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Syntax Basics

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• “Create Numeric Arrays” on page 1-3
• “Continue Long Statements on Multiple Lines” on page 1-5
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• “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.

\[ x = 5.71; \]
\[ A = \begin{bmatrix} 1 & 2 & 3; \\ 4 & 5 & 6; \\ 7 & 8 & 9 \end{bmatrix}; \]
\[ I = \text{besseli}(x,A); \]

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

\[ \text{ans} = \]
\[ 5.7100 \]

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,

\[
\text{whos } A
\]

returns

\[
\begin{array}{cccc}
\text{Name} & \text{Size} & \text{Bytes} & \text{Class} & \text{Attributes} \\
A & 1x1 & 8 & \text{double} & \\
\end{array}
\]

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).

\[
B =
\begin{bmatrix}
12 & 62 & 93 & -8 & 22 \\
16 & 2 & 87 & 43 & 91 \\
-4 & 17 & -72 & 95 & 6
\end{bmatrix}
\]

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”

1-3
• “Matrix Indexing”
Continue Long Statements on Multiple Lines

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

\[
s = 1 - 1/2 + 1/3 - 1/4 + 1/5 \ldots
- 1/6 + 1/7 - 1/8 + 1/9;
\]

Build a long character string by concatenating shorter strings together:

\[
\text{mystring} = ['Accelerating the pace of ' \ldots
\text{engineering and science'}];
\]

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:

\[
\text{mystring} = 'Accelerating the pace of ...\text{engineering and science'}
\]

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

\[
x = [1.23\ldots
4.56];
\]

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:

\[
\text{max}(A)
\]

Separate multiple inputs with commas:

\[
\text{max}(A,B)
\]

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

\[
\text{maxA} = \text{max}(A)
\]

Enclose multiple outputs in square brackets:

\[
[\text{maxA}, \text{location}] = \text{max}(A)
\]

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

\[
\text{clc}
\]

Enclose text string inputs in single quotation marks:

\[
\text{disp('hello world')}
\]

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.

```matlab
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.

```matlab
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 (~).

```matlab
[~,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

```matlab
[~,~,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:      Invalid names:

x6                           6x
lastValue                    end
n_factorial                  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”

**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® 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.

\[ y = \sin (3 \times \pi) / 2 \]
\[ y = \sin(3\pi)/2 \]

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

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

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.

\[ [1 \ \sin (\pi) \ 3] \]
\[ \text{Error using sin} \]

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

\[
[\text{output}_1, \ldots, \text{output}_M] = \text{functionName}(\text{input}_1, \ldots, \text{input}_N)
\]

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**:

\[
\text{functionName} \ \text{input}_1 \ldots \text{input}_N
\]

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:

\[
\text{disp 'hello world'}
\]

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,
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:

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

The following table illustrates common misapplications of command syntax.

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

**Passing Variable Names**

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

```matlab
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 element-wise 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

In this section...

“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”

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](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
B454554BADECED4258 \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

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

- “Array vs. Matrix Operations” on page 2-2
- “Relational Operators” on page 2-7
- “Operator Precedence” on page 2-9
- “Average Similar Data Points Using a Tolerance” on page 2-11
- “Group Scattered Data Using a Tolerance” on page 2-14
- “Special Values” on page 2-17
- “Conditional Statements” on page 2-19
- “Loop Control Statements” on page 2-21
- “Regular Expressions” on page 2-23
- “Lookahead Assertions in Regular Expressions” on page 2-38
- “Tokens in Regular Expressions” on page 2-41
- “Dynamic Regular Expressions” on page 2-47
- “Comma-Separated Lists” on page 2-55
- “Alternatives to the eval Function” on page 2-64
- “Shell Escape Functions” on page 2-68
- “Symbol Reference” on page 2-69
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.

\[
A = [1 \ 1 \ 1] \\
A = \\
\begin{bmatrix}
1 & 1 & 1
\end{bmatrix}
\]

\[
B = 1:3 \\
B = \\
\begin{bmatrix}
1 & 2 & 3
\end{bmatrix}
\]
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.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Purpose</th>
<th>Description</th>
<th>Reference Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>Addition</td>
<td>A+B adds A and B.</td>
<td>plus</td>
</tr>
</tbody>
</table>
Program Components

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

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.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Purpose</th>
<th>Description</th>
<th>Reference Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>*</td>
<td>Matrix multiplication</td>
<td>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.</td>
<td>mtimes</td>
</tr>
<tr>
<td>/</td>
<td>Matrix right division</td>
<td>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' \ B')'.</td>
<td>mrdivide</td>
</tr>
<tr>
<td>Operator</td>
<td>Purpose</td>
<td>Description</td>
<td>Reference Page</td>
</tr>
<tr>
<td>----------</td>
<td>------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>\</td>
<td>Matrix left division</td>
<td>( x = A\backslash B ) is the solution to the equation ( Ax = B ). Matrices ( A ) and ( B ) must have the same number of rows.</td>
<td>mldivide</td>
</tr>
<tr>
<td>^</td>
<td>Matrix power</td>
<td>( A^B ) is ( A ) to the power ( B ), if ( B ) is a scalar. For other values of ( B ), the calculation involves eigenvalues and eigenvectors.</td>
<td>mpower</td>
</tr>
<tr>
<td>'</td>
<td>Complex conjugate transpose</td>
<td>( A' ) is the linear algebraic transpose of ( A ). For complex matrices, this is the complex conjugate transpose.</td>
<td>ctranspose</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;</td>
<td>Less than</td>
</tr>
<tr>
<td>&lt;=</td>
<td>Less than or equal to</td>
</tr>
<tr>
<td>&gt;</td>
<td>Greater than</td>
</tr>
<tr>
<td>&gt;=</td>
<td>Greater than or equal to</td>
</tr>
<tr>
<td>==</td>
<td>Equal to</td>
</tr>
<tr>
<td>~=</td>
<td>Not equal to</td>
</tr>
</tbody>
</table>

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.

```matlab
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 (.ackslash), 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:

```matlab
A = [3 9 5];
B = [2 1 5];
C = A./B.^2
C =
    0.7500    9.0000    0.2000
```
\[ C = (A./B).^2 \]
\[ C = \begin{array}{ccc}
2.2500 & 81.0000 & 1.0000 \\
\end{array} \]
Average Similar Data Points Using a Tolerance

This example shows how to use `uniquetol` to find the average \( z \)-coordinate of 3-D points that have similar (within tolerance) \( x \) and \( y \) coordinates.

Use random points picked from the `peaks` function in the domain \([-3, 3] \times [-3, 3]\) as the data set. Add a small amount of noise to the data.

\[
\begin{align*}
xy &= \text{rand}(10000,2) \ast 6 - 3; \\
z &= \text{peaks}(xy(:,1), xy(:,2)) + 0.5 \ast \text{rand}(10000,1); \\
A &= [xy \ z]; \\
\text{plot3}(A(:,1), A(:,2), A(:,3), '.') \\
\text{view}(-28,32)
\end{align*}
\]
Find points that have similar x and y coordinates using `uniquetol` with these options:

- Specify `ByRows` as `true`, since the rows of A contain the point coordinates.
- Specify `OutputAllIndices` as `true` to return the indices for all points that are within tolerance of each other.
- Specify `DataScale` as `[1 1 Inf]` to use an absolute tolerance for the x and y coordinates, while ignoring the z-coordinate.

```matlab
DS = [1 1 Inf];
[C,ia] = uniquetol(A, 0.3, 'ByRows', true, ...
    'OutputAllIndices', true, 'DataScale', DS);
```

Average each group of points that are within tolerance (including the z-coordinates), producing a reduced data set that still holds the general shape of the original data.

```matlab
for k = 1:length(ia)
    aveA(k,:) = mean(A(ia{k},:),1);
end
```

Plot the resulting averaged-out points on top of the original data.

```matlab
hold on
plot3(aveA(:,1), aveA(:,2), aveA(:,3), '.r', 'MarkerSize', 15)
```
Group Scattered Data Using a Tolerance

This example shows how to group scattered data points based on their proximity to points of interest.

Create a set of random 2-D points. Then create and plot a grid of equally spaced points on top of the random data.

```matlab
x = rand(10000,2);
[a,b] = meshgrid(0:0.1:1);
gridPoints = [a(:), b(:)];
plot(x(:,1), x(:,2), '.
hold on
plot(gridPoints(:,1), gridPoints(:,2), 'xr', 'Markersize', 6)
```
Use `ismembertol` to locate the data points in \( x \) that are within tolerance of the grid points in `gridPoints`. Use these options with `ismembertol`:

- Specify `ByRows` as `true`, since the point coordinates are in the rows of \( x \).
- Specify `OutputAllIndices` as `true` to return all of the indices for rows in \( x \) that are within tolerance of the corresponding row in `gridPoints`.

\[
[LIA,LocB] = ismembertol(gridPoints, x, 0.05, ... \\
    'ByRows', true, 'OutputAllIndices', true);
\]

For each grid point, plot the points in \( x \) that are within tolerance of that grid point.

```matlab
figure
hold on
for k = 1:length(LocB)
    plot(x(LocB{k},1), x(LocB{k},2), '.')
end
plot(gridPoints(:,1), gridPoints(:,2), 'xr', 'Markersize', 6)
```
Program Components
**Special Values**

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

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

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

\[
x = 2 \times \pi \\
x = 6.2832 \\
A = \begin{bmatrix} 3+2i & 7-8i \end{bmatrix}
\]
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:

```matlab
% 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:

```matlab
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:

```matlab
[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:

```matlab
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:

```matlab
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:

```matlab
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):

```matlab
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):

```matlab
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**.
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:

```matlab
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:

\[
\text{'k' or 'kilo' followed by ...}
\]
\[
\text{'m' or 'meters' followed by ...}
\]
\[
\text{'/' or 'per' followed by ...}
\]
\[
\text{'h' or 'hr' or 'hour'}
\]

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

\[
\text{pattern} = 'k(ilo)?m(eters)?(\//\s)h(\w|our)?';
\]

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

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

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.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>regexp</td>
<td>Match regular expression.</td>
</tr>
<tr>
<td>regexpi</td>
<td>Match regular expression, ignoring case.</td>
</tr>
<tr>
<td>regexprep</td>
<td>Replace part of string using regular expression.</td>
</tr>
<tr>
<td>regexptranslate</td>
<td>Translate string into regular expression.</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Unique patterns of an email address</th>
<th>General description of each pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start with the account name</td>
<td>One or more lowercase letters and underscores</td>
</tr>
<tr>
<td>jan_stephens ...</td>
<td></td>
</tr>
<tr>
<td>Add '@'</td>
<td></td>
</tr>
<tr>
<td>jan_stephens@ ...</td>
<td>@ sign</td>
</tr>
<tr>
<td>Add the ISP</td>
<td>One or more lowercase letters, no underscores</td>
</tr>
<tr>
<td>jan_stephens@horizon ...</td>
<td></td>
</tr>
<tr>
<td>Add a dot (period)</td>
<td>Dot (period) character</td>
</tr>
<tr>
<td>jan_stephens@horizon. ...</td>
<td></td>
</tr>
<tr>
<td>Finish with the domain</td>
<td>com or net</td>
</tr>
<tr>
<td><a href="mailto:jan_stephens@horizon.net">jan_stephens@horizon.net</a></td>
<td></td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Description of each segment</th>
<th>Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>One or more lowercase letters and underscores</td>
<td>[a-z_]+</td>
</tr>
<tr>
<td>@ sign</td>
<td>@</td>
</tr>
<tr>
<td>One or more lowercase letters, no underscores</td>
<td>[a-z]+</td>
</tr>
<tr>
<td>Dot (period) character</td>
<td>.</td>
</tr>
<tr>
<td>com or net</td>
<td>(com</td>
</tr>
</tbody>
</table>
Assembling these patterns into one string gives you the complete expression:

```plaintext
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:

```plaintext
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:

```plaintext
eemail = '[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.

```plaintext
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:

```plaintext
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:

```plaintext
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 2-28
- “Character Representation” on page 2-29
- “Quantifiers” on page 2-30
- “Grouping Operators” on page 2-31
- “Anchors” on page 2-32
- “Lookaround Assertions” on page 2-32
- “Logical and Conditional Operators” on page 2-33
- “Token Operators” on page 2-34
- “Dynamic Expressions” on page 2-35
- “Comments” on page 2-36
- “Search Flags” on page 2-37

Metacharacters

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

<table>
<thead>
<tr>
<th>Metacharacter</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>.</td>
<td>Any single character, including white space</td>
<td>'...ain' matches sequences of five consecutive characters that end with 'ain'.</td>
</tr>
<tr>
<td>[c₁c₂c₃]</td>
<td>Any character contained within the brackets. The following characters are treated literally: $</td>
<td>.</td>
</tr>
<tr>
<td>[^c₁c₂c₃]</td>
<td>Any character not contained within the brackets. The following characters are treated literally: $</td>
<td>.</td>
</tr>
<tr>
<td>Metacharacter</td>
<td>Description</td>
<td>Example</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------</td>
<td>---------</td>
</tr>
<tr>
<td>[c_1-c_2]</td>
<td>Any character in the range of (c_1) through (c_2)</td>
<td>' [A-G] ' matches a single character in the range of A through G.</td>
</tr>
<tr>
<td>\w</td>
<td>Any alphabetic, numeric, or underscore character. For English character sets, \w is equivalent to [a-zA-Z_0-9]</td>
<td>'\w*' identifies a word.</td>
</tr>
<tr>
<td>\W</td>
<td>Any character that is not alphabetic, numeric, or underscore. For English character sets, \W is equivalent to [^a-zA-Z_0-9]</td>
<td>'\W*' identifies a substring that is not a word.</td>
</tr>
<tr>
<td>\s</td>
<td>Any white-space character; equivalent to [ \f\n\r\t\v]</td>
<td>'\w*n\s' matches words that end with the letter n, followed by a white-space character.</td>
</tr>
<tr>
<td>\S</td>
<td>Any non-white-space character; equivalent to [^ \f\n\r\t\v]</td>
<td>'\d \S' matches a numeric digit followed by any non-white-space character.</td>
</tr>
<tr>
<td>\d</td>
<td>Any numeric digit; equivalent to [0-9]</td>
<td>'\d*' matches any number of consecutive digits.</td>
</tr>
<tr>
<td>\D</td>
<td>Any nondigit character; equivalent to [^0-9]</td>
<td>'\w\D&gt;' matches words that do not end with a numeric digit.</td>
</tr>
<tr>
<td>\oN or \o{N}</td>
<td>Character of octal value N</td>
<td>'\o{40}' matches the space character, defined by octal 40.</td>
</tr>
<tr>
<td>\xN or \x{N}</td>
<td>Character of hexadecimal value N</td>
<td>'\x2C' matches the comma character, defined by hex 2C.</td>
</tr>
</tbody>
</table>

**Character Representation**

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>\a</td>
<td>Alarm (beep)</td>
</tr>
<tr>
<td>\b</td>
<td>Backspace</td>
</tr>
<tr>
<td>\f</td>
<td>Form feed</td>
</tr>
<tr>
<td>\n</td>
<td>New line</td>
</tr>
<tr>
<td>\r</td>
<td>Carriage return</td>
</tr>
<tr>
<td>\t</td>
<td>Horizontal tab</td>
</tr>
</tbody>
</table>
Program Components

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>\v</td>
<td>Vertical tab</td>
</tr>
<tr>
<td>\char</td>
<td>Any character with special meaning in regular expressions that you want to match literally (for example, use \ to match a single backslash)</td>
</tr>
</tbody>
</table>

Quantifiers

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

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

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

<table>
<thead>
<tr>
<th>Mode</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>exprq</td>
<td>Greedy expression: match as many characters as possible.</td>
<td>Given the string '&lt;tr&gt;&lt;td&gt;&lt;p&gt;text&lt;/p&gt;&lt;/td&gt;', the expression '&lt;/?t.*&gt;' matches all characters between &lt;tr and /td&gt;:</td>
</tr>
</tbody>
</table>
### Regular Expressions

<table>
<thead>
<tr>
<th>Mode</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
</table>
| expr? | Lazy expression: match as few characters as necessary. | Given the string `<tr><td><p>text</p></td>'
the expression `</?t.*>*>' ends each match at the first occurrence of the closing bracket (>):<br>`<tr>' '<td>' '</td>' |
| expr+ | 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.

<table>
<thead>
<tr>
<th>Grouping Operator</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>(expr)</td>
<td>Group elements of the expression and capture tokens.</td>
<td>'Joh?n\s(\w*)' captures a token that contains the last name of any person with the first name John or Jon.</td>
</tr>
<tr>
<td>(?::expr)</td>
<td>Group, but do not capture tokens.</td>
<td>'(?:[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.</td>
</tr>
<tr>
<td>(?&gt;expr)</td>
<td>Group atomically. Do not backtrack within the group to complete the match, and do not capture tokens.</td>
<td>'A(?&gt;.<em>)Z' does not match 'AtoZ', although 'A(?::)Z' does. Using the atomic group, Z is captured using .</em> and is not rescanned.</td>
</tr>
<tr>
<td>(expr1</td>
<td>expr2)</td>
<td>Match expression expr1 or expression expr2.</td>
</tr>
</tbody>
</table>
### Grouping

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>expr1</td>
<td>If there is a match with $expr1$, then $expr2$ is ignored. You can include ?: or ?&gt; after the opening parenthesis to suppress tokens or group atomically.</td>
<td></td>
</tr>
</tbody>
</table>

### Anchors

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

<table>
<thead>
<tr>
<th>Anchor</th>
<th>Matches the...</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>^expr</td>
<td>Beginning of the input string.</td>
<td>'^M\w*' matches a word starting with M at the beginning of the string.</td>
</tr>
<tr>
<td>expr$</td>
<td>End of the input string.</td>
<td>'\w*m$' matches words ending with m at the end of the string.</td>
</tr>
<tr>
<td>&lt;expr</td>
<td>Beginning of a word.</td>
<td>'&lt;\n\w*' matches any words starting with n.</td>
</tr>
<tr>
<td>expr&gt;</td>
<td>End of a word.</td>
<td>'\w*e&gt;' matches any words ending with e.</td>
</tr>
</tbody>
</table>

### 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.

<table>
<thead>
<tr>
<th>Lookaround Assertion</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>expr(?=test)</td>
<td>Look ahead for characters that match test.</td>
<td>'\w*(?=ing)' matches strings that are followed by ing, such as 'Fly' and 'fall' in the input string 'Flying, not falling.'</td>
</tr>
</tbody>
</table>
### Lookaround Assertion

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

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

### Logical and Conditional Operators

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

For more information, see “Lookahead Assertions in Regular Expressions” on page 2-38.

### 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 2-32.)

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

<table>
<thead>
<tr>
<th>Conditional Operator</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>`expr1</td>
<td>expr2`</td>
<td>Match expression <code>expr1</code> or expression <code>expr2</code>.</td>
</tr>
</tbody>
</table>
### Conditional Operator

<table>
<thead>
<tr>
<th>Conditional Operator</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(cond)expr$</td>
<td>If condition cond is true, then match expr.</td>
<td>'$(?(@ispc)[A-Z]:\)' matches a drive name, such as C:, when run on a Windows system.</td>
</tr>
<tr>
<td>$(cond)expr1</td>
<td>expr2$</td>
<td>If condition cond is true, then match expr1. Otherwise, match expr2.</td>
</tr>
</tbody>
</table>

### 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.

<table>
<thead>
<tr>
<th>Ordinal Token Operator</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(expr)$</td>
<td>Capture in a token the characters that match the enclosed expression.</td>
<td>'Joh?n\s(\w*)' captures a token that contains the last name of any person with the first name John or Jon.</td>
</tr>
<tr>
<td>$\N$</td>
<td>Match the Nth token.</td>
<td>'&lt;=(\w+).<em>.</em>/1&gt;' captures tokens for HTML tags, such as 'title' from the string '=&lt;title&gt;Some text&lt;/title&gt;'.</td>
</tr>
<tr>
<td>$(N)expr1</td>
<td>expr2$</td>
<td>If the Nth token is found, then match expr1. Otherwise, match expr2.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Named Token Operator</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
</table>
| $(<name>expr)$       | 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
### Named Token Operator

<table>
<thead>
<tr>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Match the token referred to by name.</td>
<td>'&lt;(&lt;tag&gt;[^&gt;]*&lt;/&lt;tag&gt;&gt;)' captures tokens for HTML tags, such as 'title' from the string '&lt;title&gt;Some text&lt;/title&gt;'.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parse expr and include the resulting string in the match expression. When parsed, expr must correspond to a complete, valid regular expression. Dynamic expressions that use the backslash escape character () require two backslashes: one for the backslash and one for the special character.</td>
<td>'^(\d+)((??\w{$1}))' 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</td>
<td></td>
</tr>
</tbody>
</table>
Program Components

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>initial parsing of <code>expr</code>, and one for the complete match.</td>
<td>'5XXXXX' captures tokens for '5' and 'XXXXX'.</td>
<td></td>
</tr>
<tr>
<td><code>(??@cmd)</code></td>
<td>Execute the MATLAB command represented by <code>cmd</code>, and include the string returned by the command in the match expression.</td>
<td>'(.{2,}).?(@flip1r($1))' finds palindromes that are at least four characters long, such as 'abba'.</td>
</tr>
<tr>
<td><code>(??@cmd)</code></td>
<td>Execute the MATLAB command represented by <code>cmd</code>, but discard any output the command returns. (Helpful for diagnosing regular expressions.)</td>
<td>'\w*?(@disp($1))\1\w*' matches words that include double letters (such as pp), and displays intermediate results.</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Replacement String Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>&amp;&amp;</code> or <code>$0</code></td>
<td>Portion of the input string that is currently a match</td>
</tr>
<tr>
<td><code>$</code></td>
<td>Portion of the input string that precedes the current match</td>
</tr>
<tr>
<td><code>$</code></td>
<td>Portion of the input string that follows the current match (use <code>$'</code> to represent the string <code>$'</code>)</td>
</tr>
<tr>
<td><code>$N</code></td>
<td>Nth token</td>
</tr>
<tr>
<td><code>$&lt;name&gt;</code></td>
<td>Named token</td>
</tr>
<tr>
<td><code>${cmd}</code></td>
<td>String returned when MATLAB executes the command, <code>cmd</code></td>
</tr>
</tbody>
</table>

For more information, see “Dynamic Regular Expressions” on page 2-47.

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.

<table>
<thead>
<tr>
<th>Characters</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>(?#comment)</code></td>
<td>Insert a comment in the regular expression. The comment text is ignored when matching the input string.</td>
<td>'(@(# Initial digit)&lt;\d\w+) includes a comment, and matches words that begin with a number.</td>
</tr>
</tbody>
</table>
Search Flags

Search flags modify the behavior for matching expressions.

<table>
<thead>
<tr>
<th>Flag</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(?!i)</td>
<td>Match letter case (default for regexp and regexprprep).</td>
</tr>
<tr>
<td>(?!i)</td>
<td>Do not match letter case (default for regexpi).</td>
</tr>
<tr>
<td>(?s)</td>
<td>Match dot (.) in the pattern string with any character (default).</td>
</tr>
<tr>
<td>(?-s)</td>
<td>Match dot in the pattern with any character that is not a newline character.</td>
</tr>
<tr>
<td>(?-m)</td>
<td>Match the ^ and $ metacharacters at the beginning and end of a string (default).</td>
</tr>
<tr>
<td>(?m)</td>
<td>Match the ^ and $ metacharacters at the beginning and end of a line.</td>
</tr>
<tr>
<td>(?-x)</td>
<td>Include space characters and comments when matching (default).</td>
</tr>
<tr>
<td>(?x)</td>
<td>Ignore space characters and comments when matching. Use '\ ' and '#' to match space and # characters.</td>
</tr>
</tbody>
</table>

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 | regexprprep | regexptranslate

More About
- “Lookahead Assertions in Regular Expressions” on page 2-38
- “Tokens in Regular Expressions” on page 2-41
- “Dynamic Regular Expressions” on page 2-47
Lookahead Assertions in Regular Expressions

In this section...

“Lookahead Assertions” on page 2-38
“Overlapping Matches” on page 2-38
“Logical AND Conditions” on page 2-39

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 \( ?=\text{test} \) 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, \texttt{fileread.m}).

\[
\text{str} = \text{which('fileread')} \\
\text{str} = \\
\texttt{matlabroot\toolbox\matlab\iofun\fileread.m} \\
\text{regexp(str,'\w+(?=\\\w+.m)'),'match'} \\
\text{ans} = \\
\texttt{'iofun'}
\]

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

```matlab
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. phrase phrases

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.

```matlab
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:

```matlab
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:

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

```matlab
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`:

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

**See Also**

`regexp` | `regexpi` | `regexpdef`

**More About**

- “Regular Expressions” on page 2-23
Tokens in Regular Expressions

In this section...

“Introduction” on page 2-41
“Multiple Tokens” on page 2-42
“Unmatched Tokens” on page 2-43
“Tokens in Replacement Strings” on page 2-44
“Named Capture” on page 2-44

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:

```matlab
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:
Program Components

'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.

<table>
<thead>
<tr>
<th>Match</th>
<th>Token 1</th>
<th>Token 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>andy</td>
<td>y</td>
<td></td>
</tr>
<tr>
<td>ted</td>
<td>t</td>
<td>d</td>
</tr>
<tr>
<td>andrew</td>
<td>rew</td>
<td></td>
</tr>
<tr>
<td>andy</td>
<td>y</td>
<td></td>
</tr>
<tr>
<td>ted</td>
<td>t</td>
<td>d</td>
</tr>
</tbody>
</table>

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

**Unmatched Tokens**

For those tokens specified in the regular expression that have no match in the string being evaluated, \texttt{regexp} and \texttt{regexpi} 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 \texttt{regexp} on the path string \texttt{str} returned from the MATLAB \texttt{tempdir} function. The regular expression \texttt{expr} includes six token specifiers, one for each piece of the path string. The third specifier \texttt{[a-z]+} has no match in the string because this part of the path, \texttt{Profiles}, begins with an uppercase letter:

\begin{verbatim}
str = tempdir
str = C:\WINNT\Profiles\bpascal\LOCALS-1\Temp\nexpr = '\([A-Z]:\\((WINNT)\\([a-z]+)?.*\\)\) \(...\)\\([a-z]+)\\([A-Z]+~\d)\\(Temp)\);n[tok, ext] = regexp(str, expr, 'tokens', 'tokenExtents');
\end{verbatim}
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:

\[
\text{tok{:}}
\]
\[
\text{ans =}
\]
\[
'\text{C'}', '\text{WINNT}', '', 'bpascal', '\text{LOCALS-1}', 'Temp'
\]

The third token extent returned in the variable \text{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:

\[
\text{ext{:}}
\]
\[
\text{ans =}
\]
\[
1 \quad 2
4 \quad 8
10 \quad 9
19 \quad 25
27 \quad 34
36 \quad 39
\]

**Tokens in Replacement Strings**

When using tokens in a replacement string, reference them using $1$, $2$, etc. instead of \textbackslash 1, \textbackslash 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 \texttt{regexprep} returns the modified string, not a vector of starting indices.

\[
\text{regexprep('Norma Jean Baker', '([w+\s\w+])s(\w+)', '$2$, $1$')}
\]
\[
\text{ans =}
\]
\[
\text{Baker, Norma Jean}
\]

**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.:

```matlab
poest = ['While I nodded, nearly napping, ' ...
    'suddenly there came a tapping,'];

regexp(poest, '(?<anychar>.)(?<=\k<anychar>)', 'match')
```

```matlab
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:

```matlab
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:

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

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

See Also
regexp | regexpi | regexp

More About
- “Regular Expressions” on page 2-23
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:

```matlab
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:

```matlab
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)
```
Using a dynamic expression \( \texttt{\{num2str(length($2))\}} \) 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 \( \texttt{\{cmd\}} \).

\[
\text{match\_expr} = '(^\w)(\w*)(\w$)';
\text{replace\_expr} = '\$1\texttt{\{num2str(length($2))\}}\$3';
\]

\[
\text{regexp}('\text{internationalization}', \text{match\_expr}, \text{replace\_expr})
\]

\[
\text{ans} = \text{i18n}
\]

\[
\text{regexp}('\text{globalization}', \text{match\_expr}, \text{replace\_expr})
\]

\[
\text{ans} = \text{g11n}
\]

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 — \( \text{(??expr)} \)**

The \( \text{(??expr)} \) operator parses expression \( \text{expr} \), 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:

\[
\text{str} = \{'5XXXXX', '8XXXXXXXX', '1X'\};
\text{regexp}(\text{str}, '^\texttt{\{\(d\)\(??X\{$1\}\)\}}$', '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 \( X \)s 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:

```matlab
regexp(str, '^\d+(?X{\d+})X$', 'match', 'once')
```

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.

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

Locate the palindrome within the string using the dynamic expression:

```matlab
palstr = regexp(str, '(\{3,\}).?(??@fliplr($1))', 'match')
```

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:

```matlab
fun = @fliplr;

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

```matlab
palstr =
 'neveroddoreven'
```

### 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:

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

```matlab
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:

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

```matlab
i
p
p
```
ans =
   'mississippi'

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

```matlab
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:

```matlab
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:

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

regexp('Euler Cauchy Boole', expr);
```

matches

matches =
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 — $\{\text{cmd}\}$**

The $\{\text{cmd}\}$ 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 '$\{\text{convertMe}(\$1,\$2)\}'.

In this case, the entire replacement string is a dynamic expression:

```
regexprep('This highway is 125 miles long', ...)
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.

```matlab
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:

```matlab
regexprep('This highway is 125 miles long', ...
    '(%d+\.?d*)%w\(\w+\)', '{convertMe($1,$2)}')
ans =
    This highway is 201.1625 kilometers long
```

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

2-53
This pitcher holds 1.1828 litres of water

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

\[
\text{ans =}
\text{This stone weighs about 4.536 kilograms}
\]

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:

\[
A = \text{magic}(3)
\]

\[
A =
\begin{bmatrix}
8 & 1 & 6 \\
3 & 5 & 7 \\
4 & 9 & 2 \\
\end{bmatrix}
\]

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

\[
\text{ans =}
\text{The columns of matrix A are 834 159 672}
\]

**See Also**
regexp | regexpi | regexp

**More About**
* “Regular Expressions” on page 2-23
Comma-Separated Lists

In this section...

“What Is a Comma-Separated List?” on page 2-55
“Generating a Comma-Separated List” on page 2-55
“Assigning Output from a Comma-Separated List” on page 2-57
“Assigning to a Comma-Separated List” on page 2-58
“How to Use the Comma-Separated Lists” on page 2-60
“Fast Fourier Transform Example” on page 2-62

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:

\[
1, 2, 3
\]

\[
\text{ans} =
\]

\[
\begin{align*}
1 \\
2 \\
3
\end{align*}
\]

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

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

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

```matlab
C{:,5}
```

ans =

34

ans =

36

ans =

38

ans =

40

This is the same as explicitly typing

```matlab
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:

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

\[
S.f5
\]

\[
\begin{align*}
\text{ans} &= 34 \\
\text{ans} &= 36 \\
\text{ans} &= 38 \\
\text{ans} &= 40
\end{align*}
\]

This is the same as explicitly typing

\[
\]

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:

\[
C = \text{cell}(4,6);
\]

\[
\text{for } k = 1:24 \\
\quad C\{k\} = k*2;
\]

\[
\text{2-57}
\]
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 = \text{cell2struct}(C,\{'f1','f2','f3','f4','f5','f6'\},2);
\[
[sf1,sf2,sf3] = S.f5;
\]

You also can use the \texttt{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 \texttt{deal} function. This function distributes all of its input arguments to the elements of a comma-separated list.

This example uses \texttt{deal} to overwrite each element in a comma-separated list. First create a list.

\[
c\{1\} = [31 ~ 07];
\]
\[
c\{2\} = [03 ~ 78];
\]
\[
c\{::\}
\]

\[
\text{ans} = \\
31 ~ 7
\]

\[
\text{ans} = \\
\]
3    78

Use `deal` to overwrite each element in the list.

