core Processors — Setting for Most Accurate Profiling on Windows Systems” on page 25-10
- “Multi-Core Processors — Setting for Most Accurate Profiling on Linux Systems” on page 25-11

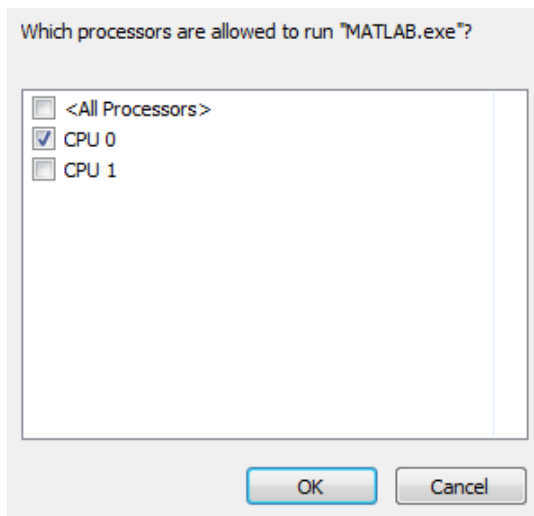
**Multi-Core Processors — Setting for Most Accurate Profiling on Windows Systems.** If your system uses multiple cores and/or processors, and you plan to profile using CPU time, set the number of active CPUs to one before you start profiling. This results in the most accurate and efficient profiling.

- 1 Open Windows Task Manager.
- 2 On the **Processes** tab, right-click `MATLAB.exe` and then click **Set Affinity**.

The Processor Affinity dialog box opens.

- 3 In the Processor Affinity dialog box, note the current settings, and then clear all the CPUs except one.

Your Processor Affinity dialog box should appear like the following image.



- 4 Click **OK**.

- 5 Reset the state of the Profiler so that it recognizes the processor affinity changes you made. The easiest way to do so is to change the Profiler timer setting to `real` and then back to `cpu`, by issuing the following in the Command Window:

```
profile -timer real
profile -timer cpu
```

Remember to set the number of CPUs back to their original settings when you finish profiling. Rerun the preceding steps, and restore the original selections in the Processor Affinity dialog box in step 3.

**Multi-Core Processors – Setting for Most Accurate Profiling on Linux® Systems.** If your system uses multiple cores and/or processors, and you plan to profile using CPU time, set the number of active CPUs to one before you start profiling. This results in the most accurate and efficient profiling.

For example, to set the processor affinity to one you can use the Linux `taskset` command, as follows:

- 1 Get the process ID (PID) of the currently running MATLAB instance:

```
ps -C MATLAB
PID  TTY  TIME  CMD
8745 pts/1 00:00:50  MATLAB
```

The PID in this example is 8745.

- 2 Call the Linux `taskset` command to get the current number of active CPUs for the MATLAB process:

```
taskset -pc 8745
pid 8745's current affinity list: 0-3
```

The `-p` option specifies that `taskset` operate on an existing PID, instead of creating a new task. The `-c` option lists the processor numbers.

- 3 Call the Linux `taskset` command again — this time to set the processor affinity for the MATLAB process to one CPU (that is, CPU #0):

```
taskset -pc 0 8745
pid 8745's current affinity list: 0-3
```

```
pid 8745's new affinity list: 0
```

For more information on the syntax of `taskset`, execute `man taskset` from a Linux terminal.

Reset the state of the Profiler so that it recognizes the processor affinity changes you made. The easiest way to do this is to change the Profiler timer setting to `real` and then back to `cpu`, by issuing the following in the Command Window:

```
profile -timer real
profile -timer cpu
```

Remember to set the number of CPUs back to its original setting when you finish profiling. Rerun the preceding steps, and then restore the original number of CPUs returned.

## Profile Summary Report

The Profile Summary report presents statistics about the overall execution of the function and provides summary statistics for each function called. The report formats these values in four columns.

- **Function Name** — A list of all the functions called by the profiled function. When first displayed, the functions are listed in order by the amount of time they took to process. To sort the functions alphabetically, click the **Function Name** link at the top of the column.
- **Calls** — The number of times the function was called while profiling was on. To sort the report by the number of times functions were called, click the **Calls** link at the top of the column.
- **Total Time** — The total time spent in a function, including all child functions called, in seconds. The time for a function includes time spent on child functions. To sort the functions by the amount of time they consumed, click the **Total Time** link at the top of the column. By default, the summary report displays profiling information sorted by **Total Time**. Be aware that the Profiler itself uses some time, which is included in the results. Also note that total time can be zero for files whose running time was inconsequential.

- **Self Time** — The total time spent in a function, *not* including time for any child functions called, in seconds. If MATLAB can determine the amount of time spent for profiling overhead, MATLAB excludes it from the self time also. (MATLAB excludes profiling overhead from the total time and the time for individual lines in the Profile Detail Report as well.)

The bottom of the Profiler page contains a message like one of the following, depending on whether MATLAB can determine the profiling overhead:

- Self time is the time spent in a function excluding:
  - The time spent in its child functions
  - Most of the overhead resulting from the process of profiling

In the present run, self time excludes 0.240 secs of profiling overhead. The amount of remaining overhead reflected in self time cannot be determined, and therefore is not excluded.


- Self time is the time spent in a function excluding the time spent in its child functions. Self time also includes some overhead resulting from the process of profiling.

To sort the functions by this time value, click the **Self Time** link at the top of the column.













- **Total Time Plot** — Graphic display showing self time compared to total time.

The following is an image of the summary report for the Lotka-Volterra model used in “Example: Using the profile Function” on page 25-21.


In the summary report, you can:

- Print it, by clicking the Print button .
- Get more detailed information about a particular function by clicking its name in the **Function Name** column. See “Profile Detail Report” on page 25-14 for more information.
- Sort by a given column by clicking the name of the column. For example, click [Function Name](#) to sort by the names of the functions included in the summary report.

**Profile Summary**  
Generated 12-Jun-2012 16:13:44 using cpu time.

Function Name	Calls	Total Time	Self Time*	Total Time Plot (dark band = self time)
<a href="#">ode23</a>	1	0.085 s	0.060 s	
<a href="#">workspacefunc</a>	4	0.032 s	0.003 s	
<a href="#">funfun\private\odearguments</a>	1	0.016 s	0.013 s	
<a href="#">workspacefunc&gt;getStatObjectsJ</a>	2	0.015 s	0.002 s	
<a href="#">workspacefunc&gt;getStatObjectJ</a>	38	0.013 s	0.000 s	
<a href="#">workspacefunc&gt;getShortValueObjectsJ</a>	1	0.012 s	0.002 s	
<a href="#">workspacefunc&gt;num2complex</a>	54	0.010 s	0.003 s	
<a href="#">workspacefunc&gt;getShortValueObjectJ</a>	19	0.010 s	0.005 s	
<a href="#">workspacefunc&gt;getStatObjectM</a>	38	0.008 s	0.002 s	
<a href="#">odeget</a>	11	0.005 s	0.005 s	
<a href="#">funfun\private\odefinalize</a>	1	0.005 s	0.005 s	
<a href="#">workspacefunc&gt;getAbstractValueSummaryJ</a>	21	0.003 s	0.000 s	

## Profile Detail Report

The Profile Detail report shows profiling results for a selected function that was called during profiling. A Profile Detail report has seven sections. The topics that follow describe each section. By default, the Profile Detail report includes all seven sections, although, depending on the function, not every section contains data. To return to the Profile Summary report from the Profile Detail report, click  in the toolbar of the Profile window.

The following topics provide details about opening and using a Profile Detail Report:

- “Opening the Profile Detail Report” on page 25-15
- “Controlling the Contents of the Detail Report Display” on page 25-15
- “Profile Detail Report Header” on page 25-15
- “Parent Functions” on page 25-16
- “Busy Lines” on page 25-16

- “Child Functions” on page 25-17
- “Code Analyzer Results” on page 25-18
- “File Coverage” on page 25-19
- “Function Listing” on page 25-19

## Opening the Profile Detail Report

To open the Profile Detail Report:

- 1 Create a Profile Summary report, as described in “Using the Profiler” on page 25-6.
- 2 Click a function name listed in the Profile Summary report.

## Controlling the Contents of the Detail Report Display

To specify which sections the Profile Detail Report includes:

- 1 Select report options from the set of check boxes at the top of the report.
- 2 Click the **Refresh** button.

## Profile Detail Report Header

The detail report header includes:

- The name of the function profiled
- The number of times the profiled function was called in the parent function
- The amount of time the profiled function used
- A link that opens the function in your default text editor
- A link that copies the report to a separate window

Creating a copy of the report is helpful when you change the file, run the Profiler for the updated file, and compare the Profile Detail reports for the two runs. Do not change files provided with products from MathWorks, that is, files in the *matlabroot*/toolbox folders.

## Parent Functions

To include the **Parents** section in the Detail Report, select the **Show parent functions** check box. This section of the report provides information about the parent functions, with links to their detail reports. Click the name of a parent function to open a Detail Report for that parent function.

---

Show parent functions       Show busy lines       Show child functions  
 Show Code Analyzer results       Show file coverage       Show function listing

---

**Parents (calling functions)**







Function Name	Function Type	Calls
<a href="#">ode23</a>	M-function	1

---

## Busy Lines

To include information about the lines of code that used the most amount of processing time in the detail report, select the **Show busy lines** check box.



Refresh					
<input type="checkbox"/> Show parent functions <input checked="" type="checkbox"/> Show busy lines <input type="checkbox"/> Show child functions <input type="checkbox"/> Show Code Analyzer results <input type="checkbox"/> Show file coverage <input type="checkbox"/> Show function listing					
Lines where the most time was spent					
Line Number	Code	Calls	Total Time	% Time	Time Plot
110	<code>f0 = feval(ode,t0,y0,args{:});...</code>	1	0.482 s	58.5%	
81	<code>if (nargin(ode) == 2) ...</code>	1	0.110 s	13.3%	
148	<code>rtol = odeget(options,'RelTol'...</code>	1	0.063 s	7.6%	
184	<code>htry = abs(odeget(options,'Ini...</code>	1	0.032 s	3.9%	
105	<code>if any( tdir*diff(tspan) &lt;=...</code>	1	0.032 s	3.9%	
All other lines			0.107 s	12.9%	
Totals			0.825 s	100%	

## Child Functions

To include the **Children** section of the detail report, select the **Show child functions** check box. This section of the report lists all the functions called by the profiled function. If the called function is a MATLAB code file, you can view the source code for the function by clicking its name.

Refresh

Show parent functions   
 Show busy lines   
 Show child functions  
 Show Code Analyzer results   
 Show file coverage   
 Show function listing

**Children** (called functions)

Function Name	Function Type	Calls	Total Time	% Time	Time Plot
<a href="#">lotka</a>	M-function	1	0.466 s	56.5%	
<a href="#">odeget</a>	M-function	5	0.032 s	3.9%	
<a href="#">double_superiorfloat</a>	M-function	1	0 s	0%	
Self time (built-ins, overhead, etc.)			0.327 s	39.6%	
Totals			0.825 s	100%	

### Code Analyzer Results

To include the **Code Analyzer results** section in the detail report display, select the **Show Code Analyzer results** check box. This section of the report provides information about problems and potential improvements for the function.

Refresh

Show parent functions   
 Show busy lines   
 Show child functions  
 Show Code Analyzer results   
 Show file coverage   
 Show function listing

**M-Lint results**

Line number	Message
52	EXIST with two input arguments is generally faster and clearer than with one input argument.
80	EXIST with two input arguments is generally faster and clearer than with one input argument.
90	The value assigned to variable 'ME' might be unused.

## File Coverage

To include the **Coverage results** section in the detail report display, select the **Show file coverage** check box. This section of the report provides statistical information about the number of lines in the code that executed during the profile run.

---

Refresh

Show parent functions   
 Show busy lines   
 Show child functions  
 Show Code Analyzer results   
 Show file coverage   
 Show function listing

**Coverage results**  
[\[ Show coverage for parent directory \]](#)

Total lines in function	190
Non-code lines (comments, blank lines)	57
Code lines (lines that can run)	133
Code lines that did run	53
Code lines that did not run	80
Coverage (did run/can run)	39.85 %

---

## Function Listing

To include the **Function listing** section in the detail report display, select the **Show function listing** check box. If the file is a MATLAB code file, the Profile Detail report includes three columns:

- The first column lists the execution time for each line.
- The second column lists the number of times the line was called
- The third column specifies the source code for the function.

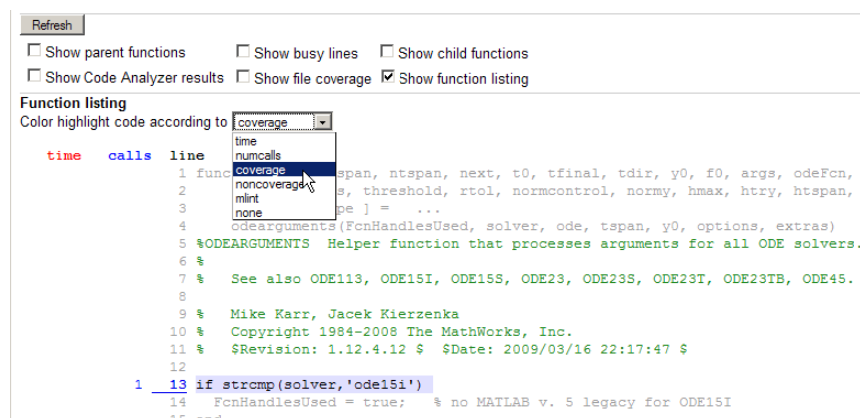
In the function listing, the color of the text indicates the following:

- Green — Comment lines
- Black — Lines of code that executed
- Gray — Lines of code that did not execute

By default, the Profile Detail report highlights lines of code with the longest execution time. The darker the highlighting, the longer the line of code took to execute.

To change the lines of code highlighted based on other criteria, use the drop-down menu in this section of the detail report. The color of the highlighting changes, depending on the drop-down option you choose. You can choose to highlight lines of code called the most, lines of code that were (or were not) executed, or lines called out by the Code Analyzer. Or, you can turn off highlighting by selecting none.

The following image shows that lines highlight in blue when you select coverage from the drop-down menu.



## The profile Function

The Profiler is based on the results returned by the `profile` function. The `profile` function provides some features that are not available in the GUI. For example, use the `profile` function to specify that statistics display the time it takes for statements to run as clock time, instead of CPU time.

This section includes the following topics with respect to the `profile` function:

- “Example: Using the profile Function” on page 25-21
- “Accessing profile Function Results” on page 25-22

- “Saving profile Function Reports” on page 25-24
- “Using the profile Function to Change the Time Type Used by the Profiler” on page 25-25

### **Example: Using the profile Function**

This example demonstrates how to run `profile`:

- 1** To start `profile`, type the following in the Command Window:

```
profile on
```

- 2** Execute a MATLAB code file. This example runs the Lotka-Volterra predator-prey population model. For more information about this model, type `lotkadem`, which runs a demonstration.

```
[t,y] = ode23('lotka',[0 2],[20;20]);
```

- 3** Generate the profile report and display it in the Profiler window. This suspends `profile`.

```
profile viewer
```

- 4** Restart `profile`, without clearing the existing statistics.

```
profile resume
```

The `profile` function is now ready to continue gathering statistics for any more files you run. It will add these new statistics to those statistics generated in the previous steps.

- 5** Stop `profile` when you finish gathering statistics.

```
profile off
```

- 6** To view the profile data, call `profile` specifying the `'info'` argument. The `profile` function returns data in a structure.

```
p = profile('info')
```

```
p =
```

```
FunctionTable: [33x1 struct]
FunctionHistory: [2x0 double]
ClockPrecision: 1.0000e-03
ClockSpeed: 3.0000e+09
Name: 'MATLAB'
Overhead: 0
```

The `FunctionTable` indicates that statistics were gathered for 33 functions.

- 7 To save the profile report, use the `profsave` function. This function stores the profile information in separate HTML files, for each function listed in `FunctionTable` of `p`.

```
profsave(p)
```

By default, `profsave` puts these HTML files in a subfolder of the current folder named `profile_results`, and displays the summary report in your system browser. You can specify another folder name as an optional second argument to `profsave`.

## Accessing profile Function Results

The `profile` function returns results in a structure. This example illustrates how you can access these results:

- 1 To start `profile`, specifying the history option, type the following in the Command Window:

```
profile on -history
```

The history option specifies that the report include information about the sequence of functions as they are entered and exited during profiling.

- 2 Execute a MATLAB code file. This example runs the Lotka-Volterra predator-prey population model. For more information about this model, type `lotkademo`, which runs a demonstration.

```
[t,y] = ode23('lotka',[0 2],[20;20]);
```

- 3 Stop profiling.

```
profile off
```

- 4 Get the structure containing profile results.

```
stats = profile('info')
stats =

    FunctionTable: [33x1 struct]
  FunctionHistory: [2x880 double]
  ClockPrecision: 1.0000e-03
    ClockSpeed: 3.0000e+09
           Name: 'MATLAB'
    Overhead: 0
```

- 5 The FunctionTable field is an array of structures, where each structure represents a MATLAB function (M-function), MATLAB local function, MEX-function, or, because the builtin option is specified, a MATLAB built-in function.

```
stats.FunctionTable
```

```
ans =
```

```
33x1 struct array with fields:
  CompleteName
  FunctionName
  FileName
  Type
  Children
  Parents
  ExecutedLines
  IsRecursive
  TotalRecursiveTime
  PartialData
  NumCalls
  TotalTime
```

- 6 View the second structure in FunctionTable.

```
stats.FunctionTable(2)
```

```
ans =  
  
    CompleteName: [1x95 char]  
    FunctionName: 'ode23'  
    FileName: [1x89 char]  
        Type: 'M-function'  
    Children: [6x1 struct]  
    Parents: [0x1 struct]  
    ExecutedLines: [139x3 double]  
    IsRecursive: 0  
    TotalRecursiveTime: 0  
    PartialData: 0  
    NumCalls: 1  
    TotalTime: 0.0920
```

- 7** To view the history data generated by `profile`, view the `FunctionHistory`, for example, `stats.FunctionHistory`. The history data is a 2-by-n array. The first row contains Boolean values, where 0 (zero) means entrance into a function and 1 means exit from a function. The second row identifies the function being entered or exited by its index in the `FunctionTable` field. To see how to create a formatted display of history data, see the example on the `profile` reference page.

### **Saving profile Function Reports**

To save the profile report, use the `profsave` function.

This function stores the profile information in separate HTML files, for each function listed in the `FunctionTable` field of the structure, `stats`.

```
profsave(stats)
```

By default, `profsave` puts these HTML files in a subfolder of the current folder named `profile_results`. You can specify another folder name as an optional second argument to `profsave`.

```
profsave(stats, 'mydir')
```



## Using the profile Function to Change the Time Type Used by the Profiler

By default, MATLAB generates the Profiler Summary report using CPU time, as opposed to real (wall clock) time. This example illustrates how you can direct MATLAB to use real time instead.

Specify that the Profiler use real time instead, by using the `profile` function with the `-timer real` option, as shown in this example:

- 1 If the Profiler is currently open, close the Profiler, and if prompted, stop profiling.
- 2 Set the timer to real time by typing the following in the Command Window:

```
profile on -timer real
```

- 3 Run the file that you want to profile. This example runs the Lotka-Volterra predator-prey population model.

```
[t,y] = ode23('lotka',[0 2],[20;20]);
```

- 4 Open the Profiler by typing the following in the Command Window:

```
profile viewer
```

The Profiler opens and indicates that it is using real time, as shown in the following image.

**Profile Summary**  
Generated 12-Jun-2012 16:27:28 using real time.

Function Name	Calls	Total Time	Self Time*	Total Time Plot (dark band = self time)
<a href="#">ode23</a>	1	0.082 s	0.061 s	
<a href="#">workspacefunc</a>	4	0.037 s	0.002 s	
<a href="#">workspacefunc&gt;getShortValueObjects.J</a>	1	0.016 s	0.003 s	

- 5 To change the timer back to using CPU time:

- a** Close the Profiler, and if prompted, stop profiling.
- b** Type the following in the Command Window:  
`profile on -timer cpu`
- c** Type the following in the Command Window to reopen the Profiler:  
`profile viewer`

## Determining Profiler Coverage

When you run the Profiler on a file, some code might not run, such as a block containing an `if` statement.

To determine how much of a file ran when you profiled it, run the Coverage Report:

- 1 In the Command Window, type `profile viewer`.
- 2 Profile a MATLAB code file in the Profiler.

For detailed instructions, see “Profiling for Improving Performance” on page 25-4.

- 3 Ensure the Profiler is not currently profiling.

The Profiler displays a **Start Profiling** button when the Profiler is not running. If the Profiler is running, then do one of the following:

- Wait for it to stop profiling before proceeding to step 4.
- Click **Stop Profiling**.


The **Stop Profiling** button is available only when the Profiler is running.

- 4 Use the Current Folder browser to navigate to the folder containing the file for which you ran the Profiler.

---

**Note** You cannot run reports when the path is a UNC (Universal Naming Convention) path; that is, a path that starts with `\\`. Instead, use an actual hard drive on your system, or a mapped network drive.

---

- 5 On the Current Folder browser, click , and then select **Reports > Coverage Report**.

The Profiler Coverage Report appears, providing a summary of coverage for the file you profiled. In the image that follows, the profiled file is `lengthofline2.m`.


- 6 Click the **Coverage** link to see the Profile Detail Report for the file.

## Profiler Coverage Report

Run the Coverage Report after you run the Profiler to identify how much of a file ran when it was profiled ([Learn More](#)).

[Rerun This Report](#) [Run Report on Current Folder](#)

Report for folder I:\my\_MATLAB\_files

<a href="#">lengthofline2.m</a>	
	<a href="#">Coverage</a> : 87.9%
	Total time: 0.2 seconds
	Total lines:
<a href="#">api2.m</a>	
<a href="#">area.m</a>	
<a href="#">basic_matrix.m</a>	
<a href="#">breakpoint.m</a>	
<a href="#">collat2z.m</a>	

## Techniques for Improving Performance

### In this section...

“Preallocating Arrays” on page 25-29

“Assigning Variables” on page 25-30

“Using Appropriate Logical Operators” on page 25-31

“Additional Tips on Improving Performance” on page 25-31

### Preallocating Arrays

for and while loops that incrementally increase the size of a data structure each time through the loop can adversely affect performance and memory use. Repeatedly resizing arrays often requires MATLAB to spend extra time looking for larger contiguous blocks of memory, and then moving the array into those blocks. Often, you can improve code execution time by preallocating the maximum amount of space required for the array.

The following code displays the amount of time needed to create a scalar variable, `x`, and then to gradually increase the size of `x` in a for loop.

```
tic
x = 0;
for k = 2:1000000
    x(k) = x(k-1) + 5;
end
toc
```

Elapsed time is 0.301528 seconds.

If you preallocate a 1-by-1,000,000 block of memory for `x` and initialize it to zero, then the code runs much faster because there is no need to repeatedly reallocate memory for the growing data structure.

```
tic
x = zeros(1, 1000000);
for k = 2:1000000
    x(k) = x(k-1) + 5;
end
```

```
toc
```

```
Elapsed time is 0.011938 seconds.
```

Use the appropriate preallocation function for the kind of array you want to initialize:

- `zeros` for numeric arrays
- `cell` for character arrays

### Preallocating a Nondouble Matrix

When you preallocate a block of memory to hold a matrix of some type other than `double`, avoid using the method

```
A = int8(zeros(100));
```

This statement preallocates a 100-by-100 matrix of `int8`, first by creating a full matrix of `double` values, and then by converts each element to `int8`. Creating the array as `int8` values saves time and memory. For example:

```
A = zeros(100, 'int8');
```

### Assigning Variables

For best performance, keep the following suggestions in mind when you assign values to variables.

- If you need to store data of a different type, it is advisable to create a new variable. Changing the class or array shape of an existing variable slows MATLAB down because it takes extra time to process.

This code changes the type of `X` from `double` to `char`, which has a negative impact on performance:

```
X = 23;
.
-- other code --
.
X = 'A';           % X changed from type double to char
.
-- other code --
```

- You should not assign a real value to a variable that already holds a complex value, and vice versa. Assigning a complex number to a variable that already holds a real number impacts the performance of your program.

## Using Appropriate Logical Operators

When performing a logical AND or OR operation, you have a choice of whether to use short-circuit operators.

Operator	Description
&,	Perform logical AND and OR on arrays element by element
&&,	Perform logical AND and OR on scalar values with short-circuiting

In `if` and `while` statements, it is more efficient to use the short-circuit operators, `&&` and `||`, because these operators often do not evaluate the entire logical expression. For example, whenever the first input argument is not numeric, MATLAB evaluates only the first part of this expression.

```
if (isnumeric(varargin{1})) && (ischar(varargin{2}))
```

See [Logical Operators: Short Circuit](#) for a discussion about using `&&` and `||`.

## Additional Tips on Improving Performance

If the performance of your program remains a concern, then consider the following suggestions:

- Split large script files into smaller ones, having the first file call the second if necessary.
- Construct separate functions (or local functions and nested functions) from the larger chunks of code.
- If you have overly complicated functions or expressions, use simpler ones to reduce size. Simpler functions often make good utility functions that you can share with others.
- Use functions instead of scripts because they are generally faster.

- Vectorize your code to take advantage of the full functionality of MATLAB.
- Use a sparse matrix structure to vectorize code without requiring large amounts of memory.
- Avoid running large processes in the background while executing your program in MATLAB.
- Avoid overloading MATLAB built-in functions on any standard MATLAB data classes because this can negatively affect performance.

**Concepts**

- “Analyzing Your Program’s Performance” on page 25-2
- “Profiling for Improving Performance” on page 25-4
- “Vectorization” on page 25-33



## Vectorization

### In this section...

“Using Vectorization” on page 25-33

“Indexing Methods for Vectorization” on page 25-34

“Array Operations” on page 25-37

“Logical Array Operations” on page 25-37

“Matrix Operations” on page 25-39

“Ordering, Setting, and Counting Operations” on page 25-41

“Functions Commonly Used in Vectorizing” on page 25-43

### Using Vectorization

MATLAB is optimized for operations involving matrices and vectors. The process of revising loop-based, scalar-oriented code to use MATLAB matrix and vector operations is called *vectorization*. Vectorizing your code is worthwhile for several reasons:

- *Appearance*: Vectorized mathematical code appears more like the mathematical expressions found in textbooks, making the code easier to understand.
- *Less Error Prone*: Without loops, vectorized code is often shorter. Fewer lines of code mean fewer opportunities to introduce programming errors.
- *Performance*: Vectorized code often runs much faster than the corresponding code containing loops.

### Vectorizing Code for General Computing

This code computes the sine of 1,001 values ranging from 0 to 10:

```
i = 0;
for t = 0:.01:10
    i = i + 1;
    y(i) = sin(t);
end
```

This is a vectorized version of the same code:

```
t = 0:.01:10;  
y = sin(t);
```

The second code sample usually executes faster than the first and is a more efficient use of MATLAB. Test execution speed on your system by creating scripts that contain the code shown, and then use the `tic` and `toc` functions to measure their execution time.

### **Vectorizing Code for Specific Tasks**

This code computes the cumulative sum of a vector at every fifth element:

```
x = 1:10000;  
ylength = (length(x) - mod(length(x),5))/5;  
y(1:ylength) = 0;  
for n= 5:5:length(x)  
    y(n/5) = sum(x(1:n));  
end
```

Using vectorization, you can write a much more concise MATLAB process. This code shows one way to accomplish the task:

```
x = 1:10000;  
xsums = cumsum(x);  
y = xsums(5:5:length(x));
```

### **Indexing Methods for Vectorization**

Many vectorizing techniques rely on flexible MATLAB indexing methods. Three basic types of indexing exist:

- “Subscripted Indexing” on page 25-35
- “Linear Indexing” on page 25-35
- “Logical Indexing” on page 25-36

## Subscripted Indexing

In subscripted indexing, the index values indicate their position within the matrix. Thus, if `A = 6:10`, then `A([3 5])` denotes the third and fifth elements of vector `A`:

```
A = 6:10;  
A([3 5])
```

```
ans =
```

```
     8     10
```

Multidimensional arrays or matrices use multiple index parameters for subscripted indexing.

```
A = [11 12 13; 14 15 16; 17 18 19]  
A(2:3,2:3)
```

```
A =
```

```
    11    12    13  
    14    15    16  
    17    18    19
```

```
ans =
```

```
    15    16  
    18    19
```

## Linear Indexing

In linear indexing, MATLAB assigns every element of a matrix a single index as if the entire matrix structure stretches out into one column vector.

```
A = [11 12 13; 14 15 16; 17 18 19];  
A(6)  
A([3,1,8])  
A([3;1;8])
```

```
ans =  
  
    18  
  
ans =  
  
    17    11    16  
  
ans =  
  
    17  
    11  
    16
```

In the previous example, the returned matrix elements preserve the shape specified by the index parameter. If the index parameter is a row vector, MATLAB returns the specified elements as a row vector.

---

**Note** Use the functions `sub2ind` and `ind2sub` to convert between subscripted and linear indices.

---

### Logical Indexing

With logical indexing, the index parameter is a logical matrix that is the same size as `A` and contains only 0s and 1s.

MATLAB selects elements of `A` that contain a 1 in the corresponding position of the logical matrix:

```
A = [11 12 13; 14 15 16; 17 18 19];  
A(logical([0 0 1; 0 1 0; 1 1 1]))
```

```
ans =  
  
    17  
    15
```

18  
13  
19

## Array Operations

Array operators perform the same operation for all elements in the data set. These types of operations are useful for repetitive calculations. For example, suppose you collect the volume ( $V$ ) of various cones by recording their diameter ( $D$ ) and height ( $H$ ). If you collect the information for just one cone, you can calculate the volume for that single cone:

$$V = 1/12*\pi*(D^2)*H;$$

Now, collect information on 10,000 cones. The vectors  $D$  and  $H$  each contain 10,000 elements, and you want to calculate 10,000 volumes. In most programming languages, you need to set up a loop similar to this MATLAB code:

```
for n = 1:10000
    V(n) = 1/12*pi*(D(n)^2)*H(n);
end
```

With MATLAB, you can perform the calculation for each element of a vector with similar syntax as the scalar case:

```
%Vectorized Calculation
V = 1/12*pi*(D.^2).*H;
```

---

**Note** Placing a period (.) before the operators  $*$ ,  $/$ , and  $^$ , transforms them into array operators.

---

## Logical Array Operations

A logical extension of the bulk processing of arrays is to vectorize comparisons and decision making. MATLAB comparison operators accept vector inputs and return vector outputs.

For example, suppose while collecting data from 10,000 cones, you record several negative values for the diameter. You can determine which values in a vector are valid with the `>=` operator:

```
D = [-0.2 1.0 1.5 3.0 -1.0 4.2 3.14];  
D >= 0
```

```
ans =
```

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

You can directly exploit the logical indexing power of MATLAB to select the valid cone volumes, `Vgood`, for which the corresponding elements of `D` are nonnegative:

```
Vgood = V(D >= 0);
```

MATLAB allows you to perform a logical AND or OR on the elements of an entire vector with the functions `all` and `any`, respectively. You can throw a warning if all values of `D` are below zero:

```
if all(D < 0)  
    warning('All values of diameter are negative.');
```

```
    return;
```

```
end
```

MATLAB can compare two vectors of the same size, allowing you to impose further restrictions. This code finds all the values where `V` is nonnegative and `D` is greater than `H`:

```
V((V >= 0) & (D > H))
```

The resulting vector is the same size as the inputs.