```matlab
[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:

```matlab
s(1).field1 = [31 07];
s(2).field1 = [03 78];
s.field1
```
```
ans =
    31     7
ans =
    3     78
```

Use `deal` to overwrite the structure fields.

```matlab
[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 2-60
- “Displaying Arrays” on page 2-60
- “Concatenation” on page 2-61
- “Function Call Arguments” on page 2-61
- “Function Return Values” on page 2-62

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 =

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

ans =

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

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

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 = cell(2,3);
C{1,1} = 'LineWidth';
C{2,1} = 2;
C{1,2} = 'MarkerEdgeColor';
C{2,2} = 'k';
C{1,3} = 'MarkerFaceColor';
C{2,3} = 'g';
figure
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 \texttt{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, \texttt{fftshift} performs this swap along each dimension.

\texttt{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, \texttt{fftshift} must construct an index vector for each dimension. A comma-separated list makes this task much simpler.

Here is the \texttt{fftshift} function:

\begin{verbatim}
function y = fftshift(x)
    numDims = ndims(x);
    idx = cell(1,numDims);
    for k = 1:numDims
        m = size(x,k);
        idx{k} = (1:m/2) + (m/2+1:m);
        idx{k} = [m:-1:m/2 idx{k} m/2+1:m];
    end
    y = reshape(x, idx{:});
end
\end{verbatim}
p = ceil(m/2);
idx{k} = [p+1:m 1:p];
end
y = x(idx{:});
end

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:

```matlab
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

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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”
• “Create a Structure Array”

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:

```matlab
cnumFiles = 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”
- “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:

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

  ```matlab
  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:

```matlab
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”.

**Error Handling**

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

```matlab
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.

```matlab
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

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</tr>
</tbody>
</table>

### 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” for more information.
**Class Folder Designator**

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

```matlab
@include\get.m
```

See the documentation on “Class and Path 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

```matlab
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

```matlab
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:

```matlab
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:

```matlab
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:

\[ A = \text{rand}(3,4); \]
\[ A(:) = 1:12; \]

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:

\[ \text{function } [\text{data}, \text{text}] = \text{xlsread}(\text{file}, \text{sheet}, \text{range}, \text{mode}) \]

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:

\[ \text{for } k = 1:10, \quad \text{sum}(A(k)), \quad \text{end} \]

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:
\[
C = \{[2.6 \ 4.7 \ 3.9], \text{rand}(8)\ast6, \ 'C. \ Coolidge'\}
\]

**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:

\[\text{funds}(5,2).\text{bondtype} = 'Corporate';\]

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:

\[\text{val} = \text{asset.current_value}\]

**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

\[\text{cd} \ldots\ldots\text{test}\]
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:

```matlab
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:

```matlab
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:

```matlab
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,

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

is equivalent to
not_valid = [1 2 zeros (1,3)]

which returns an error. Place the ellipsis 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” 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 2-68 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 \( \mathbf{x} = (1:10) \)) 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”. 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” 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.

```markdown
{%
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:

```matlab
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:

```matlab
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:

\[
A = 12.5; \quad B = 42.7, \quad C = 1.25;
\]

\[
B = 42.7000
\]

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

\[
A = [5.92 \ 8.13 \ 3.53]
\]

\[
A = \\
5.9200 \quad 8.1300 \quad 3.5300
\]
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:

```matlab
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:

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

On a UNIX system, use only the forward slash:

```matlab
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:

```matlab
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:

```matlab
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:

\[ \text{[data, text]} = \text{xlsread(file, sheet, range, mode)} \]

**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 \( a\neq b \):

\[
a = \text{primes}(29); \quad b = [2 \ 4 \ 6 \ 7 \ 11 \ 13 \ 20 \ 22 \ 23 \ 29]; \\
\text{not\_prime} = b(a\neq b) \\
\text{not\_prime} = 4 \quad 6 \quad 20 \quad 22
\]

**Logical NOT**

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

\[
a = [35 \ 42 \ 0 \ 18 \ 0 \ 0 \ 0 \ 16 \ 34 \ 0]; \\
\text{\_\_a} \\
\text{ans} = \\
0 \quad 0 \quad 1 \quad 0 \quad 1 \quad 1 \quad 1 \quad 0 \quad 0 \quad 1
\]

**Argument Placeholder**

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

\[
[\text{\_\_, \_\_, filenameExt}] = \text{fileparts(fileSpec)};
\]

See “Ignore Function Inputs” in the MATLAB Programming documentation for more information.
Classes (Data Types)
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.

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Documentation</th>
<th>Intended Use</th>
</tr>
</thead>
</table>
| `double, single`     | Floating-Point Numbers    | • Required for fractional numeric data.  
                        |                           | • Double and Single precision.  
                        |                           | • Use `realmin` and `realmax` to show range of values.  
                        |                           | • Two-dimensional arrays can be sparse.  
                        |                           | • Default numeric type in MATLAB.            |
| `int8, uint8, int16, uint16, int32, uint32, int64, uint64` | Integers                  | • Use for signed and unsigned whole numbers.  
                        |                           | • More efficient use of memory.  
                        |                           | • Use `intmin` and `intmax` to show range of values.  
                        |                           | • Choose from 4 sizes (8, 16, 32, and 64 bits). |
| `char`               | “Characters and Strings”   | • Data type for text.  
                        |                           | • Native or Unicode®.  
                        |                           | • Converts to/from numeric.  
                        |                           | • Use with regular expressions.  
                        |                           | • For multiple strings, use cell arrays.      |
| `logical`            | “Logical Operations”      | • Use in relational conditions or to test state.  
                        |                           | • Can have one of two values: `true` or `false`.  
                        |                           | • Also useful in array indexing.  
                        |                           | • Two-dimensional arrays can be sparse.        |
| `function_handle`    | “Function Handles”        | • Pointer to a function.  
                        |                           | • Enables passing a function to another function |
                        |                           | • Can also call functions outside usual scope.
<table>
<thead>
<tr>
<th>Class Name</th>
<th>Documentation</th>
<th>Intended Use</th>
</tr>
</thead>
</table>
|            |               | • Useful in Handle Graphics callbacks.  
|            |               | • Save to MAT-file and restore later.  |
| table      | “Tables”      | • Rectangular container for mixed-type, column-oriented  
|            |               |   data.  
|            |               | • Row and variable names identify contents.  
|            |               | • Use **Table Properties** to store metadata such as  
|            |               |   variable units.  
|            |               | • Manipulation of elements similar to numeric or logical  
|            |               |   arrays.  
|            |               | • Access data by numeric or named index.  
|            |               | • Can select a subset of data and preserve the table  
|            |               |   container or can extract the data from a table.  |
| struct     | “Structures”  | • Fields store arrays of varying classes and sizes.  
|            |               | • Access one or all fields/indices in single operation.  
|            |               | • Field names identify contents.  
|            |               | • Method of passing function arguments.  
|            |               | • Use in comma-separated lists.  
|            |               | • More memory required for overhead  |
| cell       | “Cell Arrays” | • Cells store arrays of varying classes and sizes.  
|            |               | • Allows freedom to package data as you want.  
|            |               | • Manipulation of elements is similar to numeric or logical  
|            |               |   arrays.  
|            |               | • Method of passing function arguments.  
|            |               | • Use in comma-separated lists.  
|            |               | • More memory required for overhead  |

**More About**

- “Valid Combinations of Unlike Classes”
Numeric Classes

- “Integers” on page 4-2
- “Floating-Point Numbers” on page 4-6
- “Complex Numbers” on page 4-16
- “Infinity and NaN” on page 4-18
- “Identifying Numeric Classes” on page 4-21
- “Display Format for Numeric Values” on page 4-22
- “Function Summary” on page 4-25
Integers

In this section...

“Integer Classes” on page 4-2
“Creating Integer Data” on page 4-3
“Arithmetic Operations on Integer Classes” on page 4-4
“Largest and Smallest Values for Integer Classes” on page 4-5
“Integer Functions” on page 4-5

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:

<table>
<thead>
<tr>
<th>Class</th>
<th>Range of Values</th>
<th>Conversion Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signed 8-bit integer</td>
<td>(-2^7 \text{ to } 2^7 - 1)</td>
<td>int8</td>
</tr>
<tr>
<td>Signed 16-bit integer</td>
<td>(-2^{15} \text{ to } 2^{15} - 1)</td>
<td>int16</td>
</tr>
<tr>
<td>Signed 32-bit integer</td>
<td>(-2^{31} \text{ to } 2^{31} - 1)</td>
<td>int32</td>
</tr>
<tr>
<td>Signed 64-bit integer</td>
<td>(-2^{63} \text{ to } 2^{63} - 1)</td>
<td>int64</td>
</tr>
<tr>
<td>Unsigned 8-bit integer</td>
<td>0 \text{ to } 2^8 - 1</td>
<td>uint8</td>
</tr>
<tr>
<td>Unsigned 16-bit integer</td>
<td>0 \text{ to } 2^{16} - 1</td>
<td>uint16</td>
</tr>
<tr>
<td>Unsigned 32-bit integer</td>
<td>0 \text{ to } 2^{32} - 1</td>
<td>uint32</td>
</tr>
</tbody>
</table>
### 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

```matlab
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:

```matlab
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:

```matlab
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:

```matlab
int16(325) * 4.39
ans =
1427
```
The integer conversion functions are also useful when converting other classes, such as strings, to integers:

```matlab
str = 'Hello World';
int8(str)
ans =
   72  101  108  108  111   32   87  111  114  108  100
```

If you convert a NaN value into an integer class, the result is a value of 0 in that integer class. For example,

```matlab
int32(NaN)
ans =
   0
```

**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:

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

  ```matlab
  x = uint32([132 347 528]) .* 75.49;
class(x)
anss =
   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 4-2 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 \texttt{intmax} and \texttt{intmin} functions:

\begin{verbatim}
intmax('int8') intmin('int8')
\end{verbatim}

\begin{verbatim}
ans = ans =
127 -128
\end{verbatim}

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,

\begin{verbatim}
x = int8(300) x = int8(-300)
x = x =
127 -128
\end{verbatim}

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:

\begin{verbatim}
x = int8(100) * 3 x = int8(-100) * 3
x = x =
127 -128
\end{verbatim}

Integer Functions

See Integer Functions for a list of functions most commonly used with integers in MATLAB.
Floating-Point Numbers

In this section...

“Double-Precision Floating Point” on page 4-6
“Single-Precision Floating Point” on page 4-6
“Creating Floating-Point Data” on page 4-7
“Arithmetic Operations on Floating-Point Numbers” on page 4-8
“Largest and Smallest Values for Floating-Point Classes” on page 4-9
“Accuracy of Floating-Point Data” on page 4-11
“Avoiding Common Problems with Floating-Point Arithmetic” on page 4-12
“Floating-Point Functions” on page 4-14
“References” on page 4-14

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:

<table>
<thead>
<tr>
<th>Bits</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>Sign (0 = positive, 1 = negative)</td>
</tr>
<tr>
<td>62 to 52</td>
<td>Exponent, biased by 1023</td>
</tr>
<tr>
<td>51 to 0</td>
<td>Fraction f of the number 1.f</td>
</tr>
</tbody>
</table>

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:
Floating-Point Numbers

<table>
<thead>
<tr>
<th>Bits</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>Sign (0 = positive, 1 = negative)</td>
</tr>
<tr>
<td>30 to 23</td>
<td>Exponent, biased by 127</td>
</tr>
<tr>
<td>22 to 0</td>
<td>Fraction ( f ) of the number 1.f</td>
</tr>
</tbody>
</table>

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
Floating-Point Numbers

- 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;

\[
\text{class(c)}
\]
\[
\text{ans} = \text{double}
\]

\[
\text{char(c)}
\]
\[
\text{ans} = \text{UPPERCASE}
\]

**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:

\[
x = \text{single}([1.32 \ 3.47 \ 5.28]) .* 7.5;
\]

\[
\text{class(x)}
\]
\[
\text{ans} = \text{single}
\]

**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:

```matlab
str = 'The range for double is:
\t%g to %g and
\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:

```matlab
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:

```matlab
str = 'The range for single is:
\t%g to %g and
\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:

```matlab
realmax('single') + .0001e+038
ans =
```
Inf
-realmx('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 + eps(5). If a double-precision computation returns the answer 5, the result is only accurate to within eps(5).

The value of eps(x) depends on x. This example shows that, as x gets larger, so does eps(x):

eps(50)
ans =
  7.105427357601002e-15

If you enter eps with no input argument, MATLAB returns the value of 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,

\[
x = \text{single}(5);
\text{eps}(x)
\]

returns

\[
\text{ans} = 4.7684 \times 10^{-07}
\]

Note that this result is larger than \( \text{eps}(5) \). 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`, \( \text{eps}(\text{single}(x)) \) 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

\[
\text{double}(	ext{single}(3.14) - 3.14)
\]

\[
\text{ans} = 1.0490 \times 10^{-07}
\]

The amount that \( 3.14 \) is rounded is less than

\[
\text{eps}(\text{single}(3.14))
\]

\[
\text{ans} = 2.3842 \times 10^{-07}
\]

**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.

\[
e = 1 - 3 \times (\frac{4}{3} - 1)
\]

\[
e = 2.2204e-16
\]

Similarly, 0.1 is not exactly representable as a binary number. Thus, you get the following nonintuitive behavior:

\[
a = 0.0;
\]

\[
for \ i = 1:10
\]

\[
\quad a = a + 0.1;
\]

\[
end
\]

\[
a == 1
\]

\[
ans = 0
\]

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:

\[
\sin(\pi)
\]

\[
ans =
\]
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).

\[
\sqrt{1.0 \times 10^{-16} + 1} - 1
\]

\[
\text{ans} = 0
\]

Some functions in MATLAB, such as \texttt{expm1} and \texttt{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:

\[
A = \text{diag([2 eps])};
\]
\[
b = [2; eps];
\]
\[
y = A \backslash b;
\]

\text{Warning: Matrix is close to singular or badly scaled.}
\text{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 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


Complex Numbers

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:

```matlab
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:

```matlab
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:

```matlab
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 =
```
Complex Numbers

-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 for a list of functions most commonly used with MATLAB complex numbers in MATLAB.
Infinity and NaN

In this section...

“Infinity” on page 4-18
“NaN” on page 4-18
“Infinity and NaN Functions” on page 4-20

Infinity

MATLAB represents infinity by the special value \( \text{inf} \). 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 \( \text{inf} \) 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.

\[
\begin{array}{ll}
\text{x} &= \text{1/0} \\
\text{x} &= 1.\text{e}1000 \\
\text{x} &= \text{inf} \\
\text{x} &= \text{exp}(1000) \\
\text{x} &= \text{log}(0) \\
\text{x} &= -\text{inf}
\end{array}
\]

Use the \( \text{isinf} \) function to verify that \( x \) is positive or negative infinity:

\[
\begin{align*}
\text{x} &= \text{log}(0) \\
\text{isinf}(x) \\
\text{ans} &= 1
\end{align*}
\]

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 \( \text{inf}/\text{inf} \) result in NaN, as do any arithmetic operations involving a NaN:
\[
x = 0/0 \\
x = \\
\text{NaN}
\]

You can also create NaNs by:

\[
x = \text{NaN};
\]

\[
\text{whos x}
\]

\[
\begin{array}{llll}
\text{Name} & \text{Size} & \text{Bytes} & \text{Class} \\
\hline
x & 1x1 & 8 & \text{double}
\end{array}
\]

The NaN function returns one of the IEEE arithmetic representations for NaN as a double scalar value. The exact bit-wise hexadecimal representation of this NaN value is,

\[
\text{format hex}
\]

\[
x = \text{NaN}
\]

\[
x = \\
fff8000000000000
\]

Always use the isnan function to verify that the elements in an array are NaN:

\[
\text{isnan(x)}
\]

\[
\text{ans} =
\]

\[
1
\]

MATLAB preserves the “Not a Number” status of alternate NaN representations and treats all of the different representations of NaN equivalently. However, in some special cases (perhaps due to hardware limitations), MATLAB does not preserve the exact bit pattern of alternate NaN representations throughout an entire calculation, and instead uses the canonical NaN bit pattern defined above.

**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):

\[
\text{NaN} > \text{NaN}
\]

\[
\text{ans} =
\]
0

NaN == NaN
ans =
1

**Infinity and NaN Functions**

See Infinity and NaN Functions 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.

<table>
<thead>
<tr>
<th>Command</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>whos x</code></td>
<td>Display the data type of ( x ).</td>
</tr>
<tr>
<td><code>xType = class(x);</code></td>
<td>Assign the data type of ( x ) to a variable.</td>
</tr>
<tr>
<td><code>isnumeric(x)</code></td>
<td>Determine if ( x ) is a numeric type.</td>
</tr>
<tr>
<td><code>isa(x, 'integer')</code></td>
<td>Determine if ( x ) is the specified numeric type. (Examples for any integer, unsigned 64-bit integer, any floating point, double precision, and single precision are shown here).</td>
</tr>
<tr>
<td><code>isa(x, 'uint64')</code></td>
<td></td>
</tr>
<tr>
<td><code>isa(x, 'float')</code></td>
<td></td>
</tr>
<tr>
<td><code>isa(x, 'double')</code></td>
<td></td>
</tr>
<tr>
<td><code>isa(x, 'single')</code></td>
<td></td>
</tr>
<tr>
<td><code>isreal(x)</code></td>
<td>Determine if ( x ) is real or complex.</td>
</tr>
<tr>
<td><code>isnan(x)</code></td>
<td>Determine if ( x ) is Not a Number (NaN).</td>
</tr>
<tr>
<td><code>isinf(x)</code></td>
<td>Determine if ( x ) is infinite.</td>
</tr>
<tr>
<td><code>isfinite(x)</code></td>
<td>Determine if ( x ) is finite.</td>
</tr>
</tbody>
</table>
Display Format for Numeric Values

In this section...

“Default Display” on page 4-22
“Display Format Examples” on page 4-22
“Setting Numeric Format in a Program” on page 4-23

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:

\[
\text{Check the current format setting:}
\]

\[\text{get(0, 'format')}\]
\[\text{ans} =\]
\[\text{short}\]
Set the value for \( x \) and display in 5-digit scaled fixed point:

\[
x = \begin{bmatrix} 4/3 & 1.2345e-6 \end{bmatrix}
x = \\
1.3333 & 0.0000
\]

Set the format to 5-digit floating point:

\[
\text{format short e} \\
x
x = \\
1.3333e+00 & 1.2345e-06
\]

Set the format to 15-digit scaled fixed point:

\[
\text{format long} \\
x
x = \\
1.333333333333333 & 0.000001234500000
\]

Set the format to 'rational' for small integer ratio output:

\[
\text{format rational} \\
x
x = \\
4/3 & 1/810045
\]

Set an integer value for \( x \) and display it in hexadecimal (base 16) format:

\[
\text{format hex} \\
x = \text{uint32}(876543210) \\
x = \\
343efcea
\]

**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
• Floating-Point Functions
• Complex Number Functions
• Infinity and NaN Functions
• Class Identification Functions
• Output Formatting Functions

Integer Functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>int8, int16, int32, int64</td>
<td>Convert to signed 1-, 2-, 4-, or 8-byte integer.</td>
</tr>
<tr>
<td>uint8, uint16, uint32, uint64</td>
<td>Convert to unsigned 1-, 2-, 4-, or 8-byte integer.</td>
</tr>
<tr>
<td>ceil</td>
<td>Round towards plus infinity to nearest integer.</td>
</tr>
<tr>
<td>class</td>
<td>Return the data type of an object.</td>
</tr>
<tr>
<td>fix</td>
<td>Round towards zero to nearest integer.</td>
</tr>
<tr>
<td>floor</td>
<td>Round towards minus infinity to nearest integer.</td>
</tr>
<tr>
<td>isa</td>
<td>Determine if input value has the specified data type.</td>
</tr>
<tr>
<td>isinteger</td>
<td>Determine if input value is an integer array.</td>
</tr>
<tr>
<td>isnumeric</td>
<td>Determine if input value is a numeric array.</td>
</tr>
<tr>
<td>round</td>
<td>Round towards the nearest integer.</td>
</tr>
</tbody>
</table>

Floating-Point Functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>double</td>
<td>Convert to double precision.</td>
</tr>
<tr>
<td>single</td>
<td>Convert to single precision.</td>
</tr>
<tr>
<td>class</td>
<td>Return the data type of an object.</td>
</tr>
<tr>
<td>isa</td>
<td>Determine if input value has the specified data type.</td>
</tr>
<tr>
<td>Function</td>
<td>Description</td>
</tr>
<tr>
<td>------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>isfloat</td>
<td>Determine if input value is a floating-point array.</td>
</tr>
<tr>
<td>isnumeric</td>
<td>Determine if input value is a numeric array.</td>
</tr>
<tr>
<td>eps</td>
<td>Return the floating-point relative accuracy. This value is the tolerance MATLAB uses in its calculations.</td>
</tr>
<tr>
<td>realmax</td>
<td>Return the largest floating-point number your computer can represent.</td>
</tr>
<tr>
<td>realmin</td>
<td>Return the smallest floating-point number your computer can represent.</td>
</tr>
</tbody>
</table>

### Complex Number Functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>complex</td>
<td>Construct complex data from real and imaginary components.</td>
</tr>
<tr>
<td>i or j</td>
<td>Return the imaginary unit used in constructing complex data.</td>
</tr>
<tr>
<td>real</td>
<td>Return the real part of a complex number.</td>
</tr>
<tr>
<td>imag</td>
<td>Return the imaginary part of a complex number.</td>
</tr>
<tr>
<td>isreal</td>
<td>Determine if a number is real or imaginary.</td>
</tr>
</tbody>
</table>

### Infinity and NaN Functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>inf</td>
<td>Return the IEEE value for infinity.</td>
</tr>
<tr>
<td>isnan</td>
<td>Detect NaN elements of an array.</td>
</tr>
<tr>
<td>isinf</td>
<td>Detect infinite elements of an array.</td>
</tr>
<tr>
<td>isfinite</td>
<td>Detect finite elements of an array.</td>
</tr>
<tr>
<td>nan</td>
<td>Return the IEEE value for Not a Number.</td>
</tr>
</tbody>
</table>

### Class Identification Functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>class</td>
<td>Return data type (or class).</td>
</tr>
<tr>
<td>isa</td>
<td>Determine if input value is of the specified data type.</td>
</tr>
<tr>
<td>isfloat</td>
<td>Determine if input value is a floating-point array.</td>
</tr>
<tr>
<td>Function</td>
<td>Description</td>
</tr>
<tr>
<td>------------</td>
<td>------------------------------------------</td>
</tr>
<tr>
<td>isinteger</td>
<td>Determine if input value is an integer array.</td>
</tr>
<tr>
<td>isnumeric</td>
<td>Determine if input value is a numeric array.</td>
</tr>
<tr>
<td>isreal</td>
<td>Determine if input value is real.</td>
</tr>
<tr>
<td>whos</td>
<td>Display the data type of input.</td>
</tr>
</tbody>
</table>

### Output Formatting Functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>format</td>
<td>Control display format for output.</td>
</tr>
</tbody>
</table>
The Logical Class

- “Find Array Elements That Meet a Condition” on page 5-2
- “Determine if Arrays Are Logical” on page 5-7
- “Reduce Logical Arrays to Single Value” on page 5-10
- “Truth Table for Logical Operations” on page 5-13
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 (> , < , >= , <= , == , ~= ) 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 ~ .

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   1   1   1
1   0   0   0   0
Find Array Elements That Meet a Condition

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
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.

\[
A(A<9 & A>2)
\]

\[
\text{ans} = \\
\begin{array}{c}
5 \\
3 \\
8 \\
3 \\
7 \\
\end{array}
\]

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 \( A(2<A \mid A<9) \).

Next, find the elements in \( A \) that are less than 9 AND even numbered.

\[
A(A<9 & \sim \text{mod}(A,2))
\]

\[
\text{ans} = \\
\begin{array}{c}
2 \\
2 \\
8 \\
\end{array}
\]

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 \( \text{mod}(A,2) \) 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.

\[ A(A < 9 \land \neg \text{mod}(A, 2) \land A \neq 2) \]

\[ \text{ans} = 8 \]

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.

\[ \text{find}(A < 9 \land \neg \text{mod}(A, 2) \land A \neq 2) \]

\[ \text{ans} = 14 \]

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.

\[ A(A > 10) = 10 \]

\[ A = \]

\[
\begin{array}{cccccc}
10 & 2 & 3 & 3 & 10 \\
10 & 5 & 10 & 7 & 1 \\
2 & 9 & 10 & 10 & 10 \\
10 & 10 & 8 & 10 & 10 \\
10 & 10 & 10 & 10 & 10 \\
\end{array}
\]

A now has a maximum value of 10.

Replace all values in A that are not equal to 10 with a \text{NaN} value.
The Logical Class

\[ A(A \neq 10) = \text{NaN} \]

\[ A = \]

\[
\begin{array}{cccccc}
10 & \text{NaN} & \text{NaN} & \text{NaN} & 10 \\
10 & \text{NaN} & 10 & \text{NaN} & \text{NaN} \\
\text{NaN} & \text{NaN} & 10 & 10 & 10 \\
10 & 10 & \text{NaN} & 10 & 10 \\
10 & 10 & 10 & 10 & 10 \\
\end{array}
\]

The resulting matrix has element values of 10 or \text{NaN}.

Replace all of the \text{NaN} values in \( A \) with zeros and apply the logical NOT operator, \( \sim A \).

\[ A(\text{isnan}(A)) = 0; \]
\[ C = \sim A \]

\[ C = \]

\[
\begin{array}{cccccc}
0 & 1 & 1 & 1 & 0 \\
0 & 1 & 0 & 1 & 1 \\
1 & 1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
\end{array}
\]

The resulting matrix has values of logical 1 (true) in place of the \text{NaN} values, and logical 0 (false) in place of the 10s. The logical NOT operation, \( \sim A \), 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**

and | find | isnan | Logical Operators: Short Circuit | nan | not | or | xor
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.

<table>
<thead>
<tr>
<th>In this section...</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Identify Logical Matrix” on page 5-7</td>
</tr>
<tr>
<td>“Test an Entire Array” on page 5-7</td>
</tr>
<tr>
<td>“Test Each Array Element” on page 5-8</td>
</tr>
<tr>
<td>“Summary Table” on page 5-9</td>
</tr>
</tbody>
</table>

Identify Logical Matrix

Create a 3-by-6 matrix and locate all elements greater than 0.5.

\[ A = \text{gallery('uniformdata',[3,6],0) > 0.5} \]

\[
A =
\begin{bmatrix}
1 & 0 & 0 & 0 & 1 & 0 \\
0 & 1 & 0 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 0 & 1
\end{bmatrix}
\]

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, \( A \).

\[
\text{whos A}
\]

<table>
<thead>
<tr>
<th>Name</th>
<th>Size</th>
<th>Bytes</th>
<th>Class</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3x6</td>
<td>18</td>
<td>logical</td>
<td></td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Function Syntax</th>
<th>Output Size</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>whos(A)</code></td>
<td>N/A</td>
<td>Displays the name, size, storage bytes, class, and attributes of variable A.</td>
</tr>
<tr>
<td><code>islogical(A)</code></td>
<td>scalar</td>
<td>Returns logical 1 (true) if A is a logical array; otherwise, it returns logical 0 (false). The result is the same as using <code>isa(A, 'logical')</code>.</td>
</tr>
<tr>
<td><code>isa(A, 'logical')</code></td>
<td>scalar</td>
<td>Returns logical 1 (true) if A is a logical array; otherwise, it returns logical 0 (false). The result is the same as using <code>islogical(A)</code>.</td>
</tr>
<tr>
<td><code>class(A)</code></td>
<td>single string</td>
<td>Returns a string with the name of the class of variable A.</td>
</tr>
<tr>
<td><code>cellfun('islogical',A)</code></td>
<td>Array of the same size as A</td>
<td>For cell arrays only. Returns logical 1 (true) for each cell that contains a logical array; otherwise, it returns logical 0 (false).</td>
</tr>
<tr>
<td><code>arrayfun(@islogical,A)</code></td>
<td>Array of the same size as A</td>
<td>Returns an array of logical 1 (true) values if A is logical; otherwise, it returns an array of logical 0 (false) values.</td>
</tr>
</tbody>
</table>

## See Also

`arrayfun` | `cellfun` | `class` | `isa` | `islogical` | `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.

```matlab
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.

```matlab
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.

```matlab
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.

```matlab
all(~A(:))
ans =
   0
```

The result is logical `0` (false).

Determine whether any main or super diagonal elements in `A` are even.

```matlab
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, `||`.

```matlab
any(diag(A)) || any(diag(A,1))
ans =
```

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The result is logical 1 (true). It no longer matters that \( \text{diag}(A) \) and \( \text{diag}(A, 1) \) are not the same size.

**See Also**
all | and | any | Logical Operators: Short Circuit | or | xor
## 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.

<table>
<thead>
<tr>
<th>Inputs A and B</th>
<th>and A &amp; B</th>
<th>or A</th>
<th>B</th>
<th>xor (A, B)</th>
<th>not ~A</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### See Also

and | Logical Operators: Short Circuit | not | or | xor
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 6-23
- “Searching and Replacing” on page 6-26
- “Converting from Numeric to String” on page 6-28
- “Converting from String to Numeric” on page 6-30
- “Function Summary” on page 6-33
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:

```matlab
name = "Thomas R. Lee";
title = "Sr. Developer";
company = "SFTware Corp.";

full_name = [name ', ' title ', ' company]
```

MATLAB returns

```matlab
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:

```matlab
name   = 'myname   ';
domain = 'mydomain ';
ext    = 'com    ';

address = strcat(name, '@', domain, '.', ext)
```

MATLAB returns

```matlab
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:

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ischar</td>
<td>Determine whether the input is a character array.</td>
</tr>
<tr>
<td>isletter</td>
<td>Find all alphabetic letters in the input string.</td>
</tr>
<tr>
<td>isspace</td>
<td>Find all space characters in the input string.</td>
</tr>
<tr>
<td>isstrprop</td>
<td>Find all characters of a specific category.</td>
</tr>
</tbody>
</table>

```matlab
str = 'Find the space characters in this string';
%                          | | | | | | |
```
Working with Space Characters

The `blanks` function creates a string of space characters. The following example creates a string of 15 space characters:

```matlab
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:

```matlab
['|' s '|']
```

You can justify the positioning of these characters to the left or right using the `strjust` function:

```matlab
sLeft = strjust(s, 'left');
```

```matlab
['|' sLeft '|']
```

```matlab
sRight = strjust(s, 'right');
```

```matlab
['|' sRight '|']
```
Remove all trailing space characters with `deblank`:

```matlab
sDeblank = deblank(s);
```

```matlab
['|' sDeblank '|'']         % Make result visible.
ans =
    |       AAAAA|
```

Remove all leading and trailing spaces with `strtrim`:

```matlab
sTrim = strtrim(s);
```

```matlab
['|' 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:

```matlab
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:

```matlab
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:

```matlab
length(celldata{3})
an1 = 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`:

```matlab
iscellstr(celldata)
an1 = 1
```
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 11-5.

**Functions for Cell Arrays of Strings**

This table describes the MATLAB functions for working with cell arrays.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>cellstr</code></td>
<td>Convert a character array to a cell array of strings.</td>
</tr>
<tr>
<td><code>char</code></td>
<td>Convert a cell array of strings to a character array.</td>
</tr>
<tr>
<td><code>deblank</code></td>
<td>Remove trailing blanks from a string.</td>
</tr>
<tr>
<td><code>iscellstr</code></td>
<td>Return <code>true</code> for a cell array of strings.</td>
</tr>
<tr>
<td><code>sort</code></td>
<td>Sort elements in ascending or descending order.</td>
</tr>
<tr>
<td><code>strcat</code></td>
<td>Concatenate strings.</td>
</tr>
<tr>
<td><code>strcmp</code></td>
<td>Compare strings.</td>
</tr>
</tbody>
</table>

You can also use the following `set` functions with cell arrays of strings.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>intersect</code></td>
<td>Set the intersection of two vectors.</td>
</tr>
<tr>
<td><code>ismember</code></td>
<td>Detect members of a set.</td>
</tr>
<tr>
<td><code>setdiff</code></td>
<td>Return the set difference of two vectors.</td>
</tr>
<tr>
<td>Function</td>
<td>Description</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>setxor</td>
<td>Set the exclusive OR of two vectors.</td>
</tr>
<tr>
<td>union</td>
<td>Set the union of two vectors.</td>
</tr>
<tr>
<td>unique</td>
<td>Set the unique elements of a vector.</td>
</tr>
</tbody>
</table>
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 6-19
“Restrictions for Using Identifiers” on page 6-21

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:

- **sprintf** — 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:

```matlab
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.

<table>
<thead>
<tr>
<th>To Insert a . . .</th>
<th>Use . . .</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single quotation mark</td>
<td><code>'</code></td>
</tr>
<tr>
<td>Percent character</td>
<td><code>%%</code></td>
</tr>
</tbody>
</table>
### To Insert a . . .

<table>
<thead>
<tr>
<th>To Insert</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backslash</td>
<td>\</td>
</tr>
<tr>
<td>Alarm</td>
<td>\a</td>
</tr>
<tr>
<td>Backspace</td>
<td>\b</td>
</tr>
<tr>
<td>Form feed</td>
<td>\f</td>
</tr>
<tr>
<td>New line</td>
<td>\n</td>
</tr>
<tr>
<td>Carriage return</td>
<td>\r</td>
</tr>
<tr>
<td>Horizontal tab</td>
<td>\t</td>
</tr>
<tr>
<td>Vertical tab</td>
<td>\v</td>
</tr>
<tr>
<td>Hexadecimal number, (N)</td>
<td>\xN</td>
</tr>
<tr>
<td>Octal number, (N)</td>
<td>\N</td>
</tr>
</tbody>
</table>

### Input Value Arguments

In the syntax

```plaintext
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:

```plaintext
sprintf('%s = %d
', 'A', 479, 'B', 352, 'C', 651)
```

```plaintext
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:

```plaintext
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 6-18.

<table>
<thead>
<tr>
<th>Ordered Sequentially</th>
<th>Ordered By Identifier</th>
</tr>
</thead>
</table>
| sprintf('%s %s %s', ...  
  '1st', '2nd', '3rd') | sprintf('%3$s %2$s %1$s', ...  
  '1st', '2nd', '3rd') |
| ans = 1st 2nd 3rd     | ans = 3rd 2nd 1st |

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 
% .2f 
%+.2f 
%12.2f 
%012.2f 
', A)
ans =
314.159265 % Display in fixed-point notation (%f)
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).

% 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)

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 6-20 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.

<table>
<thead>
<tr>
<th>Specifier</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>c</td>
<td>Single character</td>
</tr>
<tr>
<td>d</td>
<td>Decimal notation (signed)</td>
</tr>
<tr>
<td>e</td>
<td>Exponential notation (using a lowercase e as in 3.1415e+00)</td>
</tr>
<tr>
<td>E</td>
<td>Exponential notation (using an uppercase E as in 3.1415E+00)</td>
</tr>
<tr>
<td>f</td>
<td>Fixed-point notation</td>
</tr>
<tr>
<td>g</td>
<td>The more compact of %e or %f. (Insignificant zeros do not print.)</td>
</tr>
<tr>
<td>G</td>
<td>Same as %g, but using an uppercase E</td>
</tr>
<tr>
<td>o</td>
<td>Octal notation (unsigned)</td>
</tr>
<tr>
<td>s</td>
<td>String of characters</td>
</tr>
<tr>
<td>u</td>
<td>Decimal notation (unsigned)</td>
</tr>
<tr>
<td>x</td>
<td>Hexadecimal notation (using lowercase letters a–f)</td>
</tr>
<tr>
<td>X</td>
<td>Hexadecimal notation (using uppercase letters A–F)</td>
</tr>
</tbody>
</table>

This example uses conversion characters to display the number 46 in decimal, fixed-point, exponential, and hexadecimal formats:

```matlab
A = 46*ones(1,4);
sprintf('%d %f %e %X', A)
ans =
```

```plaintext
% 1$ *2$ .*3$ e
Value   |   |   |   | Precision
Field width
```
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:

```plaintext
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 6-20 for more information on this.

For more information on the use of `precision` in formatting, see “Setting Field Width and Precision” on page 6-19.
**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:

```matlab
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.

```matlab
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 6-20 for more information on this.

For more information on the use of field width in formatting, see “Setting Field Width and Precision” on page 6-19.

**Flags**

You can control the output using any of these optional flags:

<table>
<thead>
<tr>
<th>Character</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>A -</td>
<td>Left-justifies the converted argument in its field.</td>
<td>% -5.2d</td>
</tr>
<tr>
<td>A +</td>
<td>Always prints a sign character (±).</td>
<td>% +5.2d</td>
</tr>
<tr>
<td>A space</td>
<td>Inserts a space before the value.</td>
<td>%  5.2f</td>
</tr>
<tr>
<td>Zero (0)</td>
<td>Pads with zeros rather than spaces.</td>
<td>%05.2f</td>
</tr>
<tr>
<td>A pound sign (#)</td>
<td>Modifies selected numeric conversions:</td>
<td>%#5.0f</td>
</tr>
<tr>
<td>Character</td>
<td>Description</td>
<td>Example</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>---------</td>
</tr>
<tr>
<td>•</td>
<td>For %o, %x, or %X, print 0, 0x, or 0X prefix.</td>
<td></td>
</tr>
<tr>
<td>•</td>
<td>For %f, %e, or %E, print decimal point even when precision is 0.</td>
<td></td>
</tr>
<tr>
<td>•</td>
<td>For %g or %G, do not remove trailing zeros or decimal point.</td>
<td></td>
</tr>
</tbody>
</table>

Right- and left-justify the output. The default is to right-justify:

```matlab
sprintf('right-justify: %12.2f
left-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:

```matlab
sprintf('no sign: %12.2f
sign: %+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:

```matlab
sprintf('space-padded: %12.2f
zero-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.

<table>
<thead>
<tr>
<th>Ordered Sequentially</th>
<th>Ordered By Identifier</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>sprintf('%s %s %s', ... '1st', '2nd', '3rd')</code></td>
<td><code>sprintf('%3$s %2$s %1$s', ... '1st', '2nd', '3rd')</code></td>
</tr>
<tr>
<td>ans = 1st 2nd 3rd</td>
<td>ans = 3rd 2nd 1st</td>
</tr>
</tbody>
</table>

### 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 6-19
- “Specifying Field Width and Precision Outside the format String” on page 6-20
- “Using Identifiers In the Width and Precision Fields” on page 6-21

#### 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 $\text{precision} + 1 +$ 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:

```matlab
sprintf('%*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:

```matlab
sprintf('%*.*f', 5, 123.45678)
an =
```

6-20
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:

```plaintext
sprintf('%*f   %.*f   %*.*f', ...
    15, 123.45678, ...
    3, 16.42837, ...
    6, 4, pi)
```

```plaintext
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:

```plaintext
sprintf('%1$*4$f   %2$.*5$f   %3$*6$.*7$f', ...
    123.45678, 16.42837, pi, 15, 3, 6, 4)
```

```plaintext
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.

<table>
<thead>
<tr>
<th>Valid Syntax</th>
<th>Invalid Syntax</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>sprintf('%d %d %d %d', ...</code></td>
<td><code>sprintf('%d %3$d %d %d', ...</code></td>
</tr>
<tr>
<td>1, 2, 3, 4)</td>
<td>1, 2, 3, 4)</td>
</tr>
<tr>
<td><code>ans =</code></td>
<td><code>ans =</code></td>
</tr>
<tr>
<td>1 2 3 4</td>
<td>1</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Valid Syntax</th>
<th>Invalid Syntax</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>sprintf('d', 1, 2, 3, 4)</code></td>
<td><code>sprintf('%1$d', 1, 2, 3, 4)</code></td>
</tr>
<tr>
<td><code>ans = 1234</code></td>
<td><code>ans = 1</code></td>
</tr>
</tbody>
</table>

Also, do not use identifiers when the value arguments are in the form of a vector or array:

<table>
<thead>
<tr>
<th>Valid Syntax</th>
<th>Invalid Syntax</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>v = [1.4 2.7 3.1];</code></td>
<td><code>v = [1.4 2.7 3.1];</code></td>
</tr>
<tr>
<td><code>sprintf('f f f', v)</code></td>
<td><code>sprintf('%3$.4f %1$.4f %2$.4f', v)</code></td>
</tr>
<tr>
<td><code>ans = 1.4000 2.7000 3.1000</code></td>
<td><code>ans = Empty string: 1-by-0</code></td>
</tr>
</tbody>
</table>
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

```matlab
str1 = 'hello';
str2 = 'help';
```

Strings `str1` and `str2` are not identical, so invoking `strcmp` returns logical 0 (false). For example,

```matlab
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:

```matlab
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:

\[
A = \{\text{'pizza'}; \text{'chips'}; \text{'candy'}\}; \\
B = \{\text{'pizza'}; \text{'chocolate'}; \text{'pretzels'}\};
\]

Now apply the string comparison functions:

```matlab
strcmp(A,B)
an = 1 0 0

strncmp(A,B,1)
an = 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:

\[
A = \text{'fate'}; \\
B = \text{'cake'};
\]

```matlab
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:

```matlab
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 `mysting`:

```matlab
mysting = 'Room 401';
```

`isletter` examines each character in the string, producing an output vector of the same length as `mysting`:

```matlab
A = isletter(mysting)
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 `mysting` 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:

\[
\text{label} = 'Sample 1, 10/28/95';
\]

The \texttt{strrep} function performs the standard search-and-replace operation. Use \texttt{strrep} to change the date from '10/28' to '10/30':

\[
\text{newlabel} = \text{strrep}(\text{label}, '28', '30')
\]

\[
\text{newlabel} = 'Sample 1, 10/30/95'
\]

\texttt{strfind} returns the starting position of a substring within a longer string. To find all occurrences of the string 'amp' inside \texttt{label}, use

\[
\text{position} = \text{strfind}(\text{label}, 'amp')
\]

\[
\text{position} = 
\begin{array}{c}
2 \\
\end{array}
\]

The position within \texttt{label} where the only occurrence of 'amp' begins is the second character.

The \texttt{textscan} function parses a string to identify numbers or substrings. Describe each component of the string with conversion specifiers, such as \texttt{%s} for strings, \texttt{%d} for integers, or \texttt{%f} for floating-point numbers. Optionally, include any literal text to ignore.

For example, identify the sample number and date string from \texttt{label}:

\[
\text{parts} = \text{textscan}(\text{label}, 'Sample \%d, \%s');
\]

\[
\text{parts}{:}
\begin{array}{c}
\begin{array}{c}
1 \\
\end{array} \\
\begin{array}{c}
'10/28/95' \\
\end{array}
\end{array}
\]

To parse strings in a cell array, use the \texttt{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 6-28
“Converting to a Character Equivalent” on page 6-29
“Converting to a String of Numbers” on page 6-29
“Converting to a Specific Radix” on page 6-29

Function Summary

The functions listed in this table provide a number of ways to convert numeric data to character strings.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>char</code></td>
<td>Convert a positive integer to an equivalent character. (Truncates any fractional parts.)</td>
<td>[72 105] → 'Hi'</td>
</tr>
<tr>
<td><code>int2str</code></td>
<td>Convert a positive or negative integer to a character type. (Rounds any fractional parts.)</td>
<td>[72 105] → '72 105'</td>
</tr>
<tr>
<td><code>num2str</code></td>
<td>Convert a numeric type to a character type of the specified precision and format.</td>
<td>[72 105] → '72/105/' (format set to %1d/)</td>
</tr>
<tr>
<td><code>mat2str</code></td>
<td>Convert a numeric type to a character type of the specified precision, returning a string MATLAB can evaluate.</td>
<td>[72 105] → '[72 105]'</td>
</tr>
<tr>
<td><code>dec2hex</code></td>
<td>Convert a positive integer to a character type of hexadecimal base.</td>
<td>[72 105] → '48 69'</td>
</tr>
<tr>
<td><code>dec2bin</code></td>
<td>Convert a positive integer to a character type of binary base.</td>
<td>[72 105] → '1001000 1101001'</td>
</tr>
<tr>
<td><code>dec2base</code></td>
<td>Convert a positive integer to a character type of any base from 2 through 36.</td>
<td>[72 105] → '110 151' (base set to 8)</td>
</tr>
</tbody>
</table>
Converting to a Character Equivalent

The `char` function converts integers to Unicode character codes and returns a string composed of the equivalent characters:

```matlab
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:

```matlab
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 6-30
“Converting from a Character Equivalent” on page 6-30
“Converting from a Numeric String” on page 6-31
“Converting from a Specific Radix” on page 6-31

Function Summary

The functions listed in this table provide a number of ways to convert character strings to numeric data.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>uintN (e.g., uint8)</td>
<td>Convert a character to an integer code that represents that character.</td>
<td>'Hi' → 72 105</td>
</tr>
<tr>
<td>str2num</td>
<td>Convert a character type to a numeric type.</td>
<td>'72 105' → [72 105]</td>
</tr>
<tr>
<td>str2double</td>
<td>Similar to str2num, but offers better performance and works with cell arrays of strings.</td>
<td>{'72' '105'} → [72 105]</td>
</tr>
<tr>
<td>hex2num</td>
<td>Convert a numeric type to a character type of specified precision, returning a string that MATLAB can evaluate.</td>
<td>'A' → -1.4917e-154'</td>
</tr>
<tr>
<td>hex2dec</td>
<td>Convert a character type of hexadecimal base to a positive integer.</td>
<td>'A' → 10</td>
</tr>
<tr>
<td>bin2dec</td>
<td>Convert a character type of binary number to a decimal number.</td>
<td>'1010' → 10</td>
</tr>
<tr>
<td>base2dec</td>
<td>Convert a character type of any base number from 2 through 36 to a decimal number.</td>
<td>'12' → 10 (if base == 8)</td>
</tr>
</tbody>
</table>

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 `<code>hex2num</code>` and `<code>hex2dec</code>` functions both take hexadecimal (base 16) inputs, but `<code>hex2num</code>` returns the IEEE double-precision floating-point number it represents, while `<code>hex2dec</code>` converts to a decimal integer.
Function Summary

MATLAB provides these functions for working with character arrays:

- Functions to Create Character Arrays
- Functions to Modify Character Arrays
- Functions to Read and Operate on Character Arrays
- Functions to Search or Compare Character Arrays
- Functions to Determine Class or Content
- Functions to Convert Between Numeric and String Classes
- Functions to Work with Cell Arrays of Strings as Sets

Functions to Create Character Arrays

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>'str'</td>
<td>Create the string specified between quotes.</td>
</tr>
<tr>
<td>blanks</td>
<td>Create a string of blanks.</td>
</tr>
<tr>
<td>sprintf</td>
<td>Write formatted data to a string.</td>
</tr>
<tr>
<td>strcat</td>
<td>Concatenate strings.</td>
</tr>
<tr>
<td>char</td>
<td>Concatenate strings vertically.</td>
</tr>
</tbody>
</table>

Functions to Modify Character Arrays

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>deblank</td>
<td>Remove trailing blanks.</td>
</tr>
<tr>
<td>lower</td>
<td>Make all letters lowercase.</td>
</tr>
<tr>
<td>sort</td>
<td>Sort elements in ascending or descending order.</td>
</tr>
<tr>
<td>strjust</td>
<td>Justify a string.</td>
</tr>
<tr>
<td>strrep</td>
<td>Replace one string with another.</td>
</tr>
<tr>
<td>strtrim</td>
<td>Remove leading and trailing white space.</td>
</tr>
<tr>
<td>upper</td>
<td>Make all letters uppercase.</td>
</tr>
</tbody>
</table>

Functions to Read and Operate on Character Arrays
### Characters and Strings

In MATLAB, strings are one-dimensional arrays of characters. You can use various functions to manipulate and analyze strings. Here’s a summary of some useful functions:

<table>
<thead>
<tr>
<th><strong>Function</strong></th>
<th><strong>Description</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><code>eval</code></td>
<td>Execute a string with MATLAB expression.</td>
</tr>
<tr>
<td><code>sscanf</code></td>
<td>Read a string under format control.</td>
</tr>
</tbody>
</table>

#### Functions to Search or Compare Character Arrays

<table>
<thead>
<tr>
<th><strong>Function</strong></th>
<th><strong>Description</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><code>regexp</code></td>
<td>Match regular expression.</td>
</tr>
<tr>
<td><code>strcmp</code></td>
<td>Compare strings.</td>
</tr>
<tr>
<td><code>strcmpi</code></td>
<td>Compare strings, ignoring case.</td>
</tr>
<tr>
<td><code>strfind</code></td>
<td>Find one string within another.</td>
</tr>
<tr>
<td><code>strncmp</code></td>
<td>Compare the first N characters of strings.</td>
</tr>
<tr>
<td><code>strncmpi</code></td>
<td>Compare the first N characters, ignoring case.</td>
</tr>
<tr>
<td><code>strtok</code></td>
<td>Find a token in a string.</td>
</tr>
<tr>
<td><code>textscan</code></td>
<td>Read data from a string.</td>
</tr>
</tbody>
</table>

#### Functions to Determine Class or Content

<table>
<thead>
<tr>
<th><strong>Function</strong></th>
<th><strong>Description</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><code>iscellstr</code></td>
<td>Return <code>true</code> for a cell array of strings.</td>
</tr>
<tr>
<td><code>ischar</code></td>
<td>Return <code>true</code> for a character array.</td>
</tr>
<tr>
<td><code>isletter</code></td>
<td>Return <code>true</code> for letters of the alphabet.</td>
</tr>
<tr>
<td><code>isstrprop</code></td>
<td>Determine if a string is of the specified category.</td>
</tr>
<tr>
<td><code>isspace</code></td>
<td>Return <code>true</code> for white-space characters.</td>
</tr>
</tbody>
</table>

#### Functions to Convert Between Numeric and String Classes

<table>
<thead>
<tr>
<th><strong>Function</strong></th>
<th><strong>Description</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><code>char</code></td>
<td>Convert to a character or string.</td>
</tr>
<tr>
<td><code>cellstr</code></td>
<td>Convert a character array to a cell array of strings.</td>
</tr>
<tr>
<td><code>double</code></td>
<td>Convert a string to numeric codes.</td>
</tr>
<tr>
<td><code>int2str</code></td>
<td>Convert an integer to a string.</td>
</tr>
<tr>
<td><code>mat2str</code></td>
<td>Convert a matrix to a string you can run <code>eval</code> on.</td>
</tr>
<tr>
<td>Function</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td>num2str</td>
<td>Convert a number to a string.</td>
</tr>
<tr>
<td>str2num</td>
<td>Convert a string to a number.</td>
</tr>
<tr>
<td>str2double</td>
<td>Convert a string to a double-precision value.</td>
</tr>
</tbody>
</table>

**Functions to Work with Cell Arrays of Strings as Sets**

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>intersect</td>
<td>Set the intersection of two vectors.</td>
</tr>
<tr>
<td>ismember</td>
<td>Detect members of a set.</td>
</tr>
<tr>
<td>setdiff</td>
<td>Return the set difference of two vectors.</td>
</tr>
<tr>
<td>setxor</td>
<td>Set the exclusive OR of two vectors.</td>
</tr>
<tr>
<td>union</td>
<td>Set the union of two vectors.</td>
</tr>
<tr>
<td>unique</td>
<td>Set the unique elements of a vector.</td>
</tr>
</tbody>
</table>
Dates and Time

- “Represent Dates and Times in MATLAB” on page 7-2
- “Specify Time Zones” on page 7-6
- “Set Date and Time Display Format” on page 7-8
- “Generate Sequence of Dates and Time” on page 7-13
- “Share Code and Data Across Locales” on page 7-22
- “Extract or Assign Date and Time Components of Datetime Array” on page 7-25
- “Combine Date and Time from Separate Variables” on page 7-30
- “Date and Time Arithmetic” on page 7-32
- “Compare Dates and Time” on page 7-40
- “Plot Dates and Durations” on page 7-44
- “Core Functions Supporting Date and Time Arrays” on page 7-55
- “Convert Between Datetime Arrays, Numbers, and Strings” on page 7-56
- “Carryover in Date Vectors and Strings” on page 7-61
- “Converting Date Vector Returns Unexpected Output” on page 7-62
Represent Dates and Times in MATLAB

The primary way to store date and time information is in datetime arrays, which support arithmetic, sorting, comparisons, plotting, and formatted display. The results of arithmetic differences are returned in duration arrays or, when you use calendar-based functions, in calendarDuration arrays.

For example, create a MATLAB datetime array that represents two dates: June 28, 2014 at 6 a.m. and June 28, 2014 at 7 a.m. Specify numeric values for the year, month, day, hour, minute, and second components for the datetime.

\[ t = \text{datetime}(2014,6,28,6:7,0,0) \]

\[ t = \begin{array}{ll}
28-\text{Jun}-2014 \ 06:00:00 & 28-\text{Jun}-2014 \ 07:00:00 \\
\end{array} \]

Change the value of a date or time component by assigning new values to the properties of the datetime array. For example, change the day number of each datetime by assigning new values to the Day property.

\[ t.\text{Day} = 27:28 \]

\[ t = \begin{array}{ll}
27-\text{Jun}-2014 \ 06:00:00 & 28-\text{Jun}-2014 \ 07:00:00 \\
\end{array} \]

Change the display format of the array by changing its Format property. The following format does not display any time components. However, the values in the datetime array do not change.

\[ t.\text{Format} = '\text{MMM dd, yyyy}' \]

\[ t = \begin{array}{ll}
\text{Jun} \ 27, \ 2014 & \text{Jun} \ 28, \ 2014 \\
\end{array} \]

If you subtract one datetime array from another, the result is a duration array in units of fixed length.

\[ t2 = \text{datetime}(2014,6,29,6,30,45) \]

\[ t2 = \]
29-Jun-2014 06:30:45

d = t2 - t

d =

48:30:45   23:30:45

By default, a duration array displays in the format, hours:minutes:seconds. Change the display format of the duration by changing its Format property. You can display the duration value with a single unit, such as hours.

d.Format = 'h'

d =

48.512 hrs   23.512 hrs

You can create a duration in a single unit using the seconds, minutes, hours, days, or years functions. For example, create a duration of 2 days, where each day is exactly 24 hours.

d = days(2)

d =

2 days

You can create a calendar duration in a single unit of variable length. For example, one month can be 28, 29, 30, or 31 days long. Specify a calendar duration of 2 months.

L = calmonths(2)

L =

2mo

Use the caldays, calweeks, calquarters, and calyears functions to specify calendar durations in other units.

Add a number of calendar months and calendar days. The number of days remains separate from the number of months because the number of days in a month is not fixed, and cannot be determined until you add the calendar duration to a specific datetime.

L = calmonths(2) + caldays(35)
\[ L = 2\text{mo 35d} \]

Add calendar durations to a datetime to compute a new date.

\[
t2 = t + \text{calmonths}(2) + \text{caldays}(35)
\]

\[
t2 = \begin{align*}
\text{Oct 01, 2014} & \quad \text{Oct 02, 2014}
\end{align*}
\]

\[ t2 \] is also a datetime array.

\[
\text{whos t2}
\]

<table>
<thead>
<tr>
<th>Name</th>
<th>Size</th>
<th>Bytes</th>
<th>Class</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>t2</td>
<td>1x2</td>
<td>161</td>
<td>datetime</td>
<td></td>
</tr>
</tbody>
</table>

In summary, there are several ways to represent dates and times, and MATLAB has a data type for each approach:

- Represent a point in time, using the datetime data type.
  Example: Wednesday, June 18, 2014 10:00:00

- Represent a length of time, or a duration in units of fixed length, using the duration data type. When using the duration data type, 1 day is always equal to 24 hours, and 1 year is always equal to 365.2425 days.
  Example: 72 hours and 10 minutes

- Represent a length of time, or a duration in units of variable length, using the calendarDuration data type.
  Example: 1 month, which can be 28, 29, 30, or 31 days long.
  The calendarDuration data type also accounts for daylight saving time changes and leap years, so that 1 day might be more or less than 24 hours, and 1 year can have 365 or 366 days.
See Also
calendarDuration | datetime | datetime Properties | duration
Specify Time Zones

In MATLAB, a time zone includes the time offset from Coordinated Universal Time (UTC), the daylight saving time offset, and a set of historical changes to those values. The time zone setting is stored in the `TimeZone` property of each `datetime` array. When you create a `datetime`, it is unzoned by default. That is, the `TimeZone` property of the `datetime` is empty (`''`). If you do not work with `datetime` values from multiple time zones and do not need to account for daylight saving time, you might not need to specify this property.

You can specify a time zone when you create a `datetime`, using the `'TimeZone'` name-value pair argument. The time zone value `'local'` specifies the system time zone. To display the time zone offset for each `datetime`, include a time zone offset specifier such as `'Z'` in the value for the `'Format'` argument.

```matlab
t = datetime(2014,3,8:9,6,0,0,'TimeZone','local',...    'Format','d-MMM-y HH:mm:ss Z')
```

```
t =
     8-Mar-2014 06:00:00 -0500   9-Mar-2014 06:00:00 -0400
```

A different time zone offset is displayed depending on whether the `datetime` occurs during daylight saving time.

You can modify the time zone of an existing `datetime`. For example, change the `TimeZone` property of `t` using dot notation. You can specify the time zone value as the name of a time zone region in the IANA Time Zone Database. A time zone region accounts for the current and historical rules for standard and daylight offsets from UTC that are observed in that geographic region.

```matlab
t.TimeZone = 'Asia/Shanghai'
```

```
t =
     8-Mar-2014 19:00:00 +0800   9-Mar-2014 18:00:00 +0800
```

You also can specify the time zone value as a string of the form `+HH:mm` or `-HH:mm`, which represents a time zone with a fixed offset from UTC that does not observe daylight saving time.

```matlab
t.TimeZone = '+08:00'
```
Specify Time Zones

t =

8-Mar-2014 19:00:00 +0800   9-Mar-2014 18:00:00 +0800

Operations on datetime arrays with time zones automatically account for time zone
differences. For example, create a datetime in a different time zone.

u = datetime(2014,3,9,6,0,0,'TimeZone','Europe/London',
              'Format','d-MMM-y HH:mm:ss Z')

t =

9-Mar-2014 06:00:00 +0000

View the time difference between the two datetime arrays.

dt = t - u

dt =

-19:00:00    04:00:00

When you perform operations involving datetime arrays, the arrays either must all have
a time zone associated with them, or they must all have no time zone.

See Also
datetime | datetime Properties
Set Date and Time Display Format

In this section...

“ Formats for Individual Date and Duration Arrays” on page 7-8
“datetime Display Format” on page 7-8
“duration Display Format” on page 7-9
“calendarDuration Display Format” on page 7-10
“Default datetime Format” on page 7-11

Formats for Individual Date and Duration Arrays

datetime, duration, and calendarDuration arrays have a Format property that controls the display of values in each array. When you create a datetime array, it uses the MATLAB global default datetime display format unless you explicitly provide a format. Use dot notation to access the Format property to view or change its value. For example, to set the display format for the datetime array, t, to the default format, type:

t.Format = 'default'

Changing the Format property does not change the values in the array, only their display. For example, the following can be representations of the same datetime value (the latter two do not display any time components):

Thursday, August 23, 2012 12:35:00
August 23, 2012
23-Aug-2012

The Format property of the datetime, duration, and calendarDuration data types accepts different strings and characters as inputs.

datetime Display Format

You can set the Format property to one of these strings.

<table>
<thead>
<tr>
<th>Value of Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>'default'</td>
<td>Use the default display format.</td>
</tr>
<tr>
<td>'defaultdate'</td>
<td>Use the default date display format that does not show time components.</td>
</tr>
</tbody>
</table>
To change the default formats, see “Default datetime Format” on page 7-11.

Alternatively, you can use the letters A-Z and a-z to specify a custom date format. You can include nonletter characters such as a hyphen, space, or colon to separate the fields. This table shows several common display formats and examples of the formatted output for the date, Saturday, April 19, 2014 at 9:41:06 PM in New York City.

<table>
<thead>
<tr>
<th>Value of Format</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>'yyyy-MM-dd'</td>
<td>2014-04-19</td>
</tr>
<tr>
<td>'dd/MM/yyyy'</td>
<td>19/04/2014</td>
</tr>
<tr>
<td>'dd.MM.yyyy'</td>
<td>19.04.2014</td>
</tr>
<tr>
<td>'yyyy# MM# dd#'</td>
<td>2014# 04# 19#</td>
</tr>
<tr>
<td>'MMMM d, yyyy'</td>
<td>April 19, 2014</td>
</tr>
<tr>
<td>'eeeee, MMMM d, yyyy h:mm a'</td>
<td>Saturday, April 19, 2014 9:41 PM</td>
</tr>
<tr>
<td>'MMMM d, yyyy HH:mm:ss Z'</td>
<td>April 19, 2014 21:41:06 -0400</td>
</tr>
<tr>
<td>'yyyy-MM-dd''T''HH:mmXXX'</td>
<td>2014-04-19T21:41-04:00</td>
</tr>
</tbody>
</table>

For a complete list of valid symbolic identifiers, see the Format property for datetime arrays.

**Note:** The letter identifiers that datetime accepts are different from those used by the datestr, datenum, and datevec functions.

### duration Display Format

To display a duration as a single number that includes a fractional part (for example, 1.234 hours), specify one of these strings:

<table>
<thead>
<tr>
<th>Value of Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>'y'</td>
<td>Number of exact fixed-length years. A fixed-length year is equal to 365.2425 days.</td>
</tr>
<tr>
<td>'d'</td>
<td>Number of exact fixed-length days. A fixed-length day is equal to 24 hours.</td>
</tr>
<tr>
<td>'h'</td>
<td>Number of hours</td>
</tr>
</tbody>
</table>
### Value of Format

<table>
<thead>
<tr>
<th>Value of Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>'m'</td>
<td>Number of minutes</td>
</tr>
<tr>
<td>'s'</td>
<td>Number of seconds</td>
</tr>
</tbody>
</table>

To specify the number of fractional digits displayed, use the `format` function.

To display a duration in the form of a digital timer, specify one of the following strings.

- `'dd:hh:mm:ss'`
- `'hh:mm:ss'`
- `'mm:ss'`
- `'hh:mm'`

You also can display up to nine fractional second digits by appending up to nine `S` characters. For example, `'hh:mm:ss.SSS'` displays the milliseconds of a duration value to 3 digits.

Changing the `Format` property does not change the values in the array, only their display.

#### calendarDuration Display Format

Specify the `Format` property of a `calendarDuration` array as a string that can include the characters `y`, `q`, `m`, `w`, `d`, and `t`, in this order. The string must include `m` to display the number of months, `d` to display the number of days, and `t` to display the number of hours, minutes, and seconds. The `y`, `q`, and `w` characters are optional.

This table describes the date and time components that the characters represent.

<table>
<thead>
<tr>
<th>Character</th>
<th>Date or Time Unit</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>y</code></td>
<td>Years</td>
<td>Multiples of 12 months display as a number of years.</td>
</tr>
<tr>
<td><code>q</code></td>
<td>Quarters</td>
<td>Multiples of 3 months display as a number of quarters.</td>
</tr>
<tr>
<td><code>m</code></td>
<td>Months</td>
<td>Must be included in <code>Format</code>.</td>
</tr>
<tr>
<td><code>w</code></td>
<td>Weeks</td>
<td>Multiples of 7 days display as a number of weeks.</td>
</tr>
<tr>
<td>Character</td>
<td>Date or Time Unit</td>
<td>Details</td>
</tr>
<tr>
<td>-----------</td>
<td>------------------</td>
<td>---------</td>
</tr>
<tr>
<td>d</td>
<td>Days</td>
<td>Must be included in Format.</td>
</tr>
<tr>
<td>t</td>
<td>Time (hours, minutes, and seconds)</td>
<td>Must be included in Format.</td>
</tr>
</tbody>
</table>

To specify the number of digits displayed for fractional seconds, use the `format` function.

If the value of a date or time component is zero, it is not displayed.

Changing the `Format` property does not change the values in the array, only their display.

**Default datetime Format**

You can set default formats to control the display of `datetime` arrays created without an explicit display format. These formats also apply when you set the `Format` property of a `datetime` array to `'default'` or `'defaultdate'`. When you change the default setting, `datetime` arrays set to use the default formats are displayed automatically using the new setting.

Changes to the default formats persist across MATLAB sessions.

To specify a default format, type

```matlab
datetime.setDefaultFormats('default', fmt)
```

where `fmt` is a string composed of the letters `A-Z` and `a-z` described for the `Format` property of `datetime` arrays, above. For example,

```matlab
datetime.setDefaultFormats('default', 'yyyy-MM-dd hh:mm:ss')
```

sets the default datetime format to include a 4-digit year, 2-digit month number, 2-digit day number, and hour, minute, and second values.

In addition, you can specify a default format for datetimes created without time components. For example,

```matlab
datetime.setDefaultFormats('defaultdate', 'yyyy-MM-dd')
```

sets the default date format to include a 4-digit year, 2-digit month number, and 2-digit day number.

To reset the both the default format and the default date-only formats to the factory defaults, type
datetime.setDefaultFormats('reset')
The factory default formats depend on your system locale.

See Also
calendarDuration | datetime | datetime Properties | duration | format
Generate Sequence of Dates and Time

In this section...

| “Sequence of Datetime or Duration Values Between Endpoints with Step Size” on page 7-13 |
| “Add Duration or Calendar Duration to Create Sequence of Dates” on page 7-16 |
| “Specify Length and Endpoints of Date or Duration Sequence” on page 7-17 |
| “Sequence of Datetime Values Using Calendar Rules” on page 7-18 |

Sequence of Datetime or Duration Values Between Endpoints with Step Size

This example shows how to use the colon (:) operator to generate sequences of datetime or duration values in the same way that you create regularly spaced numeric vectors.

Use Default Step Size

Create a sequence of datetime values starting from November 1, 2013 and ending on November 5, 2013. The default step size is one calendar day.

```matlab
t1 = datetime('01-Nov-2013 08:00:00');
t2 = datetime('05-Nov-2013 08:00:00');
t = t1:t2
```

```
t =
Columns 1 through 3
       01-Nov-2013 08:00:00       02-Nov-2013 08:00:00       03-Nov-2013 08:00:00
Columns 4 through 5
       04-Nov-2013 08:00:00       05-Nov-2013 08:00:00
```

Specify Step Size

Specify a step size of 2 calendar days using the caldays function.

```matlab
t = t1:caldays(2):t2
```
Specify a step size in units other than days. Create a sequence of datetime values spaced 18 hours apart.

\[ t = t1: \text{hours}(18):t2 \]

\[ t = \]

Columns 1 through 3

\[
\begin{array}{c}
01-\text{Nov}-2013 \ 08:00:00 \\
02-\text{Nov}-2013 \ 02:00:00 \\
02-\text{Nov}-2013 \ 20:00:00
\end{array}
\]

Columns 4 through 6

\[
\begin{array}{c}
03-\text{Nov}-2013 \ 14:00:00 \\
04-\text{Nov}-2013 \ 08:00:00 \\
05-\text{Nov}-2013 \ 02:00:00
\end{array}
\]

Use the `years`, `days`, `minutes`, and `seconds` functions to create datetime and duration sequences using other fixed-length date and time units. Create a sequence of duration values between 0 and 3 minutes, incremented by 30 seconds.

\[ d = 0: \text{seconds}(30):\text{minutes}(3) \]

\[ d = \]

\[
\begin{array}{cccccc}
0 \text{ mins} & 0.5 \text{ mins} & 1 \text{ min} & 1.5 \text{ mins} & 2 \text{ mins} & 2.5 \text{ mins} & 3 \text{ mins}
\end{array}
\]

**Compare Fixed-Length Duration and Calendar Duration Step Sizes**

Assign a time zone to \( t1 \) and \( t2 \). In the `America/New_York` time zone, \( t1 \) now occurs just before a daylight saving time change.

\[
\begin{array}{l}
t1.\text{TimeZone} = '\text{America/New_York}'; \\
t2.\text{TimeZone} = '\text{America/New_York}';
\end{array}
\]

If you create the sequence using a step size of one calendar day, then the difference between successive `datetime` values is not always 24 hours.
t = t1:t2;
dt = diff(t)

dt =
   24:00:00   25:00:00   24:00:00   24:00:00

Create a sequence of datetime values spaced one fixed-length day apart,
\[ t = t1:days(1):t2 \]

\[
\begin{array}{ccc}
01-\text{Nov}-2013 & 02-\text{Nov}-2013 & 03-\text{Nov}-2013 \\
08:00:00 & 08:00:00 & 07:00:00
\end{array}
\]

\[
\begin{array}{ccc}
04-\text{Nov}-2013 & 05-\text{Nov}-2013 \\
07:00:00 & 07:00:00
\end{array}
\]

Verify that the difference between successive \texttt{datetime} values is 24 hours.
\[ dt = \text{diff}(t) \]

\[ dt =
   24:00:00   24:00:00   24:00:00   24:00:00
\]

**Integer Step Size**

If you specify a step size in terms of an integer, it is interpreted as a number of 24-hour days.
\[ t = t1:1:t2 \]

\[
\begin{array}{c}
\text{Columns 1 through 3}
\end{array}
\]
Add Duration or Calendar Duration to Create Sequence of Dates

This example shows how to add a duration or calendar duration to a datetime to create a sequence of datetime values.

Create a datetime scalar representing November 1, 2013 at 8:00 AM.

\[ t1 = \text{datetime('01-Nov-2013 08:00:00')}; \]

Add a sequence of fixed-length hours to the datetime.

\[ t = t1 + \text{hours(0:2)} \]

\[ t = \begin{array}{ccc}
01-Nov-2013 08:00:00 & 01-Nov-2013 09:00:00 & 01-Nov-2013 10:00:00 \\
\end{array} \]

Add a sequence of calendar months to the datetime.

\[ t = t1 + \text{calmonths(1:5)} \]

\[ t = \begin{array}{ccc}
01-Dec-2013 08:00:00 & 01-Jan-2014 08:00:00 & 01-Feb-2014 08:00:00 \\
Columns 4 through 5 \\
01-Mar-2014 08:00:00 & 01-Apr-2014 08:00:00 \\
\end{array} \]

Each datetime in \( t \) occurs on the first day of each month.
Verify that the dates in \( t \) are spaced 1 month apart.
\[
dt = \text{caldiff}(t)
\]
\[
dt = \\
1\text{mo} \quad 1\text{mo} \quad 1\text{mo} \quad 1\text{mo}
\]

Determine the number of days between each date.
\[
dt = \text{caldiff}(t, 'days')
\]
\[
dt = \\
31\text{d} \quad 31\text{d} \quad 28\text{d} \quad 31\text{d}
\]

Add a number of calendar months to the date, January 31, 2014, to create a sequence of dates that fall on the last day of each month.
\[
t = \text{datetime('31-Jan-2014')} + \text{calmonths(0:11)}
\]
\[
t = \\
Columns 1 through 5 \\
31-Jan-2014 \quad 28-Feb-2014 \quad 31-Mar-2014 \quad 30-Apr-2014 \quad 31-May-2014 \\
Columns 6 through 10 \\
30-Jun-2014 \quad 31-Jul-2014 \quad 31-Aug-2014 \quad 30-Sep-2014 \quad 31-Oct-2014 \\
Columns 11 through 12 \\
30-Nov-2014 \quad 31-Dec-2014
\]

**Specify Length and Endpoints of Date or Duration Sequence**

This example shows how to use the `linspace` function to create equally spaced `datetime` or `duration` values between two specified endpoints.
Create a sequence of five equally spaced dates between April 14, 2014 and August 4, 2014. First, define the endpoints.

\[ A = \text{datetime}(2014,04,14); \]
\[ B = \text{datetime}(2014,08,04); \]

The third input to `linspace` specifies the number of linearly spaced points to generate between the endpoints.

\[ C = \text{linspace}(A,B,5) \]

\[ C = \\

Create a sequence of six equally spaced durations between 1 and 5.5 hours.

\[ A = \text{duration}(1,0,0); \]
\[ B = \text{duration}(5,30,0); \]
\[ C = \text{linspace}(A,B,6) \]

\[ C = \\
01:00:00  01:54:00  02:48:00  03:42:00  04:36:00  05:30:00 \]

**Sequence of Datetime Values Using Calendar Rules**

This example shows how to use the `dateshift` function to generate sequences of dates and time where each instance obeys a rule relating to a calendar unit or a unit of time. For instance, each datetime must occur at the beginning a month, on a particular day of the week, or at the end of a minute. The resulting datetime values in the sequence are not necessarily equally spaced.