To aid comparison, MATLAB contains special values to denote overflow, underflow, and undefined operators, such as `inf` and `nan`. Logical operators `isinf` and `isnan` exist to help perform logical tests for these special values. For example, it is often useful to exclude NaN values from computations:

```
x = [2 -1 0 3 NaN 2 NaN 11 4 Inf];  
xvalid = x(~isnan(x))
```

```
xvalid =
      2      -1      0      3      2      11      4      Inf
```

---

**Note** `Inf == Inf` returns true; however, `NaN == NaN` always returns false.

---

## Matrix Operations

Matrix operations act according to the rules of linear algebra. These operations are most useful in vectorization if you are working with multidimensional data.

Suppose you want to evaluate a function,  $F$ , of two variables,  $x$  and  $y$ .

$$F(x,y) = x \cdot \exp(-x^2 - y^2)$$

To evaluate this function at every combination of points in the  $x$  and  $y$ , you need to define a grid of values:

```
x = -2:0.2:2;
y = -1.5:0.2:1.5;
[X,Y] = meshgrid(x,y);
F = X.*exp(-X.^2-Y.^2);
```

Without `meshgrid`, you might need to write two `for` loops to iterate through vector combinations. The function `ndgrid` also creates number grids from vectors, but can construct grids beyond three dimensions. `meshgrid` can only construct 2-D and 3-D grids.

In some cases, using matrix multiplication eliminates intermediate steps needed to create number grids:

```
x = -2:2;
y = -1:0.5:1;
x'*y

ans =

      2.0000      1.0000           0      -1.0000      -2.0000
```

```

1.0000    0.5000         0   -0.5000   -1.0000
         0         0         0         0         0
-1.0000   -0.5000         0    0.5000    1.0000
-2.0000   -1.0000         0    1.0000    2.0000

```

### Constructing Matrices

When vectorizing code, you often need to construct a matrix with a particular size or structure. Techniques exist for creating uniform matrices. For instance, you might need a 5-by-5 matrix of equal elements:

```
A = ones(5,5)*10;
```

Or, you might need a matrix of repeating values:

```
v = 1:5;
A = repmat(v,3,1)
```

A =

```

1     2     3     4     5
1     2     3     4     5
1     2     3     4     5

```

The function `repmat` possesses flexibility in building matrices from smaller matrices or vectors. `repmat` creates matrices by repeating an input matrix:

```
A = repmat(1:3,5,2)
B = repmat([1 2; 3 4],2,2)
```

A =

```

1     2     3     1     2     3
1     2     3     1     2     3
1     2     3     1     2     3
1     2     3     1     2     3
1     2     3     1     2     3

```

B =

```

1     2     1     2

```



```

3     4     3     4
1     2     1     2
3     4     3     4

```

The `bsxfun` function provides a way of combining matrices of different dimensions. Suppose that matrix `A` represents test scores, the rows of which denote different classes. You want to calculate the difference between the average score and individual scores for each class. Your first thought might be to compute the simple difference, `A - mean(A)`. However, MATLAB throws an error if you try this code because the matrices are not the same size. Instead, `bsxfun` performs the operation without explicitly reconstructing the input matrices so that they are the same size.

```

A = [97 89 84; 95 82 92; 64 80 99;76 77 67;...
     88 59 74; 78 66 87; 55 93 85];
dev = bsxfun(@minus,A,mean(A))

```

```
dev =
```

```

18     11     0
16     4     8
-15     2    15
-3     -1   -17
 9    -19   -10
-1    -12     3
-24    15     1

```

## Ordering, Setting, and Counting Operations

In many applications, calculations done on an element of a vector depend on other elements in the same vector. For example, a vector, `x`, might represent a set. How to iterate through a set without a `for` or `while` loop is not obvious. The process becomes much clearer and the syntax less cumbersome when you use vectorized code.

### Eliminating Redundant Elements

A number of different ways exist for finding the redundant elements of a vector. One way involves the function `diff`. After sorting the vector elements, equal adjacent elements produce a zero entry when you use the `diff` function on that vector. Because `diff(x)` produces a vector that has one fewer element

than `x`, you must add an element that is not equal to any other element in the set. `NaN` always satisfies this condition. Finally, you can use logical indexing to choose the unique elements in the set:

```
x = [2 1 2 2 3 1 3 2 1 3];
x = sort(x);
difference = diff([x,NaN]);
y = x(difference~=0)
```

```
y =
```

```
     1     2     3
```

Alternatively, you could accomplish the same operation by using the `unique` function:

```
y=unique(x);
```

However, the `unique` function might provide more functionality than is needed and slow down the execution of your code. Use the `tic` and `toc` functions if you want to measure the performance of each code snippet.

### Counting Elements in a Vector

Rather than merely returning the set, or subset, of `x`, you can count the occurrences of an element in a vector. After the vector sorts, you can use the `find` function to determine the indices of zero values in `diff(x)` and to show where the elements change value. The difference between subsequent indices from the `find` function indicates the number of occurrences for a particular element:

```
x = [2 1 2 2 3 1 3 2 1 3];
x = sort(x);
difference = diff([x,max(x)+1]);
count = diff(find([1,difference]))
y = x(find(difference))
```

```
count =
```

```
     3     4     3
```

y =

1 2 3

The `find` function does not return indices for NaN elements. You can count the number of NaN and Inf values using the `isnan` and `isinf` functions.

```
count_nans = sum(isnan(x(:)));
count_infs = sum(isinf(x(:)));
```

## Functions Commonly Used in Vectorizing

Function	Description
<code>all</code>	Test to determine if all elements are nonzero
<code>any</code>	Test for any nonzeros
<code>cumsum</code>	Find cumulative sum
<code>diff</code>	Find differences and approximate derivatives
<code>find</code>	find indices and values of nonzero elements
<code>ind2sub</code>	Convert from linear index to subscripts
<code>ipermute</code>	Inverse permute dimensions of a multidimensional array
<code>logical</code>	Convert numeric values to logical
<code>meshgrid</code>	Generate X and Y arrays for 3-D plots
<code>ndgrid</code>	Generate arrays for multidimensional functions and interpolations
<code>permute</code>	Rearrange dimensions of a multidimensional array
<code>prod</code>	Find product of array elements
<code>repmat</code>	Replicate and tile an array
<code>reshape</code>	Change the shape of an array
<code>shiftdim</code>	Shift array dimensions
<code>sort</code>	Sort array elements in ascending or descending order
<code>squeeze</code>	Remove singleton dimensions from an array

<b>Function</b>	<b>Description</b>
sub2ind	Convert from subscripts to linear index
sum	find the sum of array elements

**Concepts**

- “Techniques for Improving Performance” on page 25-29

**External  
Web Sites**

- MathWorks Newsletter: Matrix Indexing in MATLAB

# Memory Usage

---

- “Memory Allocation” on page 26-2
- “Memory Management Functions” on page 26-12
- “Strategies for Efficient Use of Memory” on page 26-15
- “Resolving “Out of Memory” Errors” on page 26-23

## Memory Allocation

In this section...
“Memory Allocation for Arrays” on page 26-2
“Data Structures and Memory” on page 26-6

### Memory Allocation for Arrays

The topics below provide information on how the MATLAB software allocates memory when working with arrays and variables. The purpose is to help you use memory more efficiently when writing code. Most of the time, however, you should not need to be concerned with these internal operations as MATLAB handles data storage for you automatically.

- “Creating and Modifying Arrays” on page 26-2
- “Copying Arrays” on page 26-3
- “Array Headers” on page 26-4
- “Function Arguments” on page 26-6

---

**Note** Any information on how the MATLAB software handles data internally is subject to change in future releases.

---

### Creating and Modifying Arrays

When you assign a numeric or character array to a variable, MATLAB allocates a contiguous virtual block of memory and stores the array data in that block. MATLAB also stores information about the array data, such as its class and dimensions, in a separate, small block of memory called a *header*.

If you add new elements to an existing array, MATLAB expands the existing array in memory in a way that keeps its storage contiguous. This usually requires finding a new block of memory large enough to hold the expanded array. MATLAB then copies the contents of the array from its original location to this new block in memory, adds the new elements to the array in this block, and frees up the original array location in memory.

If you remove elements from an existing array, MATLAB keeps the memory storage contiguous by removing the deleted elements, and then compacting its storage in the original memory location.

**Working with Large Data Sets.** If you are working with large data sets, you need to be careful when increasing the size of an array to avoid getting errors caused by insufficient memory. If you expand the array beyond the available contiguous memory of its original location, MATLAB must make a copy of the array and set this copy to the new value. During this operation, there are two copies of the original array in memory. This temporarily doubles the amount of memory required for the array and increases the risk of your program running out of memory during execution. It is better to preallocate sufficient memory for the largest potential size of the array at the start. See “Preallocating Arrays” on page 25-29.

## Copying Arrays

Internally, multiple variables can point to the same block of data, thus sharing that array's value. When you copy a variable to another variable (e.g., `B = A`), MATLAB makes a copy of the array reference, but not the array itself. As long as you do not modify the contents of the array, there is no need to store more than one copy of it. If you do modify any elements of the array, MATLAB makes a copy of the array and then modifies that copy.

The following example demonstrates this. Start by creating a simple script `memUsed.m` to display how much memory is currently being used by your MATLAB process. Put these two lines of code in the script:

```
[usr, sys] = memory;  
usr.MemUsedMATLAB
```

Get an initial reading of how much memory is currently being used by your MATLAB process:

```
format short eng;  
memUsed  
ans =  
    295.4977e+006
```

Create a 2000-by-2000 numeric array `A`. This uses about 32MB of memory:

```
A = magic(2000);
memUsed
ans =
    327.6349e+006
```

Make a copy of array A in B. As there is no need at this point to have two copies of the array data, MATLAB only makes a copy of the array reference. This requires no significant additional memory:

```
B = A;
memUsed
ans =
    327.6349e+006
```

Now modify B by making it one half its original size (i.e., set 1000 rows to empty). This requires that MATLAB make a copy of at least the first 1000 rows of the A array, and assign that copy to B:

```
B(1001:2000,:) = [];
format short;    size(B)
ans =
        1000         2000
```

Check the memory used again. Even though B is significantly smaller than it was originally, the amount of memory used by the MATLAB process has increased by about 16 MB (1/2 of the 32 MB originally required for A) because B could no longer remain as just a reference to A:

```
format short eng;    memUsed
ans =
    343.6421e+006
```

### **Array Headers**

When you assign an array to a variable, MATLAB also stores information about the array (such as class and dimensions) in a separate piece of memory called a header. For most arrays, the memory required to store the header is insignificant. There is a small advantage to storing large data sets in a small



number of large arrays as opposed to a large number of small arrays. This is because the former configuration requires fewer array headers.

**Structure and Cell Arrays.** For structures and cell arrays, MATLAB creates a header not only for each array, but also for each field of the structure and for each cell of a cell array. Because of this, the amount of memory required to store a structure or cell array depends not only on how much data it holds, but also on how it is constructed.

For example, take a scalar structure array `S1` having fields `R`, `G`, and `B`. Each field of size 100-by-50 requires one array header to describe the overall structure, one header for each unique field name, and one header per field for the 1-by-1 structure array. This makes a total of seven array headers for the entire data structure:

```
S1.R(1:100,1:50)
S1.G(1:100,1:50)
S1.B(1:100,1:50)
```

On the other hand, take a 100-by-50 structure array `S2` in which each element has scalar fields `R`, `G`, and `B`. In this case, you need one array header to describe the overall structure, one for each unique field name, and one per field for each of the 5,000 elements of the structure, making a total of 15,004 array headers for the entire data structure:

```
S2(1:100,1:50).R
S2(1:100,1:50).G
S2(1:100,1:50).B
```

Even though `S1` and `S2` contain the same amount of data, `S1` uses significantly less space in memory. Not only is less memory required, but there is a corresponding speed benefit to using the `S1` format, as well.

See “Cell Arrays” and “Structures” under “Data Structures and Memory” on page 26-6.

**Memory Usage Reported By the whos Function.** The `whos` function displays the amount of memory consumed by any variable. For reasons of simplicity, `whos` reports only the memory used to store the actual data. It does not report storage for the array header, for example.

## Function Arguments

MATLAB handles arguments passed in function calls in a similar way. When you pass a variable to a function, you are actually passing a reference to the data that the variable represents. As long as the input data is not modified by the function being called, the variable in the calling function and the variable in the called function point to the same location in memory. If the called function modifies the value of the input data, then MATLAB makes a copy of the original array in a new location in memory, updates that copy with the modified value, and points the input variable in the called function to this new array.

In the example below, function `myfun` modifies the value of the array passed into it. MATLAB makes a copy in memory of the array pointed to by `A`, sets variable `X` as a reference to this new array, and then sets one row of `X` to zero. The array referenced by `A` remains unchanged:

```
A = magic(500);  
myfun(A);
```

```
function myfun(X)  
X(400,:) = 0;
```

If the calling function needs the modified value of the array it passed to `myfun`, you need to return the updated array as an output of the called function, as shown here for variable `A`:

```
A = magic(500);  
A = myfun(A);  
sprintf('The new value of A is %d', A)
```

```
function Y = myfun(X)  
X(400,:) = 0;  
Y = X;
```

## Data Structures and Memory

Memory requirements differ for the various types of MATLAB data structures. You may be able to reduce the amount of memory used for these structures by considering how MATLAB stores them.

## Numeric Arrays

MATLAB requires 1, 2, 4, or 8 bytes to store 8-bit, 16-bit, 32-bit, and 64-bit signed and unsigned integers, respectively. For floating-point numbers, MATLAB uses 4 or 8 bytes for `single` and `double` types. To conserve memory when working with numeric arrays, MathWorks recommends that you use the smallest integer or floating-point type that will contain your data without overflowing. For more information, see “Numeric Types”.

## Complex Arrays

MATLAB stores complex data as separate real and imaginary parts. If you make a copy of a complex array variable, and then modify only the real or imaginary part of the array, MATLAB creates a new array containing both real and imaginary parts.

## Sparse Matrices

It is best to store matrices with values that are mostly zero in sparse format. Sparse matrices can use less memory and may also be faster to manipulate than full matrices. You can convert a full matrix to sparse format using the `sparse` function.

Compare two 1000-by-1000 matrices: `X`, a matrix of doubles with 2/3 of its elements equal to zero; and `Y`, a sparse copy of `X`. The following example shows that the sparse matrix requires approximately half as much memory:

```
whos
  Name      Size      Bytes  Class
  X         1000x1000    8000000  double array
  Y         1000x1000    4004000  double array (sparse)
```

## Cell Arrays

In addition to data storage, cell arrays require a certain amount of additional memory to store information describing each cell. This information is recorded in a *header*, and there is one header for each cell of the array. You can determine the amount of memory required for a cell array header by finding the number of bytes consumed by a 1-by-1 cell that contains no data, as shown below for a 32-bit system:

```
A = {}; % Empty cell array
```

```
whos A
  Name      Size      Bytes  Class  Attributes
  A         1x1         60    cell
```

In this case, MATLAB shows the number of bytes required for each header in the cell array on a 32-bit system to be 60. This is the header size that is used in all of the 32-bit examples in this section. For 64-bit systems, the header size is assumed to be 112 bytes in this documentation. You can find the correct header size on a 64-bit system using the method just shown for 32 bits.

To predict the size of an entire cell array, multiply the number you have just derived for the header by the total number of cells in the array, and then add to that the number of bytes required for the data you intend to store in the array:

$$(\text{header\_size} \times \text{number\_of\_cells}) + \text{data}$$

So a 10-by-20 cell array that contains 400 bytes of data would require 22,800 bytes of memory on a 64-bit system:

$$(112 \times 200) + 400 = 22800$$

---

**Note** While numeric arrays must be stored in contiguous memory, structures and cell arrays do not.

---

**Example 1 – Memory Allocation for a Cell Array.** The following 4-by-1 cell array records the brand name, screen size, price, and on-sale status for three laptop computers:

```
Laptops = {'SuperrrFast 89X', 'ReliablePlus G5', ...
           'UCanA4dIt 140L6'}; ...
           [single(17), single(15.4), single(14.1)]; ...
           [2499.99, 1199.99, 499.99]; ...
           [true, true, false]];
```

On a 32-bit system, the cell array header alone requires 60 bytes per cell:

4 cells \* 60 bytes per cell = 240 bytes for the cell array

Calculate the memory required to contain the data in each of the four cells:

45 characters \* 2 bytes per char = 90 bytes

3 doubles \* 8 bytes per double = 24 bytes

3 singles \* 4 bytes per single = 12 bytes

3 logicals \* 1 byte per logical = 3 bytes

90 + 24 + 12 + 3 = 129 bytes for the data

Add the two, and then compare your result with the size returned by MATLAB:

240 + 129 = 369 bytes total

```
whos Laptops
  Name          Size          Bytes  Class  Attributes
  Laptops       4x1            369   cell
```

## Structures

```
S.A = [];
B = whos('S');
B.bytes - 60
ans =
    64
```

Compute the memory needed for a structure array as follows:

32-bit systems: fields x ((60 x array elements) + 64) + data

64-bit systems: fields x ((112 x array elements) + 64) + data

On a 64-bit computer system, a 4-by-5 structure `Clients` with fields `Address` and `Phone` uses 4,608 bytes just for the structure:

2 fields x ((112 x 20) + 64) = 2 x (2240 + 64) = 4608 bytes

To that sum, you must add the memory required to hold the data assigned to each field. If you assign a 25-character string to `Address` and a 12-character

string to Phone in each element of the 4-by-5 Clients array, you use 1480 bytes for data:

$(25+12)$  characters \* 2 bytes per char \* 20 elements = 1480 bytes

Add the two and you see that the entire structure consumes 6,088 bytes of memory.

**Example 1 – Memory Allocation for a Structure Array.** Compute the amount of memory that would be required to store the following 6-by-5 structure array having the following four fields on a 32-bit system:

A: 5-by-8-by-6 signed 8-bit integer array  
 B: 1-by-500 single array  
 C: 30-by-30 unsigned 16-bit integer array  
 D: 1-by-27 character array

Construct the array:

```
A = int8(ones(5,8,6));
B = single(1:500);
C = uint16(magic(30));
D = 'Company Name: MathWorks';

s = struct('f1', A, 'f2', B, 'f3', C, 'f4', D);

for m=1:6
    for n=1:5
        s(m,n)=s(1,1);
    end
end
```

Calculate the amount of memory required for the structure itself, and then for the data it contains:

structure = fields x ((60 x array elements) + 64) =  
 4 x ((60 x 30) + 64) = 7,456 bytes

data = (field1 + field2 + field3 + field4) x array elements =  
 (240 + 2000 + 1800 + 54) x 30 = 122,820 bytes

Add the two, and then compare your result with the size returned by MATLAB:

Total bytes calculated for structure s:  $7,456 + 122,820 = 130,276$

```
whos s
```

Name	Size	Bytes	Class	Attributes
s	6x5	130036	struct	

## Memory Management Functions

The following functions can help you to manage memory use while running the MATLAB software:

- `memory` displays or returns information about how much memory is available and how much is used by MATLAB. This includes the following:
  - Size of the largest single array MATLAB can create at this time.
  - Total size of the virtual address space available for data.
  - Total amount of memory used by the MATLAB process for both libraries and data.
  - Available and total Virtual Memory for the MATLAB software process.
  - Available system memory, including both physical memory and paging file.
  - Available and the total physical memory (RAM) of the computer.
- `whos` shows how much memory MATLAB currently has allocated for variables in the workspace.
- `pack` saves existing variables to disk, and then reloads them contiguously. This reduces the chances of running into problems due to memory fragmentation.
- `clear` removes variables from memory. One way to increase the amount of available memory is to periodically clear variables from memory that you no longer need.

If you use `pack` and there is still not enough free memory to proceed, you probably need to remove some of the variables you are no longer using from memory. Use `clear` to do this.

- `save selectively` stores variables to the disk. This is a useful technique when you are working with large amounts of data. Save data to the disk periodically, and then use the `clear` function to remove the saved data from memory.
- `load` reloads a data file saved with the `save` function.



- `quit` exits MATLAB and returns all allocated memory to the system. This can be useful on UNIX systems, which do not free up memory allocated to an application (e.g., MATLAB) until the application exits.

You can use the `save` and `load` functions in conjunction with the `quit` command to free memory by:

- 1 Saving any needed variables with the `save` function.
- 2 Quitting MATLAB to free all memory allocated to MATLAB.
- 3 Starting a new MATLAB session and loading the saved variables back into the clean MATLAB workspace.

## The `whos` Function

The `whos` command can give you an idea of the memory used by MATLAB variables.

```
A = ones(10,10);
whos
```

Name	Size	Bytes	Class	Attributes
A	10x10	800	double	

Note that `whos` does not include information about

- Memory used by MATLAB (for example, Java code and plots).
- Memory used for most objects (e.g., time series, custom) .
- Memory for variables not in the calling workspace .
- Shared data copies. `whos` shows bytes used for a shared data copy even when it does not use any memory. This example shows that `whos` reports an array (A) and a shared data copy of that array (B) separately, even though the data exists only once in memory:

Store 400 MB array as A. Memory used = 381MB (715 MB – 334 MB) :

```
memory
Memory used by MATLAB:                334 MB (3.502e+008 bytes)
```

```
A = rand(5e7,1);
```

```
memory
Memory used by MATLAB:          715 MB (7.502e+008 bytes)
```

```
whos
  Name          Size          Bytes  Class  Attributes
  A             50000000x1      400000000  double
```

Create B and point it to A. Note that although whos shows both A and B, there is only one copy of the data in memory. No additional memory is consumed by assigning A to B:

```
B = A;
```

```
memory
Memory used by MATLAB:          715 MB (7.502e+008 bytes)
```

```
whos
  Name          Size          Bytes  Class  Attributes
  A             50000000x1      400000000  double
  B             50000000x1      400000000  double
```

Modifying B(1) copies all of A to B and changes the value of B(1). Memory used = 382MB (1097 MB – 715 MB). Now there are two copies of the data in memory, yet the output of whos does not change:

```
B(1) = 3;
```

```
memory
Memory used by MATLAB:          1097 MB (1.150e+009 bytes)
```

```
whos
  Name          Size          Bytes  Class  Attributes
  A             50000000x1      400000000  double
  B             50000000x1      400000000  double
```

## Strategies for Efficient Use of Memory

### In this section...

“Ways to Reduce the Amount of Memory Required” on page 26-15

“Using Appropriate Data Storage” on page 26-17

“How to Avoid Fragmenting Memory” on page 26-20

“Reclaiming Used Memory” on page 26-21

### Ways to Reduce the Amount of Memory Required

The source of many "out of memory" problems often involves analyzing or processing an existing large set of data such as in a file or a database. This requires bringing all or part of the data set into the MATLAB software process. The following techniques deal with minimizing the required memory during this stage.

#### Load Only As Much Data As You Need

Only import into MATLAB as much of a large data set as you need for the problem you are trying to solve. This is not usually a problem when importing from sources such as a database, where you can explicitly search for elements matching a query. But this is a common problem with loading large flat text or binary files. Rather than loading the entire file, use the appropriate MATLAB function to load parts of files.

**MAT-Files.** Load part of a variable by indexing into an object that you create with the `matfile` function.

**Text Files.** Use the `textscan` function to access parts of a large text file by reading only the selected columns and rows. If you specify the number of rows or a repeat format number with `textscan`, MATLAB calculates the exact amount of memory required beforehand.

**Binary Files.** You can use low-level binary file I/O functions, such as `fread`, to access parts of any file that has a known format. For binary files of an unknown format, try using memory mapping with the `memmapfile` function.

**Image, HDF, Audio, and Video Files.** Many of the MATLAB functions that support loading from these types of files allow you to select portions of the data to read. For details, see the function reference pages listed in “Supported File Formats for Import and Export”.

### **Process Data By Blocks**

Consider block processing, that is, processing a large data set one section at a time in a loop. Reducing the size of the largest array in a data set reduces the size of any copies or temporaries needed. You can use this technique in either of two ways:

- For a subset of applications that you can break into separate chunks and process independently.
- For applications that only rely on the state of a previous block, such as filtering.

### **Avoid Creating Temporary Arrays**

Avoid creating large temporary variables, and also make it a practice to clear those temporary variables you do use when they are no longer needed. For example, when you create a large array of zeros, instead of saving to a temporary variable *A*, and then converting *A* to a single:

```
A = zeros(1e6,1);  
As = single(A);
```

use just the one command to do both operations:

```
A = zeros(1e6,1,'single');
```

Using the `repmat` function, array preallocation and `for` loops are other ways to work on `nondouble` data without requiring temporary storage in memory.

### **Use Nested Functions to Pass Fewer Arguments**

When working with large data sets, be aware that MATLAB makes a temporary copy of an input variable if the called function modifies its value. This temporarily doubles the memory required to store the array, which causes MATLAB to generate an error if sufficient memory is not available.

One way to use less memory in this situation is to use nested functions. A nested function shares the workspace of all outer functions, giving the nested function access to data outside of its usual scope. In the example shown here, nested function `setrowval` has direct access to the workspace of the outer function `myfun`, making it unnecessary to pass a copy of the variable in the function call. When `setrowval` modifies the value of `A`, it modifies it in the workspace of the calling function. There is no need to use additional memory to hold a separate array for the function being called, and there also is no need to return the modified value of `A`:

```
function myfun
A = magic(500);

    function setrowval(row, value)
        A(row,:) = value;
    end

setrowval(400, 0);
disp('The new value of A(399:401,1:10) is')
A(399:401,1:10)
end
```

## Using Appropriate Data Storage

MATLAB provides you with different sizes of data classes, such as `double` and `uint8`, so you do not need to use large classes to store your smaller segments of data. For example, it takes 7 KB less memory to store 1,000 small unsigned integer values using the `uint8` class than it does with `double`.

## Use the Appropriate Numeric Class

The numeric class you should use in MATLAB depends on your intended actions. The default class `double` gives the best precision, but requires 8 bytes per element of memory to store. If you intend to perform complicated math such as linear algebra, you must use a floating-point class such as a `double` or `single`. The `single` class requires only 4 bytes. There are some limitations on what you can do with `singles`, but most MATLAB Math operations are supported.

If you just need to carry out simple arithmetic and you represent the original data as integers, you can use the integer classes in MATLAB. The following is

a list of numeric classes, memory requirements (in bytes), and the supported operations.

Class (Data Type)	Bytes	Supported Operations
single	4	Most math
double	8	All math
logical	1	Logical/conditional operations
int8, uint8	1	Arithmetic and some simple functions
int16, uint16	2	Arithmetic and some simple functions
int32, uint32	4	Arithmetic and some simple functions
int64, int64	8	Arithmetic and some simple functions

### Reduce the Amount of Overhead When Storing Data

MATLAB arrays (implemented internally as `mxArrays`) require room to store meta information about the data in memory, such as type, dimensions, and attributes. This takes about 80 bytes per array. This overhead only becomes an issue when you have a large number (e.g., hundreds or thousands) of small `mxArrays` (e.g., scalars). The `whos` command lists the memory used by variables, but does not include this overhead.

Because simple numeric arrays (comprising one `mxArray`) have the least overhead, you should use them wherever possible. When data is too complex to store in a simple array (or matrix), you can use other data structures.

Cell arrays are comprised of separate `mxArrays` for each element. As a result, cell arrays with many small elements have a large overhead.

Structures require a similar amount of overhead per field (see the documentation on “Array Headers” on page 26-4 above). Structures with many fields and small contents have a large overhead and should be avoided. A large array of structures with numeric scalar fields requires much more memory than a structure with fields containing large numeric arrays.

Also note that while MATLAB stores numeric arrays in contiguous memory, this is not the case for structures and cell arrays.

## Import Data to the Appropriate MATLAB Class

When reading data from a binary file with `fread`, it is a common error to specify only the class of the data in the file, and not the class of the data MATLAB uses once it is in the workspace. As a result, the default `double` is used even if you are reading only 8-bit values. For example,

```
fid = fopen('large_file_of_uint8s.bin', 'r');
a = fread(fid, 1e3, 'uint8');           % Requires 8k
whos a
  Name          Size          Bytes  Class  Attributes

  a             1000x1          8000  double

a = fread(fid, 1e3, 'uint8=>uint8');   % Requires 1k
whos a
  Name          Size          Bytes  Class  Attributes

  a             1000x1          1000  uint8
```

## Make Arrays Sparse When Possible

If your data contains many zeros, consider using sparse arrays, which store only nonzero elements. The example below compares the space required for storage of an array of mainly zeros:

```
A = diag(1e3,1e3);   % Full matrix with ones on the diagonal
As = sparse(A)       % Sparse matrix with only nonzero elements
whos
  Name          Size          Bytes  Class

  A             1001x1001      8016008  double array
  As            1001x1001         4020    double array (sparse)
```

You can see that this array requires only approximately 4 KB to be stored as sparse, but approximately 8 MB as a full matrix. In general, for a sparse double array with `nnz` nonzero elements and `ncol` columns, the memory required is

- $16 * nnz + 8 * ncol + 8$  bytes (on a 64 bit machine)
- $12 * nnz + 4 * ncol + 4$  bytes (on a 32 bit machine)

Note that MATLAB does not support all mathematical operations on sparse arrays.

## **How to Avoid Fragmenting Memory**

MATLAB always uses a contiguous segment of memory to store a numeric array. As you manipulate this data, however, the contiguous block can become fragmented. When memory is fragmented, there may be plenty of free space, but not enough contiguous memory to store a new large variable. Increasing fragmentation can use significantly more memory than is necessary.

### **Preallocate Contiguous Memory When Creating Arrays**

In the course of a MATLAB session, memory can become fragmented due to dynamic memory allocation and deallocation. `for` and `while` loops that incrementally increase, or *grow*, the size of a data structure each time through the loop can add to this fragmentation as they have to repeatedly find and allocate larger blocks of memory to store the data.

To make more efficient use of your memory, preallocate a block of memory large enough to hold the matrix at its final size before entering the loop. When you preallocate memory for an array, MATLAB reserves sufficient contiguous space for the entire full-size array at the beginning of the computation. Once you have this space, you can add elements to the array without having to continually allocate new space for it in memory.

For more information on preallocation, see “Preallocating Arrays” on page 25-29.

### **Allocate Your Larger Arrays First**

MATLAB uses a heap method of memory management. It requests memory from the operating system when there is not enough memory available in the heap to store the current variables. It reuses memory as long as the size of the memory segment required is available in the heap.

The following statements can require approximately 4.3 MB of RAM. This is because MATLAB may not be able to reuse the space previously occupied by two 1 MB arrays when allocating space for a 2.3 MB array:

```
a = rand(1e6,1);
```



```
b = rand(1e6,1);  
clear  
c = rand(2.3e6,1);
```

The simplest way to prevent overallocation of memory is to allocate the largest vectors first. These statements require only about 2.0 MB of RAM:

```
c = rand(2.3e6,1);  
clear  
a = rand(1e6,1);  
b = rand(1e6,1);
```

### **Long-Term Usage (Windows Systems Only)**

On 32-bit Microsoft Windows, the workspace of MATLAB can fragment over time due to the fact that the Windows memory manager does not return blocks of certain types and sizes to the operating system. Clearing the MATLAB workspace does not fix this problem. You can minimize the problem by allocating the largest variables first. This cannot address, however, the eventual fragmentation of the workspace that occurs from continual use of MATLAB over many days and weeks, for example. The only solution to this is to save your work and restart MATLAB.

The pack command, which saves all variables to disk and loads them back, does not help with this situation.

### **Reclaiming Used Memory**

One simple way to increase the amount of memory you have available is to clear large arrays that you no longer use.

### **Save Your Large Data Periodically to Disk**

If your program generates very large amounts of data, consider writing the data to disk periodically. After saving that portion of the data, use the `clear` function to remove the variable from memory and continue with the data generation.