**Dates on Specific Day of Week**

Generate a sequence of dates consisting of the next three occurrences of Monday. First, define today's date.

\[ t1 = \text{datetime('today','Format','dd-MMM-yyyy eee')} \]
t1 =

23-Feb-2015 Mon

The first input to `dateshift` is always the `datetime` array from which you want to generate a sequence. Specify `'dayofweek'` as the second input to indicate that the `datetime` values in the output sequence must fall on a specific day of the week.

\[ t = \text{dateshift}(t1, 'dayofweek', 'Monday', 1:3) \]

\[ t = \]

23-Feb-2015 Mon   02-Mar-2015 Mon   09-Mar-2015 Mon

**Dates at Start of Month**

Generate a sequence of start-of-month dates beginning with April 1, 2014. Specify `'start'` as the second input to `dateshift` to indicate that all `datetime` values in the output sequence should fall at the start of a particular unit of time. The third input argument defines the unit of time, in this case, month. The last input to `dateshift` can be an array of integer values that specifies how `t1` should be shifted. In this case, 0 corresponds to the end of the current month, and 4 corresponds to the end of the fourth month from `t1`.

\[ t1 = \text{datetime}(2014, 04, 01); \]
\[ t = \text{dateshift}(t1, 'start', 'month', 0:4) \]

\[ t = \]

01-Apr-2014   01-May-2014   01-Jun-2014   01-Jul-2014   01-Aug-2014

**Dates at End of Month**

Generate a sequence of end-of-month dates beginning with April 1, 2014.

\[ t1 = \text{datetime}(2014, 04, 01); \]
\[ t = \text{dateshift}(t1, 'end', 'month', 0:2) \]

\[ t = \]
Determine the number of days between each date.

\[ dt = \text{caldiff}(t, 'days') \]

\[ dt = \]

\[ 31d \quad 30d \]

The dates are not equally spaced.

**Other Units of Dates and Time**

You can specify other units of time such as week, day, and hour.

\[ t1 = \text{datetime('now')} \]

\[ t1 = \]

\[ 23\text{-Feb-2015} \ 10:11:55 \]

\[ t = \text{dateshift}(t1, 'start', 'hour', 0:4) \]

\[ t = \]

Columns 1 through 3

\[ 23\text{-Feb-2015} \ 10:00:00 \quad 23\text{-Feb-2015} \ 11:00:00 \quad 23\text{-Feb-2015} \ 12:00:00 \]

Columns 4 through 5

\[ 23\text{-Feb-2015} \ 13:00:00 \quad 23\text{-Feb-2015} \ 14:00:00 \]

**Previous Occurrences of Dates and Time**

Generate a sequence of datetime values beginning with the previous hour. Negative integers in the last input to `dateshift` correspond to datetime values earlier than \( t1 \).
t = dateshift(t1,'start','hour',-1:1)

t =

    23-Feb-2015 09:00:00    23-Feb-2015 10:00:00    23-Feb-2015 11:00:00

See Also
dateshift | linspace
Share Code and Data Across Locales

In this section...

“Write Locale-Independent Date and Time Code” on page 7-22
“Write Dates in Other Languages” on page 7-23
“Read Dates in Other Languages” on page 7-24

Write Locale-Independent Date and Time Code

Follow these best practices when sharing code that handles dates and time with MATLAB® users in other locales. These practices ensure that the same code produces the same output display and that output files containing dates and time are read correctly on systems in different countries or with different language settings.

Create language-independent datetime values. That is, create datetime values that use month numbers rather than month names, such as 01 instead of January. Avoid using day of week names.

For example, do this:

```matlab
t = datetime('today','Format','yyyy-MM-dd')
```

```matlab
t =
2015-02-23
```

instead of this:

```matlab
t = datetime('today','Format','eeee, dd-MMM-yyyy')
```

```matlab
t =
Monday, 23-Feb-2015
```

Display the hour using 24-hour clock notation rather than 12-hour clock notation. Use the 'HH' identifiers when specifying the display format for datetime values.

For example, do this:
t = datetime('now','Format','HH:mm')

t =

10:02

instead of this:

t = datetime('now','Format','hh:mm a')

t =

10:02 AM

When specifying the display format for time zone information, use the Z or X identifiers instead of the lowercase z to avoid the creation of time zone names that might not be recognized in other languages or regions.

Assign a time zone to t.

t.TimeZone = 'America/New_York';

Specify a language-independent display format that includes a time zone.

t.Format = 'dd-MM-yyyy Z'

t =

23-02-2015 -0500

If you share files but not code, you do not need to write locale-independent code while you work in MATLAB. However, when you write to a file, ensure that any date and time strings are language-independent. Then, other MATLAB users can read the files easily without having to specify a locale in which to interpret date and time data.

**Write Dates in Other Languages**

Specify an appropriate format for date and time strings when you use the `char` or `cellstr` functions. For example, convert two datetime values to a cell array of strings

```matlab
```
using `cellstr`. Specify the format of the datetime values and the locale of the strings to create.

\[ t = \text{[datetime('today');datetime('tomorrow')]} \]

\[
t = \\
23\text{- Feb}\text{- 2015}
24\text{- Feb}\text{- 2015}
\]

\[ S = \text{cellstr}(t,'dd. MMMM yyyy','de\_DE') \]

\[
S = \\
'23. Februar 2015'
'24. Februar 2015'
\]

\( S \) is a cell array of German date strings. You can export \( S \) to a text file to use with systems in the de\_DE locale.

**Read Dates in Other Languages**

You can read text files containing dates and time in a language other than the language that MATLAB uses, which depends on your system locale. Use the `textscan` or `readtable` functions with the `DateLocale` name-value pair argument to specify the locale in which the function interprets the dates in the file. In addition, you might need to specify the character encoding of a file that contains characters that are not recognized by your computer's default encoding.

- When reading text files using the `textscan` function, specify the file encoding when opening the file with `fopen`. The encoding is the fourth input argument to `fopen`.
- When reading text files using the `readtable` function, use the `FileEncoding` name-value pair argument to specify the character encoding associated with the file.

**See Also**

`cellstr` | `char` | `datetime` | `readtable` | `textscan`
Extract or Assign Date and Time Components of Datetime Array

This example shows two ways to extract date and time components from existing datetime arrays: accessing the array properties or calling a function. Then, the example shows how to modify the date and time components by modifying the array properties.

**Access Properties to Retrieve Date and Time Component**

Create a `datetime` array.

```matlab
   t = datetime('now') + calyears(0:2) + calmonths(0:2) + hours(20:20:60)
```

```matlab
t =
```

Get the year values of each datetime in the array. Use dot notation to access the `Year` property of `t`.

```matlab
   t_years = t.Year
```

```matlab
t_years =
   2015        2016        2017
```

The output, `t_years`, is a numeric array.

Get the month values of each datetime in `t` by accessing the `Month` property.

```matlab
   t_months = t.Month
```

```matlab
t_months =
   2     3     4
```

You can retrieve the day, hour, minute, and second components of each datetime in `t` by accessing the `Hour`, `Minute`, and `Second` properties, respectively.
Use Functions to Retrieve Date and Time Component

Use the `month` function to get the month number for each datetime in `t`. Using functions is an alternate way to retrieve specific date or time components of `t`.

```matlab
m = month(t)
```

```matlab
m =
    2     3     4
```

Use the `month` function rather than the `Month` property to get the full month names of each datetime in `t`.

```matlab
m = month(t,'name')
```

```matlab
m =
    'February'    'March'    'April'
```

You can retrieve the year, quarter, week, day, hour, minute, and second components of each datetime in `t` using the `year`, `quarter`, `week`, `hour`, `minute`, and `second` functions, respectively.

Get the week of year numbers for each datetime in `t`.

```matlab
w = week(t)
```

```matlab
w =
    9    13    17
```

Get Multiple Date and Time Components

Use the `ymd` function to get the year, month, and day values of `t` as three separate numeric arrays.

```matlab
[y, m, d] = ymd(t)
```
Use the `hms` function to get the hour, minute, and second values of `t` as three separate numeric arrays.

```matlab
[h,m,s] = hms(t)
```

**Modify Date and Time Components**

Assign new values to components in an existing `datetime` array by modifying the properties of the array. Use dot notation to access a specific property.

Change the year number of all datetime values in `t` to 2014. Use dot notation to modify the `Year` property.
t.Year = 2014

t =


Change the months of the three datetime values in \( t \) to January, February, and March, respectively. You must specify the new value as a numeric array.

\[
t.\text{Month} = [1,2,3]
\]

\[
t =

\]

Set the time zone of \( t \) by assigning a value to the \texttt{TimeZone} property.

\[
t.\text{TimeZone} = 'Europe/Berlin';
\]

Change the display format of \( t \) to display only the date, and not the time information.

\[
t.\text{Format} = 'dd-MMM-yyyy'
\]

\[
t =

\]

If you assign values to a datetime component that are outside the conventional range, MATLAB® normalizes the components. The conventional range for day of month numbers is from 1 to 31. Assign day values that exceed this range.

\[
t.\text{Day} = [-1 1 32]
\]

\[
t =

    30-Dec-2013   01-Feb-2014   01-Apr-2014
\]
The month and year numbers adjust so that all values remain within the conventional range for each date component. In this case, January -1, 2014 converts to December 30, 2013.

**See Also**

datetime Properties | hms | week | ymd
Combine Date and Time from Separate Variables

This example shows how to read date and time data from a text file. Then, it shows how to combine date and time information stored in separate variables into a single datetime variable.

Create a space-delimited text file named `schedule.txt` that contains the following (to create the file, use any text editor, and copy and paste):

```
Date Name Time
10.03.2015 Joe 14:31
10.03.2015 Bob 15:33
11.03.2015 Bob 11:29
12.03.2015 Kim 12:09
12.03.2015 Joe 13:05
```

Read the file using the `readtable` function. Use the `%D` conversion specifier to read the first and third columns of data as datetime values.

```
T = readtable('schedule.txt','Format','%{dd.MM.uuuu}D %s %{HH:mm}D','Delimiter',' ')
```

`readtable` returns a table containing three variables.

```
T =
    Date   Name     Time
    ________    _____    _____
   10.03.2015    'Joe'    14:31
   10.03.2015    'Bob'    15:33
   11.03.2015    'Bob'    11:29
   12.03.2015    'Kim'    12:09
   12.03.2015    'Joe'    13:05
```

Change the display format for the `T.Date` and `T.Time` variables to view both date and time information. Since the data in the first column of the file ("Date") have no time information, the time of the resulting datetime values in `T.Date` default to midnight. Since the data in the third column of the file ("Time") have no associated date, the date of the datetime values in `T.Time` defaults to the current date.

```
T.Date.Format = 'dd.MM.uuuu HH:mm';
T.Time.Format = 'dd.MM.uuuu HH:mm';
T
```

```
T =
    Date   Name     Time
    ________    _____    _____
    10.03.2015    'Joe'    14:31
    10.03.2015    'Bob'    15:33
    11.03.2015    'Bob'    11:29
    12.03.2015    'Kim'    12:09
    12.03.2015    'Joe'    13:05
```
Combine the date and time information from two different table variables by adding `T.Date` and the time values in `T.Time`. Extract the time information from `T.Time` using the `timeofday` function.

```matlab
myDatetime = T.Date + timeofday(T.Time)
```

`myDatetime` = `T.Date + timeofday(T.Time)`

```matlab
myDatetime =
10.03.2015 14:31
10.03.2015 15:33
11.03.2015 11:29
12.03.2015 12:09
12.03.2015 13:05
```

**See Also**

`readtable` | `timeofday`
Date and Time Arithmetic

This example shows how to add and subtract date and time values to calculate future and past dates and elapsed durations in exact units or calendar units. You can add, subtract, multiply, and divide date and time arrays in the same way that you use these operators with other MATLAB® data types. However, there is some behavior that is specific to dates and time.

Add and Subtract Durations to Datetime Array

Create a datetime scalar. By default, datetime arrays are not associated with a time zone.

\[
\text{t1 = datetime('now')}\]

\[
t1 =
\begin{align*}
23\text{-Feb-2015 10:07:08}
\end{align*}
\]

Find future points in time by adding a sequence of hours.

\[
\text{t2 = t1 + hours(1:3)}
\]

\[
t2 =
\begin{align*}
23\text{-Feb-2015 11:07:08} & \quad 23\text{-Feb-2015 12:07:08} & \quad 23\text{-Feb-2015 13:07:08}
\end{align*}
\]

Verify that the difference between each pair of datetime values in \( t2 \) is 1 hour.

\[
\text{dt = diff(t2)}
\]

\[
dt =
\begin{align*}
01:00:00 & \quad 01:00:00
\end{align*}
\]

diff returns durations in terms of exact numbers of hours, minutes, and seconds.

Subtract a sequence of minutes from a datetime to find past points in time.
t2 = t1 - minutes(20:10:40)

```
t2 =
```

Add a numeric array to a datetime array. MATLAB® treats each value in the numeric array as a number of exact, 24-hour days.

```
t2 = t1 + [1:3]
```

```
t2 =
```

**Add to Datetime with Time Zone**

If you work with datetime values in different time zones, or if you want to account for daylight saving time changes, work with datetime arrays that are associated with time zones. Create a datetime scalar representing March 8, 2014 in New York.

```
t1 = datetime(2014,3,8,0,0,0,'TimeZone','America/New_York')
```

```
t1 =
    08-Mar-2014 00:00:00
```

Find future points in time by adding a sequence of fixed-length (24-hour) days.

```
t2 = t1 + days(0:2)
```

```
t2 =
    08-Mar-2014 00:00:00   09-Mar-2014 00:00:00   10-Mar-2014 01:00:00
```

Because a daylight saving time shift occurred on March 9, 2014, the third datetime in t2 does not occur at midnight.
Verify that the difference between each pair of datetime values in \( t2 \) is 24 hours.

\[
dt = \text{diff}(t2)
\]

\[
dt = \\
24:00:00 \quad 24:00:00
\]

You can add fixed-length durations in other units such as years, hours, minutes, and seconds by adding the outputs of the \texttt{years}, \texttt{hours}, \texttt{minutes}, and \texttt{seconds} functions, respectively.

To account for daylight saving time changes, you should work with calendar durations instead of durations. Calendar durations account for daylight saving time shifts when they are added to or subtracted from datetime values.

Add a number of calendar days to \( t1 \).

\[
t3 = t1 + \text{caldays}(0:2)
\]

\[
t3 = \\
08-Mar-2014 00:00:00 \quad 09-Mar-2014 00:00:00 \quad 10-Mar-2014 00:00:00
\]

View that the difference between each pair of datetime values in \( t3 \) is not always 24 hours due to the daylight saving time shift that occurred on March 9.

\[
dt = \text{diff}(t3)
\]

\[
dt = \\
24:00:00 \quad 23:00:00
\]

**Add Calendar Durations to Datetime Array**

Add a number of calendar months to January 31, 2014.

\[
t1 = \text{datetime}(2014,1,31)
\]
t1 = 31-Jan-2014

t2 = t1 + calmonths(1:4)

t2 =

Each datetime in t2 occurs on the last day of each month.

Calculate the difference between each pair of datetime values in t2 in terms of a number of calendar days using the caldiff function.

dt = caldiff(t2,'days')

dt =
   31d   30d   31d

The number of days between successive pairs of datetime values in dt is not always the same because different months consist of a different number of days.

Add a number of calendar years to January 31, 2014.

t2 = t1 + calyears(0:4)

t2 =
   31-Jan-2014   31-Jan-2015   31-Jan-2016   31-Jan-2017   31-Jan-2018

Calculate the difference between each pair of datetime values in t2 in terms of a number of calendar days using the caldiff function.

dt = caldiff(t2,'days')

dt = 
The number of days between successive pairs of datetime values in \( \text{dt} \) is not always the same because 2016 is a leap year and has 366 days.

You can use the `calquarters`, `calweeks`, and `caldays` functions to create arrays of calendar quarters, calendar weeks, or calendar days that you add to or subtract from datetime arrays.

Adding calendar durations is not commutative. When you add more than one `calendarDuration` array to a datetime, MATLAB® adds them in the order in which they appear in the command.

Add 3 calendar months followed by 30 calendar days to January 31, 2014.

\[
t_2 = \text{datetime}(2014,1,31) + \text{calmonths}(3) + \text{caldays}(30)
\]

\[
t_2 = \\
30-\text{May}-2014
\]

First add 30 calendar days to the same date, and then add 3 calendar months. The result is not the same because when you add a calendar duration to a datetime, the number of days added depends on the original date.

\[
t_2 = \text{datetime}(2014,1,31) + \text{caldays}(30) + \text{calmonths}(3)
\]

\[
t_2 = \\
02-\text{Jun}-2014
\]

**Calendar Duration Arithmetic**

Create two calendar durations and then find their sum.

\[
d_1 = \text{calyears}(1) + \text{calmonths}(2) + \text{caldays}(20)
\]

\[
d_1 = 
\]
1y 2mo 20d

d2 = calmonths(11) + caldays(23)

d2 =

11mo 23d

d = d1 + d2

d =

2y 1mo 43d

When you sum two or more calendar durations, a number of months greater than 12 roll over to a number of years. However, a large number of days does not roll over to a number of months, because different months consist of different numbers of days.

Increase d by multiplying it by a factor of 2. Calendar duration values must be integers, so you can multiply them only by integer values.

2*d

ans =

4y 2mo 86d

**Calculate Elapsed Time in Exact Units**

Subtract one datetime array from another to calculate elapsed time in terms of an exact number of hours, minutes, and seconds.

Find the exact length of time between a sequence of datetime values and the start of the previous day.

\[ t2 = \text{datetime('now')} + \text{caldays}(1:3) \]
t2 =
t1 = datetime('yesterday')
t1 =
22-Feb-2015
dt = t2 - t1
dt =
58:07:08  82:07:08  106:07:08
whos dt
Name    Size  Bytes  Class         Attributes
dt      1x3    144  duration

dt contains durations in the format, hours:minutes:seconds.
View the elapsed durations in units of days by changing the Format property of dt.
dt.Format = 'd'
dt =
2.4216 days  3.4216 days  4.4216 days
Scale the duration values by multiplying dt by a factor of 1.2. Because durations have an exact length, you can multiply and divide them by fractional values.
dt2 = 1.2*dt
dt2 =
   2.906 days   4.106 days   5.306 days

**Calculate Elapsed Time in Calendar Units**

Use the `between` function to find the number of calendar years, months, and days elapsed between two dates.

t1 = datetime('today')

t1 =
   23-Feb-2015

t2 = t1 + calmonths(0:2) + caldays(4)

t2 =

dt = between(t1,t2)

dt =
   4d   1mo 4d   2mo 4d

**See Also**

between | caldiff | diff
Compare Dates and Time

This example shows how to compare `datetime` and `duration` arrays. You can perform an element-by-element comparison of values in two `datetime` arrays or two `duration` arrays using relational operators, such as `>` and `<.

**Compare Datetime Arrays**

Compare two `datetime` arrays. The arrays must be the same size or one can be a scalar.

```plaintext
A = datetime(2013,07,26) + calyears(0:2:6)
B = datetime(2014,06,01)
```

A =


B =

01-Jun-2014

A < B

ans =

1     0     0     0

The `<` operator returns logical 1 (true) where a `datetime` in A occurs before a `datetime` in B.

Compare a `datetime` array to a date string.

A >= 'September 26, 2014'

ans =

0     1     1     1
Comparisons of `datetime` arrays account for the time zone information of each array.

Compare September 1, 2014 at 4:00 p.m. in Los Angeles with 5:00 p.m. on the same day in New York.

```matlab
A = datetime(2014,09,01,16,0,0,'TimeZone','America/Los_Angeles',...
               'Format','dd-MMMM-yyyy HH:mm:ss Z')
```

```
A =
 01-Sep-2014 16:00:00 -0700
```

```matlab
B = datetime(2014,09,01,17,0,0,'TimeZone','America/New_York',...
               'Format','dd-MMMM-yyyy HH:mm:ss Z')
```

```
B =
 01-Sep-2014 17:00:00 -0400
```

```matlab
A < B
```

```
ans =
 0
```

4:00 p.m. in Los Angeles occurs after 5:00 p.m. on the same day in New York.

**Compare Durations**

Compare two `duration` arrays.

```matlab
A = duration([2,30,30;3,15,0])
B = duration([2,40,0;2,50,0])
```

```
A =
 02:30:30
 03:15:00
```
B =

02:40:00
02:50:00

A >= B

ans =

0
1

Compare a duration array to a numeric array. Elements in the numeric array are treated as a number of fixed-length (24-hour) days.

A < [1; 1/24]

ans =

1
0

Determine if Dates and Time Are Contained Within an Interval

Use the isbetween function to determine whether values in a datetime array lie within a closed interval.

Define endpoints of an interval.

tlower = datetime(2014,08,01)
tupper = datetime(2014,09,01)

tlower =

01-Aug-2014

tupper =
Create a `datetime` array and determine whether the values lie within the interval bounded by `t1` and `t2`.

```matlab
A = datetime(2014,08,21) + calweeks(0:2)
```

```matlab
A =
    21-Aug-2014   28-Aug-2014   04-Sep-2014
```

```matlab
tf = isbetween(A,tlower,tupper)
```

```matlab
tf =
    1   1   0
```

**See Also**
- `isbetween`

**More About**
- “Relational Operators”
Plot Dates and Durations

This example shows how to create line and scatter plots of datetime and duration values using the `plot` function. Then, it shows how to convert datetime and duration values to numeric values to create other types of plots.

**Line Plot with Dates**

Create a line plot with datetime values on the x-axis.

Define `t` as a sequence of dates.

```matlab
t = datetime(2014,6,28) + caldays(1:10);
```

Define `y` as random data. Then, plot the vectors using the `plot` function.

```matlab
y = rand(1,10);
plot(t,y);
```
By default, `plot` chooses tick mark locations based on the range of data. When you zoom in and out of a plot, the tick labels automatically adjust to the new axis limits.

Replot the data and specify a format for the datetime tick labels, using the `DatetimeTickFormat` name-value pair argument.

```
plot(t,y,'DatetimeTickFormat','dd-MMM-yyyy')
```
When you specify a value for the `DatetimeTickFormat` argument, `plot` always formats the tick labels according to the specified value.

**Line Plot with Durations**

Create a line plot with duration values on the x-axis.

Define `t` as seven linearly spaced duration values between 0 and 3 minutes. Define `y` as a vector of random data.

```matlab
t = 0:seconds(30):minutes(3);
y = rand(1,7);
```
Plot the data and specify the format of the duration tick marks in terms of a single unit, seconds.

```matlab
h = plot(t,y,'DurationTickFormat','s');
```

View the x-axis limits

```matlab
xlim
```

```
ans =
     0   180
```
The x-axis limits are stored as numeric values in units of seconds.

Change the format of the duration tick marks by replotting the same data. Specify the format of the duration tick marks in the form of a digital timer that includes more than one unit.

```matlab
figure
h = plot(t,y,'DurationTickFormat','mm:ss');
```

View the x-axis limits

```matlab
xlim
```

```
ans =
```

```matlab
00:00 00:30 01:00 01:30 02:00 02:30 03:00
```

01 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1

00:00 00:30 01:00 01:30 02:00 02:30 03:00
The x-axis limits are stored in units of 24-hour days when the duration tick format is not a single unit.

**Change Axis Limits**

Plot dates and random data.

```matlab
t = datetime(2014,6,28) + calweeks(1:10);
y = rand(1,10);
plot(t,y);
```
View the x-axis limits

```matlab
format longG
xlim
```

```matlab
ans =
        735781.8        735850.3
```

The axis limits for datetime values are stored as serial date numbers.

Change the x-axis limits by specifying the new bounds in terms of serial date numbers. Use the `datenum` function to create serial date numbers.

```matlab
xmin = datenum(2014,7,14)
```

```matlab
xmin =
        735794
```

```matlab
xmax = datenum(2014,8,23)
```

```matlab
xmax =
        735834
```

Specify the new x-axis limits using the `xlim` function.

```matlab
xlim([xmin xmax])
```
Properties Stored as Numeric Values

In addition to axis limits, the locations of tick labels and the x-, y-, and z-values for dates and durations in line plots are also stored as numeric values. The following properties represent these aspects of line plots.

- XData, YData, ZData
- XLim, YLim, ZLim
- XTick, YTick, ZYTick
**Scatter Plot**

Create a scatter plot with datetime or duration inputs using the `plot` function. The `scatter` function does not accept datetime and duration inputs.

Use the `plot` function to create a scatter plot, specifying the marker symbol, `'o'`.

```matlab
t = datetime('today') + caldays(1:100);
y = linspace(10,40,100) + 10*rand(1,100);
plot(t,y,'o')
```
Other Plot Types

Other MATLAB plotting functions do not accept datetime and duration inputs. Convert
datetime and duration values to numeric values before plotting them using a function
other than plot.

Convert the datetime values in \( t \) to numeric values by subtracting a datetime origin.

\[
dt = t - \text{datetime(}'1\text{-Sep-2010}'\text{'})
\]

\( dt \) is a duration array. Convert \( dt \) to a double array of values in units of years, days,
minutes, or seconds using the \texttt{years}, \texttt{days}, \texttt{hours}, \texttt{minutes}, or \texttt{seconds} function,
respectively.

\[
x = \text{days}(dt);
\]

\texttt{whos x}

\begin{array}{|l|l|l|}
\hline
\text{Name} & \text{Size} & \text{Bytes} & \text{Class} & \text{Attributes} \\
\hline
x & 1\times100 & 800 & \text{double} & \\
\hline
\end{array}

Plot \( x \) using the \texttt{bar} function, which accepts double inputs.

\texttt{bar(x,y)}
See Also
datetime | plot
Core Functions Supporting Date and Time Arrays

Many functions in MATLAB operate on date and time arrays in much the same way that they operate on other arrays.

This table lists notable MATLAB functions that operate on `datetime`, `duration`, and `calendarDuration` arrays in addition to other arrays.

<table>
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<tr>
<th>size</th>
<th>isequal</th>
<th>intersect</th>
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</thead>
<tbody>
<tr>
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<td>setdiff</td>
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<td>floor</td>
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<td>round</td>
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<td>min</td>
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<td>max</td>
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<td>mldivide</td>
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<td>char</td>
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<tr>
<td></td>
<td></td>
<td>cellstr</td>
</tr>
</tbody>
</table>
**Convert Between Datetime Arrays, Numbers, and Strings**

**Overview**

`datetime` is the best data type for representing points in time. `datetime` values have flexible display formats and up to nanosecond precision, and can account for time zones, daylight saving time, and leap seconds. However, if you work with code authored in MATLAB R2014a or earlier, or if you share code with others who use such a version, you might need to work with dates and time stored in one of these 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. Serial date numbers are useful as inputs to some MATLAB functions that do not accept the `datetime` or `duration` data types.
  
  Example: 7.3510e+005

Date strings, vectors, and numbers can be stored as arrays of values. Store multiple date strings in a cell array, multiple date vectors in an m-by-6 matrix, and multiple serial date numbers in a matrix.

You can convert any of these formats to a `datetime` array using the `datetime` function. If your existing MATLAB code expects a serial date number or date vector, use the `datenum` or `datevec` functions, respectively, to convert a `datetime` array to the expected data format. To convert a `datetime` array to a string, use the `char` or `cellstr` functions.
Convert Between Datetime and 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'

A date string includes characters that separate the fields, such as the hyphen, space, and colon used here:

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

Convert one or more date strings to a datetime array using the datetime function. For best performance, specify the format of the input date strings as an input to datetime.

```
t = datetime(d,'InputFormat','dd-MMM-yyyy HH:mm:ss:')
```

Although the date string, d, and the datetime scalar, t, look similar, they are not equal. View the size and data type of each variable.

```
whos d t
```

<table>
<thead>
<tr>
<th>Name</th>
<th>Size</th>
<th>Bytes</th>
<th>Class</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>t</td>
<td>1x1</td>
<td>121</td>
<td>datetime</td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>1x20</td>
<td>40</td>
<td>char</td>
<td></td>
</tr>
</tbody>
</table>

Convert a datetime array to a string using char or cellstr. For example, convert the current date and time to a timestamp to append to a file name.

```
t = datetime('now','Format','yyyy-MM-dd''T''HH:mm:ss')
```
t = 2014-11-19T145812
S = char(t);
filename = ['myTest_',S]
filename = myTest_2014-11-19T145812

Convert Between Datetime and Date Vectors

A date vector is a 1-by-6 vector of double-precision numbers. Elements of a date vector are integer-valued, except for the seconds element, which can be fractional. Time values are expressed in 24-hour notation. There is no AM or PM setting.

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]

Convert one or more date vectors to a datetime array using the datetime function:
t = datetime([2012 10 24 10 45 07])
t = 24-Oct-2012 10:45:07

Instead of using datevec to extract components of datetime values, use functions such as year, month, and day instead:
y = year(t)
y = 2012

Alternatively, access the corresponding property, such as t.Year for year values:
y = t.Year


\texttt{y = 2012}

\textbf{Convert Serial Date Numbers to Datetime}

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.

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

Convert one or more serial date numbers to a \texttt{datetime} array using the \texttt{datetime} function. Specify the type of date number that is being converted:

\texttt{t = datetime(731885.75,'ConvertFrom','datenum')}

\texttt{t =}

\texttt{31-Oct-2003 18:00:00}

\textbf{Convert Datetime Arrays to Numeric Values}

Some MATLAB functions accept numeric data types but not datetime values as inputs. To apply these functions to your date and time data, convert datetime values to meaningful numeric values. Then, call the function. For example, the \texttt{log} function accepts \texttt{double} inputs, but not \texttt{datetime} inputs. Suppose that you have a \texttt{datetime} array of dates spanning the course of a research study or experiment.

\texttt{t = datetime('18-Jun-2014') + calmonths(1:4)}

\texttt{t =}


Subtract the origin value. For example, the origin value might be the starting day of an experiment.

\texttt{dt = t - '1-Jul-2014'}

\texttt{dt =}

\texttt{408:00:00 1152:00:00 1896:00:00 2616:00:00}
dt is a duration array. Convert dt to a double array of values in units of years, days, hours, minutes, or seconds using the years, days, hours, minutes, or seconds function, respectively.

\[ x = \text{hours}(dt) \]

\[ x = \]

\[
\begin{array}{cccc}
408 & 1152 & 1896 & 2616
\end{array}
\]

Pass the double array as the input to the log function.

\[ y = \text{log}(x) \]

\[ y = \]

\[
\begin{array}{cccc}
6.0113 & 7.0493 & 7.5475 & 7.8694
\end{array}
\]

See Also

cellstr | char | datenum | datetime | datevec

More About

- “Represent Dates and Times in MATLAB” on page 7-2
- “Components of Dates and Time”


**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
```
**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:

\[
\text{datestr([2014 06 21 10 51 00])}
\]

\[
\text{ans =}
\]

\[
\text{21-Jun-2014 10:51:00}
\]

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

\[
\text{datestr([2014 06 2110 10 51 00])}
\]

\[
\text{ans =}
\]

\[
\text{06-Jul-0005}
\]
\[
\text{06-Jan-0000}
\]
\[
\text{10-Oct-0005}
\]
\[
\text{10-Jan-0000}
\]
\[
\text{20-Feb-0000}
\]
\[
\text{00-Jan-0000}
\]

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.
Categorical Arrays

• “Create Categorical Arrays” on page 8-2
• “Convert Table Variables Containing Strings to Categorical” on page 8-6
• “Plot Categorical Data” on page 8-11
• “Compare Categorical Array Elements” on page 8-19
• “Combine Categorical Arrays” on page 8-22
• “Combine Categorical Arrays Using Multiplication” on page 8-26
• “Access Data Using Categorical Arrays” on page 8-29
• “Work with Protected Categorical Arrays” on page 8-35
• “Advantages of Using Categorical Arrays” on page 8-40
• “Ordinal Categorical Arrays” on page 8-43
• “Core Functions Supporting Categorical Arrays” on page 8-47
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.

```matlab
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.

```matlab
state = categorical(state)
```

```matlab
class(state)
```

```matlab
state =
    Columns 1 through 9
        MA    ME    CT    VT    ME    NH    VT    MA    NH
    Columns 10 through 11
        CT    RI
```
Create Categorical Arrays

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.

```matlab
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.

```matlab
valueset = {'small','medium','large'};
sizeOrd = categorical(AllSizes,valueset,'Ordinal',true)
class(sizeOrd)
```
Categorical Arrays

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 Numeric Data

Create a vector of 100 random numbers between zero and 50.

x = rand(100,1)*50;

Use the discretize function to create a categorical array by binning the values of x.
Put all values between zero and 15 in the first bin, all the values between 15 and 35 in
the second bin, and all the values between 35 and 50 in the third bin. Each bin includes
the left endpoint, but does not include the right endpoint.

catnames = {'small','medium','large'};
binnedData = discretize(x,[0 15 35 50],'categorical',catnames);

binnedData is a 100-by-1 ordinal categorical array with three categories, such that small < medium < large.

Use the summary function to print the number of elements in each category.

summary(binnedData)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>small</td>
<td>30</td>
</tr>
<tr>
<td>medium</td>
<td>35</td>
</tr>
<tr>
<td>large</td>
<td>35</td>
</tr>
</tbody>
</table>

See Also
categorical | categories | discretize | summary

Related Examples
• “Convert Table Variables Containing Strings to Categorical” on page 8-6
• “Access Data Using Categorical Arrays” on page 8-29
• “Compare Categorical Array Elements” on page 8-19

More About
• “Advantages of Using Categorical Arrays” on page 8-40
• “Ordinal Categorical Arrays” on page 8-43
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

<table>
<thead>
<tr>
<th>Name</th>
<th>Size</th>
<th>Bytes</th>
<th>Class</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>100x1</td>
<td>800</td>
<td>double</td>
<td></td>
</tr>
<tr>
<td>Diastolic</td>
<td>100x1</td>
<td>800</td>
<td>double</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>100x1</td>
<td>12212</td>
<td>cell</td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>100x1</td>
<td>800</td>
<td>double</td>
<td></td>
</tr>
<tr>
<td>LastName</td>
<td>100x1</td>
<td>12416</td>
<td>double</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>100x1</td>
<td>15008</td>
<td>cell</td>
<td></td>
</tr>
<tr>
<td>SelfAssessedHealthStatus</td>
<td>100x1</td>
<td>12340</td>
<td>cell</td>
<td></td>
</tr>
<tr>
<td>Smoker</td>
<td>100x1</td>
<td>100</td>
<td>logical</td>
<td></td>
</tr>
<tr>
<td>Systolic</td>
<td>100x1</td>
<td>800</td>
<td>double</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>100x1</td>
<td>800</td>
<td>double</td>
<td></td>
</tr>
</tbody>
</table>

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`.