### **Clear Old Variables from Memory When No Longer Needed**

When you are working with a very large data set repeatedly or interactively, clear the old variable first to make space for the new variable. Otherwise, MATLAB requires temporary storage of equal size before overriding the variable. For example,

```
a = rand(100e6,1)           % 800 MB array
b = rand(100e6,1)           % New 800 MB array
Error using rand
Out of memory. Type HELP MEMORY for your options.

clear a
a = rand(100e6,1)           % New 800 MB array
```

## Resolving “Out of Memory” Errors

### In this section...

“General Suggestions for Reclaiming Memory” on page 26-23

“Setting the Process Limit” on page 26-23

“Disabling Java VM on Startup” on page 26-25

“Increasing System Swap Space” on page 26-25

“Using the 3GB Switch on Windows Systems” on page 26-26

“Freeing Up System Resources on Windows Systems” on page 26-27

### General Suggestions for Reclaiming Memory

The MATLAB software generates an Out of Memory message whenever it requests a segment of memory from the operating system that is larger than what is currently available. When you see the Out of Memory message, use any of the techniques discussed under “Strategies for Efficient Use of Memory” on page 26-15 to help optimize the available memory. If the Out of Memory message still appears, you can try any of the following:

- Compress data to reduce memory fragmentation.
- If possible, break large matrices into several smaller matrices so that less memory is used at any one time.
- If possible, reduce the size of your data.
- Make sure that there are no external constraints on the memory accessible to MATLAB. (On UNIX systems, use the `limit` command to check).
- Increase the size of the swap file. We recommend that you configure your system with twice as much swap space as you have RAM. See “Increasing System Swap Space” on page 26-25, below.
- Add more memory to the system.

### Setting the Process Limit

The platforms and operating systems that MATLAB supports have different memory characteristics and limitations. In particular, the *process limit* is the

maximum amount of virtual memory a single process (or application) can address. On 32-bit systems, this is the most important factor limiting data set size. The process limit must be large enough for MATLAB to store all of the data it is to process, any MATLAB program files, the MATLAB executable itself, and additional state information.

Where possible, choose an operating system that maximizes this number, that is, a 64-bit operating system. The following is a list of MATLAB supported operating systems and their process limits.

Operating System	Process Limit
32-bit Microsoft Windows XP, Windows Vista™, Windows 7 and higher	2 GB
32-bit Windows XP with 3 GB <code>boot.ini</code> switch or 32-bit Windows Vista or Windows 7 and higher with <code>increaseuserva</code> set (see later)	3 GB
32-bit Linux (Linux is a registered trademark of Linus Torvalds)	~3 GB
64-bit Windows or Linux running 32-bit MATLAB	≤ 4 GB
64-bit Windows, Apple Macintosh OS X, or Linux running 64-bit MATLAB	8 TB

To verify the current process limit of MATLAB on Windows systems, use the `memory` function.

```

Maximum possible array:          583 MB (6.111e+008 bytes) *
Memory available for all arrays: 1515 MB (1.588e+009 bytes) **
Memory used by MATLAB:          386 MB (4.050e+008 bytes)
Physical Memory (RAM):          2014 MB (2.112e+009 bytes)

```

\* Limited by contiguous virtual address space available.

\*\* Limited by virtual address space available.

When called with one output variable, the `memory` function returns or displays the following values. See the function reference for `memory` to find out how to use it with more than one output.

memory Return Value	Description
MaxPossibleArrayBytes	Size of the largest single array MATLAB can currently create
MemAvailableAllArrays	Total size of the virtual address space available for data
MemUsedMATLAB	Total amount of memory used by the MATLAB process

View the value against the Total entry in the Virtual Memory section. It is shown as 2 GB in the table, which is the default on Windows XP systems. On UNIX systems, see the `ulimit` command to view and set user limits including virtual memory.

## Disabling Java VM on Startup

On UNIX systems, you can increase the workspace size by approximately 400 MB if you start MATLAB without the Java JVM™. To do this, use the command line option `-nojvm` to start MATLAB. This also increases the size of the largest contiguous block (and therefore the largest matrix) by about the same.

Using `-nojvm` comes with a penalty in that you will lose many features that rely on the Java software, including the entire development environment.

Starting MATLAB with the `-nodesktop` option does not save any substantial amount of memory.

Shutting down other applications and services (e.g., using `msconfig` on Windows systems) can help if total system memory is the limiting factor, but usually process limit (on 32-bit machines) is the main limiting factor.

## Increasing System Swap Space

The total memory available to applications on your computer is comprised of physical memory (RAM), plus a *page file*, or *swap file*, on disk. The swap file can be very large (e.g., 16 TB on 32-bit Windows, 512 TB on 64-bit Windows). The operating system allocates the virtual memory of each process to physical

memory or to the swap file, depending on the needs of the system and other processes.

Most systems allow you to control the size of your swap file. The steps involved depend on the system you are running on.

---

**Note** There is no interface for directly controlling the swap space on Macintosh OS X systems.

---

### **Windows Systems**

Use the Windows Control Panel to change the size of the virtual memory paging file on your system. For more information, refer to the Windows help.

### **Linux Systems**

You can change your swap space by using the `mkswap` and `swapon` commands. For more information on the above commands, type `man` followed by the command name at the Linux prompt.

### **Using the 3GB Switch on Windows Systems**

Microsoft Windows XP systems can allocate 3 GB (instead of the default 2 GB) to processes, if you set an appropriate switch in the `boot.ini` file of the system. MathWorks recommends that you only do this with Windows XP SP2 systems or later. This gives an extra 1 GB of virtual memory to MATLAB, not contiguous with the rest of the memory. This enables you to store more data, but not larger arrays, as these are limited by contiguous space. This is mostly beneficial if you have enough RAM (e.g., 3 or 4 GB) to use it.

After setting the switch, confirm the new value of the virtual memory after restarting your computer and using the `memory` function.

```
[userview systemview] = memory;  
  
systemview.VirtualAddressSpace  
ans =  
    Available: 1.6727e+009    % Virtual memory available to MATLAB.  
    Total: 2.1474e+009    % Total virtual memory
```

For more documentation on this option, use the following URL:

<http://support.microsoft.com/kb/291988>

Similarly, on machines running Microsoft Windows Vista and Windows 7 and higher, you can achieve the same effect by using the command:

```
BCDEdit /set increaseuserva 3072
```

For more information on this option, go to the following website:

<http://msdn.microsoft.com>

## **Freeing Up System Resources on Windows Systems**

There are no functions implemented to manipulate the way MATLAB handles Microsoft Windows system resources. Windows systems use these resources to track fonts, windows, and screen objects. Resources can be depleted by using multiple figure windows, multiple fonts, or several UI controls. One way to free up system resources is to close all inactive windows. Windows system icons still use resources.





# Custom Help and Documentation

---

- “Create Help for Classes” on page 27-2
- “Check Which Programs Have Help” on page 27-10
- “Create Help Summary Files (Contents.m)” on page 27-13
- “Display Custom Documentation” on page 27-16
- “Display Custom Examples” on page 27-25

## Create Help for Classes

### In this section...

“Help Text from the doc Command” on page 27-2

“Custom Help Text” on page 27-3

### Help Text from the doc Command

When you use the `doc` command to display help for a class, MATLAB automatically displays information that it derives from the class definition.

For example, create a class definition file named `someClass.m` with several properties and methods, as shown.

```
classdef someClass
    %someClass Summary of this class goes here
    % Detailed explanation goes here

    properties
        One    % First public property
        Two    % Second public property
    end
    properties (Access=private)
        Three % Do not show this property
    end

    methods
        function obj = someClass
            % Summary of constructor
        end
        function myMethod(obj)
            % Summary of myMethod
            disp(obj)
        end
    end
    methods (Static)
        function myStaticMethod
            % Summary of myStaticMethod
        end
    end
end
```

```

        end
    end

end

```

View the help text and the details from the class definition using the `doc` command.

```
doc someClass
```

The screenshot shows the MATLAB File Help interface for a class named `someClass`. At the top, there is a header bar with the text "MATLAB File Help: someClass" and two links: "View code for someClass" and "Default Topics". Below the header, the class name "someClass" is displayed in a large, bold, red font. Underneath, there is a summary of the class: "someClass Summary of this class goes here" followed by "Detailed explanation goes here". The next section is "Class Details", which lists two properties: "Sealed" with a value of "false" and "Construct on load" with a value of "false". The "Constructor Summary" section follows, with a link to "someClass" and the text "Summary of constructor". The "Property Summary" section lists two properties: "One" with the description "First public property" and "Two" with the description "Second public property". Finally, the "Method Summary" section lists two methods: "myMethod" with the description "Summary of myMethod" and "Static myStaticMethod" with the description "Summary of myStaticMethod".

## Custom Help Text

You can add information about your classes that both the `doc` command and the `help` command include in their displays. The `doc` command displays the help text at the top of the generated HTML pages, above the information derived from the class definition. The `help` command displays the help text in the Command Window. For details, see:

- “Classes” on page 27-4
- “Methods” on page 27-5
- “Properties” on page 27-6
- “Enumerations” on page 27-7
- “Events” on page 27-8

## Classes

Create help text for classes by including comments on lines immediately after the `classdef` statement in a file. For example, create a file named `myClass.m`, as shown.

```
classdef myClass
    % myClass    Summary of myClass
    % This is the first line of the description of myClass.
    % Descriptions can include multiple lines of text.
    %
    % myClass Properties:
    %   a - Description of a
    %   b - Description of b
    %
    % myClass Methods:
    %   doThis - Description of doThis
    %   doThat - Description of doThat

    properties
        a
        b
    end

    methods
        function obj = myClass
            end
        function doThis(obj)
            end
        function doThat(obj)
            end
    end
end
```

```
end
```

Lists and descriptions of the properties and methods in the initial comment block are optional. If you include comment lines that contain the name of your class followed by `Properties` or `Methods` and a colon (:), then MATLAB creates hyperlinks to the help for the properties or methods.

View the help text for the class in the Command Window using the `help` command.

```
help myClass
```

```
myClass Summary of myClass  
This is the first line of the description of myClass.  
Descriptions can include multiple lines of text.
```

```
myClass Properties:  
  a - Description of a  
  b - Description of b
```

```
myClass Methods:  
  doThis - Description of doThis  
  doThat - Description of doThat
```

## Methods

Create help for a method by inserting comments immediately after the function definition statement. For example, modify the class definition file `myClass.m` to include help for the `doThis` method.

```
function doThis(obj)  
    % doThis Do this thing  
    % Here is some help text for the doThis method.  
    %  
    % See also DOTHAT.  
  
    disp(obj)  
end
```

View the help text for the method in the Command Window using the `help` command. Specify both the class name and method name, separated by a dot.

```
help myClass.doThis
```

```
doThis Do this thing
      Here is some help text for the doThis method.
```

```
      See also doThat.
```

## Properties

There are two ways to create help for properties:

- Insert comment lines above the property definition. Use this approach for multiline help text.
- Add a single-line comment next to the property definition.

Comments above the definition have precedence over a comment next to the definition.

For example, modify the property definitions in the class definition file `myClass.m`.

```
properties
    a          % First property of myClass

    % b - Second property of myClass
    % The description for b has several
    % lines of text.
    b          % Other comment
end
```

View the help for properties in the Command Window using the `help` command. Specify both the class name and property name, separated by a dot.

```
help myClass.a
```

```
a - First property of myClass
```

```
help myClass.b
```

```
b - Second property of myClass
The description for b has several
lines of text.
```

## Enumerations

Like properties, there are two ways to create help for enumerations:

- Insert comment lines above the enumeration definition. Use this approach for multiline help text.
- Add a single-line comment next to the enumeration definition.

Comments above the definition have precedence over a comment next to the definition.

For example, create an enumeration class in a file named `myEnumeration.m`.

```
classdef myEnumeration
    enumeration
        uno,          % First enumeration

        % DOS - Second enumeration
        % The description for DOS has several
        % lines of text.
        dos          % A comment (not help text)
    end
end
```

View the help in the Command Window using the `help` command. Specify both the class name and enumeration member, separated by a dot.

```
help myEnumeration.uno
```

```
uno - First enumeration
```

```
help myEnumeration.dos
```

```
dos - Second enumeration
The description for dos has several
lines of text.
```

## Events

Like properties and enumerations, there are two ways to create help for events:

- Insert comment lines above the event definition. Use this approach for multiline help text.
- Add a single-line comment next to the event definition.

Comments above the definition have precedence over a comment next to the definition.

For example, create an class in a file named `hasEvents.m`.

```
classdef hasEvents < handle
    events
        Alpha      % First event

        % Beta - Second event
        % Additional text about second event.
        Beta      % (not help text)
    end

    methods
        function fireEventAlpha(h)
            notify(h,'Alpha');
        end

        function fireEventBeta(h)
            notify(h,'Beta');
        end
    end
end
```

View the help in the Command Window using the `help` command. Specify both the class name and event, separated by a dot.

```
help hasEvents.Alpha

Alpha - First event
```



```
help hasEvents.Beta
```

```
Beta - Second event  
Additional text about second event.
```

## See Also

```
help | doc
```


## Concepts

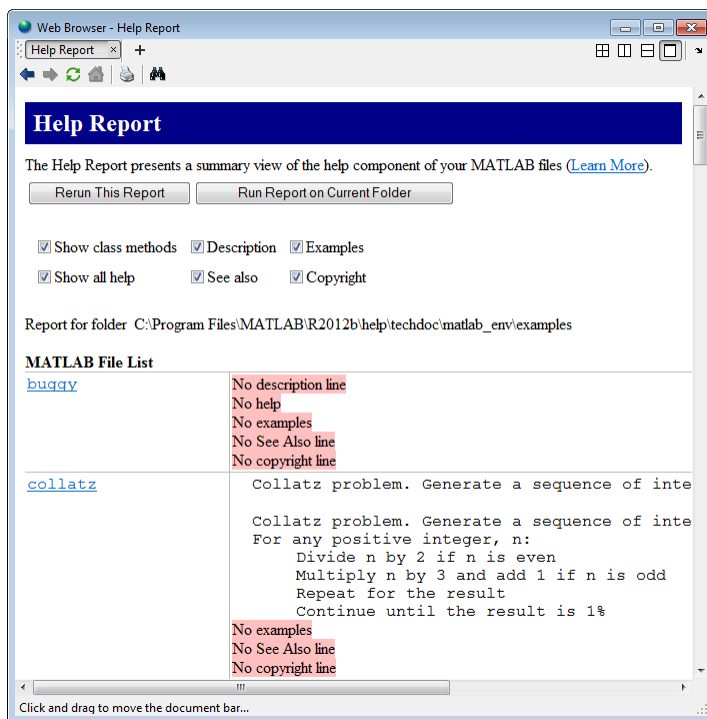
- “Classes in the MATLAB Language”
- “User-Defined Classes”

## Check Which Programs Have Help

To determine which of your programs files have help text, you can use the Help Report.

In the Help Report, you specify a set of help components for which you want to search, such as examples or See Also lines. For each file searched, MATLAB displays the help text for the components it finds. Otherwise, MATLAB displays a highlighted message to indicate that the component is missing.

To generate a Help Report, in the Current Folder browser, navigate to the folder you want to check, click , and then select **Reports > Help Report**. The Help Report displays in the MATLAB Web browser.



---

**Note** You cannot run reports when the path is a UNC (Universal Naming Convention) path; that is, a path that starts with \\ . Instead, use an actual hard drive on your system, or a mapped network drive.

---

This table describes the available options for Help Reports.

<b>Help Report Option</b>	<b>Description</b>
<b>Show class methods</b>	Include methods in the report. If you do not select this option, then the report includes results for classes, but not for methods within a class definition file.
<b>Show all help</b>	<p>Display all help text found in each file. If you also select individual help components, such as <b>Description</b>, then help text appears twice in the report for each file: once for the overall help text, and once for the component.</p> <p>If your program has the same name as other programs on the MATLAB search path, then the <code>help</code> command generates a list of those <i>overloaded</i> items and automatically adds links to the help for those items.</p>
<b>Description</b>	Check for an initial, nonempty comment line in the file. This line is sometimes called the H1 line.
<b>Examples</b>	Check for examples in the help text. The Help Report performs a case-insensitive search for a help line with a single-word variant of <code>example</code> . The report displays that line and subsequent nonblank comment lines, along with the initial line number.

<b>Help Report Option</b>	<b>Description</b>
<b>See Also</b>	<p>Check for a line in the help that begins with the string <code>See also</code>. The report displays the text and the initial line number.</p> <p>If the programs listed after <code>See also</code> are on the search path, then the <code>help</code> command generates hyperlinks to the help for those programs. The Help Report indicates when a program in the <code>See also</code> line is not on the path.</p>
<b>Copyright</b>	<p>Check for a comment line in the file that begins with the string <code>Copyright</code>. When there is a copyright line, the report also checks whether the end year is current. The date check requires that the copyright line includes either a single year (such as 2012) or a range of years with no spaces (such as 2001-2012).</p> <p>The recommended practice is to include a range of years from the year you created the file to the current year.</p>

**Related Examples**

- “Add Help for Your Program” on page 17-5
- “Create Help Summary Files (Contents.m)” on page 27-13

## Create Help Summary Files (Contents.m)

### In this section...

“What Is a Contents.m File?” on page 27-13

“Create a Contents.m File” on page 27-14

“Check an Existing Contents.m File” on page 27-14

### What Is a Contents.m File?

A `Contents.m` file provides a summary of the programs in a particular folder. The `help`, `doc`, and `ver` functions refer to `Contents.m` files to display information about folders.

`Contents.m` files contain only comment lines. The first two lines are headers that describe the folder. Subsequent lines list the program files in the folder, along with their descriptions. Optionally, you can group files and include category descriptions. For example, view the functions available in the `codetools` folder:

```
help codetools
```

```
Commands for creating and debugging code  
MATLAB Version 8.0 (R2012b) 02-Oct-2012
```

```
Editing and publishing
```

```
edit      - Edit or create a file  
grabcode  - Copy MATLAB code from published HTML  
mlint     - Check files for possible problems  
notebook  - Open MATLAB Notebook in Microsoft Word  
publish   - Publish file containing cells to output file  
snapnow   - Force snapshot of image for published document
```

```
Directory tools
```


```
mlintrpt  - Run mlint for file or folder, reporting results in browser  
visdiff   - Compare two files (text, MAT, or binary) or folders
```

```
...
```

If you do *not* want others to see a summary of your program files, place an empty `Contents.m` file in the folder. An empty `Contents.m` file causes `help foldername` to report `No help found for foldername`. Without a `Contents.m` file, the `help` and `doc` commands display a generated list of all program files in the folder.

## Create a Contents.m File

When you have a set of existing program files in a folder, the easiest way to create a `Contents.m` file is to use the Contents Report. The primary purpose of the Contents Report is to check that an existing `Contents.m` file is up-to-date. However, it also checks whether `Contents.m` exists, and can generate a new file based on the contents of the folder. Follow these steps to create a file:


- 1 In the Current Folder browser, navigate to the folder that contains your program files.
- 2 Click , and then select **Reports > Contents Report**.
- 3 In the report, where prompted to make a `Contents.m` file, click **yes**. The new file includes the names of all program files in the folder, using the description line (the first nonempty comment line) whenever it is available.
- 4 Open the generated file in the Editor, and modify the file so that the second comment line is in this form:

```
% Version xxx dd-mmm-yyyy
```

Do not include any spaces in the date. This comment line enables the `ver` function to detect the version information.

## Check an Existing Contents.m File

Verify whether your `Contents.m` file reflects the current contents of the folder using the Contents Report, as follows:

- 1 In the Current Folder browser, navigate to the folder that contains the `Contents.m` file.
- 2 Click , and then select **Reports > Contents Report**.

---

**Note** You cannot run reports when the path is a UNC (Universal Naming Convention) path; that is, a path that starts with \\ . Instead, use an actual hard drive on your system, or a mapped network drive.

---

The Contents Report performs the following checks.

Check Whether the Contents.m File...	Details
Exists	If there is no Contents.m file in the folder, you can create one from the report.
Includes all programs in the folder	Missing programs appear in gray highlights. You do not need to add programs that you do not want to expose to end users.
Incorrectly lists nonexistent files	Listed programs that are not in the folder appear in pink highlights.
Matches the program file descriptions	The report compares file descriptions in Contents.m with the first nonempty comment line in the corresponding file. Discrepancies appear in pink highlights. You can update either the program file or the Contents.m file.
Uses consistent spacing between file names and descriptions	Fix the alignment by clicking <b>fix spacing</b> at the top of the report.

You can make all the suggested changes by clicking **fix all**, or open the file in the Editor by clicking **edit Contents.m**.

## See Also

doc | help | ver

## Display Custom Documentation

### In this section...

“Overview” on page 27-16

“Identify Your Documentation (info.xml)” on page 27-17

“Create a Table of Contents (helptoc.xml)” on page 27-20

“Build a Search Database” on page 27-22

“Address Validation Errors for info.xml Files” on page 27-23

### Overview

If you create a toolbox that works with MathWorks products—even if it only contains a few functions—you can include with it HTML documentation files. Providing HTML files for your toolbox allows you to include figures, diagrams, screen captures, equations, and formatting to make your toolbox help more usable.

To display custom documentation:

- 1 Create HTML help files. Store these files in a common folder, such as an `html` subfolder relative to your primary program files. This folder must be on the MATLAB search path, but outside the `matlabroot` folder.

Documentation sets often contain:

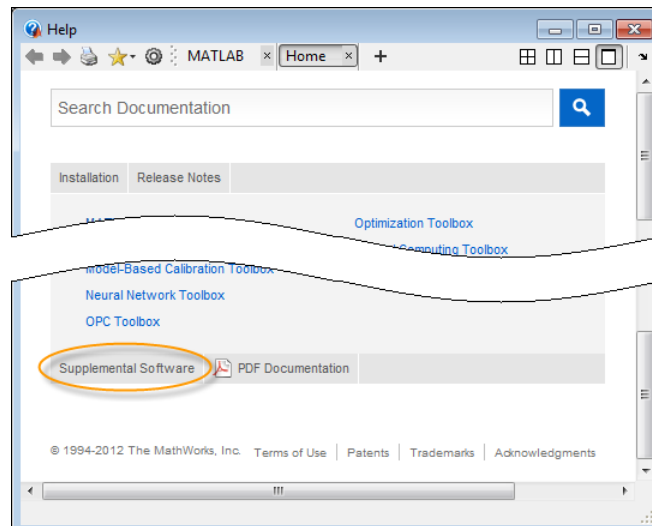
- A roadmap page (that is, an initial landing page for the documentation)
- Examples and topics that explain how to use the toolbox
- Function or block reference pages

You can create HTML files in any text editor or Web publishing software. MATLAB includes functionality to convert `.m` files to formatted HTML files. For more information, see “Publishing MATLAB Code” on page 20-6.

- 2 Create an `info.xml` file, which enables MATLAB to find and identify your documentation files.



- 3 Create a `helptoc.xml` file, which creates a Table of Contents for your documentation to display in the **Contents** pane of the Supplemental Software browser. Store this file in the folder that contains your HTML files.
- 4 Optionally, create a search database for your HTML help files using the `builddocsearchdb` function.
- 5 View your documentation.
  - a In the Help browser, navigate to the home page.
  - b At the bottom of the home page, click **Supplemental Software**.



The Supplemental Software browser opens in a new window.

## Identify Your Documentation (info.xml)

The `info.xml` file specifies the name and icon to display for your documentation set. It also identifies where to find your HTML help files and the `helptoc.xml` file. You must create a file named `info.xml` for each toolbox you document.

The following listing is a template for `info.xml` that you can adapt to describe your toolbox:

```
<productinfo xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:noNamespaceSchemaLocation="optional">
  <?xml-stylesheet type="text/xsl"href="optional"?>

  <matlabrelease>2012b</matlabrelease>
  <name>MyToolbox</name>
  <type>toolbox</type>
  <icon></icon>
  <help_location>html</help_location>
  <help_contents_icon>$toolbox/matlab/icons/bookicon.gif</help_contents_icon>

</productinfo>
```

The following table describes required elements of the `info.xml` file.

XML Tag	Description	Value in Template	Notes
<code>&lt;matlabrelease&gt;</code>	Release of MATLAB	R2012b	Not displayed in the browser, but indicates when you added help files.
<code>&lt;name&gt;</code>	Title of toolbox	MyToolbox	The name of your toolbox that appears in the browser <b>Contents</b> pane.
<code>&lt;type&gt;</code>	Label for the toolbox	toolbox	Allowable values: matlab, toolbox, simulink, blockset, links_targets, other.
<code>&lt;icon&gt;</code>	Icon for the <b>Start</b> button (obsolete)		No longer used, but the <code>&lt;icon&gt;</code> element is required to parse the <code>info.xml</code> file.

XML Tag	Description	Value in Template	Notes
<help_location>	Location of help files	html	Name of subfolder containing helptoc.xml and HTML help files you provide for your toolbox. If not a subfolder, specify the path to help_location relative to the info.xml file. If you provide HTML help files for multiple toolboxes, each help_location must be a different folder.
<help_contents_icon>	Icon to display in <b>Contents</b> pane	\$toolbox/matlab/icons/bookicon.gif	

When you define the info.xml file, make sure that:

- You include all required elements.
- The entries are in the same order as in the preceding list.
- File and folder names in the XML exactly match the names of your files and folders and use upper and lower case letters identically.
- The info.xml file is in a folder on the MATLAB search path.

---

**Note** MATLAB parses the info.xml file and displays your documentation when you add the folder that contains info.xml to the path. If you created an info.xml file in a folder already on the path, remove the folder from the path and then add it again, so that MATLAB parses the file. Make sure that the folder you are adding is *not* your current folder.

---

You can include comments in your info.xml file, such as copyright and contact information. Create comments by enclosing the text on a line with between <!-- and --> markup.

## Create a Table of Contents (helptoc.xml)

The `helptoc.xml` file defines a hierarchy of entries within the **Contents** pane of the Supplemental Software browser. Each `<tocitem>` entry in the `helptoc.xml` file references one of your HTML help files.

Place the `helptoc.xml` file in the folder that contains your HTML documentation files. This folder is designated as `<help_location>` in your `info.xml` file.

For example, suppose you have created the following HTML files:

- A roadmap or starting page for your toolbox, `mytoolbox.html`.
- A page that lists your functions, `funclist.html`.
- Three function reference pages: `firstfx.html`, `secondfx.html`, and `thirdfx.html`.
- An example, `myexample.html`.

Include file names and descriptions in a `helptoc.xml` file as follows:

```
<?xml version='1.0' encoding="utf-8"?>
<toc version="2.0">

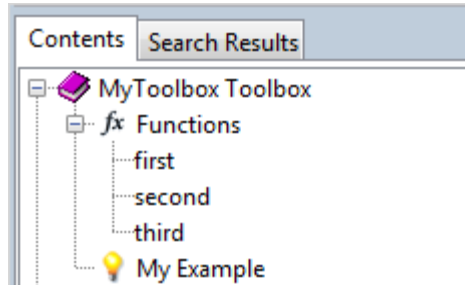
  <tocitem target="mytoolbox.html">My Toolbox
    <tocitem target="funclist.html" image="HelpIcon.FUNCTION">Functions
      <tocitem target="firstfx.html">first</tocitem>
      <tocitem target="secondfx.html">second</tocitem>
      <tocitem target="thirdfx.html">third</tocitem>
    </tocitem>
    <tocitem target="myexample.html"
      image="HelpIcon.EXAMPLES">My Example
    </tocitem>
  </tocitem>

</toc>
```

Within the top-level `<toc>` element, the nested `<tocitem>` elements define the structure of your table of contents. Each `<tocitem>` element has a `target` attribute that provides the file name. `<tocitem>` elements also can include

an `image` attribute to specify icons. Be sure that file and path names exactly match those of the files and folders, including upper- and lower-case letters.

The elements in the previous `helptoc.xml` and `info.xml` files correspond to the following display in the browser.









If your HTML pages include anchor elements, you can refer to an anchor in the `target` attribute of a `<tocitem>` element. In HTML files, anchors are of the form `<a name="anchorid">Any content</a>`. In the `helptoc.xml` file, you can create a link to that anchor using a pound sign (`#`), such as

```
<tocitem target="mypage.html#anchorid">Descriptive text</tocitem>
```

## Icons for Table of Contents Entries

You can display icons for your **Contents** pane entries within your toolbox. To use standard MathWorks icons, include any of the following icons as `image` attributes for `<tocitem>` elements.

Icon	Use For	Image Tag String
	Getting Started Guides	<code>HelpIcon.GETTING_STARTED</code>
	User Guides	<code>HelpIcon.USER_GUIDE</code>
	Functions	<code>HelpIcon.FUNCTION</code>
	Blocks	<code>HelpIcon.BLOCK</code>

Icon	Use For	Image Tag String
	Examples	HelpIcon.EXAMPLES
	Release Notes	HelpIcon.RELEASE_NOTES

Include the icons as `image` attributes in top-level TOC entries. If you provide a roadmap page, also include icons for second-level TOC entries under the roadmap.

### Template for helptoc.xml

A complete template for `helptoc.xml` files that includes `<tocitem>` elements for all standard content types, such as Getting Started, User Guide, and Release Notes, is located in an examples folder included with the MATLAB documentation. To copy the template file, `helptoc_template.xml`, to your current folder and edit the copy, click [here](#) or run the following code:

```
copyfile(fullfile(matlabroot,'help','techdoc','matlab_env', ...
    'examples','templates','helptoc_template.xml'),pwd), ...
fileattrib('helptoc_template.xml','+w')
edit('helptoc_template.xml')
```

### Build a Search Database

To support searches of your documentation, create a search database using the `bulddocsearchdb` function. When using this function, specify the complete path to the folder that contains your HTML files.

For example, suppose your HTML files are in `C:\MATLAB\MyToolbox\html`. This command creates a searchable database:

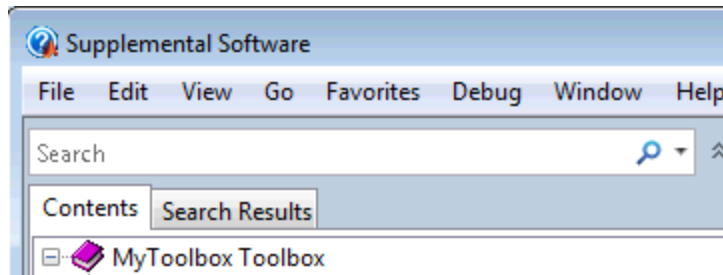
```
bulddocsearchdb('C:\MATLAB\MyToolbox\html')
```

`bulddocsearchdb` creates a subfolder of `C:\MATLAB\MyToolbox\html` named `helpsearch`, which contains three files:

- A file called `deletable`.
- A file called `segments`.

- A file having a `cfs` extension with a name that varies.

You can search for terms in your toolbox from the search bar of the Supplemental Software browser.



## Address Validation Errors for `info.xml` Files

- “About XML File Validation” on page 27-23
- “Entities Missing or Out of Order in `info.xml`” on page 27-24
- “Unrelated `info.xml` File” on page 27-24
- “Invalid Constructs in `info.xml` File” on page 27-24
- “Outdated `info.xml` File for a MathWorks Product” on page 27-24

### About XML File Validation

When MATLAB finds an `info.xml` file on the search path or in the current folder, it automatically validates the file against the supported schema. If there is an invalid construct in the `info.xml` file, MATLAB displays an error in the Command Window. The error is typically of the form:

```
Warning: File <yourxmlfile.xml> did not validate.  
...
```

An `info.xml` validation error can occur when you start MATLAB or add folders to the search path.

The following sections describe the primary causes of an XML file validation error and information to address them.

## Entities Missing or Out of Order in info.xml

If you do not list required XML elements in the prescribed order, you receive an XML validation error:

Often, errors result from incorrect ordering of XML tags. Correct the error by updating the `info.xml` file contents to follow the guidelines in the MATLAB help documentation.

For a description of the elements you need in an `info.xml` file and their required ordering, see “Identify Your Documentation (`info.xml`)” on page 27-17.