```matlab
T.SelfAssessedHealthStatus = categorical(T.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.

```matlab
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`
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 =

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown</td>
<td>49</td>
<td>64</td>
<td>119</td>
</tr>
<tr>
<td>Taylor</td>
<td>31</td>
<td>66</td>
<td>132</td>
</tr>
<tr>
<td>Anderson</td>
<td>45</td>
<td>68</td>
<td>128</td>
</tr>
<tr>
<td>Lee</td>
<td>44</td>
<td>66</td>
<td>146</td>
</tr>
<tr>
<td>Walker</td>
<td>28</td>
<td>65</td>
<td>123</td>
</tr>
<tr>
<td>Young</td>
<td>25</td>
<td>63</td>
<td>114</td>
</tr>
<tr>
<td>Campbell</td>
<td>37</td>
<td>65</td>
<td>135</td>
</tr>
<tr>
<td>Evans</td>
<td>39</td>
<td>62</td>
<td>121</td>
</tr>
<tr>
<td>Morris</td>
<td>43</td>
<td>64</td>
<td>135</td>
</tr>
<tr>
<td>Rivera</td>
<td>29</td>
<td>63</td>
<td>130</td>
</tr>
<tr>
<td>Richardson</td>
<td>30</td>
<td>67</td>
<td>141</td>
</tr>
<tr>
<td>Cox</td>
<td>28</td>
<td>66</td>
<td>111</td>
</tr>
</tbody>
</table>
```
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, \( T_2 \), 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 \( T_2 \).

\[
\text{rows} = T.\text{SelfAssessedHealthStatus} \leq '\text{Fair}';
\]

Then, define the subset of variables to include in table \( T_2 \).

\[
\text{vars} = \{ '\text{Gender}', '\text{Age}', '\text{Height}', '\text{Weight}' \};
\]

Use parentheses to create the subtable \( T_2 \).

\[
T_2 = T(\text{rows}, \text{vars})
\]

\[
\begin{array}{cccc}
\hline
\text{Gender} & \text{Age} & \text{Height} & \text{Weight} \\
\hline
\text{Johnson} & \text{Male} & 43 & 69 & 163 \\
\text{Jones} & \text{Female} & 40 & 67 & 133 \\
\text{Thomas} & \text{Female} & 42 & 66 & 137 \\
\text{Jackson} & \text{Male} & 25 & 71 & 174 \\
\text{Garcia} & \text{Female} & 27 & 69 & 131 \\
\text{Rodriguez} & \text{Female} & 39 & 64 & 117 \\
\text{Lewis} & \text{Female} & 41 & 62 & 137 \\
\text{Lee} & \text{Female} & 44 & 66 & 146 \\
\text{Hall} & \text{Male} & 25 & 70 & 189 \\
\text{Hernandez} & \text{Male} & 36 & 68 & 166 \\
\text{Lopez} & \text{Female} & 40 & 66 & 137 \\
\text{Gonzalez} & \text{Female} & 35 & 66 & 118 \\
\text{Mitchell} & \text{Male} & 39 & 71 & 164 \\
\hline
\end{array}
\]
### Related Examples
- “Create a Table” on page 9-2
- “Create Categorical Arrays” on page 8-2
- “Access Data in a Table” on page 9-26
- “Access Data Using Categorical Arrays” on page 8-29

### More About
- “Advantages of Using Categorical Arrays” on page 8-40
- “Ordinal Categorical Arrays” on page 8-43

<table>
<thead>
<tr>
<th>Name</th>
<th>Gender</th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campbell</td>
<td>Female</td>
<td>37</td>
<td>65</td>
<td>135</td>
</tr>
<tr>
<td>Parker</td>
<td>Male</td>
<td>30</td>
<td>68</td>
<td>182</td>
</tr>
<tr>
<td>Stewart</td>
<td>Male</td>
<td>49</td>
<td>68</td>
<td>170</td>
</tr>
<tr>
<td>Morris</td>
<td>Female</td>
<td>43</td>
<td>64</td>
<td>135</td>
</tr>
<tr>
<td>Watson</td>
<td>Female</td>
<td>40</td>
<td>64</td>
<td>127</td>
</tr>
<tr>
<td>Kelly</td>
<td>Female</td>
<td>41</td>
<td>65</td>
<td>127</td>
</tr>
<tr>
<td>Price</td>
<td>Male</td>
<td>31</td>
<td>72</td>
<td>178</td>
</tr>
<tr>
<td>Bennett</td>
<td>Female</td>
<td>35</td>
<td>64</td>
<td>131</td>
</tr>
<tr>
<td>Wood</td>
<td>Male</td>
<td>32</td>
<td>68</td>
<td>183</td>
</tr>
<tr>
<td>Patterson</td>
<td>Female</td>
<td>37</td>
<td>65</td>
<td>120</td>
</tr>
<tr>
<td>Foster</td>
<td>Female</td>
<td>30</td>
<td>70</td>
<td>124</td>
</tr>
<tr>
<td>Griffin</td>
<td>Male</td>
<td>49</td>
<td>70</td>
<td>186</td>
</tr>
<tr>
<td>Hayes</td>
<td>Male</td>
<td>48</td>
<td>66</td>
<td>177</td>
</tr>
</tbody>
</table>

T2 is a 26-by-4 table.
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

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.

```matlab
SelfAssessedHealthStatus = categorical(SelfAssessedHealthStatus,...
    {'Poor' 'Fair' 'Good' 'Excellent'},'Ordinal',true);
```

Summarize the categorical array, `SelfAssessedHealthStatus`.

```matlab
summary(SelfAssessedHealthStatus)
```

```
Poor           11
Fair           15
Good           40
Excellent      34
```

**Plot Histogram**

Create a histogram bar plot directly from a categorical array.

```matlab
figure
hist(SelfAssessedHealthStatus)
title('Self Assessed Health Status From 100 Patients')
```
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.

```matlab
figure
hist(Location(SelfAssessedHealthStatus<='Fair'))
title('Location of Patients in Fair or Poor Health')
```
Create Pie Chart

Create a pie chart directly from a categorical array.

```matlab
figure
pie(SelfAssessedHealthStatus);
title('Self Assessed Health Status From 100 Patients')
```
The function `pie` accepts the categorical array, `SelfAssessedHealthStatus`, and plots a pie chart of the four categories.

**Create Pareto Chart**

Create a Pareto chart from the category counts for each of the four categories of `SelfAssessedHealthStatus`.

```matlab
figure
A = countcats(SelfAssessedHealthStatus);
C = categories(SelfAssessedHealthStatus);
pareto(A,C);
title('Self Assessed Health Status From 100 Patients')
```
The first input argument to \texttt{pareto} must be a vector. If a categorical array is a matrix or multidimensional array, reshape it into a vector before calling \texttt{countcats} and \texttt{pareto}.

\textbf{Create Scatter Plot}

Convert the cell array of strings to a categorical array.

\begin{verbatim}
Gender = categorical(Gender);
\end{verbatim}

Summarize the categorical array, \texttt{Gender}.

\begin{verbatim}
summary(Gender)
\end{verbatim}

\begin{verbatim}
Female 53
\end{verbatim}
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.

```matlab
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.

```matlab
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
bar | categorical | countcats | hist | pie | rose | scatter | summary

Related Examples
- “Access Data Using Categorical Arrays” on page 8-29
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.

```matlab
C = {'blue' 'red' 'green' 'blue';
     'blue' 'green' 'green' 'blue'};
```

```matlab
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.

```matlab
categories(colors)
```

```
an =
      'blue'
      'green'
      'red'
```

Determine If Elements Are Equal

Use the relational operator, `eq (==)`, to compare the first and second rows of colors.

```matlab
colors(1,:) == colors(2,:)
```

```
an =
    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.

```matlab
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.

```matlab
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`.

```matlab
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.

```matlab
colors(:,1) > colors(:,2)
```

```plaintext
ans =

1
1
```

Both values in the first column, `blue`, are greater than the corresponding values in the second column, `red` and `green`.

Find all the elements in `colors` that are less than `'blue'`.

```matlab
colors < 'blue'
```

```plaintext
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 8-29

**More About**
- “Relational Operations”
- “Advantages of Using Categorical Arrays” on page 8-40
- “Ordinal Categorical Arrays” on page 8-43
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.

\[
A = \text{gallery}('integerdata',3,[25,1],1); \\
A = \text{categorical}(A,1:3,\{'milk' 'water' 'juice'\});
\]

\( A \) is a 25-by-1 categorical array with three distinct categories: milk, water, and juice.

Summarize the categorical array, \( A \).

\[
\text{summary}(A)
\]

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>milk</td>
<td>8</td>
</tr>
<tr>
<td>water</td>
<td>8</td>
</tr>
<tr>
<td>juice</td>
<td>9</td>
</tr>
</tbody>
</table>

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.

\[
B = \text{gallery}('integerdata',3,[28,1],3); \\
B = \text{categorical}(B,1:3,\{'milk' 'water' 'juice'\});
\]

\( B \) is a 28-by-1 categorical array containing the same categories as \( A \).

Summarize the categorical array, \( B \).

\[
\text{summary}(B)
\]

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>milk</td>
<td>12</td>
</tr>
<tr>
<td>water</td>
<td>10</td>
</tr>
<tr>
<td>juice</td>
<td>6</td>
</tr>
</tbody>
</table>

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.

```matlab
Group1 = [A;B];
```

Summarize the categorical array, Group1

```matlab
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.

```matlab
Group2 = gallery('integerdata',4,[50,1],2);  
Group2 = categorical(Group2,1:4,{'juice' 'milk' 'soda' 'water'});
```

Summarize the categorical array, Group2.

```matlab
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.

```matlab
students = [Group1;Group2];
```

Summarize the resulting categorical array, students.
summary(students)

<table>
<thead>
<tr>
<th>Category</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>milk</td>
<td>30</td>
</tr>
<tr>
<td>water</td>
<td>27</td>
</tr>
<tr>
<td>juice</td>
<td>33</td>
</tr>
<tr>
<td>soda</td>
<td>13</td>
</tr>
</tbody>
</table>

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.

```matlab
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.

```matlab
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

- `cat`
- `categorical`
- `categories`
- `horzcat`
- `summary`
- `union`
- `vertcat`

Related Examples

- “Create Categorical Arrays” on page 8-2
- “Combine Categorical Arrays Using Multiplication” on page 8-26
- “Convert Table Variables Containing Strings to Categorical” on page 8-6
- “Access Data Using Categorical Arrays” on page 8-29

More About

- “Ordinal Categorical Arrays” on page 8-43
Combine Categorical Arrays Using Multiplication

This example shows how to use the `times` function to combine categorical arrays, including ordinal categorical arrays and arrays with undefined elements. When you call `times` on two categorical arrays, the output is a categorical array with new categories. The set of new categories is the set of all the ordered pairs created from the categories of the input arrays, or the Cartesian product. `times` forms each element of the output array as the ordered pair of the corresponding elements of the input arrays. The output array has the same size as the input arrays.

**Combine Two Categorical Arrays**

Combine two categorical arrays using `times`. The input arrays must have the same number of elements, but can have different numbers of categories.

```matlab
A = categorical({'blue','red','green'});
B = categorical({'+','-','+'});
C = A.*B
```

```matlab
C =
       blue +       red -       green +
```

**Cartesian Product of Categories**

Show the categories of `C`. The categories are all the ordered pairs that can be created from the categories of `A` and `B`, also known as the Cartesian product.

```matlab
categories(C)
```

```matlab
ans =
    'blue +'
    'blue -'
    'green +'
    'green -'
    'red +'
    'red -'
```

As a consequence, `A.*B` does not equal `B.*A`. 

D = B.*A

D =
    + blue    - red    + green

categories(D)

ans =
    '+ blue'
    '+ green'
    '+ red'
    '- blue'
    '- green'
    '- red'

**Multiplication with Undefined Elements**

Combine two categorical arrays. If either A or B have an undefined element, the corresponding element of C is undefined.

A = categorical({'blue','red','green','black'});
B = categorical({'+','-','+','-'});
A = removecats(A,{'black'});
C = A.*B

C =
    blue +    red -    green +    <undefined>

**Cartesian Product of Ordinal Categorical Arrays**

Combine two ordinal categorical arrays. C is an ordinal categorical array only if A and B are both ordinal. The ordering of the categories of C follows from the orderings of the input categorical arrays.

A = categorical({'blue','red','green'},{'green','red','blue'},'Ordinal',true);
B = categorical({'+','-','+'},'Ordinal',true);
C = A.*B;
categories(C)

ans =
    'green +'
    'green -'
    'red +'
    'red -'
    'blue +'
    'blue -'

See Also
- categorical
- categories
- summary
- times

Related Examples
- “Create Categorical Arrays” on page 8-2
- “Combine Categorical Arrays” on page 8-22
- “Access Data Using Categorical Arrays” on page 8-29

More About
- “Ordinal Categorical Arrays” on page 8-43
Access Data Using Categorical Arrays

In this section...

“Select Data By Category” on page 8-29
“Common Ways to Access Data Using Categorical Arrays” on page 8-29

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      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

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')

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.

```matlab
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`.

```matlab
Location = removecats(Location,'VA Hospital');
```

Verify that the category, **VA Hospital**, was removed.

```matlab
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`.

```matlab
Location = removecats(Location,'County General Hospital');
```

Display the first eight elements of the categorical array, `Location`.

```matlab
Location(1:8)
```

```
ans =
    <undefined>
    St. Mary's Medical Center
    <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
any | categorical | categories | hist | isundefined | removecats | summary

Related Examples
• “Create Categorical Arrays” on page 8-2
• “Convert Table Variables Containing Strings to Categorical” on page 8-6
• “Plot Categorical Data” on page 8-11
• “Compare Categorical Array Elements” on page 8-19
• “Work with Protected Categorical Arrays” on page 8-35

More About
• “Advantages of Using Categorical Arrays” on page 8-40
• “Ordinal Categorical Arrays” on page 8-43
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'`.

```matlab
A = categorical({'M';'L';'S';'S';'M';'L';'M';'L';'M';'S'},... {'S','M','L'},{'small','medium','large'},'Ordinal',true)
```

```matlab
A =
    medium
    large
    small
    small
    medium
    large
    medium
```
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 ADDCATS 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
small
medium
large
medium
large
medium
large
small
xlarge
small
small
xsmall
The values from B are appended to the values from A.

List the categories of C.

```matlab
categories(C)
```

```matlab
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**

`addcats` | `categorical` | `categories` | `isordinal` | `isprotected` | `summary`

**Related Examples**

- “Create Categorical Arrays” on page 8-2
- “Convert Table Variables Containing Strings to Categorical” on page 8-6
- “Access Data Using Categorical Arrays” on page 8-29
- “Combine Categorical Arrays” on page 8-22
- “Combine Categorical Arrays Using Multiplication” on page 8-26

**More About**

- “Ordinal Categorical Arrays” on page 8-43
Advantages of Using Categorical Arrays

<table>
<thead>
<tr>
<th>In this section...</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Natural Representation of Categorical Data” on page 8-40</td>
</tr>
<tr>
<td>“Mathematical Ordering for Strings” on page 8-40</td>
</tr>
<tr>
<td>“Reduce Memory Requirements” on page 8-40</td>
</tr>
</tbody>
</table>

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.

```matlab
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`.

```matlab
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.

```matlab
state = categorical(state);
```

Display the discrete categories in the variable `state`.

```matlab
categories(state)
```

```
ans =
    'CA'
    'MA'
    'NY'
```

`state` contains 150 elements, but only three distinct categories.

Display information about the variable `state`.

```matlab
whos state
Name         Size            Bytes  Class    Attributes
```
There is a significant reduction in the memory required to store the variable.

**See Also**
categorical | categories

**Related Examples**
- “Create Categorical Arrays” on page 8-2
- “Convert Table Variables Containing Strings to Categorical” on page 8-6
- “Compare Categorical Array Elements” on page 8-19
- “Access Data Using Categorical Arrays” on page 8-29

**More About**
- “Ordinal Categorical Arrays” on page 8-43
Ordinal Categorical Arrays

In this section...

“Order of Categories” on page 8-43
“How to Create Ordinal Categorical Arrays” on page 8-43
“Working with Ordinal Categorical Arrays” on page 8-46

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.

\[
A = \begin{pmatrix}
\text{medium} & \text{large} \\
\text{small} & \text{medium} \\
\text{large} & \text{small}
\end{pmatrix};
\]
\[
\text{valueset} = \{ \text{small}, \text{medium}, \text{large} \};
\]
\[
sizes = \text{categorical}(A, \text{valueset}, 'Ordinal', \text{true})
\]

\[
sizes =
\begin{array}{cc}
\text{medium} & \text{large} \\
\text{small} & \text{medium} \\
\text{large} & \text{small}
\end{array}
\]

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.

\[
A2 = [2 3; 1 2; 3 1];
\]
\[
\text{valueset} = 1:3;
\]
\[
\text{catnames} = \{ 'small', 'medium', 'large' \};
\]
\[
sizes2 = \text{categorical}(A2, \text{valueset}, \text{catnames}, 'Ordinal', \text{true})
\]

\[
sizes2 =
\begin{array}{cc}
\text{medium} & \text{large} \\
\text{small} & \text{medium} \\
\text{large} & \text{small}
\end{array}
\]

Compare sizes and sizes2

isequal(sizes, sizes2)
sizess 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 8-35.

**See Also**
categorical | categories | isequal | isordinal

**Related Examples**

- “Create Categorical Arrays” on page 8-2
- “Convert Table Variables Containing Strings to Categorical” on page 8-6
- “Compare Categorical Array Elements” on page 8-19
- “Access Data Using Categorical Arrays” on page 8-29

**More About**

- “Advantages of Using Categorical Arrays” on page 8-40
Core 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.

<table>
<thead>
<tr>
<th>size</th>
<th>length</th>
<th>cat</th>
<th>horzcat</th>
<th>vertcat</th>
</tr>
</thead>
<tbody>
<tr>
<td>isequal</td>
<td>isequaln</td>
<td>intersect</td>
<td>ismember</td>
<td>setdiff</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>setxor</td>
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<td>union</td>
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<td>isrow</td>
<td>iscolumn</td>
<td>hist</td>
<td>pie</td>
<td>times</td>
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<tr>
<td></td>
<td></td>
<td>min</td>
<td>max</td>
<td>median</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td>mode</td>
</tr>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td>hist</td>
<td>pie</td>
<td>sort</td>
<td>sortrows</td>
<td>issorted</td>
</tr>
<tr>
<td>times</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>double</td>
<td>single</td>
<td>int8</td>
<td>int16</td>
<td>int32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>int64</td>
<td>uint8</td>
<td>uint16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>uint32</td>
<td>char</td>
<td>cellstr</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Tables

- “Create a Table” on page 9-2
- “Add and Delete Table Rows” on page 9-8
- “Add and Delete Table Variables” on page 9-12
- “Clean Messy and Missing Data in Tables” on page 9-16
- “Modify Units, Descriptions and Table Variable Names” on page 9-22
- “Access Data in a Table” on page 9-26
- “Calculations on Tables” on page 9-34
- “Advantages of Using Tables” on page 9-38
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,SelfAssessedHealthStatus
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`.

```matlab
T = readtable('patients.dat');
```

Return the size of the table.

```matlab
size(T)
```

ans =

```matlab
ans =
```
Create a Table

The table, T, contains 100 rows and ten variables.

Display the first five rows and first five variables of the table.

\[ T(1:5,1:5) \]

\[
\begin{array}{cccccc}
\text{LastName} & \text{Gender} & \text{Age} & \text{Location} & \text{Height} \\
\hline
'\text{Smith}' & '\text{Male}' & 38 & '\text{County General Hospital}' & 71 \\
'\text{Johnson}' & '\text{Male}' & 43 & '\text{VA Hospital}' & 69 \\
'\text{Williams}' & '\text{Female}' & 38 & '\text{St. Mary's Medical Center}' & 64 \\
'\text{Jones}' & '\text{Female}' & 40 & '\text{VA Hospital}' & 67 \\
'\text{Brown}' & '\text{Female}' & 49 & '\text{County General Hospital}' & 64 \\
\end{array}
\]

By default, \texttt{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 \texttt{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.

<table>
<thead>
<tr>
<th>Data Source in MATLAB Workspace</th>
<th>Function for Conversion to Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heterogeneous collection of workspace variables</td>
<td>\texttt{table}</td>
</tr>
<tr>
<td>Numeric array</td>
<td>\texttt{array2table}</td>
</tr>
<tr>
<td>Cell array</td>
<td>\texttt{cell2table}</td>
</tr>
<tr>
<td>Structure array</td>
<td>\texttt{struct2table}</td>
</tr>
</tbody>
</table>

\textbf{Summarize the Table}

View the data type, description, units, and other descriptive statistics for each variable by using \texttt{summary} to summarize the table.

\texttt{format compact}
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.

```matlab
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.

```matlab
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.

```matlab
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**.

\[
\text{T.BloodPressure} = [\text{T.Systolic} \ \text{T.Diastolic}]; \\
\text{T(:,\{'Systolic' 'Diastolic'\})} = []; \\
\]

Return the size of the table.

\[
\text{size(T)} \\
\text{ans} = \\
\hspace{3em} 100 \hspace{1em} 8 \\
\]

**T** contains 100 rows and eight variables. The row and variable names, respectively, are not included in the size of a table. Furthermore, \texttt{size} counts eight variables, even though the variable **BloodPressure** contains two columns.

Display the first five rows and last four variables of the table.

\[
\text{T(1:5,5:8)} \\
\text{ans} = \\
\begin{array}{cccc}
\text{Smith} & 176 & 1 & \text{'Excellent'} & 124 & 93 \\
\text{Johnson} & 163 & 0 & \text{'Fair'} & 109 & 77 \\
\text{Williams} & 131 & 0 & \text{'Good'} & 125 & 83 \\
\text{Jones} & 133 & 0 & \text{'Fair'} & 117 & 75 \\
\text{Brown} & 119 & 0 & \text{'Good'} & 122 & 80 \\
\end{array} \\
\]

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.

\[
\text{T.BMI} = (\text{T.Weight} * 0.453592) / (\text{T.Height} * 0.0254)^2; \\
\]
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      BMI
       ______    ________________________    _______________    ______
     Smith       1         'Excellent'                 124          93    24.547
     Johnson     0         'Fair'                      109          77    24.071
     Williams    0         'Good'                      125          83    22.486
     Jones       0         'Fair'                      117          75    20.831
     Brown       0         'Good'                      122          80    20.426

See Also
array2table | cell2table | readtable | struct2table | summary | table | Table Properties

Related Examples

•   “Add and Delete Table Rows” on page 9-8
•   “Add and Delete Table Variables” on page 9-12
•   “Clean Messy and Missing Data in Tables” on page 9-16
•   “Modify Units, Descriptions and Table Variable Names” on page 9-22
•   “Access Data in a Table” on page 9-26

More About

•   “Advantages of Using Tables” on page 9-38
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.

```matlab
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.

```matlab
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, \( T(\text{end+1:end+4,:}) = T2 \).

### 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.

```matlab
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.

```matlab
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.

```matlab
toDelete = Tnew.Age<30;
Tnew(toDelete,:) = [];
size(Tnew)
ans =
    85   7
```

The table now has 17 fewer rows.

**See Also**
array2table | cell2table | readtable | struct2table | table | Table Properties

**Related Examples**
- “Add and Delete Table Variables” on page 9-12
- “Clean Messy and Missing Data in Tables” on page 9-16
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.

```matlab
load patients

T = table(Age,Gender,Smoker);
T1 = table(Height,Weight,Systolic,Diastolic);
```

Display the first five rows of each table.

```matlab
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 $T_1$ has 100 rows and 4 variables.

**Add Variables by Concatenating Tables**

Add variables to the table, $T$, by horizontally concatenating it with $T_1$.

$$T = [T \ T_1];$$

Display the first five rows of the table, $T$.

$$T(1:5,:);$$

ans =

<table>
<thead>
<tr>
<th>Age</th>
<th>Gender</th>
<th>Smoker</th>
<th>Height</th>
<th>Weight</th>
<th>Systolic</th>
<th>Diastolic</th>
</tr>
</thead>
<tbody>
<tr>
<td>38</td>
<td>'Male'</td>
<td>true</td>
<td>71</td>
<td>176</td>
<td>124</td>
<td>93</td>
</tr>
<tr>
<td>43</td>
<td>'Male'</td>
<td>false</td>
<td>69</td>
<td>163</td>
<td>109</td>
<td>77</td>
</tr>
<tr>
<td>38</td>
<td>'Female'</td>
<td>false</td>
<td>64</td>
<td>131</td>
<td>125</td>
<td>83</td>
</tr>
<tr>
<td>40</td>
<td>'Female'</td>
<td>false</td>
<td>67</td>
<td>133</td>
<td>117</td>
<td>75</td>
</tr>
<tr>
<td>49</td>
<td>'Female'</td>
<td>false</td>
<td>64</td>
<td>119</td>
<td>122</td>
<td>80</td>
</tr>
</tbody>
</table>

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, \( T \).

\[ T(1:5,:) \]

\[
\begin{array}{cccccc}
\text{Age} & \text{Gender} & \text{Smoker} & \text{Height} & \text{Weight} & \text{BloodPressure} \\
38 & 'Male' & true & 71 & 176 & 124 \\
43 & 'Male' & false & 69 & 163 & 109 \\
38 & 'Female' & false & 64 & 131 & 125 \\
40 & 'Female' & false & 67 & 133 & 117 \\
49 & 'Female' & false & 64 & 119 & 122 \\
\end{array}
\]

\( T \) now has 6 variables and 100 rows.

Add a new variable, \( \text{BMI} \), in the table, \( T \), to contain the body mass index for each patient. \( \text{BMI} \) is a function of height and weight.

\( T.\text{BMI} = (T.\text{Weight} \times 0.453592)/(T.\text{Height} \times 0.0254)^2; \)

The operators \( ./ \) and \( .^2 \) in the calculation of \( \text{BMI} \) indicate element-wise division and exponentiation, respectively.

Display the first five rows of the table, \( T \).

\[ T(1:5,:) \]

\[
\begin{array}{cccccccc}
\text{Age} & \text{Gender} & \text{Smoker} & \text{Height} & \text{Weight} & \text{BloodPressure} & \text{BMI} \\
38 & 'Male' & true & 71 & 176 & 124 & 24.547 \\
43 & 'Male' & false & 69 & 163 & 109 & 24.071 \\
38 & 'Female' & false & 64 & 131 & 125 & 22.486 \\
40 & 'Female' & false & 67 & 133 & 117 & 20.831 \\
49 & 'Female' & false & 64 & 119 & 122 & 20.426 \\
\end{array}
\]
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, \( T \).

\[ T(1:5,:) \]

\[
\begin{array}{cccc}
\text{Age} & \text{Gender} & \text{Height} & \text{Weight} & \text{BMI} \\
--- & ________ & ______ & ______ & ______ \\
38 & 'Male' & 71 & 176 & 24.547 \\
43 & 'Male' & 69 & 163 & 24.071 \\
38 & 'Female' & 64 & 131 & 22.486 \\
40 & 'Female' & 67 & 133 & 20.831 \\
49 & 'Female' & 64 & 119 & 20.426 \\
\end{array}
\]

T has 100 rows and 5 variables.

**See Also**

array2table | cell2table | readtable | struct2table | table

**Related Examples**

- “Add and Delete Table Rows” on page 9-8
- “Clean Messy and Missing Data in Tables” on page 9-16
- “Modify Units, Descriptions and Table Variable Names” on page 9-22
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.

```plaintext
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 =

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>afe1</td>
<td>3</td>
<td>'yes'</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>egh3</td>
<td>NaN</td>
<td>'no'</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>wth4</td>
<td>3</td>
<td>'yes'</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>atn2</td>
<td>23</td>
<td>'no'</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>arg1</td>
<td>5</td>
<td>'yes'</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>jre3</td>
<td>34.6</td>
<td>'yes'</td>
<td>34.6</td>
<td>34.6</td>
</tr>
<tr>
<td>wen9</td>
<td>234</td>
<td>'yes'</td>
<td>234</td>
<td>234</td>
</tr>
<tr>
<td>ple2</td>
<td>2</td>
<td>'no'</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>dbo8</td>
<td>5</td>
<td>'no'</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>oii4</td>
<td>5</td>
<td>'yes'</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>wnk3</td>
<td>245</td>
<td>'yes'</td>
<td>245</td>
<td>245</td>
</tr>
<tr>
<td>abk6</td>
<td>563</td>
<td>''</td>
<td>563</td>
<td>563</td>
</tr>
<tr>
<td>pnj5</td>
<td>463</td>
<td>'no'</td>
<td>463</td>
<td>463</td>
</tr>
<tr>
<td>wnn3</td>
<td>23</td>
<td>'yes'</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>oks9</td>
<td>NaN</td>
<td>'yes'</td>
<td>NaN</td>
<td>14</td>
</tr>
<tr>
<td>wba3</td>
<td>2</td>
<td>'no'</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>adw3</td>
<td>22</td>
<td>'no'</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>poj2</td>
<td>-99</td>
<td>'yes'</td>
<td>-99</td>
<td>-99</td>
</tr>
<tr>
<td>bas8</td>
<td>23</td>
<td>'no'</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>gry5</td>
<td>NaN</td>
<td>'yes'</td>
<td>NaN</td>
<td>21</td>
</tr>
</tbody>
</table>

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
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.

\[ T = \text{standardizeMissing}(T, -99) \]

\[ T = \]

<table>
<thead>
<tr>
<th>Var1</th>
<th>Var2</th>
<th>Var3</th>
<th>Var4</th>
<th>Var5</th>
</tr>
</thead>
<tbody>
<tr>
<td>'afe1'</td>
<td>3</td>
<td>'yes'</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>'egh3'</td>
<td>NaN</td>
<td>'no'</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>'wth4'</td>
<td>3</td>
<td>'yes'</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>'atn2'</td>
<td>23</td>
<td>'no'</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>'arg1'</td>
<td>5</td>
<td>'yes'</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>'jre3'</td>
<td>34.6</td>
<td>'yes'</td>
<td>34.6</td>
<td>34.6</td>
</tr>
<tr>
<td>'wen9'</td>
<td>234</td>
<td>'yes'</td>
<td>234</td>
<td>234</td>
</tr>
<tr>
<td>'ple2'</td>
<td>2</td>
<td>'no'</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>'dbo8'</td>
<td>5</td>
<td>'no'</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>'oi4'</td>
<td>5</td>
<td>'yes'</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>'wnk3'</td>
<td>245</td>
<td>'yes'</td>
<td>245</td>
<td>245</td>
</tr>
<tr>
<td>'abk6'</td>
<td>563</td>
<td>'no'</td>
<td>563</td>
<td>563</td>
</tr>
<tr>
<td>'pnj5'</td>
<td>463</td>
<td>'no'</td>
<td>463</td>
<td>463</td>
</tr>
<tr>
<td>'wnn3'</td>
<td>6</td>
<td>'no'</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>'oks9'</td>
<td>23</td>
<td>'yes'</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>'wba3'</td>
<td>NaN</td>
<td>'yes'</td>
<td>NaN</td>
<td>14</td>
</tr>
<tr>
<td>'pkn4'</td>
<td>2</td>
<td>'no'</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>'adw3'</td>
<td>22</td>
<td>'no'</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>'poj2'</td>
<td>NaN</td>
<td>'yes'</td>
<td>NaN</td>
<td>NaN</td>
</tr>
<tr>
<td>'bas8'</td>
<td>23</td>
<td>'no'</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>'gry5'</td>
<td>NaN</td>
<td>'yes'</td>
<td>NaN</td>
<td>21</td>
</tr>
</tbody>
</table>

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.

\[ TF = \text{ismissing}(T); \]
\[
T2 = T(-\text{any}(TF, 2), :) \\
\]

\[
T2 = 
\begin{array}{ccccc}
\text{Var1} & \text{Var2} & \text{Var3} & \text{Var4} & \text{Var5} \\
\hline
'afe1' & 3 & 'yes' & 3 & 3 \\
'wth4' & 3 & 'yes' & 3 & 3 \\
'atn2' & 23 & 'no' & 23 & 23 \\
'arg1' & 5 & 'yes' & 5 & 5 \\
'jre3' & 34.6 & 'yes' & 34.6 & 34.6 \\
'wen9' & 234 & 'yes' & 234 & 234 \\
'ple2' & 2 & 'no' & 2 & 2 \\
'dbo8' & 5 & 'no' & 5 & 5 \\
'ooi4' & 5 & 'yes' & 5 & 5 \\
'wnk3' & 245 & 'yes' & 245 & 245 \\
'pnj5' & 463 & 'no' & 463 & 463 \\
'wnn3' & 6 & 'no' & 6 & 6 \\
'oks9' & 23 & 'yes' & 23 & 23 \\
'pkn4' & 2 & 'no' & 2 & 2 \\
'adw3' & 22 & 'no' & 22 & 22 \\
'bas8' & 23 & 'no' & 23 & 23 \\
\end{array}
\]

\[
T2 = \text{sortrows}(T2, \{'\text{Var3}', '\text{Var1}'\}, \{'\text{descend}', '\text{ascend}'\})
\]

\[
T2 = 
\begin{array}{ccccc}
\text{Var1} & \text{Var2} & \text{Var3} & \text{Var4} & \text{Var5} \\
\hline
'afe1' & 3 & 'yes' & 3 & 3 \\
'arg1' & 5 & 'yes' & 5 & 5 \\
'jre3' & 34.6 & 'yes' & 34.6 & 34.6 \\
'ooi4' & 5 & 'yes' & 5 & 5 \\
'oks9' & 23 & 'yes' & 23 & 23 \\
'wen9' & 234 & 'yes' & 234 & 234 \\
'wth4' & 3 & 'yes' & 3 & 3 \\
\end{array}
\]
In Var3, the rows are grouped first grouped by 'yes', followed by 'no'. Then in Var1, the rows are listed alphabetically.

See Also
ismissing | readtable | sortrows | summary

Related Examples
• “Add and Delete Table Rows” on page 9-8
• “Add and Delete Table Variables” on page 9-12
• “Modify Units, Descriptions and Table Variable Names” on page 9-22
• “Access Data in a Table” on page 9-26
**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.

```matlab
code```

```matlab
load patients
BloodPressure = [Systolic Diastolic];
T = table(Gender,Age,Height,Weight,Smoker,BloodPressure);
```

Display the first five rows of the table, T.

```matlab
code```

```matlab
T(1:5,:)
```

```matlab
ans =

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
<th>Smoker</th>
<th>BloodPressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Male'</td>
<td>38</td>
<td>71</td>
<td>176</td>
<td>true</td>
<td>124</td>
</tr>
<tr>
<td>'Male'</td>
<td>43</td>
<td>69</td>
<td>163</td>
<td>false</td>
<td>109</td>
</tr>
<tr>
<td>'Female'</td>
<td>38</td>
<td>64</td>
<td>131</td>
<td>false</td>
<td>125</td>
</tr>
<tr>
<td>'Female'</td>
<td>40</td>
<td>67</td>
<td>133</td>
<td>false</td>
<td>117</td>
</tr>
<tr>
<td>'Female'</td>
<td>49</td>
<td>64</td>
<td>119</td>
<td>false</td>
<td>122</td>
</tr>
</tbody>
</table>
```

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.

```matlab
code```

```matlab
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`.

```matlab
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.

```matlab
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
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**.

```matlab
T.Properties.VariableNames{'Gender'} = 'Sex';
```

Display the first five rows of the table, **T**.

```matlab
T(1:5,:)
```

```
ans =

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
<th>Smoker</th>
<th>BloodPressure_1</th>
<th>BloodPressure_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Male'</td>
<td>38</td>
<td>71</td>
<td>176</td>
<td>true</td>
<td>124</td>
<td>93</td>
</tr>
<tr>
<td>'Male'</td>
<td>43</td>
<td>69</td>
<td>163</td>
<td>false</td>
<td>109</td>
<td>77</td>
</tr>
<tr>
<td>'Female'</td>
<td>38</td>
<td>64</td>
<td>131</td>
<td>false</td>
<td>125</td>
<td>83</td>
</tr>
<tr>
<td>'Female'</td>
<td>40</td>
<td>67</td>
<td>133</td>
<td>false</td>
<td>117</td>
<td>75</td>
</tr>
<tr>
<td>'Female'</td>
<td>49</td>
<td>64</td>
<td>119</td>
<td>false</td>
<td>122</td>
<td>80</td>
</tr>
</tbody>
</table>
```
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**
array2table | cell2table | readtable | struct2table | summary | table | Table Properties

**Related Examples**
- “Add and Delete Table Variables” on page 9-12
- “Access Data in a Table” on page 9-26
Access Data in a Table

In this section...

“Ways to Index into a Table” on page 9-26
“Create Table from Subset of Larger Table” on page 9-27
“Create Array from the Contents of Table” on page 9-30

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, \( T \).

<table>
<thead>
<tr>
<th>Type of Indexing</th>
<th>Result</th>
<th>Syntax</th>
<th>rows</th>
<th>vars/var</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parentheses</td>
<td>table</td>
<td>( T(rows,vars) )</td>
<td>One or more rows</td>
<td>One or more variables</td>
</tr>
<tr>
<td>Curly Braces</td>
<td>extracted data</td>
<td>( T{rows,vars} )</td>
<td>One or more rows</td>
<td>One or more variables</td>
</tr>
<tr>
<td>Dot Indexing</td>
<td>extracted data</td>
<td>( T.var )</td>
<td>All rows</td>
<td>One variable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( T(varindex) )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dot Indexing</td>
<td>extracted data</td>
<td>( T.var(rows) )</td>
<td>One or more rows</td>
<td>One variable</td>
</tr>
</tbody>
</table>
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, \( \text{rows} = \text{T.Var2} > 0 \) 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 \( \text{T.var} \). For a single variable index, specified as a positive integer, use \( \text{T.(varindex)} \).

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)
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.

\[ T1 = \text{patients}(1:5,:) \]

\[
T1 =
\begin{array}{cccccc}
\text{Age} & \text{Gender} & \text{Height} & \text{Weight} & \text{Smoker} \\
\_ & \_ & \_ & \_ & \_
\end{array}
\]
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.

\[
T2 = \text{patients}(['Adams', 'Brown'], :) \\
\]

\[
T2 = \\
\begin{array}{cccc}
\text{Age} & \text{Gender} & \text{Height} & \text{Weight} & \text{Smoker} \\
\hline
\text{Adams} & 48 & \text{'Female'} & 66 & 137 & \text{false} \\
\text{Brown} & 49 & \text{'Female'} & 64 & 119 & \text{false} \\
\end{array}
\]

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.

\[
\text{rows} = \text{patients.A}ge<30; \\
\text{vars} = \{'\text{Gender}', '\text{Height}', '\text{Weight}'\}; \\
\]

\text{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 =

<table>
<thead>
<tr>
<th>Gender</th>
<th>Height</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moore</td>
<td>'Male'</td>
<td>68</td>
</tr>
<tr>
<td>Jackson</td>
<td>'Male'</td>
<td>71</td>
</tr>
<tr>
<td>Garcia</td>
<td>'Female'</td>
<td>69</td>
</tr>
<tr>
<td>Walker</td>
<td>'Female'</td>
<td>65</td>
</tr>
<tr>
<td>Hall</td>
<td>'Male'</td>
<td>70</td>
</tr>
<tr>
<td>Young</td>
<td>'Female'</td>
<td>63</td>
</tr>
<tr>
<td>Hill</td>
<td>'Female'</td>
<td>64</td>
</tr>
<tr>
<td>Rivera</td>
<td>'Female'</td>
<td>63</td>
</tr>
<tr>
<td>Cooper</td>
<td>'Female'</td>
<td>65</td>
</tr>
<tr>
<td>Cox</td>
<td>'Female'</td>
<td>66</td>
</tr>
<tr>
<td>Howard</td>
<td>'Female'</td>
<td>68</td>
</tr>
<tr>
<td>James</td>
<td>'Male'</td>
<td>66</td>
</tr>
<tr>
<td>Jenkins</td>
<td>'Male'</td>
<td>69</td>
</tr>
<tr>
<td>Perry</td>
<td>'Female'</td>
<td>64</td>
</tr>
<tr>
<td>Alexander</td>
<td>'Male'</td>
<td>69</td>
</tr>
</tbody>
</table>

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.

```matlab
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}.

\[
A = \text{patients(1:5,{'Height','Weight'})}
\]

\[
A =
\begin{array}{cc}
71 & 176 \\
69 & 163 \\
64 & 131 \\
67 & 133 \\
64 & 119 \\
\end{array}
\]

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.

```matlab
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.

```matlab
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
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
summary | table | Table Properties

Related Examples
• “Create a Table” on page 9-2
• “Modify Units, Descriptions and Table Variable Names” on page 9-22
• “Calculations on Tables” on page 9-34

More About
• “Advantages of Using Tables” on page 9-38
Calculations on Tables

This example shows how to perform calculation on tables.

The functions \texttt{rowfun} and \texttt{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, \texttt{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.

\[
T = \texttt{readtable(}'testScores.csv',\texttt{'}ReadRowNames\texttt{',true)}
\]

\[
T =
\begin{array}{cccc}
\text{Gender} & \text{Test1} & \text{Test2} & \text{Test3} \\
\hline
\text{HOWARD} & \text{'male'} & 90 & 87 & 93 \\
\text{WARD} & \text{'male'} & 87 & 85 & 83 \\
\text{TORRES} & \text{'male'} & 86 & 85 & 88 \\
\text{PETERSON} & \text{'female'} & 75 & 80 & 72 \\
\text{GRAY} & \text{'female'} & 89 & 86 & 87 \\
\text{RAMIREZ} & \text{'female'} & 96 & 92 & 98 \\
\text{JAMES} & \text{'male'} & 78 & 75 & 77 \\
\text{WATSON} & \text{'female'} & 91 & 94 & 92 \\
\text{BROOKS} & \text{'female'} & 86 & 83 & 85 \\
\end{array}
\]
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
KELLY       'male'    79     76      82
```
### Compute Statistics Using a Grouping Variable

Compute the mean and maximum of \( \text{TestAvg} \) for each gender.

```matlab
varfun(@mean,T,'InputVariables','TestAvg',... 'GroupingVariables','Gender')
```

`ans =

<table>
<thead>
<tr>
<th>Gender</th>
<th>GroupCount</th>
<th>mean_TestAvg</th>
</tr>
</thead>
<tbody>
<tr>
<td>female</td>
<td>'female'</td>
<td>87.067</td>
</tr>
<tr>
<td>male</td>
<td>'male'</td>
<td>83.4</td>
</tr>
</tbody>
</table>
```

### 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.

\[
T(:,2:end) = T(:,2:end) \times \frac{25}{100}
\]

\[
T =

<table>
<thead>
<tr>
<th>Gender</th>
<th>Test1</th>
<th>Test2</th>
<th>Test3</th>
<th>TestAvg</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOWARD</td>
<td>'male'</td>
<td>22.5</td>
<td>21.75</td>
<td>23.25</td>
</tr>
<tr>
<td>WARD</td>
<td>'male'</td>
<td>21.75</td>
<td>21.25</td>
<td>20.75</td>
</tr>
<tr>
<td>TORRES</td>
<td>'male'</td>
<td>21.5</td>
<td>21.25</td>
<td>22.0</td>
</tr>
<tr>
<td>PETERSON</td>
<td>'female'</td>
<td>18.75</td>
<td>20.0</td>
<td>18.0</td>
</tr>
<tr>
<td>GRAY</td>
<td>'female'</td>
<td>22.25</td>
<td>21.5</td>
<td>21.75</td>
</tr>
</tbody>
</table>
```
### Change a Variable Name

Change the variable name from TestAvg to Final.

```matlab
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     22.0      21.583
 PETERSON    'female'    18.75    20.0     18.0      18.917
    GRAY      'female'    22.25    21.5     21.75      21.833
 RAMIREZ     'female'     24.0    23.0     24.5      23.833
   JAMES      'male'     19.5    18.75    19.25      19.167
  WATSON     'female'     22.75    23.5     23.0      23.083
 BROOKS      'female'     21.5    20.75    21.25      21.167
   KELLY      'male'     19.75    19.0     20.5      19.75
```

### See Also

- `rowfun`
- `summary`
- `table`
- `Table Properties`
- `varfun`

### Related Examples

- “Access Data in a Table” on page 9-26
Advantages of Using Tables

In this section...

“Conveniently Store Mixed-Type Data in Single Container” on page 9-38
“Access Data Using Numeric or Named Indexing” on page 9-41
“Use Table Properties to Store Metadata” on page 9-42

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.

```matlab
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.

```matlab
BloodPressure = [Systolic Diastolic];
Gender = categorical(Gender);
```

```matlab
whos('Gender','Age','Smoker','BloodPressure')
```

<table>
<thead>
<tr>
<th>Name</th>
<th>Size</th>
<th>Bytes</th>
<th>Class</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>100x1</td>
<td>800</td>
<td>double</td>
<td></td>
</tr>
<tr>
<td>BloodPressure</td>
<td>100x2</td>
<td>1600</td>
<td>double</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>100x1</td>
<td>550</td>
<td>categorical</td>
<td></td>
</tr>
<tr>
<td>Smoker</td>
<td>100x1</td>
<td>100</td>
<td>logical</td>
<td></td>
</tr>
</tbody>
</table>
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.

```matlab
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.

```matlab
T(end+1,:) = {37,{'Female'},true,[130 84]}
```

```
Error using table/subsasgnParens (line 200)
Invalid RHS for assignment to a categorical array.
```

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`.

```matlab
StructArray = table2struct(T)
```

```
'StructArray =

101x1 struct array with fields:
```
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`.

```text
StructArray(1)
```

```text
ans =
```

```text
    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.

```text
ScalarStruct = struct(...
    'Gender',{Gender},...
    'Age',Age,...
    'Smoker',Smoker,...
    'BloodPressure',BloodPressure)
```

```text
ScalarStruct =
```

```text
    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.

```matlab
T.Properties.RowNames = LastName;
T(1:5,:)
```

```plaintext
ans =

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age</th>
<th>Smoker</th>
<th>BloodPressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smith</td>
<td>Male</td>
<td>38</td>
<td>true</td>
</tr>
<tr>
<td>Johnson</td>
<td>Male</td>
<td>43</td>
<td>false</td>
</tr>
<tr>
<td>Williams</td>
<td>Female</td>
<td>38</td>
<td>false</td>
</tr>
<tr>
<td>Jones</td>
<td>Female</td>
<td>40</td>
<td>false</td>
</tr>
<tr>
<td>Brown</td>
<td>Female</td>
<td>49</td>
<td>false</td>
</tr>
</tbody>
</table>
```

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 age and blood pressure of the
patients Williams and Brown.

```matlab
T({'Williams','Brown'},{'Age','BloodPressure'})
```

```plaintext
ans =

<table>
<thead>
<tr>
<th>Age</th>
<th>BloodPressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```
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 =

<table>
<thead>
<tr>
<th>Age</th>
<th>BloodPressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Williams</td>
<td>38</td>
</tr>
<tr>
<td>Brown</td>
<td>49</td>
</tr>
</tbody>
</table>

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 9-26.

### 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`.

```matlab
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
Structures and cell arrays do not have properties for storing metadata.

**See Also**

summary | table

**Related Examples**

- “Create a Table” on page 9-2
- “Modify Units, Descriptions and Table Variable Names” on page 9-22
- “Access Data in a Table” on page 9-26
Structures

- “Create a Structure Array” on page 10-2
- “Access Data in a Structure Array” on page 10-6
- “Concatenate Structures” on page 10-10
- “Generate Field Names from Variables” on page 10-12
- “Access Data in Nested Structures” on page 10-13
- “Access Elements of a Nonscalar Struct Array” on page 10-15
- “Ways to Organize Data in Structure Arrays” on page 10-17
- “Memory Requirements for a Structure Array” on page 10-21
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.

\[
\text{patient}(1).\text{name} = \text{'John Doe'}; \\
\text{patient}(1).\text{billing} = 127.00; \\
\text{patient}(1).\text{test} = [79, 75, 73; 180, 178, 177.5; 220, 210, 205]; \\
\text{patient}
\]

\[
\begin{array}{c}
\text{name: 'John Doe'} \\
\text{billing: 127} \\
\text{test: [3x3 double]}
\end{array}
\]

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.

```matlab
patient(3).name = 'New Name';
patient(3)
```

```matlab
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.

```matlab
amount_due = patient(1).billing
bar(patient(1).test)
title(['Test Results for ', patient(1).name])
```

```matlab
amount_due =
    127
```
Create a Structure Array

Related Examples
• “Access Data in a Structure Array” on page 10-6
• “Create a Cell Array” on page 11-3
• “Create a Table” on page 9-2

More About
• “Cell vs. Struct Arrays” on page 11-17
• “Advantages of Using Tables” on page 9-38
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.

```matlab
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:

```matlab
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:

```matlab
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`:

```matlab
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):

```matlab
image(S(1).X)
colormap(S(1).map)
```

Add indices to select and redisplay the upper left corner of the field contents:

```matlab
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 10-13
- “Access Elements of a Nonscalar Struct Array” on page 10-15
- “Generate Field Names from Variables” on page 10-12
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:

```matlab
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,

```matlab
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:

```matlab
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:

```matlab
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:

```matlab
larger = [combined; new]
```

This code returns a 3-by-2 structure array,

```matlab
larger =
    3x2 struct array with fields:
    a
    b
```

where, for example,

```matlab
larger(2,1).a =
    1
```

For related information, see:

- “Creating and Concatenating Matrices”
- “Access Data in a Structure Array” on page 10-6
- “Access Elements of a Nonscalar Struct Array” on page 10-15
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

\[
\text{structName.}(\text{dynamicExpression})
\]

where \text{dynamicExpression} is a variable or expression that returns a character or string. Field names that you reference with expressions are called \textit{dynamic field names}.

For example, create a field name from the current date:

\[
\text{currentDate} = \text{datestr}(\text{now},'\text{mmmdd}');
\text{myStruct.}(\text{currentDate}) = [1,2,3]
\]

If the current date reported by your system is February 29, then this code assigns data to a field named \textit{Feb29}:

\[
\text{myStruct} = \\
\begin{array}{c}
\text{Feb29: [1 2 3]}
\end{array}
\]

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”.


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

\[
\text{structName(index).nestedStructName(index).fieldName(indices)}
\]

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 \( c \):

\[
\begin{align*}
\text{s.n.a} &= \ones(3); \\
\text{s.n.b} &= \eye(4); \\
\text{s.n.c} &= \magic(5);
\end{align*}
\]

Access the third row of field \( b \):

\[
\text{third\_row\_b} = \text{s.n.b}(3,:)
\]

Variable \( \text{third\_row\_b} \) contains the third row of \( \eye(4) \).

\[
\text{third\_row\_b} =
\begin{bmatrix}
0 & 0 & 1 & 0
\end{bmatrix}
\]

Expand \( s \) so that both \( s \) and \( n \) are nonscalar (1-by-2):

\[
\begin{align*}
\text{s(1).n(2).a} &= 2*\ones(3); \\
\text{s(1).n(2).b} &= 2*\eye(4); \\
\text{s(1).n(2).c} &= 2*\magic(5); \\
\text{s(2).n(1).a} &= '1a'; \\
\text{s(2).n(2).a} &= '2a'; \\
\text{s(2).n(1).b} &= '1b'; \\
\text{s(2).n(2).b} &= '2b'; \\
\text{s(2).n(1).c} &= '1c'; \\
\text{s(2).n(2).c} &= '2c';
\end{align*}
\]

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:

\[
\text{part\_two\_eye} = s(1).n(2).b(1:2,1:2)
\]

This returns the 2-by-2 upper left corner of \(2\times\text{eye}(4)\):

\[
\begin{bmatrix}
2 & 0 \\
0 & 2
\end{bmatrix}
\]
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`:

```matlab
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

```matlab
s(1:3).f
```

or

```matlab
s.f
```

MATLAB returns the data from the elements in a *comma-separated list*, which displays as follows:

```plaintext
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

```matlab
[v1, v2, v3] = s.f;
```

or assign to elements of a cell array, such as

```matlab
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:

```matlab
c nums(1).f = 1;
nums(2).f = 2;
nums(3).f = 3;
```

```matlab
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`:

```matlab
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”
- “Anonymous Functions”
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 10-17
- “Element-by-Element Organization” on page 10-19

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”.

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:

```matlab
    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:

```matlab
    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`:

```matlab
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:

```matlab
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:

```matlab
aveResultsDoe = mean(patient(1).test,2)
```

This code returns
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 10-6.
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

```matlab
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

```matlab
newStruct(25,50).a = [];
newStruct(25,50).b = [];
newStruct(25,50).c = [];
```

or, equivalently,

```matlab
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”
Cell Arrays

- “What Is a Cell Array?” on page 11-2
- “Create a Cell Array” on page 11-3
- “Access Data in a Cell Array” on page 11-5
- “Add Cells to a Cell Array” on page 11-8
- “Delete Data from a Cell Array” on page 11-9
- “Combine Cell Arrays” on page 11-10
- “Pass Contents of Cell Arrays to Functions” on page 11-11
- “Preallocate Memory for a Cell Array” on page 11-16
- “Cell vs. Struct Arrays” on page 11-17
- “Multilevel Indexing to Access Parts of Cells” on page 11-19
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 11-3
- “Access Data in a Cell Array” on page 11-5
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, {}:

```matlab
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:

```matlab
myCell =
    [   1]    [           2]    [       3]
    'text'    [5x10x2 double]    {3x1 cell}
```

You also can use the {} operator to create an empty 0-by-0 cell array,

```matlab
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:

```matlab
emptyCell = cell(3,4,2)
```

`emptyCell` is a 3-by-4-by-2 cell array, where each cell contains an empty array, []:

```matlab
emptyCell(:,:,1) =
    []    []    []    []
    []    []    []    []
    []    []    []    []

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

Related Examples

- “Access Data in a Cell Array” on page 11-5
• “Multidimensional Cell Arrays”
• “Create a Structure Array” on page 10-2
• “Create a Table” on page 9-2

More About
• “Cell vs. Struct Arrays” on page 11-17
• “Advantages of Using Tables” on page 9-38
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:

\[
C = \begin{bmatrix} \text{'one'}, \text{'two'}, \text{'three'}; \\
1, 2, 3 \end{bmatrix};
\]

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

\[
\text{upperLeft} = C(1:2,1:2)
\]

creates a 2-by-2 cell array:

\[
\text{upperLeft} =
\begin{bmatrix}
\text{'one'} & \text{'two'} \\
\end{bmatrix}
\]

Update sets of cells by replacing them with the same number of cells. For example, the statement

\[
C(1,1:3) = \begin{bmatrix} \text{'first'}, \text{'second'}, \text{'third'} \end{bmatrix}
\]

replaces the cells in the first row of \( C \) with an equivalent-sized (1-by-3) cell array:

\[
C =
\begin{bmatrix}
\text{'first'} & \text{'second'} & \text{'third'} \\
\end{bmatrix}
\]

If cells in your array contain numeric data, you can convert the cells to a numeric array using the `cell2mat` function:

\[
\text{numericCells} = C(2,1:3)
\]

\[
\text{numericVector} = \text{cell2mat(numericCells)}
\]

\text{numericCells} \text{ is a 1-by-3 cell array, but numericVector is a 1-by-3 array of type double.}
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

\[
\text{last} = \text{C}\{2,3\}
\]

creates a numeric variable of type \textit{double}, because the cell contains a \textit{double} value:

\[
\text{last} = 3
\]

Similarly, this command

\[
\text{C}\{2,3\} = 300
\]

replaces the contents of the last cell of \textit{C} with a new, numeric value:

\[
\text{C} = \\
\begin{bmatrix}
\text{'first'} & \text{'second'} & \text{'third'} \\
\end{bmatrix}
\]

When you access the contents of multiple cells, such as

\[
\text{C}\{1:2,1:2\}
\]

MATLAB creates a \textit{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,

\[
[r1c1, r2c1, r1c2, r2c2] = \text{C}\{1:2,1:2\}
\]

returns

\[
\begin{align*}
r1c1 & = \\
& \text{first} \\
r2c1 & = \\
\end{align*}
\]
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 11-19
• “Comma-Separated Lists”
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:

\[ C = \begin{bmatrix}
[ ] & [ ] & [ ] & [ ] \\
[ ] & [ ] & [ ] & [ ] \\
[ ] & [ ] & [ ] & [ ] \\
[ ] & [ ] & [ ] & [44]
\end{bmatrix} \]

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:

\[ C = \begin{bmatrix}
[ ] & [ ] & [ ] & [ ] & [ ] \\
[ ] & [ ] & [ ] & [ ] & [ ] \\
[ ] & [ ] & [ ] & [44] & [ ] \\
[ ] & [ ] & [ ] & [ ] & [ ]
\end{bmatrix} \]

For related examples, see:

- “Access Data in a Cell Array” on page 11-5
- “Combine Cell Arrays” on page 11-10
- “Delete Data from a Cell Array” on page 11-9
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:

\[
C = \begin{bmatrix}
1 & 2 & 3 \\
4 & 5 & 6 \\
7 & 8 & 9
\end{bmatrix};
\]

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 

\[
C =
\begin{bmatrix}
\end{bmatrix}
\]

Delete sets of cells using standard array indexing with smooth parentheses, ( ). For example, this command

\[
C(2,:) = []
\]

removes the second row of \( C \):

\[
C =
\begin{bmatrix}
\end{bmatrix}
\]

For related examples, see:

- “Add Cells to a Cell Array” on page 11-8
- “Access Data in a Cell Array” on page 11-5
Cell Arrays

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:

\[
C4 = [C1; C2; C3]
\]

\[
C4 = \begin{bmatrix}
1 & 2 & 3 \\
'A' & 'B' & 'C' \\
10 & 20 & 30
\end{bmatrix}
\]

Create a nested cell array with the cell array construction operator, {}:

\[
C5 = \{C1; C2; C3\}
\]

\[
C5 = \{\{1x3 cell\}, \{1x3 cell\}, \{1x3 cell\}
\]

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.

```matlab
randCell = {'Random Data', rand(20,2)};
plot(randCell{1,2})
title(randCell{1,1})
```

![Random Data](image)
Plot only the first column of data by indexing further into the content (multilevel indexing).

```matlab
figure
plot(randCell{1,2}(:,1))
title('First Column of Data')
```

Combine numeric data from multiple cells using the `cell2mat` 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.

```matlab
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.
\[
\begin{align*}
X &= -\pi:\pi/10:\pi; \\
Y &= \tan(\sin(X)) - \sin(\tan(X)); \\
C(:,1) &= \{\text{'LineWidth'}; 2\}; \\
C(:,2) &= \{\text{'MarkerEdgeColor'}; \text{'k'}\}; \\
C(:,3) &= \{\text{'MarkerFaceColor'}; \text{'g'}\}; \\
\text{plot}(X, Y, \text{'--rs'}, C{:})
\end{align*}
\]
• “Comma-Separated Lists”
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:

```matlab
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”
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.

 ```matlab
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.

 ```matlab
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.

 ```matlab
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 | struct | table

Related Examples

• “Access Data in a Cell Array” on page 11-5
• “Access Data in a Structure Array” on page 10-6
• “Access Data in a Table” on page 9-26

More About

• “Advantages of Using Tables” on page 9-38
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:

```matlab
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,

```matlab
C{1,2}
```

returns the numeric vector from that cell:

```matlab
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
  ```matlab
  C{1,1}(1,2)
  ```
  which returns
  ```matlab
  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
  ```matlab
  C{2,1}{1,2}
  ```
  which returns
  ```matlab
  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

  \[ \text{ans} = 5 \]

You can nest any number of cell and structure arrays. For example, add nested cells and structures to `C`.

```matlab
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:

```matlab
copy_pi =
    3.1416

part_magic =
     16     2
      5    11

nested_cell =
    more text
```

**Related Examples**

- “Access Data in a Cell Array” on page 11-5
Function Handles

- “What Is a Function Handle?” on page 12-2
- “Creating a Function Handle” on page 12-3
- “Calling a Function Using Its Handle” on page 12-7
- “Preserving Data from the Workspace” on page 12-10
- “Applications of Function Handles” on page 12-13
- “Saving and Loading Function Handles” on page 12-19
- “Advanced Operations on Function Handles” on page 12-20
- “Functions That Operate on Function Handles” on page 12-26
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 12-13 for an explanation of each of these applications.
Creating a Function Handle

You construct a handle for a specific function by preceding the function name with an @ sign. The syntax is:

\[ h = \text{@functionname} \]

where \( h \) is the variable to which the returned function handle is assigned.

Use only the function \textit{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 \texttt{plot} that is on your MATLAB path:

\[ h = \text{@plot}; \]

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 \texttt{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 \( \text{namelengthmax} \) characters. (The term \( \text{segment} \) refers to any portion of the name that lies before, between, or after a dot. For example, \( \text{java.lang.String} \) 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 \( \text{double} \) or \( \text{char} \), 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, \( \text{updateObj} \), defines a listener for an event called \( \text{Update} \), and the other, \( \text{callbackfcn} \), 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:

```matlab
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

```matlab
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:

```matlab
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 18-23 for more information.

**Arrays of Function Handles**

To create an array of function handles, you must use a cell array:

```matlab
trigFun = {@sin, @cos, @tan};
```

For example, to plot the cosine of the range \(-\pi\) to \(\pi\) at 0.01 intervals, use

```matlab
plot(trigFun{2}(-pi:0.01:pi))
```
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:

```matlab
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:

```matlab
% This identifies the handle. % This invokes the function.

fHandle = @computer;
fHandle();
ans =
    @computer
    PCWIN
```

**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 \texttt{find} function which returns up to three outputs, you can specify from 0 to 3 outputs in the call:

\[
m = \begin{bmatrix} 3 & 2 & 0 \\ -5 & 0 & 7 \\ 0 & 0 & 1 \end{bmatrix}
\]

\[
m =
\begin{array}{ccc}
3 & 2 & 0 \\
-5 & 0 & 7 \\
0 & 0 & 1 \\
\end{array}
\]

\[
[row \ col \ val] = f(m);
\]

\[
val
\]

\[
val =
\begin{array}{c}
3 \\
-5 \\
2 \\
7 \\
1 \\
\end{array}
\]

**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 \texttt{getHandle} returns a function handle \( fHandle \) to a caller that is outside of the file:

```matlab
function fHandle = getHandle
fHandle = @subFun;
end
```

```matlab
function res = subFun(t1, t2, varargin);
...
end
```

Call \texttt{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:

```matlab
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

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:
Preserving Data from the Workspace

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 18-24 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 18-32 and “Using Handles to Store Function Parameters” on page 18-33 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:

```matlab
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:

```matlab
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 12-20 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 18-33.

**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 12-13
“Pass a Function to Another Function” on page 12-13
“Capture Data Values For Later Use By a Function” on page 12-15
“Call Functions Outside of Their Normal Scope” on page 12-17
“Save the Handle in a MAT-File for Use in a Later MATLAB Session” on page 12-18

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).

```matlab
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].

```matlab
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)
an = 
    3.0472

integral(@sin, a, b)
an = 
    0.7163

integral(@humps, a, b)
an = 
    12.3566

**Example 2 — Run integral on Anonymous Functions**

Run `integral` on a MATLAB built-in function or an anonymous function:

```matlab
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:

```matlab
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 \([a, b]\):

```matlab
a = 0; b = 10;
int1 = integral(@cos,a,b)
```

```matlab
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`:

```matlab
x = a:b;
y = cos(x);
pp = spline(x,y);
```
Applications of Function Handles

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:

```matlab
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:

```matlab
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 12-20 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;  
```
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:

\[
x = 300; \\
h = @()x;
\]

\[
x = 50; \\
h() \\
an\ = 300
\]

\[
clear x \\
h() \\
an\ = 300
\]

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 12-15.

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**

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<td>“Converting to and from a String” on page 12-21</td>
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**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 12-15 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:

```matlab
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:

```matlab
f = functions(h)
f =
    function: 'get_plot_handle/draw_plot'
```
Advanced Operations on Function Handles

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:

```matlab
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:

```matlab
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 strncmp(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 ...
', 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 12-22
• “Comparing Handles to Anonymous Functions” on page 12-23
• “Comparing Handles to Nested Functions” on page 12-23
• “Comparing Handles Saved to a MAT-File” on page 12-24

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.

```matlab
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:

```matlab
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),
an =
    1

while those constructed from different calls are not considered equal:

[q1 q2] = test_eq(3, -1, 2);

isequal(h1, q1)
an =
    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)
an =
    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)
an =
   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.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
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<tbody>
<tr>
<td>functions</td>
<td>Return information describing a function handle.</td>
</tr>
<tr>
<td>func2str</td>
<td>Construct a function name string from a function handle.</td>
</tr>
<tr>
<td>str2func</td>
<td>Construct a function handle from a function name string.</td>
</tr>
<tr>
<td>save</td>
<td>Save a function handle from the current workspace to a MAT-file.</td>
</tr>
<tr>
<td>load</td>
<td>Load a function handle from a MAT-file into the current workspace.</td>
</tr>
<tr>
<td>isa</td>
<td>Determine if a variable contains a function handle.</td>
</tr>
<tr>
<td>isequal</td>
<td>Determine if two function handles are handles to the same function.</td>
</tr>
</tbody>
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Map Containers

- “Overview of the Map Data Structure” on page 13-2
- “Description of the Map Class” on page 13-4
- “Creating a Map Object” on page 13-6
- “Examining the Contents of the Map” on page 13-9
- “Reading and Writing Using a Key Index” on page 13-10
- “Modifying Keys and Values in the Map” on page 13-15
- “Mapping to Different Value Types” on page 13-18
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.

<table>
<thead>
<tr>
<th>KEYS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>327.2</td>
</tr>
<tr>
<td>Feb</td>
<td>368.2</td>
</tr>
<tr>
<td>Mar</td>
<td>197.6</td>
</tr>
<tr>
<td>Apr</td>
<td>178.4</td>
</tr>
<tr>
<td>May</td>
<td>100.0</td>
</tr>
<tr>
<td>Jun</td>
<td>69.9</td>
</tr>
<tr>
<td>Jul</td>
<td>32.3</td>
</tr>
<tr>
<td>Aug</td>
<td>37.3</td>
</tr>
<tr>
<td>Sep</td>
<td>19.0</td>
</tr>
<tr>
<td>Oct</td>
<td>37.0</td>
</tr>
<tr>
<td>Nov</td>
<td>73.2</td>
</tr>
<tr>
<td>Dec</td>
<td>110.9</td>
</tr>
<tr>
<td>Annual</td>
<td>1551.0</td>
</tr>
</tbody>
</table>

*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.
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.

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
<th>Default</th>
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</thead>
<tbody>
<tr>
<td>Count</td>
<td>Unsigned 64-bit integer that represents the total number of key/value pairs contained in the <code>Map</code> object.</td>
<td>0</td>
</tr>
<tr>
<td>KeyType</td>
<td>String that indicates the type of all keys contained in the <code>Map</code> 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>.</td>
<td><code>char</code></td>
</tr>
<tr>
<td>ValueType</td>
<td>String that indicates the type of values contained in the <code>Map</code> object. If the values in a <code>Map</code> 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>.</td>
<td><code>any</code></td>
</tr>
</tbody>
</table>

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

```matlab
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.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>isKey</td>
<td>Check if Map contains specified key</td>
</tr>
<tr>
<td>keys</td>
<td>Names of all keys in Map</td>
</tr>
<tr>
<td>length</td>
<td>Length of Map</td>
</tr>
<tr>
<td>remove</td>
<td>Remove key and its value from Map</td>
</tr>
<tr>
<td>size</td>
<td>Dimensions of Map</td>
</tr>
<tr>
<td>values</td>
<td>Values contained in Map</td>
</tr>
</tbody>
</table>
Creating a Map Object

In this section...