## Unrelated info.xml File

Suppose you have a file named `info.xml` that has nothing to do with custom documentation. Because this `info.xml` file is an unrelated file, if the file causes an error, the validation error is irrelevant. In this case, the error is not actually causing any problems, so you can safely ignore it. To prevent the error message from reoccurring, rename the offending `info.xml` file, or ensure that the file is not on the search path or in the current folder.

## Invalid Constructs in info.xml File

If the purpose of the `info.xml` file is to display custom documentation, correct the reported problem. Use the message in the error to isolate the problem or use any validator. One validator you can use is from the W3C® at <http://www.w3.org/2001/03/webdata/xsv>. For more information about the structure of the `info.xml` file, consult its schema, located at `matlabroot/sys/namespace/info/v1/info.xsd`.

## Outdated info.xml File for a MathWorks Product

If you have an `info.xml` file from a different version of MATLAB, that file could contain constructs that are not valid with your version. To identify an `info.xml` file from another version, look at the full path names reported in the error message. The path usually includes a version number, for example, `... \MATLAB\R14\...`. In this situation, the error is not actually causing any problems, so you can safely ignore the error message. To ensure that the error does not reoccur, remove the offending `info.xml` file, or ensure that the file is not on the search path or in the current folder.



## Display Custom Examples

### In this section...

“How to Display Examples” on page 27-25

“Elements of the demos.xml File” on page 27-28

“Thumbnail Images” on page 27-29

## How to Display Examples

If you have videos, published program scripts, or other files that illustrate the use of your programs, you can display these examples in a MATLAB browser, as follows.

- 1 Create your example files. Store the files in a folder that is on the MATLAB search path, but outside the *matlabroot* folder.

---

**Tip** MATLAB includes a publishing feature that converts scripts or functions to formatted HTML files, which you can display as examples. For information about creating these HTML files, see “Publishing MATLAB Code” on page 20-6.

---

- 2 Create a `demos.xml` file that describes the name, type, and display information for your examples.

For example, suppose you have a toolbox named `My Sample`, which contains a script named `my_example` that you published to HTML. This `demos.xml` file allows you to display `my_example` and a MATLAB video:

```
<?xml version="1.0" encoding="utf-8"?>
<demos>
  <name>My Sample</name>
  <type>toolbox</type>
  <icon>HelpIcon.DEMOS</icon>
  <description>This text appears on the main page for your examples.</description>
  <website><a href="http://www.mathworks.com">Link to your Web site</a></website>
```

```
<demosession>
  <label>First Section</label>
  <demoitem>
    <label>My Example Title</label>
    <type>M-file</type>
    <source>my_example</source>
  </demoitem>
</demosession>

<demosession>
  <label>Second Section</label>
  <demoitem>
    <label>My Video (5 min, 21 sec)</label>
    <type>video</type>
    <callback>
      playbackdemo('WorkingInTheDevelopmentEnvironment','toolbox/matlab/web/demos');
    </callback>
  </demoitem>
</demosession>

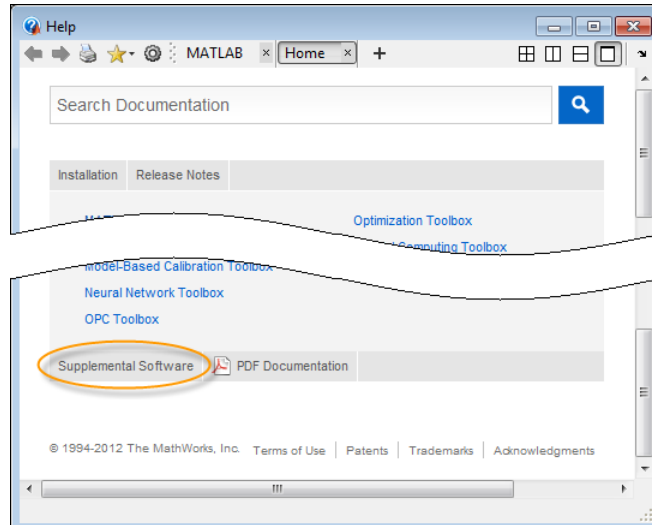
</demos>
```

---

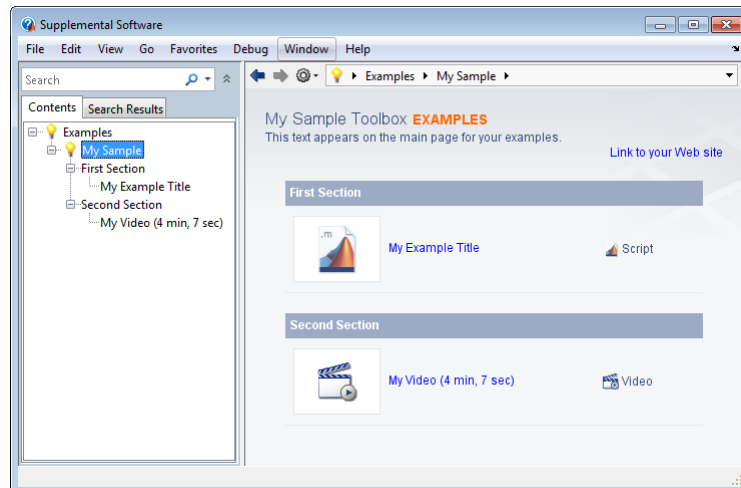
**Note** <demosession> elements are optional.

---

- 3 View your examples.
  - a In the Help browser, navigate to the home page.
  - b At the bottom of the home page, click **Supplemental Software**.



The Supplemental Software browser opens in a new window. The **Contents** pane contains an **Examples** node, which contains the entries corresponding to your `demos.xml` file.



---

**Tip** If your examples do not appear, refresh the browser. In the **Contents** pane, right-click **Examples**, and then select **Refresh Examples**.

Alternatively, force a refresh by removing the folder that contains `demos.xml` from the path, and then adding it back. When you add the folder back to the path, make sure it is not the current folder.

---

## Elements of the `demos.xml` File

- “General Information in `<demos>`” on page 27-28
- “Categories Using `<demosession>` (Optional)” on page 27-29
- “Information About Each Example in `<demositem>`” on page 27-29

### General Information in `<demos>`

Within the `demos.xml` file, the root tag is `<demos>`. This tag includes elements that determine the contents of the main page for your examples.

XML Tag	Notes
<code>&lt;name&gt;</code>	Name of your toolbox or collection of examples.
<code>&lt;type&gt;</code>	Possible values are <code>matlab</code> , <code>simulink</code> , <code>toolbox</code> , or <code>blockset</code> .
<code>&lt;icon&gt;</code>	Icon for your example. You can use a standard icon, <code>HelpIcon.DEMOS</code> , or provide a custom icon by specifying a path to the icon relative to the location of the <code>demos.xml</code> file.
<code>&lt;description&gt;</code>	The description that appears on the main page for your examples.
<code>&lt;website&gt;</code>	(Optional) Link to a Web site. For example, MathWorks examples include a link to the product page at <a href="http://www.mathworks.com">http://www.mathworks.com</a> .

## Categories Using `<demosection>` (Optional)

Define categories for your examples by including a `<demosection>` for each category. If you include *any* categories, then *all* examples must be in categories.

Each `<demosection>` element contains a `<label>` that provides the category name, and the associated `<demoitem>` elements.

## Information About Each Example in `<demoitem>`

XML Tag	Notes
<code>&lt;label&gt;</code>	Defines the title to display in the browser.
<code>&lt;type&gt;</code>	Possible values are M-file, model, M-GUI, video, or other.
<code>&lt;source&gt;</code>	If <code>&lt;type&gt;</code> is M-file, model, M-GUI, then <code>&lt;source&gt;</code> is the name of the associated .m file or model file, with no extension. Otherwise, do not include a <code>&lt;source&gt;</code> element, but include a <code>&lt;callback&gt;</code> element.
<code>&lt;file&gt;</code>	Use this element only for examples with a <code>&lt;type&gt;</code> value other than M-file when you want to display an HTML file that describes the example. Specify a relative path from the location of <code>demos.xml</code> .
<code>&lt;callback&gt;</code>	Use this element only for examples with a <code>&lt;type&gt;</code> value of video or other to specify an executable file or a MATLAB command to run the example.
<code>&lt;dependency&gt;</code>	(Optional) Specifies other products required to run the example, such as another toolbox. The text must match a product name specified in an <code>info.xml</code> file that is on the search path or in the current folder.

## Thumbnail Images

If your example has an HTML file to describe it, you can include a *thumbnail*, a small image typifying the example. The `demos.xml` file does not specify thumbnail images directly.

To include a thumbnail, supply a `.png` image file in the same folder as the HTML file. Keep the image size to within 96-by-64 pixels (width-by-height). Give the `.png` file the same name as the HTML file. Thus, if the `<file>` element for your example is `./html/my_example.html`, then your thumbnail must be named `my_example.png` and reside in the same folder.

When you publish a script to HTML within MATLAB, you get a `.png` thumbnail file in the correct place with the correct name by default.

# Source Control Interface

---

The source control interface provides access to your source control system from the MATLAB desktop. Source control systems, also known as version control, revision control, configuration management, and file management systems, are platform dependent—the topics for the Microsoft Windows platforms appear first, followed by the topics for the UNIX platforms.

- “Source Control Interface on Microsoft Windows” on page 28-2
- “Set Up Source Control (Microsoft Windows)” on page 28-3
- “Check Files In and Out (Microsoft Windows)” on page 28-11
- “Additional Source Control Actions (Microsoft Windows)” on page 28-14
- “Access Source Control from Editors (Microsoft Windows)” on page 28-23
- “Troubleshoot Source Control Problems (Microsoft Windows)” on page 28-24
- “Source Control Interface on UNIX Platforms” on page 28-26
- “Specify Source Control System (UNIX Platforms)” on page 28-27
- “Check In Files (UNIX Platforms)” on page 28-30
- “Check Out Files (UNIX Platforms)” on page 28-32
- “Undo the Checkout (UNIX Platforms)” on page 28-35

## Source Control Interface on Microsoft Windows

If you use source control systems to manage your files, you can interface with the systems to perform source control actions from within the MATLAB, Simulink, and Stateflow<sup>®</sup> products. Use menu items in the MATLAB, Simulink, or Stateflow products, or run functions in the MATLAB Command Window to interface with your source control systems.

The source control interface on Windows works with any source control system that conforms to the Microsoft Common Source Control standard, Version 1.1. If your source control system does not conform to the standard, use a Microsoft Source Code Control API wrapper product for your source control system so that you can interface with it from the MATLAB, Simulink, and Stateflow products.

This documentation uses the Microsoft Visual SourceSafe<sup>®</sup> software as an example. Your source control system might use different terminology and not support the same options or might use them in a different way. Regardless, you should be able to perform similar actions with your source control system based on this documentation.

Perform most source control interface actions from the Current Folder browser. You can also perform many of these actions for a single file from the MATLAB Editor, a Simulink model window, or a Stateflow chart window—for more information, see “Access Source Control from Editors (Microsoft Windows)” on page 28-23. Another way to access many of the source control actions is with the `verctrl` function.



## Set Up Source Control (Microsoft Windows)

### In this section...

“Create Projects in Source Control System” on page 28-3

“Specify Source Control System with MATLAB Software” on page 28-5

“Register Source Control Project with MATLAB Software” on page 28-7

“Add Files to Source Control” on page 28-9

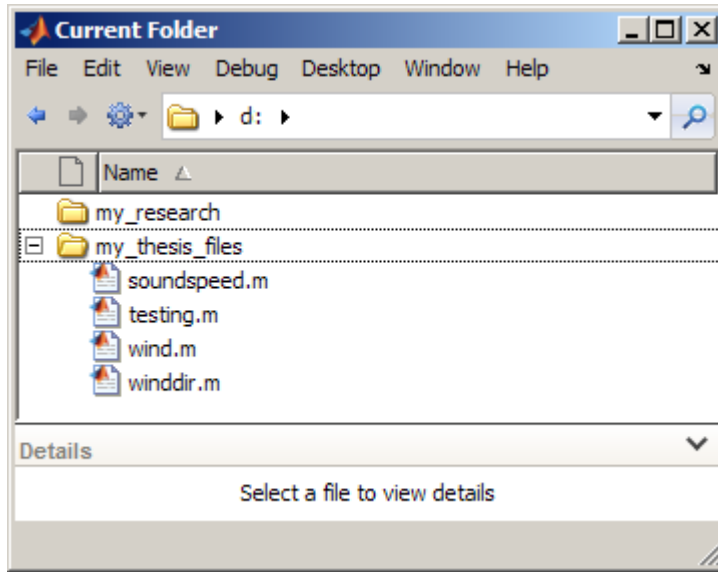
### Create Projects in Source Control System

In your source control system, create the projects that your folders and files will be associated with.

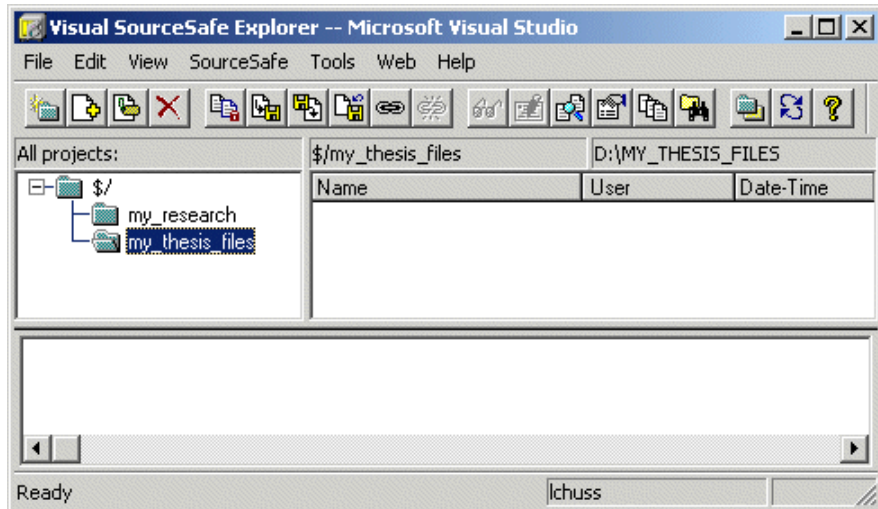
All files in a folder must belong to the same source control project. Be sure the working folder for the project in the source control system specifies the correct path to the folder on disk.

#### Example of Creating Source Control Project

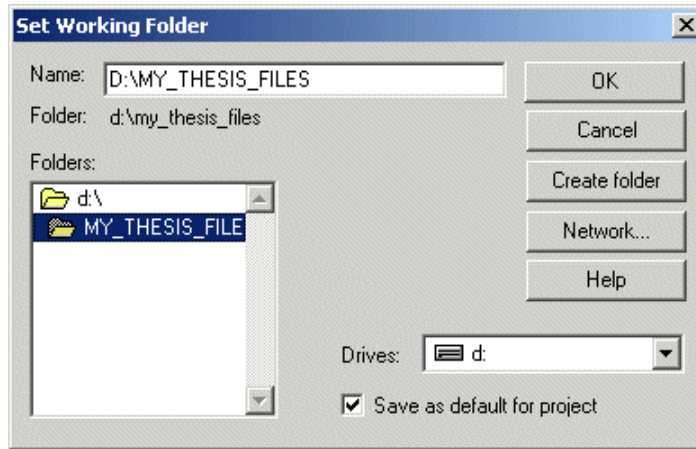
This example uses the project `my_thesis_files` in Microsoft Visual SourceSafe. This illustration of the Current Folder browser shows the path to the folder on disk, `D:\my_thesis_files`.



The following illustration shows the example project in the source control system.



To set the working folder in Microsoft Visual SourceSafe for this example, select `my_thesis_files`, right-click, select **Set Working Folder** from the context menu, and specify `D:\my_thesis_files` in the resulting dialog box.

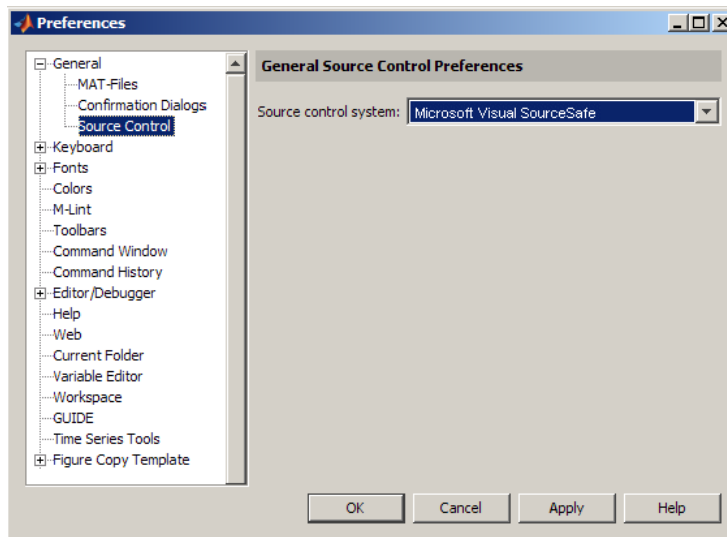


## Specify Source Control System with MATLAB Software

In MATLAB, specify the source control system you want to access. On the **Home** tab, in the **Environment** section, click **Preferences > MATLAB > General > Source Control**.

The currently selected system is shown in the Preferences dialog box. The list includes all installed source control systems that support the Microsoft Common Source Control standard.

Select the source control system you want to interface with and click **OK**.



MATLAB remembers preferences between sessions, so you only need to perform this action again when you want to access a different source control system.

### Source Control with 64-Bit Versions of MATLAB

If you run a 64-bit version of MATLAB and want MATLAB to interface with your source control system, your source control system must be 64-bit compliant. If you have a 32-bit source control system, or if you have a 64-bit source control system running in 32-bit compatibility mode, MATLAB cannot use it. In that event, MATLAB displays a warning about the problem in the Source Control preference pane.

### Function Alternative for Specifying Source Control System

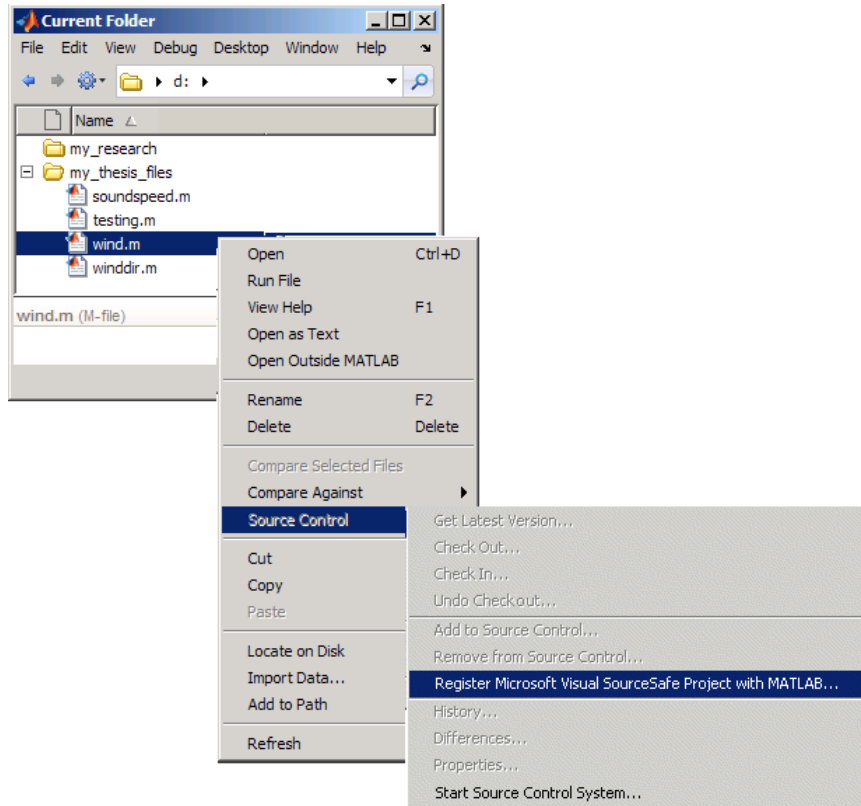
A function alternative to select a source control system is not available, but you can list all available source control systems using `verctrl` with the `all_systems` argument. Use `cmopts` to display the name of the currently selected source control system.

## Register Source Control Project with MATLAB Software

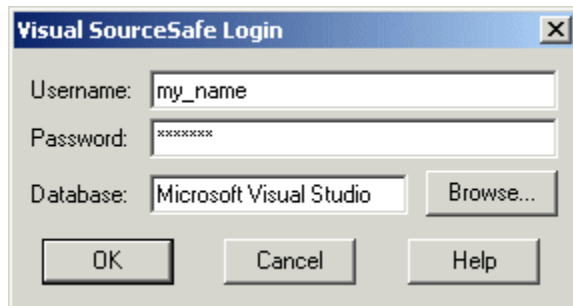
Register a source control system project with a folder in MATLAB, that is, associate a source control system project with a folder and all files in that folder. Do this only one time for any file in the folder, which registers all files in that folder:

- 1** In the MATLAB Current Folder browser, select a file that is in the folder you want to associate with a project in your source control system. For example, select `D:\my_thesis_files\wind.m`. This will associate all files in the `my_thesis_files` folder.
- 2** Right-click, and from the context menu, select **Source Control > Register Name\_of\_Source\_Control\_System Project with MATLAB**. The **Name\_of\_Source\_Control\_System** is the source control system you selected using preferences as described in “Specify Source Control System with MATLAB Software” on page 28-5.

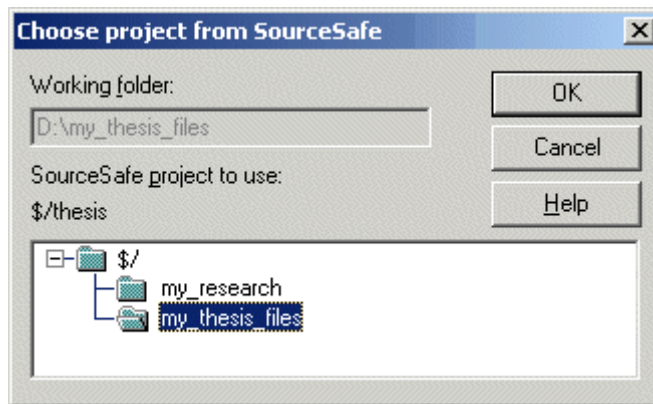
The following example shows Microsoft Visual SourceSafe.



- 3 In the resulting **Name\_of\_Source\_Control\_System Login** dialog box, provide the user name and password you use to access your source control system, and click **OK**.



- 4 In the resulting **Choose project from Name\_of\_Source\_Control\_System** dialog box, select the source control system project to associate with the folder and click **OK**. This example shows `my_thesis_files`.



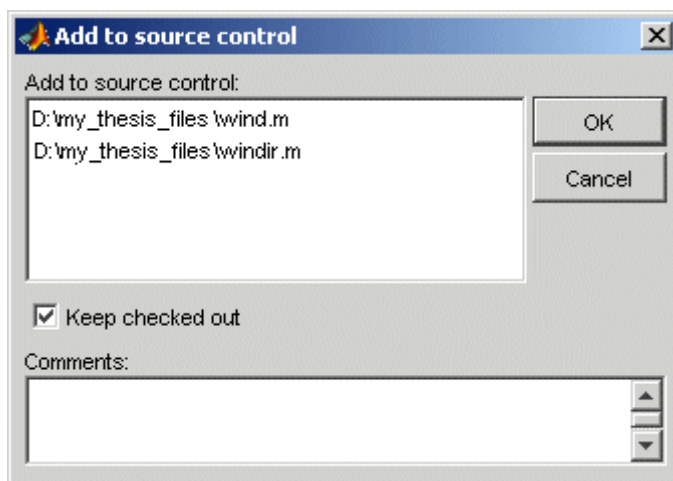
The selected file, its folder, and all files in the folder, are associated with the source control system project you selected. For the example, MATLAB associates all files in `D:\my_thesis_files` with the source control project `my_thesis_files`.

## Add Files to Source Control

Add files to the source control system. Do this only once for each file:

- 1 In the Current Folder browser, select files you want to add to the source control system.

- 2** Right-click, and from the context menu, select **Source Control > Add to Source Control**.
- 3** The resulting **Add to source control** dialog box lists files you selected to add. You can add text in the **Comments** field. If you expect to use the files soon, select the **Keep checked out** check box (which is selected by default). Click **OK**.



If you try to add an unsaved file, the file is automatically saved upon adding.

### **Function Alternative**

The function alternative is `verctrl` with the `add` argument.



## Check Files In and Out (Microsoft Windows)

### In this section...

“Check Files Into Source Control” on page 28-11

“Check Files Out of Source Control” on page 28-11

“Undoing the Checkout” on page 28-12

Before checking files into and out of your source control system from the MATLAB desktop, be sure to set up your system for use with MATLAB as described in “Set Up Source Control (Microsoft Windows)” on page 28-3.

### Check Files Into Source Control

After creating or modifying files using MATLAB software or related products, check the files into the source control system by performing these steps:

- 1 In the Current Folder browser, select the files to check in. A file can be open or closed when you check it in, but it must be saved, that is, it cannot contain unsaved changes.
- 2 Right-click, and from the context menu, select **Source Control > Check In**.
- 3 In the resulting **Check in file(s)** dialog box, you can add text in the **Comments** field. If you want to continue working on the files, select the check box **Keep checked out**. Click **OK**.

If a file contains unsaved changes when you try to check it in, you will be prompted to save the changes to complete the checkin. If you did not keep the file checked out and you keep the file open, note that it is a read-only version.

### Function Alternative

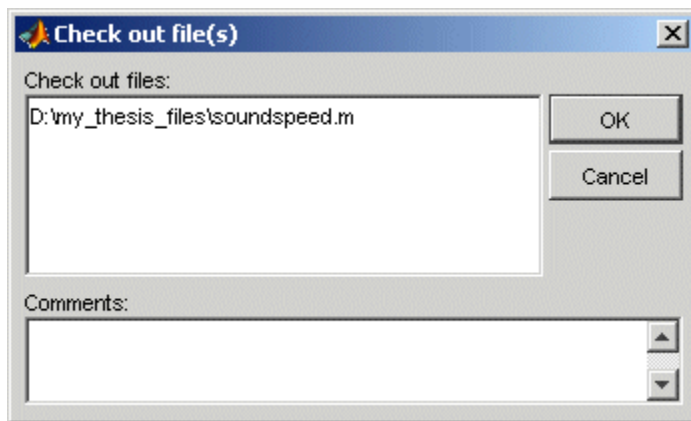
The function alternative is `verctrl` with the `checkin` argument.

### Check Files Out of Source Control

From MATLAB, to check out the files you want to modify, perform these steps:

- 1 In the Current Folder browser, select the files to check out.

- 2 Right-click, and from the context menu, select **Source Control > Check Out**.
- 3 The resulting **Check out file(s)** dialog box lists files you selected to check out. Enter comment text in the **Comments** field, which appears if your source control system supports comments on checkout. Click **OK**.



After checking out a file, make changes to it in MATLAB or another product, and save the file. For example, edit a file in the Editor.

If you try to change a file without first having checked it out, the file is read-only, as seen in the title bar, and you will not be able to save any changes. This protects you from accidentally overwriting the source control version of the file.

If you end the MATLAB session, the file remains checked out. You can check in the file from within MATLAB during a later session, or folder from your source control system.

### Function Alternative

The function alternative is `verctrl` with the `checkout` argument.

### Undoing the Checkout

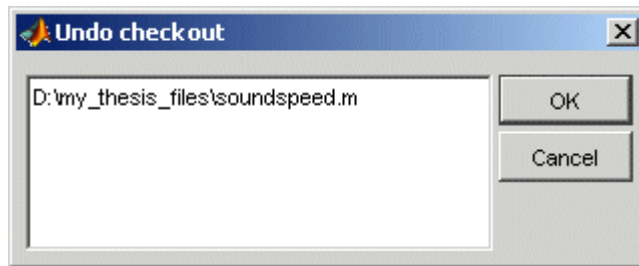
You can undo the checkout for files. The files remain checked in, and do not have any of the changes you made since you last checked them out. To save

any changes you have made since checking out a particular file click **Save** on the **Editor** tab, select **Save As**, and supply a different file name before you undo the checkout.

To undo a checkout, follow these steps:

- 1** In the MATLAB Current Folder browser, select the files for which you want to undo the checkout.
- 2** Right-click, and from the context menu, select **Source Control > Undo Checkout**.

The MATLAB **Undo checkout** dialog box opens, listing the files you selected.



- 3** Click **OK**.

### **Function Alternative**

The function alternative is `verctrl` with the `undocheckout` argument.

## Additional Source Control Actions (Microsoft Windows)

### In this section...

“Getting the Latest Version of Files for Viewing or Compiling” on page 28-14

“Removing Files from the Source Control System” on page 28-15

“Showing File History” on page 28-16

“Comparing the Working Copy of a File to the Latest Version in Source Control” on page 28-18

“Viewing Source Control Properties of a File” on page 28-20

“Starting the Source Control System” on page 28-21

### Getting the Latest Version of Files for Viewing or Compiling

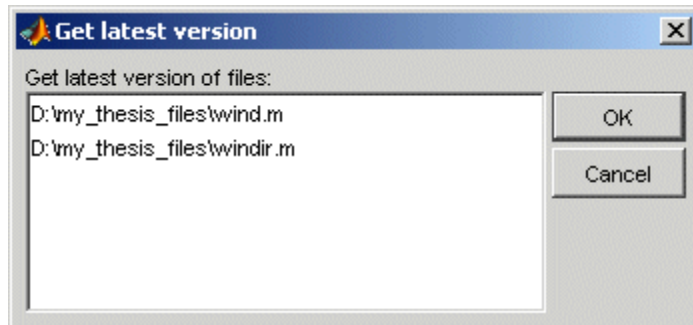
You can get the latest version of a file from the source control system for viewing or running. Getting a file differs from checking it out. When you get a file, it is write protected so you cannot edit it, but when you check out a file, you can edit it.

To get the latest version, follow these steps:

- 1 In the MATLAB Current Folder browser, select the folders or files that you want to get. If you select files, you cannot select folders too.

- 2 Right-click, and from the context menu, select **Source Control > Get Latest Version**.

The MATLAB Get latest version dialog box opens, listing the files or folders you selected.



- 3 Click **OK**.

You can now open the file to view it, run the file, or check out the file for editing.

### **Function Alternative**

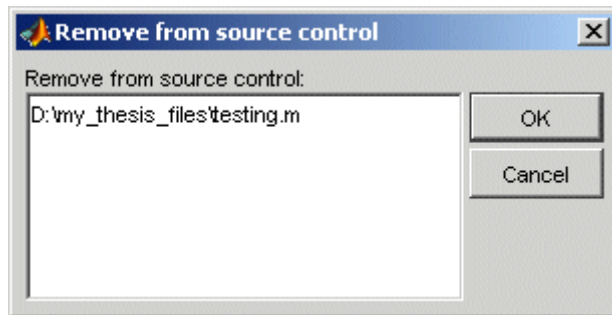
The function alternative is `verctrl` with the `get` argument.

## **Removing Files from the Source Control System**

To remove files from the source control system, follow these steps:

- 1 In the MATLAB Current Folder browser, select the files you want to remove.
- 2 Right-click, and from the context menu, select **Source Control > Remove from Source Control**.

The MATLAB **Remove from source control** dialog box opens, listing the files you selected.



- 3 Click **OK**.