“Constructing an Empty Map Object” on page 13-6
“Constructing An Initialized Map Object” on page 13-7
“Combining Map Objects” on page 13-8

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:

```matlab
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:

```matlab
newMap = containers.Map()
```

newMap =

```
Map with properties:

    Count: 0
    KeyType: char
    ValueType: any
```

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 13-5
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:

```plaintext
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

```plaintext
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.

<table>
<thead>
<tr>
<th>KEYS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>327.2</td>
</tr>
<tr>
<td>Feb</td>
<td>368.2</td>
</tr>
<tr>
<td>Mar</td>
<td>197.6</td>
</tr>
<tr>
<td>Apr</td>
<td>178.4</td>
</tr>
<tr>
<td>May</td>
<td>100.0</td>
</tr>
<tr>
<td>Jun</td>
<td>69.9</td>
</tr>
<tr>
<td>Jul</td>
<td>32.3</td>
</tr>
<tr>
<td>Aug</td>
<td>37.3</td>
</tr>
<tr>
<td>Sep</td>
<td>19.0</td>
</tr>
<tr>
<td>Oct</td>
<td>37.0</td>
</tr>
<tr>
<td>Nov</td>
<td>73.2</td>
</tr>
<tr>
<td>Dec</td>
<td>110.9</td>
</tr>
<tr>
<td>Annual</td>
<td>1551.0</td>
</tr>
</tbody>
</table>

```plaintext
k = {'Jan', 'Feb', 'Mar', 'Apr', 'May', 'Jun', ...
     'Jul', 'Aug', 'Sep', 'Oct', 'Nov', 'Dec', 'Annual'};
```
\begin{verbatim}
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 =
    Map with properties:
       Count: 13
       KeyType: char
       ValueType: double

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 13-12, 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 `ticketMap` that maps airline ticket numbers to the holders of those tickets. Construct the Map with four key/value pairs:

```matlab
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:

```matlab
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:

<table>
<thead>
<tr>
<th>keys</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>2R175</td>
<td>James Enright</td>
</tr>
<tr>
<td>A479GY</td>
<td>Sarah Latham</td>
</tr>
<tr>
<td>B7398</td>
<td>Carl Haynes</td>
</tr>
<tr>
<td>NZ1452</td>
<td>Bradley Reid</td>
</tr>
</tbody>
</table>

The `values` method uses the same ordering of values:

```matlab
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 13-10
“Adding Key/Value Pairs” on page 13-11
“Building a Map with Concatenation” on page 13-12

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);

Start with the Map ticketMap:

ticketMap = containers.Map(...
   {'2R175', 'B7398', 'A479GY', 'NZ1452'}, ...
   {'James Enright', 'Carl Haynes', 'Sarah Latham', ...
   'Bradley Reid'});

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:

\[
\text{printf(' Would passenger %s please come to the desk?\n', ...) \\
ticketMap('A479GY'))}
\]

\[
\text{ans =}
\]

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:

\[
\text{values(ticketMap, {'2R175', 'B7398'})}
\]

\[
\text{ans =}
\]

'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:

\[
\text{ticketMap('2R175':'B7398')} \\
\text{ticketMap(:)}
\]

**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:

\[
\text{existingMapObj(newKeyName) = newValue;}
\]

Start with the Map `ticketMap`:

\[
\text{ticketMap = containers.Map(...} \\
\text{  {'2R175', 'B7398', 'A479GY', 'NZ1452'}, ...} \\
\text{  {'James Enright', 'Carl Haynes', 'Sarah Latham', ...} \\
\text{  'Bradley Reid'}}}
\]

Add two more entries to the `ticketMap` Map. Verify that `ticketMap` now has six key/value pairs:
ticketMap('947F4') = 'Susan Spera';
ticketMap('417R93') = 'Patricia Hughes';

ticketMap.Count
ans =
 6

List all of the keys and values in ticketMap:
keys(ticketMap),  values(ticketMap)
ans =
  '2R175'    '417R93'    '947F4'    'A479GY'    'B7398'    'NZ1452'
ans =
  'James Enright'    'Patricia Hughes'    'Susan Spera'    '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 Map objects, 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 Map objects. 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 Map objects:

```matlab
  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 =
   'James Enright'    'Patricia Hughes'    'Susan Spera'    '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 =
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 13-15
“Modifying Values” on page 13-16
“Modifying Keys” on page 13-16
“Modifying a Copy of the Map” on page 13-17

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 13-17, 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');

Start with the Map ticketMap:

ticketMap = containers.Map(...
    {'2R175', 'B7398', 'A479GY', 'NZ1452'}, ...
    {'James Enright', 'Carl Haynes', 'Sarah Latham', ...
     'Bradley Reid'});

Remove one entry (the specified key and its value) from the Map object:

remove(ticketMap, 'NZ1452');
values(ticketMap)
ans =
    'James Enright'    '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**:

```matlab
ticketMap('A479GY')
ans =
Sarah Latham
```

Change the passenger's first name to **Anna Latham** by overwriting the original value for the A479GY key:

```matlab
ticketMap('A479GY') = 'Anna Latham';
```

Verify the change:

```matlab
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:

```matlab
remove(ticketMap, '2R175');
ticketMap('2S185') = 'James Enright';
```

```matlab
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 the `ticketMap` Map. Write to this copy, and notice that the change is applied to the original Map object itself:

```matlab
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 13-18
“Mapping to a Cell Array” on page 13-19

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 ticket numbers and destinations. Start with the Map ticketMap, which maps ticket numbers to passengers:

```matlab
ticketMap = containers.Map(...
    {'2R175', 'B7398', 'A479GY', 'NZ1452'}, ...
    {'James Enright', 'Carl Haynes', 'Sarah Latham', ...
    'Bradley Reid'});
```

Then create the following structure array, containing ticket numbers and destinations:

```matlab
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 seats to these structures:

```matlab
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'

Using `ticketMap` and `seatingMap` together, you can find the name of the person who has reserved seat 15B:

ticket = seatingMap('15B').ticketNum;
passenger = ticketMap(ticket)

passenger =

    Sarah 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 14-2
- “Combining Unlike Integer Types” on page 14-3
- “Combining Integer and Noninteger Data” on page 14-6
- “Combining Cell Arrays with Non-Cell Arrays” on page 14-7
- “Empty Matrices” on page 14-8
- “Concatenation Examples” on page 14-9
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).

<table>
<thead>
<tr>
<th>TYPE</th>
<th>character</th>
<th>integer</th>
<th>single</th>
<th>double</th>
<th>logical</th>
</tr>
</thead>
<tbody>
<tr>
<td>character</td>
<td>character</td>
<td>character</td>
<td>character</td>
<td>character</td>
<td>invalid</td>
</tr>
<tr>
<td>integer</td>
<td>character</td>
<td>integer</td>
<td>integer</td>
<td>integer</td>
<td>integer</td>
</tr>
<tr>
<td>single</td>
<td>character</td>
<td>integer</td>
<td>single</td>
<td>single</td>
<td>single</td>
</tr>
<tr>
<td>double</td>
<td>character</td>
<td>integer</td>
<td>single</td>
<td>double</td>
<td>double</td>
</tr>
<tr>
<td>logical</td>
<td>invalid</td>
<td>integer</td>
<td>single</td>
<td>double</td>
<td>logical</td>
</tr>
</tbody>
</table>

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.

More About

- “Combining Unlike Integer Types” on page 14-3
- “Combining Integer and Noninteger Data” on page 14-6
- “Combining Cell Arrays with Non-Cell Arrays” on page 14-7
- “Concatenation Examples” on page 14-9
Combining Unlike Integer Types

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:

\[ A = \text{[int16(5000) int8(50)]} \]
\[ A = \begin{bmatrix} 5000 & 50 \end{bmatrix} \]

\[ B = \text{[int8(50) int16(5000)]} \]
\[ B = \begin{bmatrix} 50 & 127 \end{bmatrix} \]

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:

\[ C = \text{[int8(50); int16(5000)]} \]
\[ C = \begin{bmatrix} 50 \\ 127 \end{bmatrix} \]

**Note** You can find the maximum or minimum values for any MATLAB integer type using the \texttt{intmax} and \texttt{intmin} functions. For floating-point types, use \texttt{realmax} and \texttt{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:

\[ A = \text{[int8(-100) uint8(100)]} \]
\[ A = \begin{bmatrix} -100 & 100 \end{bmatrix} \]

\[ B = \text{[uint8(100) int8(-100)]} \]
\[ B = \begin{bmatrix} 100 & 0 \end{bmatrix} \]

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:

\[
A = [\text{int8}(50), \text{uint8}(-50)]
\]

\[
A = \\
50 \quad 0
\]
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`:

```matlab
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:

```matlab
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:

```matlab
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 14-9
“Combining Integer and Double Types” on page 14-9
“Combining Character and Double Types” on page 14-10
“Combining Logical and Double Types” on page 14-10

Combining Single and Double Types

Combining single values with double values yields a single matrix. Note that 5.73*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).

```matlab
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).

```matlab
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:

```matlab
x = ['A' 'B' 'C' 68 69 70]
x =
   ABCDEF

class(x)
an =
   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:

```matlab
x = [true false false pi sqrt(7)]
x =
   1.0000         0         0    3.1416    2.6458

class(x)
an =
   double
Using Objects

• “MATLAB Objects” on page 15-2
• “General Purpose Vs. Specialized Arrays” on page 15-5
• “Key Object Concepts” on page 15-8
• “Creating Objects” on page 15-11
• “Accessing Object Data” on page 15-13
• “Calling Object Methods” on page 15-15
• “Desktop Tools Are Object Aware” on page 15-18
• “Getting Information About Objects” on page 15-20
• “Copying Objects” on page 15-25
• “Destroying Objects” on page 15-31
MATLAB Objects

In this section...

“Getting Oriented” on page 15-2
“What Are Objects and Why Use Them?” on page 15-2
“Working with Objects” on page 15-3
“Objects In the MATLAB Language” on page 15-3
“Other Kinds of Objects Used by MATLAB” on page 15-3

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 15-13)
- Operate on its data (see “Calling Object Methods” on page 15-15)
- 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 15-25)
- 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 15-5
“Using General-Purpose Data Structures” on page 15-5
“Using Specialized Objects” on page 15-6

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):

```matlab
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:

```matlab
plot(s)
Error using plot
Not enough input arguments.
```
While \( s \) has enough information to create a plot of Data versus Time, \texttt{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 \texttt{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 \texttt{plot} function, add a title, labels, and so on:

\begin{verbatim}
plot(s.Time,s.Data)
title(['Time Series Plot: ' s.Name])
xlabel(['Time (' s.Units ')'])
ylabel(s.Name)
\end{verbatim}

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® \texttt{timeseries} object. It is initialized to store the same data as the structure \( s \) above:

\begin{verbatim}
tsobj = timeseries(rand(10,1),.01:.01:.1,'Name','Data1');
\end{verbatim}

The function that creates the object \( \texttt{tsobj} \), accepts sample data, sample times, a property name/property value pair (\texttt{Name/Data1}), and uses a default value of \texttt{Units} (which is \texttt{seconds}).

The designer of this object created a special version of the \texttt{plot} function that works directly with this object. For example:

\begin{verbatim}
plot(tsobj)
\end{verbatim}
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

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<td>“Methods Implement Operations” on page 15-9</td>
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<td>“Events are Notices Broadcast to Listening Objects” on page 15-10</td>
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</table>

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 15-13 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:

```
tobjnew = 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:

```matlab
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 defined 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

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`:

```matlab
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 15-13 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:

```matlab
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.

```matlab
% 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 “Class and Path 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 15-13
“Getting Property Values” on page 15-13
“Setting Property Values” on page 15-14

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:

```matlab
data = me.message
ans =
In an assignment  A(I) = B, a matrix A cannot be resized.
```

See “Capture Information About Exceptions” 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:

```matlab
tsobj = timeseries(rand(10,1),1:10,'Name','Random Sample');
```

Now suppose you attempt to set the `Data` property to a three-element vector:

```matlab
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 15-15
“Method Syntax” on page 15-15
“Class of Objects Returned by Methods” on page 15-16

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:

```matlab
methods('timeseries')
```

Methods for class timeseries:

- `addevent`
- `addsample`
- `createTstoolNode`
- `ctranspose`
- `gettsbetweenevents`
- `horzcat`
- `idealfilter`
- `init`
- `set`
- `setABStime`
- `set_interp_method`
- `setprop`

Method Syntax

Call an object's method using dot notation:

```matlab
returnedValue = object.methodName(args,...)
```

You also can call a method using function syntax, passing the object as the first (left-most) argument.

```matlab
returnedValue = 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 statement 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;
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 15-18
“Editing Objects with the Variables Editor” on page 15-18

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:

![Selection Box](image)

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

The Class of Workspace Variables

All workspace variables are of a specific class. For example, consider the following variable created in your workspace:

```matlab
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:

```matlab
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

```matlab
load count.dat
tsobj = timeseries(sum(count,2),1:24,'Name','DataSum');
```
d = tsobj.Data;
t = tsobj.Time;
n = tsobj.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:

```matlab
obj = tsobj.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.

<table>
<thead>
<tr>
<th>Function</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>class</code></td>
<td>Return class of object</td>
</tr>
<tr>
<td><code>events</code></td>
<td>List of event names defined by the class</td>
</tr>
<tr>
<td><code>methods</code></td>
<td>List of methods implemented by the class</td>
</tr>
<tr>
<td><code>methodsview</code></td>
<td>Information on class methods in separate window</td>
</tr>
<tr>
<td><code>properties</code></td>
<td>List of class property names</td>
</tr>
</tbody>
</table>

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 15-22). The following functions provide logical tests for objects:
Getting Information About Objects

<table>
<thead>
<tr>
<th>Function</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>isa</em></td>
<td>Determine whether argument belongs to a particular class. True for object's class and all of object's superclasses.</td>
</tr>
<tr>
<td><em>isequal</em></td>
<td>Determine if two objects are equal.</td>
</tr>
<tr>
<td><em>isobject</em></td>
<td>Determine whether the input is a MATLAB object.</td>
</tr>
</tbody>
</table>

**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 15-29 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:

```matlab
hobj = containers.Map({'Red Sox','Yankees'}, {'Boston','New York'})
```

```
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
Copy objects

In this section...

“Two Copy Behaviors” on page 15-25
“Value Object Copy Behavior” on page 15-25
“Handle Object Copy Behavior” on page 15-26
“Testing for Handle or Value Class” on page 15-29

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:

```matlab
a = 8;
b = a;
```

Now reassign a and b is unchanged:

```matlab
a = 6;
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:
Using Objects

```matlab
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`:

```matlab
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:

```matlab
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:

```matlab
hobj1 = HdClass(8);
hobj2 = hobj1;
delete(hobj1)
hobj2
```

hobj2 =

   deleted HdClass handle

Methods, Events, Superclasses

See “Destroying Objects” on page 15-31 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:

```matlab
hobj = containers.Map({'Red Sox','Yankees'}, {'Boston','New York'});
isa(hobj,'handle')
```

ans =

```
1
```

`hobj` is also a containers.Map object:

```matlab
isa(hobj,'containers.Map')
```

ans =

```
1
```

If you query the class of `hobj`, you see that it is a containers.Map object:

```matlab
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 15-31
“Difference Between clear and delete” on page 15-31

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:

```matlab
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:

```matlab
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
Scripts

- “Create Scripts” on page 17-2
- “Add Comments to Programs” on page 17-4
- “Run Code Sections” on page 17-6
- “Scripts vs. Functions” on page 17-16
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`:

```matlab
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`:

```matlab
columns = 10000;
rows = 1;
bins = columns/100;
rng(now);
list = 100*rand(rows,columns);
histogram(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.
More About

• “Base and Function Workspaces”
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,

```matlab
% 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, %{

```matlab
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,

```matlab
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

```matlab
% This is a program that has a comment that is a little more than 75 columns wide.
disp('Hello, world')
```
Add Comments to Programs

and then press the button next to **Comment** on the **Editor** tab, the Editor wraps the comment:

```matlab
% 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

**Related Examples**

- “Add Help for Your Program”

**More About**

- “Editor/Debugger Preferences”
Run Code Sections

<table>
<thead>
<tr>
<th>In this section...</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Divide Your File into Code Sections” on page 17-6</td>
</tr>
<tr>
<td>“Evaluate Code Sections” on page 17-6</td>
</tr>
<tr>
<td>“Navigate Among Code Sections in a File” on page 17-8</td>
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<tr>
<td>“Example of Evaluating Code Sections” on page 17-8</td>
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</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run the code in the current section.</td>
<td>• Place the cursor in the code section.</td>
</tr>
<tr>
<td></td>
<td>• On the Editor tab, in the Run section, click Run Section.</td>
</tr>
<tr>
<td>Run the code in the current section,</td>
<td>• Place the cursor in the code section.</td>
</tr>
<tr>
<td>and then move to the next section.</td>
<td>• On the Editor tab, in the Run section, click Run and Advance.</td>
</tr>
<tr>
<td>Run all the code in the file.</td>
<td>• Type the saved script name in the Command Window.</td>
</tr>
<tr>
<td></td>
<td>• On the Editor tab, in the Run section, click Run.</td>
</tr>
</tbody>
</table>

**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.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Move to the next section.</td>
<td>On the Editor tab, in the Run section, click Advance.</td>
</tr>
<tr>
<td>Move to the previous section.</td>
<td>Press Ctrl + Up arrow.</td>
</tr>
<tr>
<td>Move to a specific section.</td>
<td>On the Editor tab, in the Navigate section, use the Go To to move the cursor to a selected section.</td>
</tr>
</tbody>
</table>

**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.

   \[
   \begin{align*}
   &\text{\%\% Calculate and Plot Sine Wave} \\
   &\text{\% Define the range for } x. \\
   &\text{\% Calculate and plot } y = \sin(x). \\
   &x = 0:1:6*\pi; \\
   &y = \sin(x); \\
   &\text{plot}(x,y) \\
   \end{align*}
   \]

2 Insert a blank line and a second section break after \texttt{plot(x,y)}. Add a section title, \texttt{Modify Plot Properties}, so that the entire file contains this code:

   \[
   \begin{align*}
   &\text{\%\% Calculate and Plot Sine Wave} \\
   &\text{\% Define the range for } x. \\
   &\text{\% Calculate and plot } y = \sin(x). \\
   &x = 0:1:6*\pi; \\
   &y = \sin(x); \\
   &\text{plot}(x,y) \\
   \end{align*}
   \]

   \[
   \begin{align*}
   &\text{\% Modify Plot Properties} \\
   &\text{title('Sine Wave')} \\
   &\text{xlabel('x')} \\
   &\text{ylabel('\text{sin}(x)')} \\
   &\text{fig = gcf;} \\
   &\text{fig.MenuBar = 'none';} \\
   \end{align*}
   \]

3 Save the file.

4 Place your cursor in the section titled \texttt{Calculate and Plot Sine Wave}. On the \texttt{Editor} tab, in the \texttt{Run} section, click \texttt{Run Section}.

A figure displaying a coarse plot of $\sin(x)$ appears.
5 Smooth the sine plot.

1 Highlight 1 in the statement: \( x = 0:1:6*\pi; \).

2 Right-click and select **Increment Value and Run Section**. A small dialog box appears.

3 Type 2 in the \( \div/\times \) text box.

4 Click the \( \div \) button several times.

The sine plot becomes smoother after each subsequent click.
5 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.

   ![Section display options](image)

   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:

```matlab
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.
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.

- **At the third-level of nesting**, one section exists within the `if` statement.
More About

- “Scripts vs. Functions” on page 17-16
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:

```matlab
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.

```matlab
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:

```matlab
a1 = triarea(1,5)
a2 = triarea(2,10)
a3 = triarea(3,6)
a1 =
```

```
```
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 17-2
- “Create Functions in Files”

**More About**
- “Base and Function Workspaces”
Function Basics

- “Create Functions in Files” on page 18-2
- “Add Help for Your Program” on page 18-5
- “Run Functions in the Editor” on page 18-7
- “Base and Function Workspaces” on page 18-9
- “Share Data Between Workspaces” on page 18-10
- “Check Variable Scope in Editor” on page 18-15
- “Types of Functions” on page 18-19
- “Anonymous Functions” on page 18-23
- “Local Functions” on page 18-29
- “Nested Functions” on page 18-31
- “Variables in Nested and Anonymous Functions” on page 18-38
- “Private Functions” on page 18-40
- “Function Precedence Order” on page 18-42
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:

```matlab
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.

<table>
<thead>
<tr>
<th><strong>function keyword</strong> (required)</th>
<th>Use lowercase characters for the keyword.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output arguments (optional)</td>
<td>If your function returns more than one output, enclose the output names in square brackets, such as</td>
</tr>
<tr>
<td></td>
<td><code>function [one,two,three] = myfunction(x)</code></td>
</tr>
<tr>
<td></td>
<td>If there is no output, either omit it,</td>
</tr>
<tr>
<td></td>
<td><code>function myfunction(x)</code></td>
</tr>
<tr>
<td></td>
<td>or use empty square brackets:</td>
</tr>
<tr>
<td></td>
<td><code>function [] = myfunction(x)</code></td>
</tr>
<tr>
<td>Function name (required)</td>
<td>Valid function names follow the same rules as variable names. They must start with a letter, and can contain letters, digits, or underscores.</td>
</tr>
</tbody>
</table>

**Note:** To avoid confusion, use the same name for both the file and the first function within the file. MATLAB associates your program with the file name, not the function name.
Create Functions in Files

Input arguments
(optional)

If your function accepts any inputs, enclose their names in parentheses after the function name. Separate inputs with commas, such as

```
function y = myfunction(one,two,three)
```

If there are no inputs, you can omit the parentheses.

**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**
clear | edit | function | what | which

**Related Examples**
- “Files and Folders that MATLAB Accesses”
- “Add Help for Your Program” on page 18-5
- “Support Variable Number of Inputs”

**More About**
- “Base and Function Workspaces”
- “Local Functions”
- “Nested Functions”
- “Debugging Process and Features”
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:

```matlab
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:

```matlab
% For more information, see <a href="matlab:
```

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”. 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”
- “Create Help Summary Files — Contents.m”
- “Check Which Programs Have Help”
- “Display Custom Documentation”
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`.

```matlab
function y = myfunction(x)
    y = x.^2 + x;
end
```

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.

```matlab
y = myfunction(1:10)
```

You can enter multiple commands on the same line, such as

```matlab
x = 1:10; y = myfunction(x)
```

For more complicated, multinline 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.
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:

\[
y = 2 \quad 6 \quad 12 \quad 20 \quad 30 \quad 42 \quad 56 \quad 72 \quad 90 \quad 110
\]

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**.
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 18-10

**More About**

- “Nested Functions”
Share Data Between Workspaces

In this section...
“Introduction” on page 18-10
“Best Practice: Passing Arguments” on page 18-10
“Nested Functions” on page 18-11
“Persistent Variables” on page 18-11
“Global Variables” on page 18-12
“Evaluating in Another Workspace” on page 18-13

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.

```matlab
function y1 = update1(x1)
    y1 = 1 + update2(x1);
end

function y2 = update2(x2)
    y2 = 2 * x2;
end
```

Call the update1 function from the command line and assign to variable Y in the base workspace:

```matlab
X = [1,2,3];
```
\[ Y = \text{update1}(X) \]
\[ Y = \begin{bmatrix} 3 & 5 & 7 \end{bmatrix} \]

**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:

```matlab
function primaryFx
    x = 1;
    nestedFx
        function nestedFx
            x = x + 1;
        end
    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.

```matlab
function primaryFx
    nestedFx1
    nestedFx2
        function nestedFx1
            x = 1;
        end
        function nestedFx2
            x = 2;
        end
end
```

For more information, see “Nested Functions” on page 18-31.

**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.

```matlab
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`:

```matlab
function h = falling(t)
    global GRAVITY
    h = 1/2*GRAVITY*t.^2;
```

Then, enter these commands at the prompt:

```matlab
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:

```matlab
function h = falling(t,gravity)
    h = 1/2*gravity*t.^2;
```

Then, enter these commands at the prompt:

```matlab
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:

```matlab
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');
src.String = vars;

For other programming applications, consider argument passing and the techniques described in “Alternatives to the eval Function”.

More About

• “Base and Function Workspaces” on page 18-9
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” and “Share Data Between Workspaces”.

**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”.)

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:
Example of Using Automatic Function and Variable Highlighting

Consider the code for a function rowsum:

```matlab
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:

```matlab
ans =

    10   10
```

MATLAB displays:

```matlab
ans =

    0    0    0    0    0    0    0    0    0    0    0    10
```

Examine the code by following these steps:
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.

Copy the `rowsum` code into the Editor.

Notice the variable `i` appears in teal blue, which indicates it 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.

Hover the mouse pointer over an instance of variable `i`.

A tooltip appears: The scope of variable 'i' spans multiple functions.

Click the tooltip link for information about variables whose scope span multiple functions.

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.
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.

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`.
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:

```matlab
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:

```matlab
myfunction(pi)
```

```matlab
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 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:

```matlab
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 = obj.Value;
    e.String = num2str(value);
  end

    function edittext(obj,~)
    value = str2double(obj.String);
    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 $y = s(pi)$

$$y = \begin{array}{c} 0.3130 \end{array}$$

Or, you can pass the function handle to a function that evaluates over a range of values, such as fplot:

$$\text{range} = [0.01,0.1];$$

$$\text{fplot}(s,\text{range})$$
More About
- “Local Functions” on page 18-29
- “Nested Functions” on page 18-31
- “Private Functions” on page 18-40
- “Anonymous Functions” on page 18-23
Anonymous Functions

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:

\[ q = \text{integral}(\text{sqr}, 0, 1); \]

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:

\[ q = \text{integral}(\text{@}(x) \ x.^2, 0, 1); \]

**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`.

```matlab
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:

```matlab
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:

```matlab
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)
```

```matlab
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:

```matlab
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:

```matlab
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:

```matlab
myfunction = @(x,y) (x^2 + y^2 + x*y);
```

```matlab
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:
\begin{verbatim}
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 \texttt{mygrid} to create a mesh or surface plot:

\begin{verbatim}
z = \sin(x) + \cos(y);
mesh(x,y,z)
\end{verbatim}
\end{verbatim}

\textbf{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:

\[
x = 1;
y = 10;
\]

\[
f\{1\}(x) \\
f\{2\}(y) \\
f\{3\}(x,y)
\]

\[
ans = 
1
\]

\[
ans = 
20
\]

\[
ans = 
21
\]

**More About**

- “Creating a Function Handle”
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`.

```matlab
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`

**More About**

- “Nested Functions” on page 18-31
- “Function Precedence Order”
Nested Functions

In this section...

“What Are Nested Functions?” on page 18-31
“Requirements for Nested Functions” on page 18-31
“Sharing Variables Between Parent and Nested Functions” on page 18-32
“Using Handles to Store Function Parameters” on page 18-33
“Visibility of Nested Functions” on page 18-36

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`:

```matlab
function parent
    disp('This is the parent function')
    nestedfx
end

function nestedfx
    disp('This is the nested function')
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 18-38.)

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 \( x \):

```matlab
function main1
    x = 5;
    nestfun1

    function nestfun1
        x = x + 1;
        end
    end

end

function main2
    nestfun2

    function nestfun2
        x = 5;
        end

    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 function named main, the two nested functions have their own versions of \( x \) that cannot interact with each other:

```matlab
function main
    nestedfun1
    nestedfun2

    function nestedfun1
```
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:

```matlab
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`:

```matlab
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.

```matlab
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:

```matlab
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:

```matlab
fplot(p,[-25,25])
```
You can create multiple handles to the parabola function that each use different polynomial coefficients:

```matlab
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.)

```matlab
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 18-33. Only functions that can call a nested function can create a handle to it.

More About

• “Variables in Nested and Anonymous Functions” on page 18-38
• “Calling a Function Using Its Handle”
• “Argument Checking in Nested Functions”
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.

<table>
<thead>
<tr>
<th>Type of Operation</th>
<th>Best Practice to Avoid Dynamic Assignment</th>
</tr>
</thead>
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<tr>
<td>load</td>
<td>Specify the variable name as an input to the load function. Or, assign the output from the load function to a structure array.</td>
</tr>
<tr>
<td>eval, evalin, or assignin</td>
<td>If possible, avoid using these functions altogether. See “Alternatives to the eval Function”.</td>
</tr>
<tr>
<td>Calling a MATLAB script that creates a variable</td>
<td>Convert the script to a function and pass the variable using arguments. This approach also clarifies the code.</td>
</tr>
<tr>
<td>Assigning to a variable in the MATLAB debugger</td>
<td>Create a global variable for temporary use in debugging, such as</td>
</tr>
<tr>
<td></td>
<td>K&gt;&gt; global X;</td>
</tr>
<tr>
<td></td>
<td>K&gt;&gt; X = myvalue;</td>
</tr>
</tbody>
</table>

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:

```matlab
function noerror
X = [];
nestedfx
```
Variables in Nested and Anonymous Functions

```matlab
function nestedfx
    makeX
end
end
```

**More About**

- “Base and Function Workspaces”
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`:

```matlab
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`.

```matlab
function visible
    findme
```

Change your current folder to any location and call the `visible` function.

```matlab
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:

```matlab
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.
More About

- “Function Precedence Order”
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  Loaded Simulink® models
9  Functions in the current folder
10 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 files that are not loaded, 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 18-19
• “Class Precedence and MATLAB Path”
Function Arguments

- “Find Number of Function Arguments” on page 19-2
- “Support Variable Number of Inputs” on page 19-4
- “Support Variable Number of Outputs” on page 19-6
- “Validate Number of Function Arguments” on page 19-8
- “Argument Checking in Nested Functions” on page 19-11
- “Ignore Function Inputs” on page 19-13
- “Check Function Inputs with validateattributes” on page 19-14
- “Parse Function Inputs” on page 19-17
- “Input Parser Validation Functions” on page 19-21
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`.

```matlab
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.

```matlab
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`.

```matlab
function [result,absResult] = addme2(a,b)
```
switch nargin
    case 2
        result = a + b;
    case 1
        result = a + a;
    otherwise
        result = 0;
end

if nargout > 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.

```matlab
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.

```matlab
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

```matlab
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”

More About
• “Argument Checking in Nested Functions” on page 19-11
• “Comma-Separated Lists”
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.

```matlab
function varargout = magicfill
    nOutputs = nargout;
    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.

```matlab
[first,second,third] = magicfill
```

```matlab
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

```matlab
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”

**More About**
- “Argument Checking in Nested Functions” on page 19-11
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:

```matlab
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.

```matlab
[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.

```matlab
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 = 
```
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 19-4
• “Support Variable Number of Outputs” on page 19-6
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.

```matlab
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.

```matlab
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.

```matlab
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.

```matlab
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.

```matlab
function colorButton
    figure;
    uicontrol('Style','pushbutton','String','Click me','Callback',@btnCallback)

    function btnCallback(h,~)
        set(h,'BackgroundColor',rand(3,1))
    end
end
```

The function declaration for `btnCallback` is essentially the same as

```matlab
function btnCallback(h,eventdata)
    set(h,'BackgroundColor',rand(3,1))
end
```

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

```matlab
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.

Procedure 19.6. 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.

```matlab
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.

```matlab
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.

```matlab
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.

```matlab
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.

```matlab
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.

```matlab
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
```

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:

```matlab
printPhoto('myfile.jpg')
```

File name: myfile.jpg  
Finish: glossy  
Using defaults:  
  'finish'    'color'    'width'    'height'

```matlab
printPhoto(100)
```

Error using printPhoto (line 23)  
The value of 'filename' is invalid. It must satisfy the function: ischar.

```matlab
printPhoto('myfile.jpg','satin')
```

Error using printPhoto (line 23)  
The value of 'finish' is invalid. Expected input to match one of these strings:  
  'glossy', 'matte'

The input, 'satin', did not match any of the valid strings.

```matlab
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`:

```matlab
printPhoto('myfile.gif','glossy','CMYK')  % positional
printPhoto('myfile.gif','color','CMYK')   % name and value
```

**See Also**

`inputParser` | `varargin`

**More About**

- “Input Parser Validation Functions” on page 19-21
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:

  ```matlab
  p = inputParser;
  checknum = @isnumeric;
  addRequired(p,'num',checknum)
  parse(p,'text')
  
  The value of 'num' is invalid. It must satisfy the function: isnumeric.
  ```

- Create an anonymous function. For example, check that input num is a numeric scalar greater than zero:

  ```matlab
  p = inputParser;
  checknum = @(x) isnumeric(x) && isscalar(x) && (x > 0);
  addRequired(p,'num',checknum)
  parse(p(rand(3)))
  
  The value of 'num' is invalid. It must satisfy the function: @(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:

  ```matlab
  function usenum(num)
    p = inputParser;
  ```
Function Arguments

```matlab
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)
The value of 'num' is invalid. Input must be > 0

See Also
function_handle | inputParser | is* | validateattributes

Related Examples
- “Parse Function Inputs” on page 19-17

More About
- “Anonymous Functions”
Debugging MATLAB Code
Debugging Process and Features

In this section...

“Ways to Debug MATLAB Files” on page 20-2
“Preparing for Debugging” on page 20-2
“Set Breakpoints” on page 20-5
“Run a File with Breakpoints” on page 20-8
“Step Through a File” on page 20-9
“Examine Values” on page 20-11
“Correct Problems and End Debugging” on page 20-15
“Conditional Breakpoints” on page 20-23
“Breakpoints in Anonymous Functions” on page 20-24
“Breakpoints in Methods That Overload Functions” on page 20-25
“Error Breakpoints” on page 20-26

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.

<table>
<thead>
<tr>
<th>( n )</th>
<th>Sequence</th>
<th>Number of Integers in the Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2 1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3 10 5 16 8 4 2 1</td>
<td>8</td>
</tr>
</tbody>
</table>

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:

```matlab
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.

![Plot](image)

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 20-6.
- A conditional breakpoint, which stops at a specified line in a file only under specified conditions. For details, see “Conditional Breakpoints” on page 20-23.
- 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 20-26.