### **Function Alternative**

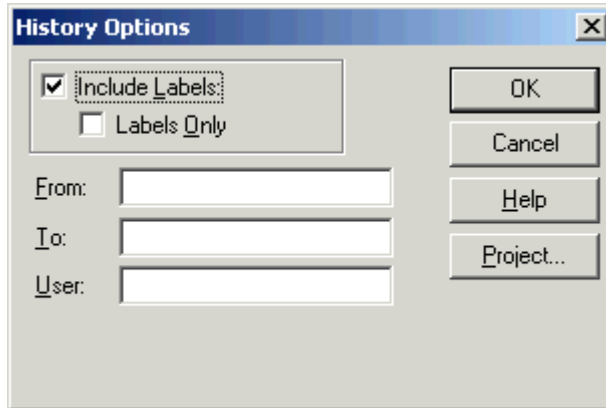
The function alternative is `verctrl` with the `remove` argument.

### **Showing File History**

To show the history of a file in the source control system, follow these steps:

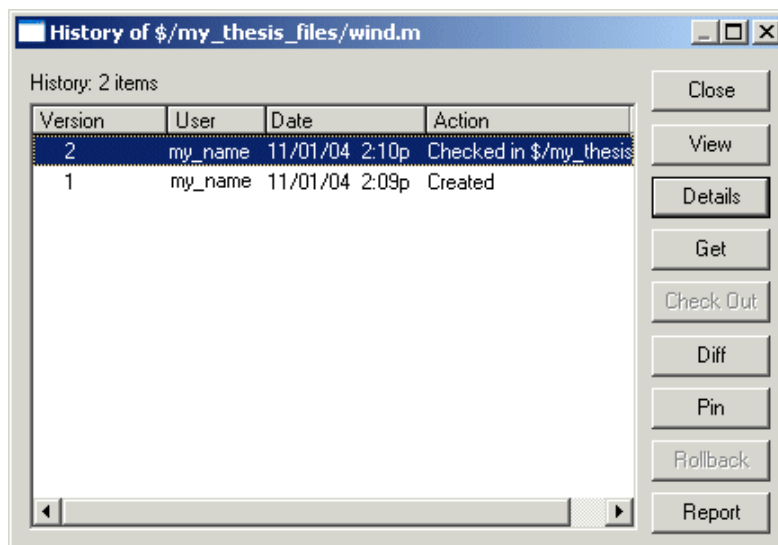
- 1 In the MATLAB Current Folder browser, select the file for which you want to view the history.
- 2 Right-click, and from the context menu, select **Source Control > History**.

A dialog box, which is specific to your source control system, opens. For Microsoft Visual SourceSafe, the **History Options** dialog box opens, as shown in the following example illustration.



- 3 Complete the dialog box to specify the range of history you want for the selected file and click **OK**. For example, enter my\_name for **User**.

The history presented depends on your source control system. For Microsoft Visual SourceSafe, the **History** dialog box opens for that file, showing the file's history in the source control system.



### Function Alternative

The function alternative is `verctrl` with the `history` argument.

## Comparing the Working Copy of a File to the Latest Version in Source Control

You can compare the current working copy of a file with the latest checked-in version of the file in the source control system. This highlights the differences between the two files, showing the changes you made since you checked out the file.

To view the differences, follow these steps:

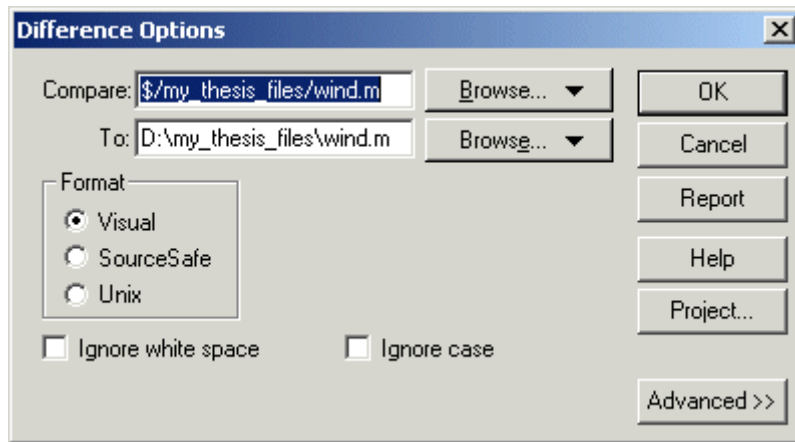
- 1 In the MATLAB Current Folder browser, select the file for which you want to view differences. This is a file that has been checked out and edited.



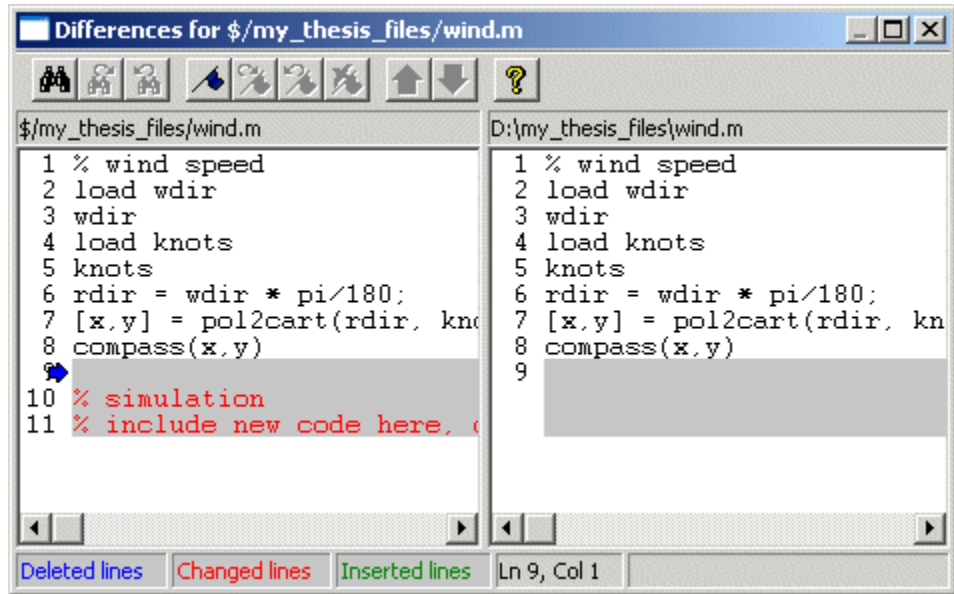
- 2 Right-click, and from the context menu, select **Source Control > Differences**.

A dialog box, which is specific to your source control system, opens. For Microsoft Visual SourceSafe, the **Difference Options** dialog box opens.

- 3 Review the default entries in the dialog box, make any needed changes, and click **OK**. The following example is for Microsoft Visual SourceSafe.



The method of presenting differences depends on your source control system. For Microsoft Visual SourceSafe, the **Differences for** dialog box opens. This highlights the differences between the working copy of the file and the latest checked-in version of the file.



### Function Alternative

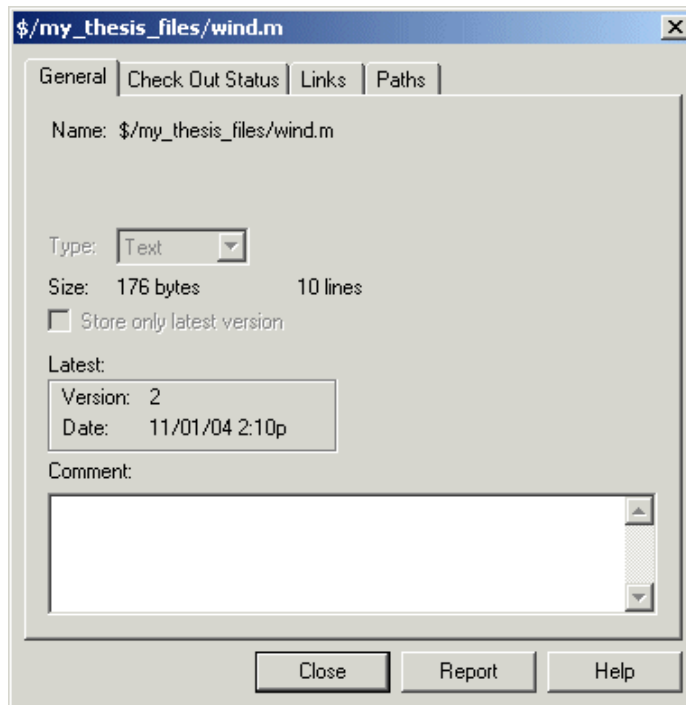
The function alternative is `verctrl` with the `showdiff` or `isdiff` argument.

### Viewing Source Control Properties of a File

To view the source control properties of a file, follow these steps:

- 1 In the MATLAB Current Folder browser, select the file for which you want to view properties.
- 2 Right-click, and from the context menu, select **Source Control > Properties**.

A dialog box, which is specific to your source control system, opens. The following example shows the Microsoft Visual SourceSafe properties dialog box.



### Function Alternative

The function alternative is `verctrl` with the `properties` argument.

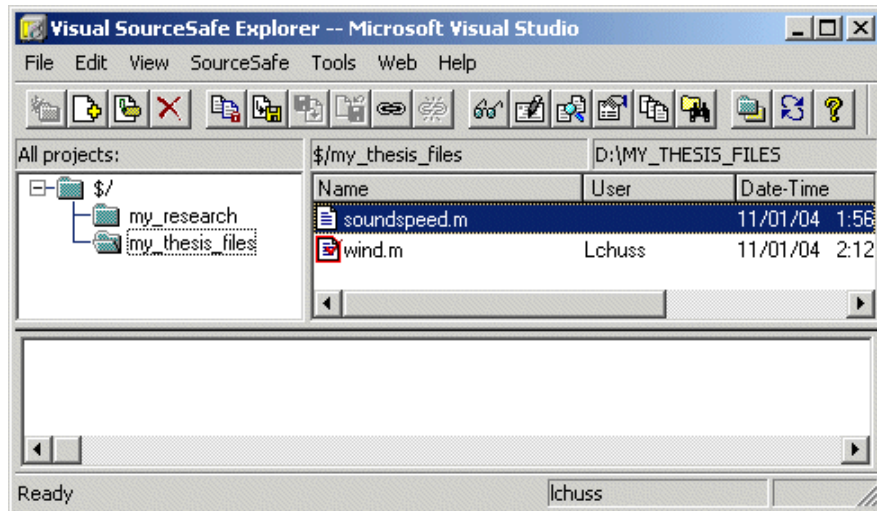
## Starting the Source Control System

All the MATLAB source control actions automatically start the source control system to perform the action, if the source control system is not already open. If you want to start the source control system from MATLAB without performing a specific action source control action,

- 1 Right-click any folder or file in the MATLAB Current Folder browser

- From the context menu, select **Source Control > Start Source Control System**.

The interface to your source control system opens, showing the source control project associated with the current folder in MATLAB. The following example shows the Microsoft Visual SourceSafe Explorer interface.



### Function Alternative

The function alternative is `verctrl` with the `runsc` argument.

## Access Source Control from Editors (Microsoft Windows)

You can create or open a file in the Editor, the Simulink or Stateflow products and perform most source control actions from their **File > Source Control** menus, rather than from the Current Folder browser. Following are some differences in the source control interface process when you use the Editor, Simulink, or Stateflow:

- You can perform actions on only one file at time.
- Some of the dialog boxes have a different icon in the title bar. For example, the **Check out file(s)** dialog box uses the MATLAB Editor icon instead of the MATLAB icon.
- You cannot add a new (Untitled) file, but must instead first save the file.
- You cannot register projects from the Simulink or Stateflow products. Instead, register a project using the Current Folder browser, as described in “Register Source Control Project with MATLAB Software” on page 28-7.

## Troubleshoot Source Control Problems (Microsoft Windows)

### In this section...

“Source Control Error: Provider Not Present or Not Installed Properly” on page 28-24

“Restriction Against @ Character” on page 28-25

“Add to Source Control Is the Only Action Available” on page 28-25

“More Solutions for Source Control Problems” on page 28-25

### Source Control Error: Provider Not Present or Not Installed Properly

In some cases, MATLAB software recognizes your source control system but you cannot use source control features for MATLAB. Specifically, when you select **MATLAB > General > Source Control** in the Preferences dialog box, or run `cmopts`, MATLAB lists your source control system, but you cannot perform any source control actions. Only the **Start Source Control System** item is available, and when you select it, MATLAB displays this error:

Source control provider is not present or not installed properly.

Often, this error occurs because a registry key that MATLAB requires from the source control application is not present. Make sure this registry key is present:

```
HKEY_LOCAL_MACHINE\SOFTWARE\SourceCodeControlProvider\  
InstalledSCCProviders
```

The registry key refers to another registry key that is similar to

```
HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\SourceSafe\ScsServerPath
```

This registry key has a path to a DLL-file in the file system. Make sure the DLL-file exists in that location. If you are not familiar with registry keys, ask your system administrator for help.

If this does not solve the problem and you use Microsoft Visual SourceSafe, try running a client setup for your source control application. When SourceSafe is installed on a server for a group to use, each machine client can run a setup but is not required to do so. However, some applications that interface with SourceSafe, including MATLAB, require you to run the client setup. Run the client setup, which should resolve the problem.

If the problem persists, access source control outside of MATLAB.

## Restriction Against @ Character

Some source control systems, such as Perforce® and Synergy™, reserve the @ character. Perforce, for example, uses it as a revision specifier. Therefore, you might experience problems if you use these source control systems with MATLAB files and folders that include the @ character in the folder or file name.

You might be able to work around this restriction by quoting nonstandard characters in file names, such as with an escape sequence, which some source control systems allow. Consult your source control system documentation or technical support resources for a workaround.

## Add to Source Control Is the Only Action Available

To use source control features for a file in the Simulink or Stateflow products, the file's source control project must first be registered with MATLAB. When a file's source control project is *not* registered with MATLAB, all **MATLAB > General > Source Control** menu items on the Preferences dialog box are disabled except **Add to Source Control**. You can select **Add to Source**, which registers the project with MATLAB, or you can register the project using the Current Folder browser, as described in "Register Source Control Project with MATLAB Software" on page 28-7. You can then perform source control actions for all files in that project (folder).

## More Solutions for Source Control Problems

The latest solutions for problems interfacing MATLAB with a source control system appear on the MathWorks Web page for support at <http://www.mathworks.com/support/>. Search Solutions and Technical Notes for "source control."

## Source Control Interface on UNIX Platforms

If you use a source control system to manage your files, you can check MATLAB program files and Simulink models, and Stateflow charts into and out of the source control system from within the MATLAB, Simulink, and Stateflow products.

The source control interface supports four popular source control systems, as well as a custom option:

- ClearCase® software from IBM® Rational®
- Concurrent Version System (CVS)
- ChangeMan® and PVCS® software from Serena®
- Revision Control System (RCS)
- Custom option — Allows you to build your own interface if you use a different source control system. For details, see the reference page for `customverctrl`.

Perform source control interface actions for a single file using menu items in the MATLAB Editor, a Simulink model window, or a Stateflow chart window. To perform source control actions on multiple files, use the Current Folder browser. Alternatively, run source control functions in the Command Window, which provide some options not supported with the menu items.



## Specify Source Control System (UNIX Platforms)


### In this section...

“MATLAB Desktop Alternative” on page 28-27

“Function Alternative” on page 28-28

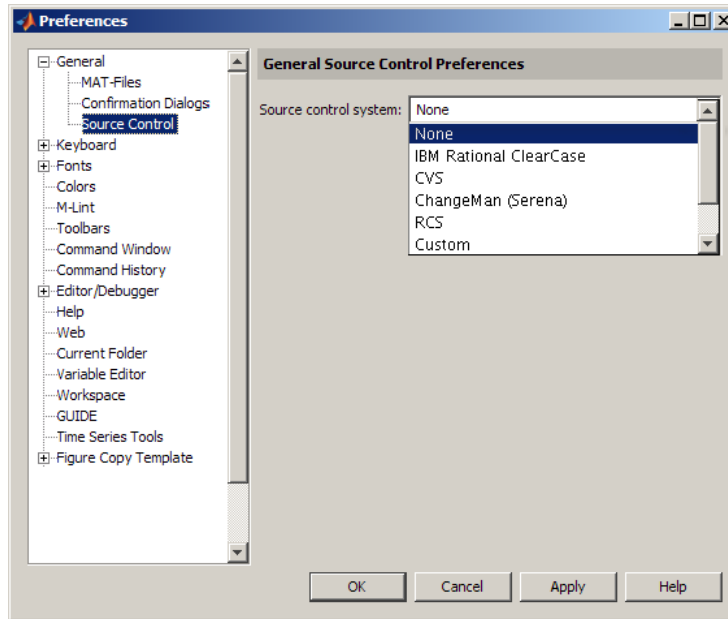
“Setting a View and Checking Out a Folder with ClearCase Software on UNIX Platforms” on page 28-28

### MATLAB Desktop Alternative

To specify the source control system you want to access, click  **Preferences** on the **Home** tab, and select **MATLAB > General > Source Control**.

The currently selected system is shown in the Preferences dialog box. The default selection is **None**.

Select the source control system with which you want to interface and click **OK**.



MATLAB remembers preferences between sessions, so you only need to perform this action when you want to access a different source control system.

## Function Alternative

A function alternative to select a source control system is not available, but you can list the currently selected source control system by running `cmopts`.

## Setting a View and Checking Out a Folder with ClearCase Software on UNIX Platforms

If you use ClearCase software on a UNIX platform, perform the following from ClearCase:

- 1 Set a view.
- 2 Check out the folder that contains files you want to save, check in, or check out.

You can now use the MATLAB, Simulink, or Stateflow source control interfaces to ClearCase software.

## Check In Files (UNIX Platforms)

### In this section...

“Checking In One or More Files Using the Current Folder Browser” on page 28-30

“Checking In One File Using the Editor, or the Simulink or Stateflow Products” on page 28-30

“Function Alternative” on page 28-31

### Checking In One or More Files Using the Current Folder Browser

- 1 From the Current Folder browser, select the file or files to check in. A file can be open or closed when you check it in, but it must be saved, that is, it cannot contain unsaved changes.
- 2 Right-click, and from the context menu, select **Source Control > Check In**.
- 3 In the resulting **Check in file(s)** dialog box, you can add text in the **Comments** field. If you want to continue working on the files, select the check box **Keep checked out**. Click **OK**.

The files are checked into the source control system. If any file contains unsaved changes when you try to check it in, you will be prompted to and must then save the changes to complete the checkin.

An error appears in the Command Window if a file is already checked in.

If you did not keep a file checked out and you keep that file open, note that it is a read-only version.

### Checking In One File Using the Editor, or the Simulink or Stateflow Products

- 1 From the Editor, or the Simulink or Stateflow products, with the file open and saved, select **File > Source Control > Check In**.

- 2 In the resulting **Check in file(s)** dialog box, you can add text in the **Comments** field. If you want to continue working on the files, select the check box **Keep checked out**. Click **OK**.

## Function Alternative

Use `checkin` to check files into the source control system. The files can be open or closed when you use `checkin`. The `checkin` function takes this form:

```
checkin({'file1', 'file2', ...}, 'comments', 'comment_text', ...  
'option', 'value')
```

For `file $n$` , use the complete path and include the file extension. You must supply the `comments` argument and a comments string with `checkin`.

Use the `option` argument to

- Check in a file and keep it checked out — set the `lock` option value to `on`.
- Check in a file even though it has not changed since the previous check in — set the `force` option value to `on`.

The `comments` argument and the `lock` and `force` options apply to all files checked in.

## Example Using checkin Function

To check in the file `clock.m` with the comment `Adjustment for leap year`, type

```
checkin('\myserver\myfiles\clock.m', 'comments', ...  
'Adjustment for leap year')
```

For other examples, see the reference page for `checkin`.

## Check Out Files (UNIX Platforms)

### In this section...

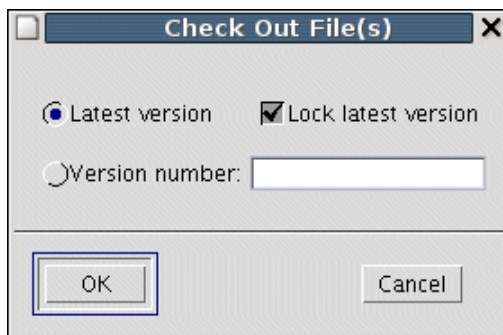
“Checking Out One or More Files Using the Current Folder Browser” on page 28-32

“Checking Out a Single File Using the Editor, or the Simulink or Stateflow Products” on page 28-33

“Function Alternative” on page 28-33

### Checking Out One or More Files Using the Current Folder Browser

- 1 In the Current Folder browser, select the file or files to check out.
- 2 Right-click, and from the context menu, select **Source Control > Check Out**. The **Check out file(s)** dialog box opens.



- 3 Complete the dialog box:
  - a To check out the versions that were most recently checked in, select the **Latest version** option.
  - b To check out a specific version of the files, select the **Version number** option and type the version number in the field.

- c To prevent others from checking out the files while you have them checked out, select **Lock latest version**. To check out read-only versions of the file, clear **Lock latest version**.

#### 4 Click **OK**.

An error appears in the Command Window if a file is already checked out.

After checking out files, make changes to them using MATLAB software or another software product, and save the files. For example, edit a file in the Editor.

If you try to change a file without first having checked it out, the file is read-only, as seen in the title bar, and you will not be able to save any changes. This protects you from accidentally overwriting the source control version of the file.

If you end the MATLAB session, the file or files remain checked out. You can check in files from within MATLAB during a later session, or directly from your source control system.

## Checking Out a Single File Using the Editor, or the Simulink or Stateflow Products

- 1 Open the MATLAB program file, Simulink model, or Stateflow chart you want to check out. The title bar indicates the file is read-only.
- 2 Select **File > Source Control > Check Out**. The **Check out file(s)** dialog box opens.
- 3 Complete the dialog box as described in step of “Checking Out One or More Files Using the Current Folder Browser” on page 28-32, and click **OK**.

### Function Alternative

Use `checkout` to check out a file from the source control system. You can check out multiple files at once and specify checkout options. The `checkout` function takes this form:

```
checkout({'file1','file2', ...},'option','value')
```

For `filename`, use the complete path and include the file extension.

Use the `option` argument to

- Check out a read-only version of the file — set the `lock` option value to `off`.
- Check out the file even if you already have it checked out — set the `force` option value to `on`.
- Check out a specific version of the file — use the `revision` option, and assign the version number to the `value` argument.

The options apply to all files being checked out. The files can be open or closed when you use `checkout`.

### **Example Using checkout Function—Check Out a Specific Version of a File**

To check out the 1.1 version of the file `clock.m`, type

```
checkout('\myserver\myfiles\clock.m','revision','1.1')
```

For other examples, see the reference page for `checkout`.



## Undo the Checkout (UNIX Platforms)


### In this section...

“Impact of Undoing a File Checkout” on page 28-35

“Undoing the Checkout for One or More Files Using the Current Folder Browser” on page 28-35

“Function Alternative” on page 28-35

### Impact of Undoing a File Checkout

When you undo the checkout for a file, the file remains checked in, and does not have any of the changes you made since you checked it out. To save any changes you have made since checking out a file, click **Save**  on the **Editor** tab, select **Save As**, and supply a different file name before you undo the checkout. Undo the checkout using the Current Folder browser.

### Undoing the Checkout for One or More Files Using the Current Folder Browser

- 1 In the MATLAB Current Folder browser, select the file or files for which you want to undo the checkout.
- 2 Right-click, and from the context menu, select **Source Control > Undo Checkout**. MATLAB undoes the checkout.

An error appears in the Command Window if the file is not checked out.

### Function Alternative

The `undocheckout` function takes this form:

```
undocheckout({'file1','file2', ...})
```

Use the complete path for `filen` and include the file extension. For example, to undo the checkout for the files `clock.m` and `calendar.m`, type

```
undocheckout({'\myserver\myfiles\clock.m',...  
'\myserver\myfiles\calendar.m'})
```



# Unit Testing

---

- “Write Simple Test Case Using Classes” on page 29-2
- “Write Setup and Teardown Code Using Classes” on page 29-6
- “Types of Qualifications” on page 29-10
- “Write Tests Using Shared Fixtures” on page 29-12
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- “Write Test Using Setup and Teardown Functions” on page 29-88

## Write Simple Test Case Using Classes

This example shows how to write a unit test for a MATLAB function, `quadraticSolver.m`.

### Create `quadraticSolver.m` Function

The following MATLAB function solves quadratic equations. Create this function in a folder on your MATLAB path.

```
function roots = quadraticSolver(a, b, c)
% quadraticSolver returns solutions to the
% quadratic equation a*x^2 + b*x + c = 0.

if ~isa(a,'numeric') || ~isa(b,'numeric') || ~isa(c,'numeric')
    error('quadraticSolver:InputMustBeNumeric', ...
        'Coefficients must be numeric.');
```

end

```
roots(1) = (-b + sqrt(b^2 - 4*a*c)) / (2*a);
roots(2) = (-b - sqrt(b^2 - 4*a*c)) / (2*a);

end
```

### Create `SolverTest` Class Definition

To use the `matlab.unittest` framework, write MATLAB functions (tests) in the form of a *test case*, a class derived from `matlab.unittest.TestCase`.

Create a subclass, `SolverTest`.

```
classdef SolverTest < matlab.unittest.TestCase

    methods (Test)

    end

end
```

The following steps show how to create specific tests. Put these tests inside the methods block with the `(Test)` attribute.

**Create Test Method for Real Solutions**

Create a test method, `testRealSolution`, to verify that `quadraticSolver` returns the right value for real solutions. For example, the equation  $x^2 - 3x + 2 = 0$  has real solutions  $x = 1$  and  $x = 2$ . This method calls `quadraticSolver` with the inputs of this equation. The solution, `expSolution`, is `[2,1]`.

Use the `matlab.unittest.TestCase` method, `verifyEqual` to compare the output of the function, `actSolution`, to the desired output, `expSolution`. If the qualification fails, the test continues execution.

```
function testRealSolution(testCase)
    actSolution = quadraticSolver(1,-3,2);
    expSolution = [2,1];
    testCase.verifyEqual(actSolution,expSolution);
end
```

Add this function inside the methods (Test) block.

**Create Test Method for Imaginary Solutions**

Create a test to verify that `quadraticSolver` returns the right value for imaginary solutions. For example, the equation  $x^2 - 2x + 10 = 0$  has imaginary solutions  $x = -1 + 3i$  and  $x = -1 - 3i$ . Add this function, `testImaginarySolution`, inside the methods (Test) block.

```
function testImaginarySolution(testCase)
    actSolution = quadraticSolver(1,2,10);
    expSolution = [-1+3i, -1-3i];
    testCase.verifyEqual(actSolution,expSolution);
end
```

The order of the tests within the block does not matter.

**Save Class Definition**

The following is the complete `SolverTest` class definition. Save this file in a folder on your MATLAB path.

```
classdef SolverTest < matlab.unittest.TestCase
```

```
% SolverTest tests solutions to the quadratic equation
% a*x^2 + b*x + c = 0

methods (Test)
    function testRealSolution(testCase)
        actSolution = quadraticSolver(1,-3,2);
        expSolution = [2,1];
        testCase.verifyEqual(actSolution,expSolution);
    end
    function testImaginarySolution(testCase)
        actSolution = quadraticSolver(1,2,10);
        expSolution = [-1+3i, -1-3i];
        testCase.verifyEqual(actSolution,expSolution);
    end
end

end
```

### Run Tests in SolverTest Test Case

Run all the tests in the SolverTest class definition file.

```
testCase = SolverTest;
res = run(testCase)
```

```
Running SolverTest
```

```
..
```

```
Done SolverTest
```

```
res =
```

```
1x2 TestResult array with properties:
```

```
    Name
```

```
    Passed
```

```
    Failed
```

```
    Incomplete
```

```
    Duration
```

```
Totals:
```

```
2 Passed, 0 Failed, 0 Incomplete.
```

```
0.029079 seconds testing time.
```

### Run Single Test Method

To run the single test, `testRealSolution`:

```
testCase = SolverTest;  
res = run(testCase, 'testRealSolution')
```

```
Running SolverTest
```

```
.
```

```
Done SolverTest
```

```
res =
```

```
  TestResult with properties:
```

```
      Name: 'SolverTest/testRealSolution'
```

```
      Passed: 1
```

```
      Failed: 0
```

```
      Incomplete: 0
```

```
      Duration: 0.0098
```

```
Totals:
```

```
  1 Passed, 0 Failed, 0 Incomplete.
```

```
  0.0097953 seconds testing time.
```

## Related Examples

- “Analyze Test Case Results” on page 29-64
- “Create Simple Test Suites” on page 29-43

## Write Setup and Teardown Code Using Classes

### In this section...

“Test Fixtures” on page 29-6

“Test Case with Method-Level Setup Code” on page 29-6

“Test Case with Class-Level Setup Code” on page 29-7

### Test Fixtures

*Test fixtures* are setup and teardown code that sets up the pretest state of the system and returns it to the original state after running the test. Setup and teardown methods are defined in the `TestCase` class by the following method attributes:

- `TestMethodSetup` and `TestMethodTeardown` methods run before and after each test method.
- `TestClassSetup` and `TestClassTeardown` methods run before and after all test methods in the test case.

It is good practice for test authors to perform all teardown activities from within the `TestMethodSetup` and `TestClassSetup` blocks using the `addTeardown` method instead of implementing corresponding teardown methods in the `TestMethodTeardown` and `TestClassTeardown` blocks. This guarantees the teardown is executed in the reverse order of the setup and also ensures that the test content is exception safe.

### Test Case with Method-Level Setup Code

The following test case, `FigurePropertiesTest`, contains setup code at the method level. The `TestMethodSetup` method creates a figure before running each test, and `TestMethodTeardown` closes the figure afterwards.

```
classdef FigurePropertiesTest < matlab.unittest.TestCase

    properties
        TestFigure
    end
```



```

methods(TestMethodSetup)
    function createFigure(testCase)
        %comment
        testCase.TestFigure = figure;
    end
end

methods(TestMethodTeardown)
    function closeFigure(testCase)
        close(testCase.TestFigure);
    end
end

methods(Test)

    function defaultCurrentPoint(testCase)

        cp = get(testCase.TestFigure, 'CurrentPoint');
        testCase.verifyEqual(cp, [0 0], ...
            'Default current point is incorrect')
    end

    function defaultCurrentObject(testCase)
        import matlab.unittest.constraints.IsEmpty;

        co = get(testCase.TestFigure, 'CurrentObject');
        testCase.verifyThat(co, IsEmpty, ...
            'Default current object should be empty');
    end

end

end

```

## Test Case with Class-Level Setup Code

The following test case, `BankAccountTest`, contains setup code at the class level.

To setup the `BankAccountTest`, which tests the `BankAccount` class example described in “Developing Classes — Typical Workflow”, add a `TestClassSetup` method, `addBankAccountClassToPath`. This method adds the path to the `BankAccount` example file.

```
classdef BankAccountTest < matlab.unittest.TestCase
    % Tests the BankAccount class.

    methods (TestClassSetup)
        function addBankAccountClassToPath(testCase)
            testCase.addTeardown(@path, addpath(fullfile(matlabroot, ...
                'help', 'techdoc', 'matlab_oop', 'examples')));
        end
    end

    methods (Test)
        function testConstructor(testCase)
            b = BankAccount(1234, 100);
            testCase.verifyEqual(b.AccountNumber, 1234, ...
                'Constructor failed to correctly set account number');
            testCase.verifyEqual(b.AccountBalance, 100, ...
                'Constructor failed to correctly set account balance');
        end

        function testConstructorNotEnoughInputs(testCase)
            import matlab.unittest.constraints.Throws;
            testCase.verifyThat(@()BankAccount, ...
                Throws('BankAccount:InvalidInitialization'));
        end

        function testDesposit(testCase)
            b = BankAccount(1234, 100);
            b.deposit(25);
            testCase.verifyEqual(b.AccountBalance, 125);
        end

        function testWithdraw(testCase)
            b = BankAccount(1234, 100);
            b.withdraw(25);
            testCase.verifyEqual(b.AccountBalance, 75);
        end
    end
end
```

```
end

function testNotifyInsufficientFunds(testCase)
    callbackExecuted = false;
    function testCallback(~,-)
        callbackExecuted = true;
    end

    b = BankAccount(1234, 100);
    b.addlistener('InsufficientFunds', @testCallback);

    b.withdraw(50);
    testCase.assertFalse(callbackExecuted, ...
        'The callback should not have executed yet');
    b.withdraw(60);
    testCase.verifyTrue(callbackExecuted, ...
        'The listener callback should have fired');
end
end
end
```

## See Also

[matlab.unittest.TestCase | addTeardown](#)

## Related Examples

- “Write Simple Test Case Using Classes” on page 29-2

## Types of Qualifications

*Qualifications* are functions for testing values and responding to failures. There are four types of qualifications:

- Verifications — Produce and record failures without throwing an exception, meaning the remaining tests run to completion.
- Assumptions — Ensure that a test runs only when certain preconditions are satisfied and the event should not produce a test failure. When an assumption failure occurs, the testing framework marks the test as filtered.
- Assertions — Ensure that the preconditions of the current test are met.
- Fatal assertions — Use this qualification when the failure at the assertion point renders the remainder of the current test method invalid or the state is unrecoverable.

Type of Test	Verification	Assumption	Assertion	Fatal Assertion
Value is true.	verifyTrue	assumeTrue	assertTrue	fatalAssertTrue
Value is false.	verifyFalse	assumeFalse	assertFalse	fatalAssertFalse
Value is equal to specified value.	verifyEqual	assumeEqual	assertEqual	fatalAssertEqual
Value is not equal to specified value.	verifyNotEqual	assumeNotEqual	assertNotEqual	fatalAssertNotEqual
Two values are handles to same instance.	verifySameHandle	assumeSameHandle	assertSameHandle	fatalAssertSameHandle
Value is not handle to specified instance.	verifyNotSameHandle	assumeNotSameHandle	assertNotSameHandle	fatalAssertNotSameHandle
Function returns true when evaluated.	verifyReturnsTrue	assumeReturnsTrue	assertReturnsTrue	fatalAssertReturnsTrue
Test produces unconditional failure.	verifyFail	assumeFail	assertFail	fatalAssertFail
Value meets given constraint.	verifyThat	assumeThat	assertThat	fatalAssertThat
Value is greater than specified value.	verifyGreaterThan	assumeGreaterThan	assertGreaterThan	fatalAssertGreaterThan
Value is greater than or equal to specified value.	verifyGreaterThanOrEqual	assumeGreaterThanOrEqual	assertGreaterThanOrEqual	fatalAssertGreaterThanOrEqual

Type of Test	Verification	Assumption	Assertion	Fatal Assertion
Value is less than specified value.	verifyLessThan	assumeLessThan	assertLessThan	fatalAssertLessThan
Value is less than or equal to specified value.	verifyLessThanOrEqual	assumeLessThanOrEqual	assertLessThanOrEqual	fatalAssertLessThanOrEqual
Value is exact specified class.	verifyClass	assumeClass	assertClass	fatalAssertClass
Value is object of specified type.	verifyInstanceOf	assumeInstanceOf	assertInstanceOf	fatalAssertInstanceOf
Value is empty.	verifyEmpty	assumeEmpty	assertEmpty	fatalAssertEmpty
Value is not empty.	verifyNotEmpty	assumeNotEmpty	assertNotEmpty	fatalAssertNotEmpty
Value has specified size.	verifySize	assumeSize	assertSize	fatalAssertSize
Value has specified length.	verifyLength	assumeLength	assertLength	fatalAssertLength
Value has specified element count.	verifyNumElements	assumeNumElements	assertNumElements	fatalAssertNumElements
String contains specified string.	verifySubstring	assumeSubstring	assertSubstring	fatalAssertSubstring
String matches specified regular expression.	verifyMatches	assumeMatches	assertMatches	fatalAssertMatches
Function throws specified exception.	verifyError	assumeError	assertError	fatalAssertError
Function issues specified warning.	verifyWarning	assumeWarning	assertWarning	fatalAssertWarning
Function issues no warnings.	verifyWarningFree	assumeWarningFree	assertWarningFree	fatalAssertWarningFree

**See Also**

Assumable | Assertable | FatalAssertable | Verifiable |  
matlab.unittest.qualifications

## Write Tests Using Shared Fixtures

This example shows how to use shared fixtures when creating tests. You can share test fixtures across test classes using the `SharedTestFixtures` attribute of the `TestCase` class. To exemplify this attribute, create multiple test classes in a subdirectory of your current working folder. The test methods are shown only at a high level.

The two test classes used in this example test the `DocPolynom` class and the `BankAccount` class. You can access both classes in MATLAB, but you must add them to the MATLAB path. A path fixture adds the directory to the current path, runs the tests, and removes the directory from the path. Since both classes require the same addition to the path, the tests use a shared fixture.

### Create a Test for the `DocPolynom` Class

Create a test file for the `DocPolynom` class. Create the shared fixture by specifying the `SharedTestFixtures` attribute for the `TestCase` and passing in a `PathFixture`.

### `DocPolynomTest` Class Definition File

```
classdef (SharedTestFixtures={matlab.unittest.fixtures.PathFixture( ...
    fullfile(matlabroot, 'help', 'techdoc', 'matlab_oop', 'examples')})
    DocPolynomTest < matlab.unittest.TestCase
    % Tests the DocPolynom class.

    properties
        msgEqn = 'Equation under test: ';
    end

    methods (Test)
        function testConstructor(testCase)
            p = DocPolynom([1, 0, 1]);
            testCase.verifyClass(p, ?DocPolynom);
        end

        function testAddition(testCase)
            p1 = DocPolynom([1, 0, 1]);
            p2 = DocPolynom([5, 2]);
```

```

        actual = p1 + p2;
        expected = DocPolynom([1, 5, 3]);

        msg = [testCase.msgEqn,...
              '(x^2 + 1) + (5*x + 2) = x^2 + 5*x + 3'];
        testCase.verifyEqual(actual, expected, msg);
    end

function testMultiplication(testCase)
    p1 = DocPolynom([1, 0, 3]);
    p2 = DocPolynom([5, 2]);

    actual = p1 * p2;
    expected = DocPolynom([5, 2, 15, 6]);

    msg = [testCase.msgEqn,...
          '(x^2 + 3) * (5*x + 2) = 5*x^3 + 2*x^2 + 15*x + 6'];
    testCase.verifyEqual(actual, expected, msg);
end

end
end

```

### Create a Test for the BankAccount Class

Create a test file for the BankAccount class. Create the shared fixture by specifying the SharedTestFixtures attribute for the TestCase and passing in a PathFixture.

### BankAccountTest Class Definition File

```

classdef (SharedTestFixtures={matlab.unittest.fixtures.PathFixture( ...
    fullfile(matlabroot, 'help', 'techdoc', 'matlab_oop', ...
    'examples'))}) BankAccountTest < matlab.unittest.TestCase
    % Tests the BankAccount class.

    methods (Test)
        function testConstructor(testCase)
            b = BankAccount(1234, 100);

```

```
        testCase.verifyEqual(b.AccountNumber, 1234, ...
            'Constructor failed to correctly set account number');
        testCase.verifyEqual(b.AccountBalance, 100, ...
            'Constructor failed to correctly set account balance');
    end

function testConstructorNotEnoughInputs(testCase)
    import matlab.unittest.constraints.Throws;
    testCase.verifyThat(@()BankAccount, ...
        Throws('BankAccount:InvalidInitialization'));
end

function testDesposit(testCase)
    b = BankAccount(1234, 100);
    b.deposit(25);
    testCase.verifyEqual(b.AccountBalance, 125);
end

function testWithdraw(testCase)
    b = BankAccount(1234, 100);
    b.withdraw(25);
    testCase.verifyEqual(b.AccountBalance, 75);
end

function testNotifyInsufficientFunds(testCase)
    callbackExecuted = false;
    function testCallback(~,-)
        callbackExecuted = true;
    end

    b = BankAccount(1234, 100);
    b.addlistener('InsufficientFunds', @testCallback);

    b.withdraw(50);
    testCase.assertFalse(callbackExecuted, ...
        'The callback should not have executed yet');
    b.withdraw(60);
    testCase.verifyTrue(callbackExecuted, ...
        'The listener callback should have fired');
end
```



```

        end
    end
end

```

### Build the Test Suite

The classes `DocPolynomTest.m` and `BankAccountTest.m` are in your working directory. Create a test suite from your current working directory. If you have additional tests, they are included in the suite when you use the `TestSuite.fromFolder` method. Create the test suite at the command prompt.

```

import matlab.unittest.TestSuite;
suiteFolder = TestSuite.fromFolder(pwd);

```

### Run the Tests

At the command prompt, run the tests in the test suite.

```

result = run(suiteFolder);

```

```

Setting up PathFixture.

```

```

Description: Adds 'C:\Program Files\MATLAB\R2013b\help\techdoc\matlab_oo\

```

```

Running BankAccountTest

```

```

.....

```

```

Done BankAccountTest

```

```

Running DocPolynomTest

```

```

...

```

```

Done DocPolynomTest

```

```

Tearing down PathFixture.

```

```

Description: Restores the path to its previous state.

```

The test framework sets up the test fixture, runs all the tests in each file, and then tears the fixture down. If the path fixture was set up and torn

down using `TestClassSetup` methods, the fixture is set up and torn down twice—once for each test file.

### **See Also**

`TestCase` | `matlab.unittest.fixtures` | `PathFixture`

## Create Basic Custom Fixture

This example shows how to create a basic custom fixture that changes the display format to hexadecimal representation. The example also shows to use the fixture to test a function that displays a column of numbers as text. After the testing completes, the framework restores the display format to its pretest state.

### Create FormatHexFixture Class Definition

In a file in your working folder, create a new class, `FormatHexFixture` that inherits from the `matlab.unittest.fixtures.Fixture` class. Since we want the fixture to restore the pretest state of the MATLAB display format, create an `OriginalFormat` property to keep track of the original display format.

```
classdef FormatHexFixture < matlab.unittest.fixtures.Fixture
    properties (Access=private)
        OriginalFormat;
    end
```

### Implement Setup and Teardown Methods

Subclasses of the `Fixture` class must implement the `setup` method. Use this method to record the pretest display format, and set the format to `'hex'`. Use the `teardown` method to restore the original display format. Define the `setup` and `teardown` methods in the `methods` block of the `FormatHexFixture.m` file.

```
    methods
        function setup(fixture)
            fixture.OriginalFormat = get(0, 'Format');
            set(0, 'Format', 'hex');
        end
        function teardown(fixture)
            set(0, 'Format', fixture.OriginalFormat);
        end
    end
end
```

### Apply Custom Fixture

In a file in your working folder, create the following test class, `SampleTest.m`.

```
classdef SampleTest < matlab.unittest.TestCase
    methods (Test)
        function test1(testCase)
            testCase.applyFixture(FormatHexFixture);
            actStr = getColumnForDisplay([1;2;3], 'Small Integers');
            expStr = ['Small Integers '
                    '3ff0000000000000'
                    '4000000000000000'
                    '4008000000000000'];
            testCase.verifyEqual(actStr, expStr);
        end
    end
end

function str = getColumnForDisplay(values, title)
    elements = cell(numel(values)+1, 1);
    elements{1} = title;
    for idx = 1:numel(values)
        elements{idx+1} = displayNumber(values(idx));
    end
    str = char(elements);
end

function str = displayNumber(n)
    str = strtrim(evalc('disp(n);'));
end
```

This test applies the custom fixture and verifies that the displayed column of hexadecimal representation is as expected.

At the command prompt, run the test.

```
run(SampleTest);
```

```
Running SampleTest
.
Done SampleTest
```

---

**See Also** `matlab.unittest.fixtures.Fixture`

**Related  
Examples**

- “Create Advanced Custom Fixture” on page 29-20
- “Write Tests Using Shared Fixtures” on page 29-12

## Create Advanced Custom Fixture

This example shows how to create a custom fixture that sets an environment variable. Prior to testing, this fixture will save the current `UserName` variable.

### Create `UserNameEnvironmentVariableFixture` Class Definition

In a file in your working folder, create a new class, `UserNameEnvironmentVariableFixture` that inherits from the `matlab.unittest.fixtures.Fixture` class. Since you want to pass the fixture a user name, create a `UserName` property to pass the data between methods.

```
classdef UserNameEnvironmentVariableFixture < ...
    matlab.unittest.fixtures.Fixture

    properties (SetAccess=private)
        UserName
    end
```

### Define Fixture Constructor

In the methods block of the `UserNameEnvironmentVariableFixture.m` file, create a constructor method that validates the input and defines the `SetupDescription`. Have the constructor accept a string and set the fixture's `UserName` property.

```
methods
    function fixture = UserNameEnvironmentVariableFixture(name)
        validateattributes(name, {'char'}, {'row'}, '', 'UserName');
        fixture.UserName = name;
        fixture.SetupDescription = sprintf( ...
            'Set the UserName environment variable to "%s".', ...
            fixture.UserName);
    end
```

### Implement `setup` Method

Subclasses of the `Fixture` class must implement the `setup` method. Use this method to save the original `UserName` variable. This method also defines

the `TeardownDescription` and registers the teardown task of setting the `UserName` to the original state after testing.

Define the `setup` method within the `methods` block of the `UserNameEnvironmentVariableFixture.m` file.

```
function setup(fixture)
    originalUserName = getenv('UserName');
    fixture.assertNotEmpty(originalUserName, ...
        'An existing UserName environment variable must be defined.');
```

```
    fixture.addTeardown(@setenv, 'UserName', originalUserName);
    fixture.TearDownDescription = sprintf(...
        'Restored the UserName environment variable to "%s".',...
        originalUserName);
    setenv('UserName', fixture.UserName);
end
end
```

### Implement `isCompatible` Method

Classes that derive from `Fixture` must implement the `isCompatible` method if the constructor is configurable. Since you can configure the `UserName` property through the constructor, `UserNameEnvironmentVariableFixture` must implement `isCompatible`.

The `isCompatible` method is called with two instances of the same class. In this case, it is called with two instances of `UserNameEnvironmentVariableFixture`. The testing framework considers the two instances compatible if their `UserName` properties are equal.

In a new `methods` block within `UserNameEnvironmentVariableFixture.m`, define an `isCompatible` method which returns logical 1 (true) or logical 0 (false).

```
methods (Access=protected)
    function bool = isCompatible(fixture, other)
        bool = strcmp(fixture.UserName, other.UserName);
    end
end
```

### Fixture Class Definition Summary

Below are the complete contents of `UserNameEnvironmentVariableFixture.m`.

```
classdef UserNameEnvironmentVariableFixture < ...
    matlab.unittest.fixtures.Fixture

    properties (SetAccess=private)
        UserName
    end

    methods
        function fixture = UserNameEnvironmentVariableFixture(name)
            validateattributes(name, {'char'}, {'row'}, '', 'UserName');
            fixture.UserName = name;
            fixture.SetupDescription = sprintf( ...
                'Set the UserName environment variable to "%s".', ...
                fixture.UserName);
        end

        function setup(fixture)
            originalUserName = getenv('UserName');
            fixture.assertNotEmpty(originalUserName, ...
                'An existing UserName environment variable must be defined.');
```

```
            fixture.addTeardown(@setenv, 'UserName', originalUserName);
            fixture.TeardownDescription = sprintf(...
                'Restored the UserName environment variable to "%s".', ...
                originalUserName);
            setenv('UserName', fixture.UserName);
        end
    end

    methods (Access=protected)
        function bool = isCompatible(fixture, other)
            bool = strcmp(fixture.UserName, other.UserName);
        end
    end
end
```

### **Apply Custom Fixture to Single Test Class**

In a file in your working folder, create the following test class, `ExampleTest.m`.



```

classdef ExampleTest < matlab.unittest.TestCase
    methods(TestMethodSetup)
        function mySetup(testCase)
            testCase.applyFixture(...
                UserNameEnvironmentVariableFixture('David'));
        end
    end

    methods (Test)
        function t1(~)
            fprintf(1, 'Current UserName: "%s"', getenv('UserName'));
        end
    end
end

```

This test uses the `UserNameEnvironmentVariableFixture` for each test in the `ExampleTest` class.

At the command prompt, run the test.

```

run(ExampleTest);

Running ExampleTest
Current UserName: "David".
Done ExampleTest

```

### Apply Custom Fixture as Shared Fixture

In your working folder, create three test classes using a shared fixture. Using a shared fixture allows the `UserNameEnvironmentVariableFixture` to be shared across classes.

Create `testA.m` as follows.

```

classdef (SharedTestFixtures={...
    UserNameEnvironmentVariableFixture('David')}) ...
    testA < matlab.unittest.TestCase
    methods (Test)
        function t1(~)
            fprintf(1, 'Current UserName: "%s"', getenv('UserName'));
        end
    end
end

```

```
        end
    end
end
```

Create testB.m as follows.

```
classdef (SharedTestFixtures={...
    UserNameEnvironmentVariableFixture('Andy')}}) ...
    testB < matlab.unittest.TestCase
    methods (Test)
        function t1(~)
            fprintf(1, 'Current UserName: "%s"', getenv('UserName'));
        end
    end
end
```

Create testC.m as follows.

```
classdef (SharedTestFixtures={...
    UserNameEnvironmentVariableFixture('Andy')}}) ...
    testC < matlab.unittest.TestCase
    methods (Test)
        function t1(~)
            fprintf(1, 'Current UserName: "%s"', getenv('UserName'));
        end
    end
end
```

At the command prompt, run the tests.

```
runtests({'testA','testB','testC'});
```

```
Setting up UserNameEnvironmentVariableFixture
```

```
Done setting up UserNameEnvironmentVariableFixture: Set the UserName enviro
```

```
Running testA
```

```
Current UserName: "David".
```

```
Done testA
```

```
Tearing down UserNameEnvironmentVariableFixture
Done tearing down UserNameEnvironmentVariableFixture: Restored the UserName
```

---

```
Setting up UserNameEnvironmentVariableFixture
Done setting up UserNameEnvironmentVariableFixture: Set the UserName enviro
```

---

```
Running testB
Current UserName: "Andy".
Done testB
```

---

```
Running testC
Current UserName: "Andy".
Done testC
```

---

```
Tearing down UserNameEnvironmentVariableFixture
Done tearing down UserNameEnvironmentVariableFixture: Restored the UserName
```

---

Recall that the fixtures are compatible if their `UserName` properties match. The tests in `testA` and `testB` use incompatible shared fixtures, since `'David'` is not equal to `'Andy'`. Therefore, the framework invokes the fixture `teardown` and `setup` methods between calls to `testA` and `testB`. However, the shared test fixture in `testC` is compatible with the fixture in `testB`, so the framework doesn't repeat fixture `teardown` and `setup` before `testC`.

### **Alternative Approach to Calling `addTeardown` in `setup` Method**

An alternate approach to using the `addTeardown` method within the `setup` method is to implement a separate `teardown` method. Instead of the `setup` method described above, implement the following `setup` and `teardown` methods within `UserNameEnvironmentVariableFixture.m`.

### **Alternate `UserNameEnvironmentVariableFixture` Class Definition**

```
classdef UserNameEnvironmentVariableFixture < ...
    matlab.unittest.fixtures.Fixture
```

```
properties (Access=private)
    OriginalUser
end
properties (SetAccess=private)
    UserName
end

methods
    function fixture = UserNameEnvironmentVariableFixture(name)
        validateattributes(name, {'char'}, {'row'}, '', 'UserName');
        fixture.UserName = name;
        fixture.SetupDescription = sprintf( ...
            'Set the UserName environment variable to "%s".', ...
            fixture.UserName);
    end

    function setup(fixture)
        fixture.OriginalUser = getenv('UserName');
        fixture.assertNotEmpty(fixture.OriginalUser, ...
            'An existing UserName environment variable must be defined.');
```

```
        setenv('UserName', fixture.UserName);
    end

    function teardown(fixture)
        fixture.TearDownDescription = sprintf(...
            'Restored the UserName environment variable to "%s".', ...
            fixture.OriginalUser);
        setenv('UserName', fixture.OriginalUser);
    end
end

methods (Access=protected)
    function bool = isCompatible(fixture, other)
        bool = strcmp(fixture.UserName, other.UserName);
    end
end
end
```

The `setup` method does not contain a call to `addTeardown` or a definition for `TeardownDescription`. These tasks are relegated to the `teardown` method. The alternative class definition contains an additional property, `OriginalUser`, which allows the information to be passed between methods.

**See Also** `matlab.unittest.fixtures.Fixture`

**Related  
Examples**

- “Create Basic Custom Fixture” on page 29-17
- “Write Tests Using Shared Fixtures” on page 29-12

## Create Basic Parameterized Test

This example shows how to create a basic parameterized test.

### Create Function to Test

In a file in your working folder, create a function in the file `sierpinski.m`. This function returns a matrix representing an image of a Sierpinski carpet fractal. It takes as input the fractal level and an optional data type.

```
function carpet = sierpinski(nLevels,classname)
if nargin == 1
    classname = 'single';
end

mSize = 3^nLevels;
carpet = ones(mSize,classname);

cutCarpet(1,1,mSize,nLevels); % begin recursion

function cutCarpet(x,y,s,cL)
    if cL
        ss = s/3; % define subsize
        for lx = 0:2
            for ly = 0:2
                if lx == 1 && ly == 1
                    % remove center square
                    carpet(x+ss:x+2*ss-1,y+ss:y+2*ss-1) = 0;
                else
                    % recurse
                    cutCarpet(x + lx*ss, y + ly*ss, ss, cL-1);
                end
            end
        end
    end
end
end
end
end
```

### Create TestCarpet Test Class

In a file in your working folder, create a new class, `TestCarpet`, to test the `sierpinski` function.

```
classdef TestCarpet < matlab.unittest.TestCase
```

### Define properties Block

Define the properties used for parameterized testing. In the `TestCarpet` class, define these properties in a property block with the `TestParameter` attribute.

```
properties (TestParameter)
    type = {'single','double','uint16'};
    level = struct('small', 2,'medium', 4, 'large', 6);
    side = struct('small', 9, 'medium', 81,'large', 729);
end
```

The `type` property contains the different data types you want to test. The `level` property contains the different fractal level you want to test. The `side` property contains the number of rows and columns in the Sierpinski carpet matrix and corresponds to the `level` property. To provide meaningful names for each parameterization value, `level` and `side` are defined as structs.

### Define Test methods Block

Define the following test methods in the `TestCarpet` class.

```
methods (Test)
    function testRemainPixels(testCase, level)
        % expected number pixels equal to 1
        expPixelCount = 8^level;
        % actual number pixels equal to 1
        actPixels = find(sierpinski(level));
        testCase.verifyNumElements(actPixels,expPixelCount);
    end

    function testClass(testCase, type, level)
        testCase.verifyClass(...
            sierpinski(level,type), type);
    end

    function testDefaultL1Output(testCase)
```

```
        exp = single([1 1 1; 1 0 1; 1 1 1]);
        testCase.verifyEqual(sierpinski(1), exp);
    end

end
```

The `testRemainPixes` method tests the output of the `sierpinski` function by verifying that the number of nonzero pixels is the same as expected for a particular level. This method uses the `level` property and, therefore, results in three test elements—one for each value in `level`. The `testClass` method tests the class of the output from the `sierpinski` function with each combination of the `type` and `level` properties. This approach results in nine test elements. The `testDefaultL1Output` test method does not use a `TestParameter` property and, therefore, is not parameterized. This test method verifies that the level 1 matrix contains the expected values. Since the test method is not parameterized, it results in a one test element.

In the test methods above, you did not define the `ParameterCombination` attribute of the `Test` methods block. This attribute is, by default, `'exhaustive'`. The test framework invokes a given test method once for every combination of the test parameters.

### **Define Test methods Block with ParameterCombination Attribute**

Define the following test methods in the `TestCarpet` class to ensure that the matrix output by the `sierpinski` function has the correct number of elements. Set the `ParameterCombination` attribute to `'sequential'`.

```
    methods (Test, ParameterCombination='sequential')
        function testNumel(testCase, level, side)
            import matlab.unittest.constraints.HasElementCount;
            testCase.verifyThat(sierpinski(level),...
                HasElementCount(side^2));
        end
    end
end
```

Test methods with the `ParameterCombination` attribute set to `'sequential'` are invoked once for each corresponding value of the parameter. The properties, `level` and `side`, must have the same number of values. Since



these properties each have three values, the `testNumel` method is invoked three times.

### **TestCarpet Class Definition Summary**

The complete contents of `TestCarpet.m` follows.

```
classdef TestCarpet < matlab.unittest.TestCase

    properties (TestParameter)
        type = {'single','double','uint16'};
        level = struct('small', 2,'medium', 4, 'large', 6);
        side = struct('small', 9, 'medium', 81,'large', 729);
    end

    methods (Test)
        function testRemainPixels(testCase, level)
            % expected number pixels equal to 1
            expPixelCount = 8^level;
            % actual number pixels equal to 1
            actPixels = find(sierpinski(level));
            testCase.verifyNumElements(actPixels,expPixelCount);
        end

        function testClass(testCase, type, level)
            testCase.verifyClass(...
                sierpinski(level,type), type);
        end

        function testDefaultL1Output(testCase)
            exp = single([1 1 1; 1 0 1; 1 1 1]);
            testCase.verifyEqual(sierpinski(1), exp);
        end
    end

    methods (Test, ParameterCombination='sequential')
        function testNumel(testCase, level, side)
            import matlab.unittest.constraints.HasElementCount;
            testCase.verifyThat(sierpinski(level),...
                HasElementCount(side^2));
        end
    end
end
```

```
        end
    end
end
```

### Run All Tests

At the command prompt, create a suite from `TestCarpet.m`.

```
suite = matlab.unittest.TestSuite.fromFile('TestCarpet.m');
{suite.Name}'
```

```
ans =
```

```
'TestCarpet/testNumel(level=small,side=small) '
'TestCarpet/testNumel(level=medium,side=medium) '
'TestCarpet/testNumel(level=large,side=large) '
'TestCarpet/testRemainPixels(level=small) '
'TestCarpet/testRemainPixels(level=medium) '
'TestCarpet/testRemainPixels(level=large) '
'TestCarpet/testClass(type=single,level=small) '
'TestCarpet/testClass(type=single,level=medium) '
'TestCarpet/testClass(type=single,level=large) '
'TestCarpet/testClass(type=double,level=small) '
'TestCarpet/testClass(type=double,level=medium) '
'TestCarpet/testClass(type=double,level=large) '
'TestCarpet/testClass(type=uint16,level=small) '
'TestCarpet/testClass(type=uint16,level=medium) '
'TestCarpet/testClass(type=uint16,level=large) '
'TestCarpet/testDefaultL1Output '
```

The suite had 16 test elements. The element's `Name` indicates any parameterization.

```
suite.run;
```

```
Running TestCarpet
.....
.....
Done TestCarpet
```

---

**Run Tests with level Parameter Property Named small**

Use the `selectIf` method of the `TestSuite` to select test elements that use a particular parameterization. Select all test elements that use the parameter name `small` in the `level` parameter property list.

```
s1 = suite.selectIf('ParameterName', 'small');
{s1.Name}'

ans =

    'TestCarpet/testNumel(level=small,side=small) '
    'TestCarpet/testRemainPixels(level=small) '
    'TestCarpet/testClass(type=single,level=small) '
    'TestCarpet/testClass(type=double,level=small) '
    'TestCarpet/testClass(type=uint16,level=small) '
```

The suite has five elements.

```
s1.run;

Running TestCarpet
.....
Done TestCarpet
```

Alternatively, create the same test suite directly from the `fromFile` method of `TestSuite`.

```
import matlab.unittest.selectors.HasParameter;
s1 = matlab.unittest.TestSuite.fromFile('TestCarpet.m',...
    HasParameter('Name', 'small'));
```

**See Also**

`matlab.unittest.TestSuite.selectIf` | `matlab.unittest.TestCase` | `matlab.unittest.selectors.HasParameter`

**Related Examples**

- “Create Advanced Parameterized Test” on page 29-34

## Create Advanced Parameterized Test

This example shows how to create a test that is parameterized in the `TestClassSetup`, `TestMethodSetup`, and `Test` methods blocks. The example test class tests the random number generator.

### Test Overview

The `TestRand` test class is parameterized at three different levels.

Parameterization Level	Method Attribute	Property Attribute
Test level	<code>Test</code>	<code>Test</code>
Method setup level	<code>TestMethodSetup</code>	<code>MethodSetupParameter</code>
Class setup level	<code>TestClassSetup</code>	<code>ClassSetupParameter</code>

At each test level, you can use the `ParameterCombination` method attribute to specify the test parameterization.

ParameterCombination Attribute	Method Invocation
'exhaustive' (default)	Methods are invoked for all combinations of parameters. The test framework uses this default combination if you do not specify the <code>ParameterCombination</code> attribute.
'sequential'	Methods are invoked with corresponding values from each parameter. Each parameter must contain the same number of values.
'pairwise'	Methods are invoked for every pair of parameter values at least once. While the test framework guarantees that tests are created for every pair of values at least once, you should not rely on that size, ordering, or specific set of test suite elements.

For example, use the combined methods attribute `TestMethodSetup`, `ParameterCombination='sequential'` to specify sequential combination of the method setup-level parameters defined in the `MethodSetupParameter` properties block.

For this example, class setup-level parameterization defines the type of random number generator. The method setup-level parameterization defines the seed for the random number generator, and the test-level parameterization defines the data type and size of the random number output.

### Create TestRand Test Class

In a file in your working folder, create a class that inherits from `matlab.unittest.TestCase`. This class tests various aspects of random number generation.

```
classdef TestRand < matlab.unittest.TestCase
```

### Define properties Blocks

Define the properties used for parameterized testing. Each properties block corresponds to parameterization at a particular level.

```
    properties (ClassSetupParameter)
        generator = {'twister','combRecursive','multFibonacci'};
    end

    properties (MethodSetupParameter)
        seed = {0, 123, 4294967295};
    end

    properties (TestParameter)
        dim1 = struct('small', 1,'medium', 2, 'large', 3);
        dim2 = struct('small', 2,'medium', 3, 'large', 4);
        dim3 = struct('small', 3,'medium', 4, 'large', 5);
        type = {'single','double'};
    end
```

### Define Test Class and Test Method Setup Methods

Define the setup methods at the test class and test method level. These methods register the initial random number generator state. After the framework runs the tests, the methods restore the original state. The `ClassSetup` method defines the type of random number generator, and the `TestMethodSetup` seeds the generator.

```
methods (TestClassSetup)
    function ClassSetup(testCase, generator)
        orig = rng;
        testCase.addTeardown(@rng, orig);
        rng(0, generator);
    end
end

methods (TestMethodSetup)
    function MethodSetup(testCase, seed)
        orig = rng;
        testCase.addTeardown(@rng, orig);
        rng(seed);
    end
end
```

### Define Sequential Parameterized Test Methods

Define a methods block with the `Test` and `ParameterCombination='sequential'` attributes. The test framework invokes these methods once for each corresponding property value.

```
methods (Test, ParameterCombination='sequential')
    function testSize(testCase,dim1,dim2,dim3)
        testCase.verifySize(rand(dim1,dim2,dim3),[dim1 dim2 dim3]);
    end
end
```

The method tests the size of the output for each corresponding parameter in `dim1`, `dim2`, and `dim3`. For example, to test all the 'medium' values use: `testCase.verifySize(rand(2,3,4),[2 3 4]);`. For a given `TestClassSetup` and `TestMethodSetup` parameterization, the framework calls the `testSize` method three times—once each for the 'small', 'medium', and 'large' values.

### Define Pairwise Parameterized Test Methods

Define a methods block with the `Test` and `ParameterCombination='pairwise'` attributes. The test framework invokes these methods at least once for every pair of property values.

```

methods (Test, ParameterCombination='pairwise')
  function testRepeatable(testCase,dim1,dim2,dim3)
    state = rng;
    firstRun = rand(dim1,dim2,dim3);
    rng(state);
    secondRun = rand(dim1,dim2,dim3);
    testCase.verifyEqual(firstRun,secondRun);
  end
end

```

The test method verifies that the random number generator results are repeatable. For a given `TestClassSetup` and `TestMethodSetup` parameterization, the framework calls the `testRepeatable` method 10 times to ensure testing of each pair of `dim1`, `dim2`, and `dim3`. However, if the parameter combination attribute is exhaustive, the framework calls the method  $3^3=27$  times.

### Define Exhaustive Parameterized Test Methods

Define a methods block with the `Test` attribute or no defined parameter combination. The parameter combination is exhaustive by default. The test framework invokes these methods once for every combination of property values.

```

methods (Test)
  function testClass(testCase,dim1,dim2,type)
    testCase.verifyClass(rand(dim1,dim2,type), type);
  end
end

```

The test method verifies that the class of the output from `rand` is the same as the expected class. For a given `TestClassSetup` and `TestMethodSetup` parameterization, the framework calls the `testClass` method  $3*3*2=18$  times to ensure testing of each combination of `dim1`, `dim2`, and `type`.

**TestRand Class Definition Summary**

```
classdef TestRand < matlab.unittest.TestCase
    properties (ClassSetupParameter)
        generator = {'twister','combRecursive','multFibonacci'};
    end

    properties (MethodSetupParameter)
        seed = {0, 123, 4294967295};
    end

    properties (TestParameter)
        dim1 = struct('small', 1, 'medium', 2, 'large', 3);
        dim2 = struct('small', 2, 'medium', 3, 'large', 4);
        dim3 = struct('small', 3, 'medium', 4, 'large', 5);
        type = {'single', 'double'};
    end

    methods (TestClassSetup)
        function ClassSetup(testCase, generator)
            orig = rng;
            testCase.addTeardown(@rng, orig);
            rng(0, generator);
        end
    end

    methods (TestMethodSetup)
        function MethodSetup(testCase, seed)
            orig = rng;
            testCase.addTeardown(@rng, orig);
            rng(seed);
        end
    end

    methods (Test, ParameterCombination='sequential')
        function testSize(testCase, dim1, dim2, dim3)
            testCase.verifySize(rand(dim1, dim2, dim3), [dim1 dim2 dim3]);
        end
    end
end
```



```

    methods (Test, ParameterCombination='pairwise')
        function testRepeatable(testCase,dim1,dim2,dim3)
            state = rng;
            firstRun = rand(dim1,dim2,dim3);
            rng(state);
            secondRun = rand(dim1,dim2,dim3);
            testCase.verifyEqual(firstRun,secondRun);
        end
    end

    methods (Test)
        function testClass(testCase,dim1,dim2,type)
            testCase.verifyClass(rand(dim1,dim2,type), type);
        end
    end
end

```

### Create Suite from All Tests

At the command prompt, create a suite from `TestRand.m` class.

```
suite = matlab.unittest.TestSuite.fromClass(?TestRand)
```

```
suite =
```

```
1x279 Test array with properties:
```

```

    Name
    Parameterization
    SharedTestFixtures

```

The test suite contains 279 test elements. For a given `TestClassSetup` and `TestMethodSetup` parameterization, the framework creates  $3+10+18=31$  test elements. These 31 elements are called three times—once for each `TestMethodSetup` parameterization resulting in  $3*31=93$  test elements for each `TestClassSetup` parameterization. There are three `TestClassSetup` parameterizations resulting in a total of  $3*93=279$  test elements.

Examine the names of the first test element.

```
suite(1).Name
```

```
ans =
```

```
TestRand[generator=twister]/[seed=value1]testClass(dim1=small,dim2=small,type=
```

The name of each element is constructed from the combination of the following:

- Test class: `TestRand`
- Class setup property and property name: `[generator=twister]`
- Method setup property and property name: `[seed=value1]`
- Test method name: `testClass`
- Test method properties and property names:  
`(dim1=small,dim2=small,type=single)`

The name for the `seed` property isn't particularly meaningful (`value1`). The testing framework provided this name because the `seed` property values are numbers. For a more meaningful name, define the `seed` property as a struct with more descriptive field names.

### Run Suite from Class Using Selector

At the command prompt, create a selector to select test elements that test the 'twister' generator for 'single' precision. Omit test elements that use properties with the 'large' name.

```
import matlab.unittest.selectors.HasParameter
s = HasParameter('Property','generator', 'Name','twister') & ...
    HasParameter('Property','type', 'Name','single') & ...
    ~HasParameter('Name','large');
```

```
suite2 = matlab.unittest.TestSuite.fromClass(?TestRand,s)
```

```
suite2 =
```

```
1x12 Test array with properties:
```

```
Name
Parameterization
SharedTestFixtures
```

If you first generate the full suite, construct the same test suite as above using the `selectIf` method.

```
suite = matlab.unittest.TestSuite.fromClass(?TestRand);
suite2 = selectIf(suite,s);
```

Run the test suite.

```
suite2.run;
```

```
Running TestRand
```

```
.....
```

```
..
```

```
Done TestRand
```

### Run Suite from Method Using Selector

At the command prompt, create a selector that omits test elements that use properties with the 'large' or 'medium' name. Limit results to test elements from the `testRepeatable` method.

```
import matlab.unittest.selectors.HasParameter
s = ~(HasParameter('Name','large') | HasParameter('Name','medium'));

suite3 = matlab.unittest.TestSuite.fromMethod(?TestRand,'testRepeatable',s);
{suite3.Name}'
```

```
ans =
```

```
'TestRand[generator=twister]/[seed=value1]testRepeatable(dim1=small,dim2=small,dim3=small)'
'TestRand[generator=twister]/[seed=value2]testRepeatable(dim1=small,dim2=small,dim3=small)'
'TestRand[generator=twister]/[seed=value3]testRepeatable(dim1=small,dim2=small,dim3=small)'
'TestRand[generator=combRecursive]/[seed=value1]testRepeatable(dim1=small,dim2=small,dim3=sm
'TestRand[generator=combRecursive]/[seed=value2]testRepeatable(dim1=small,dim2=small,dim3=sm
'TestRand[generator=combRecursive]/[seed=value3]testRepeatable(dim1=small,dim2=small,dim3=sm
'TestRand[generator=multFibonacci]/[seed=value1]testRepeatable(dim1=small,dim2=small,dim3=sm
'TestRand[generator=multFibonacci]/[seed=value2]testRepeatable(dim1=small,dim2=small,dim3=sm
'TestRand[generator=multFibonacci]/[seed=value3]testRepeatable(dim1=small,dim2=small,dim3=sm
```

Run the test suite.



## Create Simple Test Suites

This example shows how to combine tests into test suites, using the `SolverTest` test case. Use the static `from*` methods in the `matlab.unittest.TestSuite` class to create suites for combinations of your tests, whether they are organized in packages and classes or files and folders, or both.

### Create Quadratic Solver Function

Create the following function that solves roots of the quadratic equation in a file, `quadraticSolver.m`, in your working folder.

```
function roots = quadraticSolver(a, b, c)
% quadraticSolver returns solutions to the
% quadratic equation a*x^2 + b*x + c = 0.

if ~isa(a,'numeric') || ~isa(b,'numeric') || ~isa(c,'numeric')
    error('quadraticSolver:InputMustBeNumeric', ...
        'Coefficients must be numeric.');
```

end

```
roots(1) = (-b + sqrt(b^2 - 4*a*c)) / (2*a);
roots(2) = (-b - sqrt(b^2 - 4*a*c)) / (2*a);

end
```

### Create Test for Quadratic Solver Function

Create the following test class in a file, `SolverTest.m`, in your working folder.

```
classdef SolverTest < matlab.unittest.TestCase
% SolverTest tests solutions to the quadratic equation
% a*x^2 + b*x + c = 0

methods (Test)
    function testRealSolution(testCase)
        actSolution = quadraticSolver(1,-3,2);
        expSolution = [2,1];
        testCase.verifyEqual(actSolution,expSolution);
    end
end
```

```
        end
        function testImaginarySolution(testCase)
            actSolution = quadraticSolver(1,2,10);
            expSolution = [-1+3i, -1-3i];
            testCase.verifyEqual(actSolution,expSolution);
        end
    end
end
```

end

### **Import TestSuite Class**

At the command prompt, add the `matlab.unittest.TestSuite` class to the current import list.

```
import matlab.unittest.TestSuite;
```

Make sure the `SolverTest` class definition file is on your MATLAB path.

### **Create Suite from SolverTest Class**

The `fromClass` method creates a suite from all `Test` methods in the `SolverTest` class.

```
suiteClass = TestSuite.fromClass(?SolverTest);
result = run(suiteClass);
```

### **Create Suite from SolverTest Class Definition File**

The `fromFile` method creates a suite using the name of the file to identify the class.

```
suiteFile = TestSuite.fromFile('SolverTest.m');
result = run(suiteFile);
```

### **Create Suite from All Test Case Files in Current Folder**

The `fromFolder` method creates a suite from all test case files in the specified folder. For example, the following files are in the current folder:

- `BankAccountTest.m`

- DocPolynomTest.m
- FigurePropertiesTest.m
- IsSupportedTest.m
- SolverTest.m

```
suiteFolder = TestSuite.fromFolder(pwd);  
result = run(suiteFolder);
```

### **Create Suite from Single Test Method**

The fromMethod method creates a suite from a single test method.

```
suiteMethod = TestSuite.fromMethod(?SolverTest, 'testRealSolution')'  
result = run(suiteMethod);
```

**See Also** TestSuite

### **Related Examples**

- “Write Simple Test Case Using Classes” on page 29-2

## Run Tests for Various Workflows

### In this section...

“Set Up Example Tests” on page 29-46

“Run All Tests in Class or Function” on page 29-46

“Run Single Test in Class or Function” on page 29-47

“Run Test Suites by Name” on page 29-48

“Run Test Suites from Test Array” on page 29-48

“Run Tests with Customized Test Runner” on page 29-49

### Set Up Example Tests

To explore different ways to run tests, create a class-based test and a function-based test in your current working folder. For the class-based test file use the `DocPolynomTest` example test presented in the `matlab.unittest.qualifications.Verifiable` example. For the function-based test file use the `axesPropertiesTest` example test presented in “Write Test Using Setup and Teardown Functions” on page 29-88.

### Run All Tests in Class or Function

Use the `run` method of the `TestCase` class to directly run tests contained in a single test file. When running tests directly, you do not need to explicitly create a `Test` array.

```
% Directly run a single file of class-based tests
results1 = run(DocPolynomTest);
```

```
% Directly run a single file of function-based tests
results2 = run(axesPropertiesTest);
```

You can also assign the test file output to a variable and run the tests using the functional form or dot notation.

```
% Create Test or TestCase objects
t1 = DocPolynomTest;      % TestCase object from class-based test
t2 = axesPropertiesTest;  % Test object from function-based test
```



```
% Run tests using functional form
results1 = run(t1);
results2 = run(t2);

% Run tests using dot notation
results1 = t1.run;
results2 = t2.run;
```

Alternatively, you can run tests contained in a single file by using `runtests`.

## Run Single Test in Class or Function

Run a single test from within a class-based test file by specifying the test method as an input argument to the `run` method. For example, only run the test, `testMultiplication`, from the `DocPolynomTest` file.

```
results1 = run(DocPolynomTest, 'testMultiplication');
```

Function-based test files return an array of `Test` objects instead of a single `TestCase` object. You can run a particular test by indexing into the array. However, you must examine the `Name` field in the test array to ensure you run the correct test. For example, only run the test, `surfaceColorTest`, from the `axesPropertiesTest` file.

```
t2 = axesPropertiesTest; % Test object from function-based test
t2(:).Name
```

```
ans =
```

```
axesPropertiesTest/testDefaultXLim
```

```
ans =
```

```
axesPropertiesTest/surfaceColorTest
```

The `surfaceColorTest` test corresponds to the second element in the array.

Only run the `surfaceColorTest` test.

```
results2 = t2(2).run; % or results2 = run(t2(2));
```

## Run Test Suites by Name

You can run a group, or suite, of tests together. To run the test suite using `runtests`, the suite is defined as a cell array of strings representing a test file, a test class, a package that contains tests or a folder that contains tests.

```
suite = {'axesPropertiesTest', 'DocPolynomTest'};  
runtests(suite);
```

Run all tests in the current folder using the `pwd` as input to the `runtests` function.

```
runtests(pwd);
```

Alternatively, you can explicitly create Test arrays and use the `run` method to run them.

## Run Test Suites from Test Array

You can explicitly create Test arrays and use the `run` method in the `TestSuite` class to run them. Using this approach, you explicitly define `TestSuite` objects and, therefore, can examine the contents. The `runtests` function does not return the `TestSuite` object.

```
import matlab.unittest.TestSuite;  
s1 = TestSuite.fromClass(?DocPolynomTest);  
s2 = TestSuite.fromFile('axesPropertiesTest.m');  
  
% generate test suite and then run  
fullSuite = [s1 s2];  
result = run(fullSuite);
```

Since the suite is explicitly defined, it is easy for you to perform further analysis on the suite, such as rerunning failed tests.

```
failedTests = fullSuite([result.Failed]);  
result2 = run(failedTests);
```

## Run Tests with Customized Test Runner

You can specialize the test running by defining a custom test runner and adding plugins. The run method of the TestRunner class operates on a TestSuite object.

```
import matlab.unittest.TestRunner;
import matlab.unittest.TestSuite;
import matlab.unittest.plugins.TestSuiteProgressPlugin;

% Generate TestSuite.
s1 = TestSuite.fromClass(?DocPolynomTest);
s2 = TestSuite.fromFile('axesPropertiesTest.m');
suite = [s1 s2];

% Create silent test runner.
runner = TestRunner.withNoPlugins;

% Add plugin to display test progress.
runner.addPlugin(TestSuiteProgressPlugin);

% Run tests using customized runner.
result = run(runner,[s1 s2]);
```

### See Also

```
runtests | matlab.unittest.TestCase.run |
matlab.unittest.TestSuite.run | matlab.unittest.TestRunner.run
```

## Add Plugin to Test Runner

This example shows how to add a plugin to the test runner. The `matlab.unittest.plugins.TestSuiteProgressPlugin` displays progress messages about a test case. This plugin is part of the `matlab.unittest` package. MATLAB uses it for default test runners.

### Create a Test for the BankAccount Class

In a file in your working folder, create a test file for the `BankAccount` class.

```
classdef BankAccountTest < matlab.unittest.TestCase
    % Tests the BankAccount class.

    methods (TestClassSetup)
        function addBankAccountClassToPath(testCase)
            testCase.addTeardown(@path, addpath(fullfile(matlabroot, ...
                'help', 'techdoc', 'matlab_oop', 'examples')));
        end
    end

    methods (Test)
        function testConstructor(testCase)
            b = BankAccount(1234, 100);
            testCase.verifyEqual(b.AccountNumber, 1234, ...
                'Constructor failed to correctly set account number');
            testCase.verifyEqual(b.AccountBalance, 100, ...
                'Constructor failed to correctly set account balance');
        end

        function testConstructorNotEnoughInputs(testCase)
            import matlab.unittest.constraints.Throws;
            testCase.verifyThat(@()BankAccount, ...
                Throws('BankAccount:InvalidInitialization'));
        end

        function testDesposit(testCase)
            b = BankAccount(1234, 100);
            b.deposit(25);
            testCase.verifyEqual(b.AccountBalance, 125);
        end
    end
end
```

```

end

function testWithdraw(testCase)
    b = BankAccount(1234, 100);
    b.withdraw(25);
    testCase.verifyEqual(b.AccountBalance, 75);
end

function testNotifyInsufficientFunds(testCase)
    callbackExecuted = false;
    function testCallback(~,-)
        callbackExecuted = true;
    end

    b = BankAccount(1234, 100);
    b.addlistener('InsufficientFunds', @testCallback);

    b.withdraw(50);
    testCase.assertFalse(callbackExecuted, ...
        'The callback should not have executed yet');
    b.withdraw(60);
    testCase.verifyTrue(callbackExecuted, ...
        'The listener callback should have fired');
end
end
end

```

### Create Test Suite

At the command prompt, create a test suite, `ts`, from the `BankAccountTest` test case.

```
ts = matlab.unittest.TestSuite.fromClass(?BankAccountTest);
```

### Show Results with No Plugins

Create a test runner with no plugins.

```
runner = matlab.unittest.TestRunner.withNoPlugins;
res = runner.run(ts);
```

No output displayed.

**Customize Test Runner**

Add the custom plugin, `TestSuiteProgressPlugin`.

```
import matlab.unittest.plugins.TestSuiteProgressPlugin;
runner.addPlugin(TestSuiteProgressPlugin);
res = runner.run(ts);
```

```
Running BankAccountTest
.....
Done BankAccountTest
```

---

MATLAB displays progress messages about `BankAccountTest`.

**See Also**

`matlab.unittest.plugins`

## Write Plugins to Extend TestRunner

### In this section...

“Custom Plugins Overview” on page 29-53

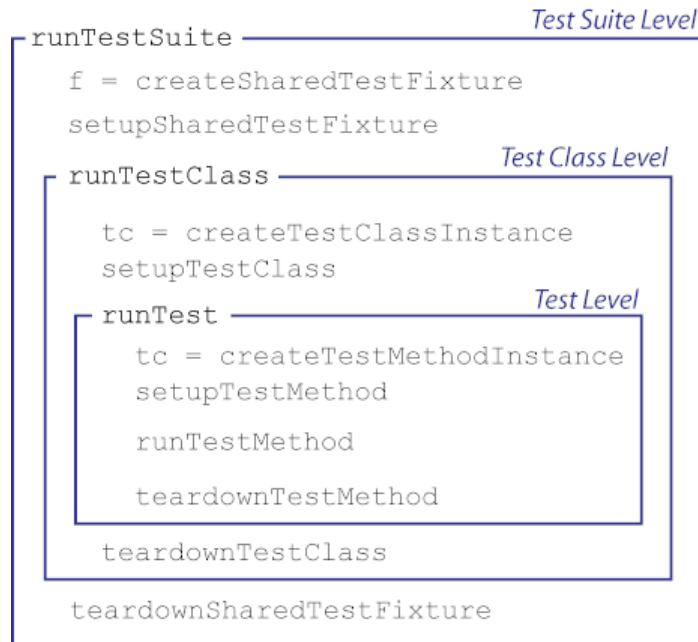
“Extending Test Level Plugin Methods” on page 29-54

“Extending Test Class Level Plugin Methods” on page 29-54

“Extending Test Suite Level Plugin Methods” on page 29-55

### Custom Plugins Overview

TestRunnerPlugin methods have three levels: Test Suite, Test Class, and Test. At each level, you implement methods to extend the creation, setup, run, and teardown of tests or test fixtures. The TestRunner runs these methods as shown in the figure.



The creation methods are the only set of `TestRunnerPlugin` methods with an output argument. Typically, you extend the creation methods to listen for various events originating from the test content at the corresponding level. Since both `TestCase` and `Fixture` instances inherit from the `handle` class, you add these listeners using the `addListener` method. The methods that set up, run and tear down test content extend the way the `TestRunner` evaluates the test content.

## Extending Test Level Plugin Methods

The `TestRunnerPlugin` methods at the test level extend the creation, setup, run, and teardown of a single test suite element. A single test element consists of one test method or, if the test is parameterized, one instance of the test's parameterization.

Type of Method	Test Level Falls Within Scope of <code>runTest</code>
creation method	<code>createTestMethodInstance</code>
setup method	<code>setupTestMethod</code>
run method	<code>runTestMethod</code>
teardown method	<code>teardownTestMethod</code>

At this level, the `createTestMethodInstance` method is the only plugin method with an output argument. It returns the `TestCase` instances created for each `Test` element. The test framework passes each of these instances into corresponding `Test` methods, and into any methods with the `TestMethodSetup` or `TestMethodTeardown` attribute.

The test framework evaluates methods at the test level within the scope of the `runTest` method. Provided the test framework completes all `TestMethodSetup` work, it invokes the plugin methods in this level a single time per test element.

## Extending Test Class Level Plugin Methods

The `TestRunnerPlugin` methods at the test class level extend the creation, setup, run, and teardown of test suite elements that belong to the same test



class or the same function-based test. These methods apply to a subset of the full `TestSuite` that the `TestRunner` runs.

Type of Method	Test Class Level Falls Within Scope of <code>runTestClass</code>
creation method	<code>createTestClassInstance</code>
setup method	<code>setupTestClass</code>
run method	<code>runTest</code>
teardown method	<code>teardownTestClass</code>

At this level, the `createTestClassInstance` method is the only plugin method with an output argument. It returns the `TestCase` instances created at the class level. For each class, the test framework passes the instance into any methods with the `TestClassSetup` or `TestClassTeardown` attribute.

A test class setup is parameterized if it contains properties with the `ClassSetupParameter` attribute. In this case, the test framework evaluates the `setupTestClass` and `teardownTestClass` methods as many times as the class setup parameterization dictates.

The run method at this level, `runTest`, extends the running of a single `TestSuite` element, and incorporates the functionality described for the test level plugin methods.

The test framework evaluates methods at the test class level within the scope of the `runTestClass` method. If `TestClassSetup` completes successfully, it invokes the `runTest` method one time for each element in the `Test` array. Each `TestClassSetup` parameterization invokes the creation, setup, and teardown methods a single time.

## Extending Test Suite Level Plugin Methods

The `TestRunnerPlugin` methods at the test suite level extend the creation, setup, run, and teardown of shared test fixtures.

Type of Method	Test Suite Level Falls Within Scope of <code>runTestSuite</code>
creation method	<code>createSharedTestFixture</code>
setup method	<code>setupSharedTestFixture</code>
run method	<code>runTestClass</code>
teardown method	<code>teardownSharedTestFixture</code>

At this level, the `createSharedTestFixture` method is the only plugin method with an output argument. It returns the `Fixture` instances for each shared fixture required by a test class. These fixture instances are available to the test through the `getSharedTestFixtures` method of `TestCase`.

The run method at this level, `runTestClass`, extends the running of tests that belong to the same test class or the same function-based test, and incorporates the functionality described for the test class level plugin methods.

## See Also

`matlab.unittest.plugins.TestRunnerPlugin` |  
`matlab.unittest.plugins.OutputStream` | `matlab.unittest.TestCase` |  
`matlab.unittest.TestRunner` | `matlab.unittest.fixtures.Fixture` |  
`addlistener`

## Related Examples

- “Create Custom Plugin” on page 29-57

## Create Custom Plugin

This example shows how to create a custom plugin that counts the number of passing and failing assertions when running a specified test suite. The plugin prints a brief summary at the end of the testing.

### Create AssertionCountingPlugin Class

In a file in your working folder, create a new class, `AssertionCountingPlugin`, that inherits from the `matlab.unittest.plugins.TestRunnerPlugin` class. For a complete version of the code for an `AssertionCountingPlugin`, see "AssertionCountingPlugin Class Definition Summary".

Keep track of the number of passing and failing assertions. Within a `properties` block, create `NumPassingAssertions` and `NumFailingAssertions` properties to pass the data between methods.

```
properties
    NumPassingAssertions = 0;
    NumFailingAssertions = 0;
end
```

### Extend Running of TestSuite

Implement the `runTestSuite` method in a `methods` block with protected access.

```
methods (Access = protected)
    function runTestSuite(plugin, pluginData)
        suiteSize = numel(pluginData.TestSuite);
        fprintf('## Running a total of %d tests\n', suiteSize);

        plugin.NumPassingAssertions = 0;
        plugin.NumFailingAssertions = 0;

        runTestSuite@matlab.unittest.plugins.TestRunnerPlugin(...
            plugin, pluginData);

        fprintf('## Done running tests\n');
        plugin.printAssertionSummary();
    end
end
```

```
        end
    end
```

The test framework evaluates this method one time. It displays information about the total number of tests, initializes the assertion count, and invokes the superclass method. After the framework completes evaluating the superclass method, the `runTestSuite` method displays the assertion count summary.

### **Extend Creation of Shared Test Fixtures and TestCase Instances**

Add listeners to `AssertionPassed` and `AssertionFailed` events to count the assertions. To add these listeners, extend the methods that the test framework uses to create the test content. The test content comprises `TestCase` instances for each `Test` element, class-level `TestCase` instances for the `TestClassSetup` and `TestClassTeardown` methods, and `Fixture` instances that are used when a `TestCase` class has the `SharedTestFixtures` attribute.

Invoke the corresponding superclass method when you override the creation methods. The creation methods return the content that the test framework creates for each of their respective contexts. When implementing one of these methods, pass this argument out of your own implementation, and add the listeners required by this plugin.

Add these creation methods to a `methods` block with protected access.

```
methods (Access = protected)
    function fixture = createSharedTestFixture(plugin, pluginData)
        fixture = createSharedTestFixture@...
            matlab.unittest.plugins.TestRunnerPlugin(plugin, pluginData);

        fixture.addlistener('AssertionPassed', ...
            @(~,~)plugin.incrementPassingAssertionsCount);
        fixture.addlistener('AssertionFailed', ...
            @(~,~)plugin.incrementFailingAssertionsCount);
    end

    function testCase = createTestClassInstance(plugin, pluginData)
        testCase = createTestClassInstance@...
            matlab.unittest.plugins.TestRunnerPlugin(plugin, pluginData);
```

```

        testCase.addListener('AssertionPassed', ...
            @(~,~)plugin.incrementPassingAssertionsCount);
        testCase.addListener('AssertionFailed', ...
            @(~,~)plugin.incrementFailingAssertionsCount);
    end

    function testCase = createTestMethodInstance(plugin, pluginData)
        testCase = createTestMethodInstance@...
            matlab.unittest.plugins.TestRunnerPlugin(plugin, pluginData);

        testCase.addListener('AssertionPassed', ...
            @(~,~)plugin.incrementPassingAssertionsCount);
        testCase.addListener('AssertionFailed', ...
            @(~,~)plugin.incrementFailingAssertionsCount);
    end
end
end

```

### Extend Running of Single Test Suite Element

Extend `runTest` to display the name of each test at run time. Include this function in a `methods` block with `protected` access. Like all plugin methods, when you override this method you must invoke the corresponding superclass method.

```

methods (Access = protected)
    function runTest(plugin, pluginData)
        fprintf('### Running test: %s\n', pluginData.Name);

        runTest@matlab.unittest.plugins.TestRunnerPlugin(...
            plugin, pluginData);
    end
end

```

### Define Helper Functions

In a `methods` block with `private` access, define three helper functions. These functions increment the number of passing or failing assertions, and print out the assertion count summary.

```

methods (Access = private)
    function incrementPassingAssertionsCount(plugin)

```

```
        plugin.NumPassingAssertions = plugin.NumPassingAssertions + 1;
    end

    function incrementFailingAssertionsCount(plugin)
        plugin.NumFailingAssertions = plugin.NumFailingAssertions + 1;
    end

    function printAssertionSummary(plugin)
        fprintf('%s\n', repmat('_', 1, 30));
        fprintf('Total Assertions: %d\n', ...
            plugin.NumPassingAssertions + plugin.NumFailingAssertions);
        fprintf('\t%d Passed, %d Failed\n', ...
            plugin.NumPassingAssertions, plugin.NumFailingAssertions);
    end
end
```

### **AssertionCountingPlugin Class Definition Summary**

```
classdef AssertionCountingPlugin < ...
    matlab.unittest.plugins.TestRunnerPlugin

    properties
        NumPassingAssertions = 0;
        NumFailingAssertions = 0;
    end

    methods (Access = protected)
        function runTestSuite(plugin, pluginData)
            suiteSize = numel(pluginData.TestSuite);
            fprintf('## Running a total of %d tests\n', suiteSize);

            plugin.NumPassingAssertions = 0;
            plugin.NumFailingAssertions = 0;

            runTestSuite@matlab.unittest.plugins.TestRunnerPlugin(...
                plugin, pluginData);

            fprintf('## Done running tests\n');
            plugin.printAssertionSummary();
        end
    end
end
```

```
function fixture = createSharedTestFixture(plugin, pluginData)
    fixture = createSharedTestFixture@...
        matlab.unittest.plugins.TestRunnerPlugin(plugin, pluginData);

    fixture.addlistener('AssertionPassed', ...
        @(~,~)plugin.incrementPassingAssertionsCount);
    fixture.addlistener('AssertionFailed', ...
        @(~,~)plugin.incrementFailingAssertionsCount);
end

function testCase = createTestClassInstance(plugin, pluginData)
    testCase = createTestClassInstance@...
        matlab.unittest.plugins.TestRunnerPlugin(plugin, pluginData);

    testCase.addlistener('AssertionPassed', ...
        @(~,~)plugin.incrementPassingAssertionsCount);
    testCase.addlistener('AssertionFailed', ...
        @(~,~)plugin.incrementFailingAssertionsCount);
end

function testCase = createTestMethodInstance(plugin, pluginData)
    testCase = createTestMethodInstance@...
        matlab.unittest.plugins.TestRunnerPlugin(plugin, pluginData);

    testCase.addlistener('AssertionPassed', ...
        @(~,~)plugin.incrementPassingAssertionsCount);
    testCase.addlistener('AssertionFailed', ...
        @(~,~)plugin.incrementFailingAssertionsCount);
end

function runTest(plugin, pluginData)
    fprintf('### Running test: %s\n', pluginData.Name);

    runTest@matlab.unittest.plugins.TestRunnerPlugin(...
        plugin, pluginData);
end

end

methods (Access = private)
```

```
function incrementPassingAssertionsCount(plugin)
    plugin.NumPassingAssertions = plugin.NumPassingAssertions + 1;
end

function incrementFailingAssertionsCount(plugin)
    plugin.NumFailingAssertions = plugin.NumFailingAssertions + 1;
end

function printAssertionSummary(plugin)
    fprintf('%s\n', repmat('_', 1, 30));
    fprintf('Total Assertions: %d\n', ...
        plugin.NumPassingAssertions + plugin.NumFailingAssertions);
    fprintf('\t%d Passed, %d Failed\n', ...
        plugin.NumPassingAssertions, plugin.NumFailingAssertions);
end
end
end
```

### Create Example Test Class

In your working folder, create the file `ExampleTest.m` containing the following test class.

```
classdef ExampleTest < matlab.unittest.TestCase
    methods(Test)
        function testOne(testCase) % Test fails
            testCase.assertEqual(5, 4);
        end
        function testTwo(testCase) % Test passes
            testCase.verifyEqual(5, 5);
        end
        function testThree(testCase) % Test passes
            testCase.assertEqual(7*2, 14);
        end
    end
end
```

### Add Plugin to TestRunner and Run Tests

At the command prompt, create a test suite from the `ExampleTest` class.



```
import matlab.unittest.TestSuite;
import matlab.unittest.TestRunner;

suite = TestSuite.fromClass(?ExampleTest);
```

Create a test runner with no plugins. This code creates a silent runner and provides you with complete control over the installed plugins.

```
runner = TestRunner.withNoPlugins;
```

Run the tests.

```
result = runner.run(suite);
```

Add `AssertionCountingPlugin` to the runner and run the tests.

```
runner.addPlugin(AssertionCountingPlugin)
result = runner.run(suite);
```

```
## Running a total of 3 tests
### Running test: ExampleTest/testOne
### Running test: ExampleTest/testTwo
### Running test: ExampleTest/testThree
## Done running tests
```

---

```
Total Assertions: 2
  1 Passed, 1 Failed
```

## See Also

```
matlab.unittest.plugins.TestRunnerPlugin |
matlab.unittest.plugins.OutputStream | matlab.unittest.TestCase |
matlab.unittest.TestRunner | matlab.unittest.fixtures.Fixture |
addlistener
```

## Related Examples

- “Write Plugins to Extend TestRunner” on page 29-53

## Analyze Test Case Results

This example shows how to analyze the information returned by a test runner created from the SolverTest test case.

### Create Quadratic Solver Function

Create the following function that solves roots of the quadratic equation in a file, `quadraticSolver.m`, in your working folder.

```
function roots = quadraticSolver(a, b, c)
% quadraticSolver returns solutions to the
% quadratic equation a*x^2 + b*x + c = 0.

if ~isa(a,'numeric') || ~isa(b,'numeric') || ~isa(c,'numeric')
    error('quadraticSolver:InputMustBeNumeric', ...
        'Coefficients must be numeric.');
```

end

```
roots(1) = (-b + sqrt(b^2 - 4*a*c)) / (2*a);
roots(2) = (-b - sqrt(b^2 - 4*a*c)) / (2*a);

end
```

### Create Test for Quadratic Solver Function

Create the following test class in a file, `SolverTest.m`, in your working folder.

```
classdef SolverTest < matlab.unittest.TestCase
% SolverTest tests solutions to the quadratic equation
% a*x^2 + b*x + c = 0

methods (Test)
    function testRealSolution(testCase)
        actSolution = quadraticSolver(1,-3,2);
        expSolution = [2,1];
        testCase.verifyEqual(actSolution,expSolution);
    end
    function testImaginarySolution(testCase)
        actSolution = quadraticSolver(1,2,10);
```

```

        expSolution = [-1+3i, -1-3i];
        testCase.verifyEqual(actSolution,expSolution);
    end
end
end

```

### Run SolverTest Test Case

Create a test suite, quadTests.

```

quadTests = matlab.unittest.TestSuite.fromClass(?SolverTest);
result = run(quadTests);

```

```

Running SolverTest
..
Done SolverTest

```

All tests passed.

### Explore Output Argument, result

The output argument, `result`, is a `matlab.unittest.TestResult` object. It contains information of the two tests in `SolverTest`.

whos result

Name	Size	Bytes	Class
result	1x2	248	matlab.unittest.TestResult

### Display Information for One Test

To see the information for one value, type:

```

result(1)

```

```

ans =
    TestResult with properties:

```

```
        Name: 'SolverTest/testRealSolution'  
        Passed: 1  
        Failed: 0  
        Incomplete: 0  
        Duration: 0.0244  
Totals:  
    1 Passed, 0 Failed, 0 Incomplete.  
    0.024365 seconds testing time.
```

**Related  
Examples**

- “Write Simple Test Case Using Classes” on page 29-2

## Analyze Failed Test Results

This example shows how to identify and rerun failed tests.

### Create an Incorrect Test Method

Using the `SolverTest` test case, add a method, `testBadRealSolution`. This test, based on `testRealSolution`, calls the `quadraticSolver` function with inputs 1,3,2, but tests the results against an incorrect solution, [2, 1].

```
function testBadRealSolution(testCase)
    actSolution = quadraticSolver(1,3,2);
    expSolution = [2,1];
    testCase.verifyEqual(actSolution,expSolution);
end
```

### Run New Test Suite

Save the updated `SolverTest` class definition and rerun the tests.

```
quadTests = matlab.unittest.TestSuite.fromClass(?SolverTest);
result1 = run(quadTests);
```

```
Running SolverTest
```

```
.
```

```
=====
Verification failed in SolverTest/testBadRealSolution.
```

```
-----
Framework Diagnostic:
-----
verifyEqual failed.
--> NumericComparator failed.
    --> The values are not equal using "isequaln".
```

```
Actual Value:
    -1    -2
Expected Value:
     2     1
```

```
-----
```

```

Stack Information:
-----
In C:\Program Files\MATLAB\R2013a\toolbox\matlab\testframework\+matlab\
In c:\work\SolverTest.m (SolverTest.testBadRealSolution) at 15
=====
....
Done SolverTest
-----

Failure Summary:

Name                                     Failed  Incomplete  Reason(s)
-----
SolverTest/testBadRealSolution           X                                     Failed by verifica

>>

```

### Analyze Results

The output tells you `SolverTest/testBadRealSolution` failed. From the Framework Diagnostic you see the following:

```

Actual Value:
    -1    -2
Expected Value:
     2     1

```

At this point, you must decide if the error is in `quadraticSolver` or in your value for `expSolution`.

### Correct Error

Edit the value of `expSolution` in `testBadRealSolution`:

```
expSolution = [-1 -2];
```

### Rerun Tests

Save `SolverTest` and rerun only the failed tests.

```
failedTests = quadTests([result1.Failed]);
```

```
result2 = run(failedTests)

Running SolverTest
.
Done SolverTest

-----

result2 =
  TestResult with properties:
      Name: 'SolverTest/testBadRealSolution'
      Passed: 1
      Failed: 0
      Incomplete: 0
      Duration: 0.0124
Totals:
  1 Passed, 0 Failed, 0 Incomplete.
  0.012382 seconds testing time.
```

## Dynamically Filtered Tests

### In this section...

“Test Methods” on page 29-70

“Method Setup and Teardown Code” on page 29-73

“Class Setup and Teardown Code” on page 29-75

Assumption failures produce *filtered tests*. In the `matlab.unittest.TestResult` class, such a test is marked `Incomplete`.

Since filtering test content through the use of assumptions does not produce test failures, it has the possibility of creating dead test code. Avoiding this requires monitoring of filtered tests.

### Test Methods

If an assumption failure is encountered inside of a `TestCase` method with the `Test` attribute, the entire method is marked as filtered, but MATLAB runs the subsequent `Test` methods.

The following class contains an assumption failure in one of the methods in the `Test` block.

```
classdef ExampleTest < matlab.unittest.TestCase
    methods(Test)
        function testA(testCase)
            testCase.verifyTrue(true);
        end
        function testB(testCase)
            testCase.assumeEqual(0,1);
            % remaining test code is not exercised
        end
        function testC(testCase)
            testCase.verifyFalse(true);
        end
    end
end
```



Since the `testB` method contains an assumption failure, when you run the test, the testing framework filters that test and marks it as incomplete. After the assumption failure in `testB`, the testing framework proceeds and executes `testC`, which contains a verification failure.

```
ts = matlab.unittest.TestSuite.fromClass(?ExampleTest);
res = ts.run;
```

```
Running ExampleTest
```

```
.
```

```
=====  
ExampleTest/testB was filtered.
```

```
  Details
```

```
=====  
.
```

```
=====  
Verification failed in ExampleTest/testC.
```

```
-----  
Framework Diagnostic:
```

```
-----  
verifyFalse failed.
```

```
--> The value must evaluate to "false".
```

```
Actual Value:
```

```
  1
```

```
-----  
Stack Information:
```

```
-----  
In C:\work\ExampleTest.m (ExampleTest.testC) at 11
```

```
=====  
.
```

```
Done ExampleTest
```

```
-----  
Failure Summary:
```

```
      Name                Failed Incomplete Reason(s)
```

```
=====
```

```
ExampleTest/testB          X      Filtered by assumption.
-----
ExampleTest/testC      X      Failed by verification.
```

If you examine the `TestResult`, you notice that there is a passed test, a failed test, and a test that did not complete due to an assumption failure.

```
res
```

```
res =
```

```
1x3 TestResult array with properties:
```

```
Name
Passed
Failed
Incomplete
Duration
```

```
Totals:
```

```
1 Passed, 1 Failed, 1 Incomplete.
0.059433 seconds testing time.
```

The testing framework keeps track of incomplete tests so that you can monitor filtered tests for nonexercised test code. You can see information about these tests within the `TestResult` object.

```
res([res.Incomplete])
```

```
ans =
```

```
TestResult with properties:
```

```
Name: 'ExampleTest/testB'
Passed: 0
Failed: 0
Incomplete: 1
Duration: 0.0400
```

```
Totals:
```

```
0 Passed, 0 Failed, 1 Incomplete.
```

```
0.040017 seconds testing time.
```

To create a modified test suite from only the filtered tests, select incomplete tests from the original test suite.

```
tsFiltered = ts([res.Incomplete])
```

```
tsFiltered =
```

```
Test with properties:
```

```

                Name: 'ExampleTest/testB'
    Parameterization: []
    SharedTestFixtures: []
```

## Method Setup and Teardown Code

If an assumption failure is encountered inside a `TestCase` method with the `TestMethodSetup` attribute, MATLAB filters the method which was to be run for that instance. If a test uses assumptions from within the `TestMethodSetup` block, consider instead using the assumptions in the `TestClassSetup` block, which likewise filters all `Test` methods in the class but is less verbose and more efficient.

One of the methods in the following `TestMethodSetup` block within `ExampleTest.m` contains an assumption failure.

```

methods(TestMethodSetup)
    function setupMethod1(testCase)
        testCase.assertEqual(1,0);
        % remaining test code is not exercised
    end
    function setupMethod2(testCase)
        disp('* Running setupMethod2 *')
        testCase.assertEqual(1,1);
    end
end
```

## Updated ExampleTest Class Definition

```

classdef ExampleTest < matlab.unittest.TestCase
    methods(TestMethodSetup)
```

```

        function setupMethod1(testCase)
            testCase.assumeEqual(1,0);
            % remaining test code is not exercised
        end
        function setupMethod2(testCase)
            disp('* Running setupMethod2 *')
            testCase.assertEqual(1,1);
        end
    end

    methods(Test)
        function testA(testCase)
            testCase.verifyTrue(true);
        end
        function testB(testCase)
            testCase.assumeEqual(0,1);
            % remaining test code is not exercised
        end
        function testC(testCase)
            testCase.verifyFalse(true);
        end
    end
end
end

```

When you run the test, you see that the framework completes executes all the methods in the `TestMethodSetup` block that do not contain the assumption failure, and it marks as incomplete all methods in the `Test` block.

```

ts = matlab.unittest.TestSuite.fromClass(?ExampleTest);
res = ts.run;

```

Running ExampleTest

```

=====
ExampleTest/testA was filtered.
  Details
=====

```

```

* Running setupMethod2 *
.
=====

```

```
ExampleTest/testB was filtered.
```

```
    Details
```

```
=====
* Running setupMethod2 *
```

```
.
```

```
ExampleTest/testC was filtered.
```

```
    Details
```

```
=====
* Running setupMethod2 *
```

```
.
```

```
Done ExampleTest
```

```
-----
Failure Summary:
```

Name	Failed	Incomplete	Reason(s)
ExampleTest/testA		X	Filtered by assumption.
ExampleTest/testB		X	Filtered by assumption.
ExampleTest/testC		X	Filtered by assumption.

The Test methods did not change but all 3 are filtered due to an assumption failure in the `TestMethodSetup` block. The testing framework executes methods in the `TestMethodSetup` block without assumption failures, such as `setupMethod2`. As expected, the testing framework executes `setupMethod2` 3 times, once before each Test method.

## Class Setup and Teardown Code

If an assumption failure is encountered inside of a `TestCase` method with the `TestClassSetup` or `TestClassTeardown` attribute, MATLAB filters the entire `TestCase` class.

The methods in the following `TestClassSetup` block within `ExampleTest.m` contains an assumption failure.

```
methods(TestClassSetup)
```

```
        function setupClass(testCase)
            testCase.assumeEqual(1,0);
            % remaining test code is not exercised
        end
    end
```

### Updated ExampleTest Class Definition

```
classdef ExampleTest < matlab.unittest.TestCase
    methods(TestClassSetup)
        function setupClass(testCase)
            testCase.assumeEqual(1,0);
            % remaining test code is not exercised
        end
    end

    methods(TestMethodSetup)
        function setupMethod1(testCase)
            testCase.assumeEqual(1,0);
            % remaining test code is not exercised
        end
        function setupMethod2(testCase)
            disp('* Running setupMethod2 *')
            testCase.assertEqual(1,1);
        end
    end

    methods(Test)
        function testA(testCase)
            testCase.verifyTrue(true);
        end
        function testB(testCase)
            testCase.assumeEqual(0,1);
            % remaining test code is not exercised
        end
        function testC(testCase)
            testCase.verifyFalse(true);
        end
    end
end
```

When you run the test, you see that the framework does not execute any of the methods in the `TestMethodSetup` or `Test`.

```
ts = matlab.unittest.TestSuite.fromClass(?ExampleTest);
res = ts.run;
```

Running `ExampleTest`

```
=====
All tests in ExampleTest were filtered.
```

```
  Details
=====
```

Done `ExampleTest`

Failure Summary:

Name	Failed	Incomplete	Reason(s)
ExampleTest/testA		X	Filtered by assumption.
ExampleTest/testB		X	Filtered by assumption.
ExampleTest/testC		X	Filtered by assumption.

The `Test` and `TestMethodSetup` methods did not change but everything is filtered due to an assumption failure in the `TestClassSetup` block.

## See Also

`matlab.unittest.qualifications.Assumable` | `TestCase` | `TestResult`

## Write Function-Based Unit Tests

### In this section...

“Create Test Function” on page 29-78

“Run the Tests” on page 29-81

“Analyze the Results” on page 29-82

### Create Test Function

Your test function is a single MATLAB file that contains a main function and your individual local test functions. Optionally, you can include file fixture and fresh fixture functions. *File fixtures* consist of setup and teardown functions shared across all the tests in a file. These functions are executed once per test file. *Fresh fixtures* consist of setup and teardown functions that are executed before and after each local test function.

### Create the Main Function

The main function collects all of the local test functions into a test array. Since it is the main function, the function name corresponds to the name of your `.m` file and follows the naming convention of starting or ending in the word ‘test’, which is case-insensitive. In this sample case, the MATLAB file is `exampleTest.m`. The main function needs to make a call to `functiontests` to generate a test array, `tests`. Use `localfunctions` as the input to `functiontests` to automatically generate a cell array of function handles to all the local functions in your file. This is a typical main function.

```
function tests = exampleTest
tests = functiontests(localfunctions);
end
```

### Create Local Test Functions

Individual test functions are included as local functions in the same MATLAB file as the main (test-generating) function. These test function names must begin or end with the case-insensitive word, ‘test’. Each of the local test functions must accept a single input, which is a function test case object, `testCase`. The Unit Test Framework automatically generates this object. For



more information on creating test functions, see “Write Simple Test Case Using Functions” on page 29-83 and “Types of Qualifications” on page 29-10. This is a typical example of skeletal local-test functions.

```
function testFunctionOne(testCase)
% Test specific code
end
```

```
function FunctionTwotest(testCase)
% Test specific code
end
```

## Create Optional Fixture Functions

Setup and teardown code, also referred to as test fixture functions, set up the pretest state of the system and return it to the original state after running the test. There are two types of these functions: file fixture functions that run once per test file, and fresh fixture functions that run before and after each local test function. These functions are not required to generate tests. In general, it is preferable to use fresh fixtures over file fixtures to increase unit test encapsulation.

A function test case object, `testCase`, must be the only input to file fixture and fresh fixture functions. The Unit Test Framework automatically generates this object. The `TestCase` object is a means to pass information between setup functions, test functions, and teardown functions. Its `TestData` property is, by default, a `struct`, which allows easy addition of fields and data. Typical uses for this test data include paths and graphics handles. For an example using the `TestData` property, see “Write Test Using Setup and Teardown Functions” on page 29-88.

**File Fixture Functions.** Use file fixture functions to share setup and teardown functions across all the tests in a file. The names for the file fixture functions must be `setupOnce` and `teardownOnce`, respectively. These functions execute a single time for each file. You can use file fixtures to set a path before testing, and then reset it to the original path after testing. This is a typical example of skeletal file fixture setup and teardown code.

```
function setupOnce(testCase) % do not change function name
% set a new path, for example
```

```
end
```

```
function teardownOnce(testCase) % do not change function name  
% change back to original path, for example  
end
```

**Fresh Fixture Functions.** Use fresh fixture functions to set up and tear down states for each local test function. The names for these fresh fixture functions must be `setup` and `teardown`, respectively. You can use fresh fixtures to obtain a new figure before testing and to close the figure after testing. This is typical example of skeletal test function level setup and teardown code.

```
function setup(testCase) % do not change function name  
% open a figure, for example  
end
```

```
function teardown(testCase) % do not change function name  
% close figure, for example  
end
```

### Program Listing Template

```
%% Main function to generate tests  
function tests = exampleTest  
tests = functiontests(localfunctions);  
end
```

```
%% Test Functions  
function testFunctionOne(testCase)  
% Test specific code  
end
```

```
function FunctionTwotest(testCase)  
% Test specific code  
end
```

```
%% Optional file fixtures  
function setupOnce(testCase) % do not change function name  
% set a new path, for example
```

```

end

function teardownOnce(testCase) % do not change function name
% change back to original path, for example
end

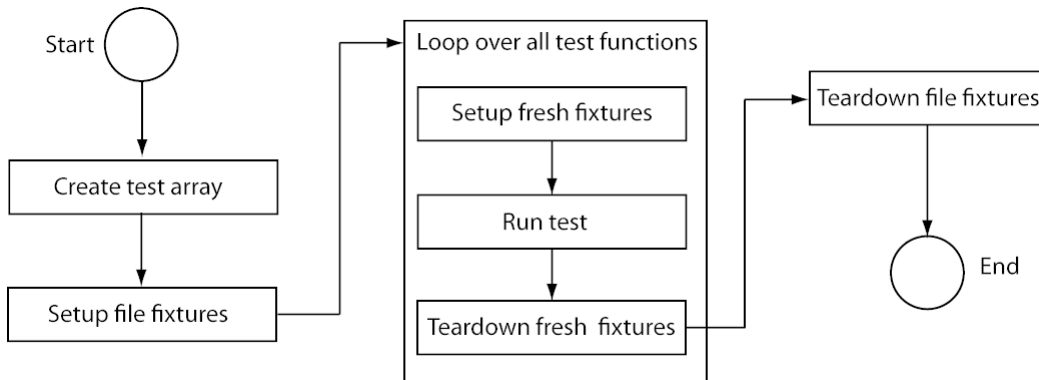
%% Optional fresh fixtures
function setup(testCase) % do not change function name
% open a figure, for example
end

function teardown(testCase) % do not change function name
% close figure, for example
end

```

## Run the Tests

The figure below details the tasks executed when you run the tests.



To run tests from the command prompt, use the `runtests` command with your MATLAB test file as input. For example:

```
results = runtests('exampleTest.m')
```

Alternatively, you can run tests using the `run` function.

```
results = run(exampleTest)
```

For more information on running tests see the `runtests` reference page and “Run Tests for Various Workflows” on page 29-46.

## **Analyze the Results**

To analyze the test results, examine the output structure from `runtests` or `run`. For each test, the result contains the name of the test function, whether it passed, failed, or didn't complete, and the time it took to run the test. For more information, see “Analyze Test Case Results” on page 29-64 and “Analyze Failed Test Results” on page 29-67.

### **See Also**

`runtests` | `functiontests` | `localfunctions`

### **Related Examples**

- “Write Simple Test Case Using Functions” on page 29-83
- “Write Test Using Setup and Teardown Functions” on page 29-88

## Write Simple Test Case Using Functions

This example shows how to write a unit test for a MATLAB function, `quadraticSolver.m`.

### Create `quadraticSolver.m` Function

This MATLAB function solves quadratic equations. Create this function in a folder on your MATLAB path.

```
function roots = quadraticSolver(a, b, c)
% quadraticSolver returns solutions to the
% quadratic equation a*x^2 + b*x + c = 0.

if ~isa(a,'numeric') || ~isa(b,'numeric') || ~isa(c,'numeric')
    error('quadraticSolver:InputMustBeNumeric', ...
        'Coefficients must be numeric.');
```

```
end

roots(1) = (-b + sqrt(b^2 - 4*a*c)) / (2*a);
roots(2) = (-b - sqrt(b^2 - 4*a*c)) / (2*a);

end
```

### Create `solverTest` Function

Create this function in a folder on your MATLAB path.

```
function tests = solverTest
tests = functiontests(localfunctions);
end
```

A call to `functiontests` using `localfunctions` as input creates an array of tests from each local function in the `solverTest.m` file. Each test is a local function that follows the naming convention of having 'test' at the beginning or end of the function name. Local functions that do not follow this convention are not included in the test array. Test functions must accept a single input argument into which the test framework passes a function test case object. The function uses this object for verifications assertions, assumptions, and fatal assertions. It contains a `TestData` structure that allows data to be passed between setup, test, and teardown functions.

### Create Test Function for Real Solutions

Create a test function, `testRealSolution`, to verify that `quadraticSolver` returns the correct value for real solutions. For example, the equation  $x^2 - 3x + 2 = 0$  has real solutions  $x = 1$  and  $x = 2$ . This function calls `quadraticSolver` with the inputs of this equation. The expected solution, `expSolution`, is `[2,1]`.

Use the qualification function, `verifyEqual`, to compare the output of the function, `actSolution`, to the desired output, `expSolution`. If the qualification fails, the framework continues executing the test. Typically, when using `verifyEqual` on floating point values, you specify a tolerance for the comparison. For more information, see `matlab.unittest.constraints`.

Add this function to the `solverTest.m` file.

```
function testRealSolution(testCase)
actSolution = quadraticSolver(1,-3,2);
expSolution = [2,1];
verifyEqual(testCase,actSolution,expSolution);
end
```

### Create Test Function for Imaginary Solutions

Create a test to verify that `quadraticSolver` returns the right value for imaginary solutions. For example, the equation  $x^2 - 2x + 10 = 0$  has imaginary solutions  $x = -1 + 3i$  and  $x = -1 - 3i$ . Typically, when using `verifyEqual` on floating point values, you specify a tolerance for the comparison. For more information, see `matlab.unittest.constraints`.

Add this function, `testImaginarySolution`, to the `solverTest.m` file.

```
function testImaginarySolution(testCase)
actSolution = quadraticSolver(1,2,10);
expSolution = [-1+3i, -1-3i];
verifyEqual(testCase,actSolution,expSolution);
end
```

The order of the tests within the `solverTest.m` file does not matter because they are fully independent test cases.

**Save solverTest Function**

The following is the complete `solverTest.m` test file. Save this file in a folder on your MATLAB path.

```
function tests = solverTest
tests = functiontests(localfunctions);
end

function testRealSolution(testCase)
actSolution = quadraticSolver(1,-3,2);
expSolution = [2,1];
verifyEqual(testCase,actSolution,expSolution);
end

function testImaginarySolution(testCase)
actSolution = quadraticSolver(1,2,10);
expSolution = [-1+3i, -1-3i];
verifyEqual(testCase,actSolution,expSolution);
end
```

**Run Tests in solverTest Function**

Run the tests.

```
results = runtests('solverTest.m')
```

```
Running solverTest
```

```
..
```

```
Done solverTest
```

```
results =
```

```
1x2 TestResult array with properties:
```

```
    Name
    Passed
    Failed
```

```
Incomplete
Duration
```

```
Totals:
  2 Passed, 0 Failed, 0 Incomplete.
  0.19172 seconds testing time.
```

Both of the tests passed.

### **Introduce an Error in quadraticSolver.m and Run Tests**

Cause one of the tests to fail by forcing roots in `quadraticSolver.m` to be real. Before ending the function, add the line: `roots = real(roots);`. (Do not change `solverTest.m`.) Save the file and run the tests.

```
results = runtests('solverTest.m')
```

```
Running solverTest
```

```
.
```

```
=====
Verification failed in solverTest/testImaginarySolution.
```

```
-----
Framework Diagnostic:
```

```
-----
verifyEqual failed.
```

```
--> NumericComparator failed.
```

```
--> Complexity does not match.
```

```
Actual Complexity:
```

```
Real
```

```
Expected Complexity:
```

```
Complex
```

```
Actual Value:
```

```
-1 -1
```

```
Expected Value:
```

```
-1.0000000000000000 + 3.0000000000000000i -1.0000000000000000 - 3.0000000000000000i
```

```
-----
Stack Information:
```



```

-----
In C:\work\solverTest.m (testImaginarySolution) at 14
In C:\Program Files\MATLAB\R2013b\toolbox\matlab\testframework\+matlab\
=====
.
Done solverTest
-----

Failure Summary:

      Name                                     Failed  Incomplete  Reason(s)
-----
solverTest/testImaginarySolution             X                                     Failed by verifi

results =

    1x2 TestResult array with properties:

    Name
    Passed
    Failed
    Incomplete
    Duration

Totals:
    1 Passed, 1 Failed, 0 Incomplete.
    0.22545 seconds testing time.

```

The imaginary test verification failed.

Restore `quadraticSolver.m` to its previous, correct version by removing the `roots = real(roots);` code.

## See Also

`matlab.unittest.constraints`

## Concepts

- “Write Function-Based Unit Tests” on page 29-78
- “Types of Qualifications” on page 29-10

## Write Test Using Setup and Teardown Functions

This example shows how to write a unit test for a couple of MATLAB figure axes properties using fresh fixtures and file fixtures.

### Create axesPropertiesTest File

Create a file containing the main function that tests figure axes properties and include two test functions. One function verifies that the x-axis limits are correct, and the other one verifies that the face color of a surface is correct.

In a folder on your MATLAB path, create `axesPropertiesTest.m`. In the main function of this file, have `functiontests` create an array of tests from each local function in `axesPropertiesTest.m` with a call to the `localfunctions` function.

```
function tests = axesPropertiesTest
tests = functiontests(localfunctions);
end
```

### Create File Fixture Functions

File fixture functions are setup and teardown code that runs a single time in your test file. These fixtures are shared across the test file. In this example, the file fixture functions create a temporary folder and set it as the current working folder. They also create and save a new figure for testing. After tests are complete, the framework reinstates the original working folder and deletes the temporary folder and saved figure.

In this example, a helper function creates a simple figure — a red cylinder. In a more realistic scenario, this code is part of the product under test and is computationally expensive, thus motivating the intent to create the figure only once and to load independent copies of the result for each test function. For this example, however, you want to create this helper function as a local function to `axesPropertiesTest`. Note that the test array does not include the function because its name does not start or end with ‘test’.

Write a helper function that creates a simple red cylinder and add it as a local function to `axesPropertiesTest`.

```
function f = createFigure
f = figure;
ax = axes('Parent', f);
cylinder(ax,10);
h = findobj(ax,'Type','surface');
set(h,'FaceColor',[1 0 0]);
end
```

You must name the setup and teardown functions of a file test fixture `setUpOnce` and `tearDownOnce`, respectively. These functions take a single input argument, `testCase`, into which the test framework automatically passes a function test case object. This test case object contains a `TestData` structure that allows data to pass between setup, test, and teardown functions. In this example, the `TestData` structure uses assigned fields to store the original path, the temporary folder name, and the figure file name.

Create the setup and teardown functions as a local functions to `axesPropertiesTest`.

```
function setUpOnce(testCase)
% create and change to temporary folder
testCase.TestData.origPath = pwd;
testCase.TestData.tmpFolder = ['tmpFolder' datestr(now,30)];
mkdir(testCase.TestData.tmpFolder)
cd(testCase.TestData.tmpFolder)

% create and save a figure
testCase.TestData.figName = 'tmpFig.fig';
aFig = createFigure;
saveas(aFig,testCase.TestData.figName,'fig')
close(aFig)
end

function tearDownOnce(testCase)
delete(testCase.TestData.figName);
cd(testCase.TestData.origPath);
rmdir(testCase.TestData.tmpFolder);
end
```

### Create Fresh Fixture Functions

Fresh fixtures are function level setup and teardown code that runs before and after each test function in your file. In this example, the functions open the saved figure and find the handles. After testing, the framework closes the figure.

You must name fresh fixture functions `setup` and `teardown`, respectively. Similar to the file fixture functions, these functions take a single input argument, `testCase`. In this example, these functions create a new field in the `TestData` structure that includes handles to the figure and to the axes. This allows information to pass between setup, test, and teardown functions.

Create the setup and teardown functions as a local functions to `axesPropertiesTest`. Open the saved figure for each test to ensure test independence.

```
function setup(testCase)
testCase.TestData.Figure = openfig(testCase.TestData.figName);
testCase.TestData.Axes = findobj(testCase.TestData.Figure,...
    'Type', 'Axes');
end

function teardown(testCase)
close(testCase.TestData.Figure);
end
```

In addition to custom setup and teardown code, the Unit Testing Framework provides some classes for creating fixtures. For more information see `matlab.unittest.fixtures`.

### **Create Test Functions**

Each test is a local function that follows the naming convention of having 'test' at the beginning or end of the function name. The test array does not include local functions that do not follow this convention. Similar to setup and teardown functions, individual test functions must accept a single input argument, `testCase`. Use this test case object for verifications, assertions, assumptions, and fatal assertions functions.

The `testDefaultXLim` function test verifies that the  $x$ -axis limits are large enough to display the cylinder. The lower limit needs to be less than -10,

and the upper limit needs to be greater than 10. These values come from the figure generated in the helper function — a cylinder with a 10 unit radius centered on the origin. This test function opens the figure created and saved in the `setupOnce` function, queries the axes limit, and verifies the limits are correct. The qualification functions, `verifyLessThanOrEqualTo` and `verifyGreaterThanOrEqualTo`, takes the test case, the actual value, the expected value, and optional diagnostic information to display in the case of failure as inputs.

Create the `testDefaultXLim` function as local function to `axesPropertiesTest`.

```
function testDefaultXLim(testCase)
xlim = get(testCase.TestData.Axes, 'XLim');
verifyLessThanOrEqualTo(testCase, xlim(1), -10,...
    'Minimum x-limit was not small enough');
verifyGreaterThanOrEqualTo(testCase, xlim(2), 10,...
    'Maximum x-limit was not big enough');
end
```

The `surfaceColorTest` function accesses the figure that you created and saved in the `setupOnce` function. `surfaceColorTest` queries the face color of the cylinder and verifies that it is red. The color red has an RGB value of `[1 0 0]`. The qualification function, `verifyEqual`, takes as inputs the test case, the actual value, the expected value, and optional diagnostic information to display in the case of failure. Typically when using `verifyEqual` on floating point-values, you specify a tolerance for the comparison. For more information, see `matlab.unittest.constraints`.

Create the `surfaceColorTest` function as local function to `axesPropertiesTest`.

```
function surfaceColorTest(testCase)
h = findobj(testCase.TestData.Axes, 'Type', 'surface');
co = get(h, 'FaceColor');
verifyEqual(testCase, co, [1 0 0], 'FaceColor is incorrect')
end
```

Now the `axesPropertiesTest.m` file is complete with a main function, file fixture functions, fresh fixture functions, and two local test functions. You are ready to run the tests.

**Run Tests**

The next step is to run the tests using the `runtests` function. In this example, the call to `runtests` results in the following steps:

- 1 The main function creates a test array.
- 2 The file fixture records the working folder, creates a temporary folder, sets the temporary folder as the working folder, then generates and saves a figure.
- 3 The fresh fixture setup opens the saved figure and finds the handles.
- 4 The `testDefaultXLim` test is run.
- 5 The fresh fixture teardown closes the figure.
- 6 The fresh fixture setup opens the saved figure and finds the handles.
- 7 The `surfaceColorTest` test is run.
- 8 The fresh fixture teardown closes the figure.
- 9 The file fixture teardown deletes the saved figure, changes back to the original path and deletes the temporary folder.

At the command prompt, generate and run the test suite.

```
results = runtests('axesPropertiesTest.m')
```

```
Running axesPropertiesTest
..
Done axesPropertiesTest
```

---

```
results =
```

```
1x2 TestResult array with properties:
```

```
Name  
Passed  
Failed  
Incomplete  
Duration
```

```
Totals:
```

```
  2 Passed, 0 Failed, 0 Incomplete.  
0.81415 seconds testing time.
```

## See Also

`matlab.unittest.fixtures` | `matlab.unittest.constraints`

## Concepts

- “Write Function-Based Unit Tests” on page 29-78
- “Types of Qualifications” on page 29-10