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 20-16. 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

```matlab
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 \textit{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 \textbf{Editor} tab, in the \textbf{Breakpoints} section, click \textbf{Breakpoints}, and then select \textbf{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.

\textbf{Set Breakpoints for the Example}

It is unclear whether the problem in the example is in \texttt{collatzplot} or \texttt{collatz}. To start, follow these steps:

1. In \texttt{collatzplot.m}, click the dash in the breakpoint alley at line 9 to set a breakpoint.

   This breakpoint enables you to step into \texttt{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.

\texttt{
\begin{verbatim}
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 demon
15 \% The plot_seq variable should be seq_length(N).
\end{verbatim}
}

\textbf{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 $\downarrow$ 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:

```plaintext
plot_seq = collatz(N);
```

The line at which you are paused displays in the Command Window. For the example:

```plaintext
plot_seq = collatz(N);
```

- The function that 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.

<table>
<thead>
<tr>
<th>Toolbar Button</th>
<th>Debug Menu Item</th>
<th>Description</th>
<th>Function Alternative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run to Cursor</td>
<td></td>
<td>Continue execution of file until the line where the cursor is positioned.</td>
<td>None</td>
</tr>
<tr>
<td>Toolbar Button</td>
<td>Debug Menu Item</td>
<td>Description</td>
<td>Function Alternative</td>
</tr>
<tr>
<td>----------------</td>
<td>----------------</td>
<td>------------------------------------------------------------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Also available on the context menu.</td>
<td></td>
</tr>
<tr>
<td>![Step Button]</td>
<td>Step</td>
<td>Execute the current line of the file.</td>
<td>dbstep</td>
</tr>
<tr>
<td>![Step In Button]</td>
<td>Step In</td>
<td>Execute the current line of the file and, if the line is a call to another function, step into that function.</td>
<td>dbstep in</td>
</tr>
<tr>
<td>![Continue Button]</td>
<td>Continue</td>
<td>Resume execution of file until completion or until another breakpoint is encountered.</td>
<td>dbcont</td>
</tr>
<tr>
<td>![Step Out Button]</td>
<td>Step Out</td>
<td>After stepping in, run the rest of the called function or local function, leave the called function, and pause.</td>
<td>dbstep out</td>
</tr>
<tr>
<td>![Quit Debugging Button]</td>
<td>Quit Debugging</td>
<td>Exit debug mode.</td>
<td>dbquit</td>
</tr>
</tbody>
</table>

**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](Images/Continue.png) 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](Images/StepIn.png) 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 $\triangleright\triangleright$, 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 20-11
- “View Values as Data Tips in the Editor” on page 20-12
- “View Values in the Command Window” on page 20-12
- “View Values in the Workspace Browser and Variables Editor” on page 20-13
- “Evaluate a Selection” on page 20-14
- “Examine Values in the Example” on page 20-14
- “Problems Viewing Variable Values from the Parent Workspace” on page 20-15

Many of these methods are used in “Examine Values in the Example” on page 20-14.

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.

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.

![Workspace Browser](image)

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.
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. 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 20-16
- “End Debugging” on page 20-16
• “Disable and Clear Breakpoints” on page 20-16
• “Save Breakpoints” on page 20-19
• “Correct Problems in a MATLAB File” on page 20-19
• “Complete the Example” on page 20-19
• “Run Parts in MATLAB Files That Have Unsaved Changes” on page 20-22

“Complete the Example” on page 20-19 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 20-7 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](image), 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 20-23.

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.

\[
\text{plot_seq} = \text{collatz}(N);
\]

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 20-7 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
   ```matlab
dbclean all in collatzplot
   ```
   in the Command Window.

4. Run `collatzplot` for \( m = 3 \) by typing
   ```matlab
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 \texttt{collatzplot} for \( m = 6 \) as well as the results for \texttt{collatz}, add this line at the end of \texttt{collatz.m}:

```matlab
sequence
```

which displays the series in the Command Window. The results for when \( n = 6 \) are

```matlab
sequence =

6     3    10     5    16     8     4     2     1
```

Then run \texttt{collatzplot} for \( m = 6 \) by typing

```matlab
collatzplot(6)
```

7 To make debugging easier, you ran \texttt{collatzplot} for a small value of \( m \). Now that you know it works correctly, run \texttt{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 \texttt{collatz.m}, by adding a semicolon to the end of the line so it appears as

```matlab
sequence;
```

Then run

```matlab
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 20-23
- “Modify, Disable, or Clear Conditional Breakpoints” on page 20-23
- “Function Alternatives for Manipulating Conditional Breakpoints” on page 20-24

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:

   \[ N \geq 2 \]

   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 Debugging MATLAB Code

To Modify a condition for a breakpoint in the current line.

Do This Right-click the conditional breakpoint icon, and then from the context menu, select **Set/Modify Condition**.

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.

<table>
<thead>
<tr>
<th>To</th>
<th>Use This Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set a conditional breakpoint.</td>
<td><code>dbstop</code></td>
</tr>
<tr>
<td>Clear a conditional breakpoint.</td>
<td><code>dbclear</code></td>
</tr>
<tr>
<td>View a list of currently set breakpoints, including the conditional expression for each conditional breakpoint.</td>
<td><code>dbstatus</code></td>
</tr>
</tbody>
</table>

### 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 \texttt{sqr} in line 2, and then run the file. When you run the file, MATLAB pauses each time that the anonymous function \texttt{sqr} executes. The green arrow shows where the code defines \texttt{sqr}. The white arrow, on line 5, indicates where the code calls \texttt{sqr}.

**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 \texttt{MyClass} that overloads the MATLAB \texttt{size} function.
2. Create an instance of \texttt{MyClass}.
3. Insert breakpoints within the \texttt{MyClass size} method.
4. Call \texttt{whos}.

When you call the \texttt{whos} function, it calls the \texttt{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 20-26
- “Error Breakpoint Types and Options” on page 20-27
- “Examples of Setting Warning and Error Breakpoints” on page 20-28
- “Function Alternative for Manipulating Error Breakpoints” on page 20-29

### 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:

```matlab
surf
MException.last
```

The Command Window displays the MException object, including the error message identifier in the identifier field. For this example, it displays:

```matlab
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:

```matlab
[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.

<table>
<thead>
<tr>
<th>To</th>
<th>Use This Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set error breakpoints.</td>
<td><code>dbstop</code></td>
</tr>
<tr>
<td>Clear error breakpoints.</td>
<td><code>dbclear</code></td>
</tr>
<tr>
<td>View a list of currently set breakpoints, including the condition and message identifier for each error breakpoint.</td>
<td><code>dbstatus</code></td>
</tr>
</tbody>
</table>
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 21-2
• “Document and Share Code Using Examples” on page 21-4
• “Publishing MATLAB Code” on page 21-6
• “Publishing Markup” on page 21-8
• “Output Preferences for Publishing” on page 21-28
• “Create a MATLAB Notebook with Microsoft Word” on page 21-42
# Options for Presenting Your Code

MATLAB provides options for presenting your code to others.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
<th>Output Formats</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Command-line help</td>
<td>Use comments at the start of a MATLAB file to display help comments when you type help file_name in the Command Window.</td>
<td>• ASCII text</td>
<td>“Add Help for Your Program”</td>
</tr>
<tr>
<td>Publish</td>
<td>Use comments with basic markup to publish a document that includes text, bulleted or numbered lists, MATLAB code, and code results.</td>
<td>• XML</td>
<td>“Publishing MATLAB Code”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• HTML</td>
<td>Publishing MATLAB Code from the Editor video</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• LaTeX</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Microsoft Word (.doc/.docx)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Microsoft PowerPoint (ppt)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• PDF</td>
<td></td>
</tr>
<tr>
<td>Help Browser Topics</td>
<td>Create HTML and XML files to provide your own MATLAB help topics for viewing from the MATLAB Help browser or the web.</td>
<td>• HTML</td>
<td>“Display Custom Documentation”</td>
</tr>
<tr>
<td>Notebook</td>
<td>Use Microsoft Word to create electronic or printed records of MATLAB sessions for class notes, textbooks, or technical reports.</td>
<td>• Microsoft Word (.doc/.docx)</td>
<td>“Create a MATLAB Notebook with Microsoft Word” on page 21-42</td>
</tr>
<tr>
<td></td>
<td>You must have Microsoft Word software installed.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MATLAB Report Generator™</td>
<td>Use MATLAB Report Generator to build complex reports.</td>
<td>• RTF</td>
<td>MATLAB Report Generator</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• PDF</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Word</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• HTML</td>
<td></td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
<td>Output Formats</td>
<td>Details</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>----------------</td>
<td>---------</td>
</tr>
<tr>
<td>You must have MATLAB Report Generator software installed.</td>
<td></td>
<td>XML</td>
<td></td>
</tr>
</tbody>
</table>
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 document the steps of a task clearly, 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.

<table>
<thead>
<tr>
<th>Titles</th>
<th>%% Square Waves from Sine Waves</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%% Add an Odd Harmonic and Plot It</td>
</tr>
<tr>
<td></td>
<td>%% Note About Gibbs Phenomenon</td>
</tr>
<tr>
<td>Variable name in italics</td>
<td>% As <em>k</em> increases, ...</td>
</tr>
<tr>
<td>LaTeX equation</td>
<td>% $$ y = y + \frac{\sin(k*t)}{k} $$</td>
</tr>
</tbody>
</table>

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. For more information on publishing to other formats, see “Specify Output File”.

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

More About
- “MATLAB Code Examples”
- “Publishing Markup” on page 21-8
- “Output Preferences for Publishing” on page 21-28

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.

<table>
<thead>
<tr>
<th>MATLAB Code with Markup</th>
<th>Published Document</th>
</tr>
</thead>
</table>
| %% Square Waves from Sine Waves
%% The Fourier series expansion for a square wave is made up of a sum of odd harmonics, as shown here using MATLAB.
%% Add an Odd Harmonic and Plot It
   t = 0:0.1:4*pi;
   y = sin(t);
   plot(t,y);
   %% In each iteration of the for loop add an odd harmonic to y. As n increases, the output approximately approximates a square wave with increasing accuracy.
   for n = 3:2:8
     % Perform the following mathematical operation at each iteration:
     % $y = y + \sin(n \times t)/n$ %
     % Display every other plot:
     % $y = y + \sin(n \times t)/n$ if mod(n,4)==1
           display(['Add an Odd Harmonic and Plot it: ']);
           display(['For n = ',num2str(n),', ']);
           clf
           plot(t,y)
   end
   %% Note About Gibbs Phenomenon
   % Even though the approximations are constantly improving, they will never be exact because of the Gibbs phenomenon, or ringing. |

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.
Publishing MATLAB Code

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. For more information on publishing to other formats, see “Specify Output File”.

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

More About

- “Publishing Markup” on page 21-8
- “Output Preferences for Publishing” on page 21-28
Publishing Markup

In this section...

“Markup Overview” on page 21-8
“Sections and Section Titles” on page 21-11
“Text Formatting” on page 21-12
“Bulleted and Numbered Lists” on page 21-13
“Text and Code Blocks” on page 21-14
“External File Content” on page 21-15
“External Graphics” on page 21-16
“Image Snapshot” on page 21-18
“LaTeX Equations” on page 21-19
“Hyperlinks” on page 21-21
“HTML Markup” on page 21-24
“LaTeX Markup” on page 21-25

Markup Overview

To insert markup, you can:

- 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 text 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.

<table>
<thead>
<tr>
<th>Result in Output</th>
<th>Example of Corresponding File Markup</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Sections and Section Titles” on page 21-11</td>
<td>% % SECTION TITLE</td>
</tr>
<tr>
<td></td>
<td>% DESCRIPTIVE TEXT</td>
</tr>
<tr>
<td></td>
<td>% % SECTION TITLE WITHOUT SECTION BREAK</td>
</tr>
<tr>
<td></td>
<td>% DESCRIPTIVE TEXT</td>
</tr>
<tr>
<td>“Text Formatting” on page 21-12</td>
<td>% <em>ITALIC TEXT</em></td>
</tr>
<tr>
<td></td>
<td>% <em>BOLD TEXT</em></td>
</tr>
<tr>
<td></td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>% Trademarks:</td>
</tr>
<tr>
<td></td>
<td>% TEXT(TM)</td>
</tr>
<tr>
<td></td>
<td>% TEXT(R)</td>
</tr>
<tr>
<td>“Bulleted and Numbered Lists” on page 21-13</td>
<td>% % Bulleted List</td>
</tr>
<tr>
<td></td>
<td>% * BULLETED ITEM 1</td>
</tr>
<tr>
<td></td>
<td>% * BULLETED ITEM 2</td>
</tr>
<tr>
<td></td>
<td>% % Numbered List</td>
</tr>
<tr>
<td></td>
<td>% # NUMBERED ITEM 1</td>
</tr>
<tr>
<td></td>
<td>% # NUMBERED ITEM 2</td>
</tr>
<tr>
<td>“Text and Code Blocks” on page 21-14</td>
<td>% %</td>
</tr>
<tr>
<td></td>
<td>% PREFORMATTED</td>
</tr>
<tr>
<td></td>
<td>% TEXT</td>
</tr>
<tr>
<td></td>
<td>% % MATLAB(R) Code</td>
</tr>
<tr>
<td></td>
<td>% for i = 1:10</td>
</tr>
<tr>
<td>Result in Output</td>
<td>Example of Corresponding File Markup</td>
</tr>
<tr>
<td>--------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>% disp x&lt;br&gt; % end %</td>
<td></td>
</tr>
<tr>
<td>“External File Content” on page 21-15</td>
<td>%&lt;include&gt;filename.m&lt;/include&gt;%</td>
</tr>
<tr>
<td>“External Graphics” on page 21-16</td>
<td>%&lt;include&gt;filename.png&lt;/include&gt;%</td>
</tr>
<tr>
<td>“Image Snapshot” on page 21-18</td>
<td>snapnow;</td>
</tr>
<tr>
<td>“LaTeX Equations” on page 21-19</td>
<td>% Inline Expression $x^2+e^{\pi i}$&lt;br&gt; % Block Equation $e^{\pi i} + 1 = 0$</td>
</tr>
<tr>
<td>“Hyperlinks” on page 21-21</td>
<td>&lt;<a href="http://www.mathworks.com">http://www.mathworks.com</a> MathWorks&gt;</td>
</tr>
<tr>
<td>“HTML Markup” on page 21-24</td>
<td>%&lt;html&gt;&lt;br&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;</td>
</tr>
<tr>
<td>“LaTeX Markup” on page 21-25</td>
<td>% LaTeX Markup Example %&lt;latex&gt;&lt;br&gt; \begin{tabular}{</td>
</tr>
</tbody>
</table>
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, this code produces a polished result when published.

```matlab
%% 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 this figure. Notice that MATLAB automatically inserts a Contents menu from the section titles in the MATLAB file.
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, these lines display each of the text formatting syntaxes if published.

```matlab
%% Calculate and Plot Sine Wave
% _Define_ the *range* for |x|
```

**Vector Operations**

You can perform a number of binary operations on vectors.

**Contents**

- Dot Product
- Cross Product

```matlab
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.

```matlab
e = 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.

```matlab
v = cross(A, B);
```
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. Simply add (R) or (TM) directly after the term in question, without any space in between.

For example, suppose that you enter these lines in a file.

```matlab
%% 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.

![Basic Matrix Operations in MATLAB®

This is a demonstration of some aspects of MATLAB® software and the Neural Network Toolbox™ software.]

Bulleted and Numbered Lists

MATLAB allows bulleted and numbered lists in the comments. You can use this syntax to produce bulleted and numbered lists.

```matlab
%% Two Lists
%
% * ITEM1
% * ITEM2
%
% # ITEM1
% # ITEM2
%
```

Publishing the example code produces this output.
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 this 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.
```

Syntax Highlighted Sample Code

Executable code appears with syntax highlighting in published documents. You also can 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 inserts the following sample code in your Editor.

```%
% Teach your computer to count to 10.
% for i = 1:10
%     disp(x)
% end
```

Publishing this code to HTML produces output in the MATLAB web browser.

```
Teach your computer to count to 10.
for i = 1:10
    disp(x)
end
```

**External File Content**

To add external file content into MATLAB published code, use the `<include>` markup. Specify the external file path relative to the location of the published file. Included MATLAB code files publish as syntax highlighted code. Any other files publish as plain text.

For example, this code inserts the contents of `sine_wave.m` into your published output:

```%
% External File Content Example
% This example includes the file contents of sine_wave.m into published output.
%<include>sine_wave.m</include>
% The file content above is properly syntax highlighted
```

Publish the file to HTML.
External Graphics

To publish an image that the MATLAB code does not generate, use text markup. By default, MATLAB already includes code-generated graphics.

This code inserts a generic image called FILENAME.PNG into your published output.

```matlab
%%
% <<FILENAME.PNG>>
%%
```

MATLAB requires that FILENAME.PNG be a relative path from the output location to your external image or a fully qualified URL. Good practice is 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 this code in the Command Window.

```matlab
saveas(surf(peaks),'surfpeaks.jpg');
```

To produce an HTML file containing surfpeaks.jpg from a MATLAB file:
Create a subfolder called `html` in your current folder.

Create `surfpeaks.jpg` by running this code in the Command Window.

```matlab
saveas(surf(peaks),'html/surfpeaks.jpg');
```

Publish this MATLAB code to HTML.

```matlab
%% 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, best practice is to use the default image format for each output type.
### Output File Format

<table>
<thead>
<tr>
<th>Output File Format</th>
<th>Default Image Format</th>
<th>Types of Images You Can Include</th>
</tr>
</thead>
<tbody>
<tr>
<td>doc</td>
<td>png</td>
<td>Any format that your installed version of Microsoft Office supports.</td>
</tr>
<tr>
<td>html</td>
<td>png</td>
<td>All formats publish successfully. Ensure that the tools you use to view and process the output files can display the output format you specify.</td>
</tr>
<tr>
<td>latex</td>
<td>png or epsc2</td>
<td>All formats publish successfully. Ensure that the tools you use to view and process the output files can display the output format you specify.</td>
</tr>
<tr>
<td>pdf</td>
<td>bmp</td>
<td>bmp and jpg.</td>
</tr>
<tr>
<td>ppt</td>
<td>png</td>
<td>Any format that your installed version of Microsoft Office supports.</td>
</tr>
<tr>
<td>xml</td>
<td>png</td>
<td>All formats publish successfully. Ensure that the tools you use to view and process the output files can display the output format you specify.</td>
</tr>
</tbody>
</table>

### 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.

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.

```matlab
%% 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 output. 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 21-28.

Scale magic Data and Display as Image

```matlab
for i=1:3
    imagesc(magic(i))
    snapnow;
end
```

**LaTeX Equations**

**Inline LaTeX Expression**

MATLAB enables 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 ($). The $ must immediately precede the first word of the inline expression, and immediately follow the last word of the inline expression, without any space in between.

**Note:**

- All publishing output types support LaTeX expressions, except Microsoft PowerPoint.
- MATLAB publishing supports standard LaTeX math mode directives. Text mode directives or directives that require additional packages are not supported.

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, this is the resulting output.

% LaTeX Display Equation

MATLAB enables you to insert LaTeX symbols in blocks that are offset from the main
comment text. Two dollar sign characters ($$) on each side of an equation denote a
block LaTeX equation. Publishing equations in separate blocks requires a blank line in
between blocks.

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.
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, 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 this output.

For more information, see our Web site: MathWorks

Eliminating the text MathWorks after the URL produces this 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 enable you to point the reader to MATLAB code or documentation, or enable 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 21-22
- “Dynamic Link to a File” on page 21-23
- “Dynamic Link to a MATLAB Function Reference Page” on page 21-23

#### Dynamic Link to Run Code

You can specify a dynamic hyperlink to run code when a user clicks the hyperlink. For example, this `matlab:` syntax creates hyperlinks in the output, which when clicked either enable or disable recycling:

```matlab
%% Recycling Preference
% Click the preference you want:
% <matlab:recycle('off') Disable recycling>
% <matlab:recycle('on') Enable recycling>
```

The published result resembles this HTML output.
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 that the setting is as you expect.

**Dynamic Link to a File**

You can specify a link to a file that you know is in the `matlabroot` of your reader. You do not need to know where each reader installed MATLAB. For example, link to the function code for `publish`.

```matlab
%%
% 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 that your reader has 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 the Command Window.

**HTML Markup**

You can insert HTML markup into your MATLAB file. You must type the HTML markup since 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.

This 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*. 
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>'')
```

**LaTeX Markup**

You can insert LaTeX markup into your MATLAB file. You must type all LaTeX markup since 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.

This code is an example of LaTeX markup.
Presenting MATLAB Code

%% LaTeX Markup Example
% This is a table:
% 
% \begin{tabular}{|c|c|} \hline
% $n$ & $n!$ \hline
% 1 & 1 \hline
% 2 & 2 \hline
% 3 & 6 \hline
% \end{tabular}
% 

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 \hline
2 & 2 \hline
3 & 6 \hline
\end{tabular}
\end{par}
MATLAB includes any additional markup necessary to compile this file with a LaTeX program.

**More About**

- “Publishing MATLAB Code” on page 21-6
- “Output Preferences for Publishing” on page 21-28
Output Preferences for Publishing

In this section...

“How to Edit Publishing Options” on page 21-28
“Specify Output File” on page 21-29
“Run Code During Publishing” on page 21-30
“Manipulate Graphics in Publishing Output” on page 21-32
“Save a Publish Setting” on page 21-36
“Manage a Publish Configuration” on page 21-38

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.

<table>
<thead>
<tr>
<th>Format</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>html</code></td>
<td>Publishes to an HTML document. You can use an Extensible Stylesheet Language (XSL) file.</td>
</tr>
<tr>
<td><code>xml</code></td>
<td>Publishes to XML document. You can use an Extensible Stylesheet Language (XSL) file.</td>
</tr>
<tr>
<td><code>latex</code></td>
<td>Publishes to LaTeX document. Does <em>not</em> preserve syntax highlighting. You can use an Extensible Stylesheet Language (XSL) file.</td>
</tr>
</tbody>
</table>
Presenting MATLAB Code

<table>
<thead>
<tr>
<th>Format</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>doc</td>
<td>Publishes to a Microsoft Word document, if your system is a PC. Does not preserve syntax highlighting.</td>
</tr>
<tr>
<td>ppt</td>
<td>Publishes to a Microsoft PowerPoint document, if your system is a PC. Does not preserve syntax highlighting.</td>
</tr>
<tr>
<td>pdf</td>
<td>Publishes to a PDF document.</td>
</tr>
</tbody>
</table>

**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/](http://docbook.sourceforge.net/release/xsl/current/doc/).

**Run Code During Publishing**

- “Specifying Code” on page 21-30
- “Evaluating Code” on page 21-30
- “Including Code” on page 21-31
- “Catching Errors” on page 21-32
- “Limiting the Amount of Output” on page 21-32

**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 run the command `function(input)`. Additional code, whose output you want to publish, appears 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 that 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]

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 that 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.

```matlab
for n = 1:100
    disp(x)
end;
```

### Manipulate Graphics in Publishing Output

- “Choosing an Image Format” on page 21-32
- “Setting an Image Size” on page 21-33
- “Capturing Figures” on page 21-33
- “Specifying a Custom Figure Window” on page 21-34
- “Creating a Thumbnail” on page 21-36

### 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 Preferences for Publishing

### Output File Format

<table>
<thead>
<tr>
<th>Output File Format</th>
<th>Default Image Format</th>
<th>Types of Images You Can Include</th>
</tr>
</thead>
<tbody>
<tr>
<td>doc</td>
<td>png</td>
<td>Any format that your installed version of Microsoft Office supports.</td>
</tr>
<tr>
<td>html</td>
<td>png</td>
<td>All formats publish successfully. Ensure that the tools you use to view and process the output files can display the output format you specify.</td>
</tr>
<tr>
<td>latex</td>
<td>png or epsc2</td>
<td>All formats publish successfully. Ensure that the tools you use to view and process the output files can display the output format you specify.</td>
</tr>
<tr>
<td>pdf</td>
<td>bmp</td>
<td>bmp and jpg.</td>
</tr>
<tr>
<td>ppt</td>
<td>png</td>
<td>Any format that your installed version of Microsoft Office supports.</td>
</tr>
<tr>
<td>xml</td>
<td>png</td>
<td>All formats publish successfully. Ensure that the tools you use to view and process the output files can display the output format you specify.</td>
</tr>
</tbody>
</table>

### 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 21-16
- 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.
<table>
<thead>
<tr>
<th>Use This Figure Capture Method</th>
<th>To Get Figure Captures with These Appearance Details</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Window Decorations</td>
</tr>
<tr>
<td>entireGUIWindow</td>
<td>Included for dialog boxes; Excluded for figures</td>
</tr>
<tr>
<td>print</td>
<td>Excluded for dialog boxes and figures</td>
</tr>
<tr>
<td>getframe</td>
<td>Excluded for dialog boxes and figures</td>
</tr>
<tr>
<td>entireFigureWindow</td>
<td>Included for dialog boxes and figures</td>
</tr>
</tbody>
</table>

**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`.

### 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 21-16.

Use the following code as a template to produce Figure windows that meet your needs.

```matlab
% 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 reproduce output easily. 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.
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 21-38
- “Creating Multiple Publish Configurations for a File” on page 21-38
- “Reassociating and Renaming Publish Configurations” on page 21-39
- “Using Publish Configurations Across Different Systems” on page 21-40

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 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 configuration 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.

**More About**

- “Publishing MATLAB Code” on page 21-6
• “Publishing Markup” on page 21-8
Create a MATLAB Notebook with Microsoft Word

In this section...

“Getting Started with MATLAB Notebooks” on page 21-42
“Creating and Evaluating Cells in a MATLAB Notebook” on page 21-44
“Formatting a MATLAB Notebook” on page 21-49
“Tips for Using MATLAB Notebooks” on page 21-51
“Configuring the MATLAB Notebook Software” on page 21-52

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 21-52. 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.](image)

- 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.

```matlab
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 21-44
- “Evaluating Input Cells” on page 21-46
- “Undefining Cells” on page 21-48
- “Defining Calc Zones” on page 21-48

**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.*

   ```matlab
   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.

   ```matlab
   [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:

```matlab
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.

```matlab
[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.

![Evaluate Loop dialog box](image)

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 21-49
- “Controlling the Format of Numeric Output” on page 21-50
- “Controlling Graphic Output” on page 21-50

**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.

<table>
<thead>
<tr>
<th>Style</th>
<th>Font</th>
<th>Size</th>
<th>Weight</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Times New Roman®</td>
<td>10 points</td>
<td>N/A</td>
<td>Black</td>
</tr>
<tr>
<td>AutoInit</td>
<td>Courier New</td>
<td>10 points</td>
<td>Bold</td>
<td>Dark blue</td>
</tr>
<tr>
<td>Error</td>
<td>Courier New</td>
<td>10 points</td>
<td>Bold</td>
<td>Red</td>
</tr>
<tr>
<td>Input</td>
<td>Courier New</td>
<td>10 points</td>
<td>Bold</td>
<td>Dark green</td>
</tr>
<tr>
<td>Output</td>
<td>Courier New</td>
<td>10 points</td>
<td>N/A</td>
<td>Blue</td>
</tr>
</tbody>
</table>

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.

![Numeric format pane](image)

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.
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:

\texttt{notebook -setup}

MATLAB configures the Notebook software and issues these messages in the Command Window:

\texttt{Welcome to the utility for setting up the MATLAB Notebook}\n\texttt{for interfacing MATLAB to Microsoft Word}\n
\texttt{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 \texttt{m-book.dot} template to the Word templates folder.


After you configure the software, typing \texttt{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:

\texttt{notebook -setup}

**More About**

- “Options for Presenting Your Code” on page 21-2
- “Publishing MATLAB Code” on page 21-6
Coding and Productivity Tips

- “Open and Save Files” on page 22-2
- “Check Code for Errors and Warnings” on page 22-6
- “Improve Code Readability” on page 22-21
- “Find and Replace Text in Files” on page 22-28
- “Go To Location in File” on page 22-33
- “Display Two Parts of a File Simultaneously” on page 22-39
- “Add Reminders to Files” on page 22-41
- “Colors in the MATLAB Editor” on page 22-44
- “Code Contains %#ok — What Does That Mean?” on page 22-46
- “MATLAB Code Analyzer Report” on page 22-47
- “Change Default Editor” on page 22-51
# Open and Save Files

In this section...

“Open Existing Files” on page 22-2
“Save Files” on page 22-3

## 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.

<table>
<thead>
<tr>
<th>Goal</th>
<th>Steps</th>
<th>Additional Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open with associated tool</td>
<td>On the Editor (or Home) tab, in the File section, click ![Open Icon]</td>
<td>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.</td>
</tr>
<tr>
<td>Open as text file</td>
<td>On the Editor tab, in the File section, click Open ⬇️, and select Open as Text</td>
<td>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.</td>
</tr>
<tr>
<td>Open function from within file</td>
<td>Position the cursor on the name within the open file, and then right-click and select Open file-name from the context menu.</td>
<td>You also can use this method to open a variable or Simulink model. For details, see “Open a File or Variable from Within a File” on page 22-37.</td>
</tr>
<tr>
<td>Reopen file</td>
<td>At the bottom of the Open ⬇️ drop-down list, select a file under Recent Files.</td>
<td>To change the number of files on the list, click</td>
</tr>
</tbody>
</table>
## Open and Save Files

<table>
<thead>
<tr>
<th>Goal</th>
<th>Steps</th>
<th>Additional Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reopen a recently used file.</td>
<td><strong>Preferences</strong>, and then select <strong>MATLAB</strong> and <strong>Editor/Debugger</strong>. Under <strong>Most recently used file list</strong>, change the value for <strong>Number of entries</strong>.</td>
<td></td>
</tr>
<tr>
<td>Reopen files at startup</td>
<td>On the <strong>Home</strong> tab, in the <strong>Environment</strong> section, click <strong>Preferences</strong> and select <strong>MATLAB</strong> and <strong>Editor/Debugger</strong>. Then, select <strong>On restart reopen files from previous MATLAB session</strong>.</td>
<td>None.</td>
</tr>
<tr>
<td>Open file displaying in another tool</td>
<td>Drag the file from the other tool into the Editor.</td>
<td>For example, drag files from the Current Folder browser or from Windows Explorer.</td>
</tr>
<tr>
<td>Open file using a function</td>
<td>Use the <strong>edit</strong> or <strong>open</strong> function.</td>
<td>For example, type the following to open <strong>collatz.m</strong>:</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>edit collatz.m</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>If <strong>collatz.m</strong> is not on the search path or in the current folder, use the relative or absolute path for the file.</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Save Option</th>
<th>Steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Save file to disk and keep file open in the Editor.</td>
<td>On the <strong>Editor</strong> tab, in the <strong>File</strong> section, click <strong>Save</strong>.</td>
</tr>
</tbody>
</table>
| Rename file, save it to disk, and make it the active Editor document. Original file remains unchanged on disk. | 1 On the **Editor** tab, in the **File** section, click **Save** and select **Save As**.  
2 Specify a new name, type, or both for the file, and then click **Save**. |
| Save file to disk under new name. Original file remains open and unsaved. | 1 On the **Editor** tab, in the **File** section, click **Save** and select **Save Copy As**.  
MATLAB opens the Select File for Backup dialog box.  
2 Specify a name and type for the backup file, and then click **Save**. |
| Save changes to all open files using current file names. All files remain open. | 1 On the **Editor** tab, in the **File** section, click **Save** and select **Save All**.  
MATLAB opens the Select File for Save As dialog box for the first unnamed file.  
2 Specify a name and type for any unnamed file, and then click **Save**.  
3 Repeat step 2 until all unnamed files are saved. |

**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”.

**Backing Up 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 backup version is useful if you have system problems and lose changes you made to your file. In that event, you can open the backup 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 > Backup Files on the Home tab, in the Environment section. You can then:

• Turn the backup feature on or off.

• Automatically delete backup files when you close the corresponding source file.

By default, MATLAB automatically deletes backup files when you close the Editor. It is best to keep backup-to-file relationships clear and current. Therefore, when you rename or remove a file, consider deleting or renaming the corresponding backup file.

• Specify the number of minutes between backup saves.

• Specify the file extension for backup files.

• Specify a location for backup files

If you edit a file in a read-only folder and the back up Location preference is Source file directories, then the Editor does not create a backup 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 22-6
“Create a Code Analyzer Message Report” on page 22-11
“Adjust Code Analyzer Message Indicators and Messages” on page 22-12
“Understand Code Containing Suppressed Messages” on page 22-15
“Understand the Limitations of Code Analysis” on page 22-16
“Enable MATLAB Compiler Deployment Messages” on page 22-19

**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](image)
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:
      ```matlab
      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.

```matlab
% [len,dim] = lengthofline(h1 h2)
%
% Copyright 1984-2004 The MathWorks, Inc.
% $Revision: 1.1.6.5 $ $Date: 2006/08/09 23:13:19$

% Find input indices that are not line objects

nohandle = ~ishandle(hline);

% The value assigned to variable 'nohandle' might be unused. **Details**

notline(0h) = ~ishandle(hline(0h)) |

% Example of a warning message
```

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.
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)`.

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.
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.

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:

```matlab
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”.
  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 22-6. 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 22-12
- “Suppress All Instances of a Message in the Current File” on page 22-13
- “Suppress All Instances of a Message in All Files” on page 22-14
- “Save and Reuse Code Analyzer Message Settings” on page 22-14

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 22-6, 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.
Check Code for Errors and Warnings

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 22-6, 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 22-6, 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 22-6, 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 22-6, 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.
Check Code for Errors and Warnings

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 22-12.

These sections describe code analysis limitations with respect to the following:

- “Distinguish Function Names from Variable Names” on page 22-17
- “Distinguish Structures from Handle Objects” on page 22-18
- “Distinguish Built-In Functions from Overloaded Functions” on page 22-18
- “Determine the Size or Shape of Variables” on page 22-19
- “Analyze Class Definitions with Superclasses” on page 22-19
- “Analyze Class Methods” on page 22-19

**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.

```matlab
function y=foo(x)
    .
    .
    .
```
\begin{verbatim}
    y = xyz(x);
end
\end{verbatim}

For example, in the following code, \texttt{xyz} can be a function, or can be a variable loaded from the MAT-file. Code analysis has no way of making a determination.

\begin{verbatim}
function y=foo(x)
    load abc.mat
    y = xyz(x);
end
\end{verbatim}

Variables might also be undetected by code analysis when you use the \texttt{eval}, \texttt{evalc}, \texttt{evalin}, or \texttt{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 \texttt{load} function, specify the variable name explicitly in the \texttt{load} command line. For example:

\begin{verbatim}
function y=foo(x)
    load abc.mat xyz
    y = xyz(x);
end
\end{verbatim}

\begin{section}{Distinguish Structures from Handle Objects}

Code analysis cannot always distinguish structures from handle objects. In the following code, if \texttt{x} is a structure, you might expect a Code Analyzer message indicating that the code never uses the updated value of the structure. If \texttt{x} is a handle object, however, then this code can be correct.

\begin{verbatim}
function foo(x)
    x.a = 3;
end
\end{verbatim}

Code analysis cannot determine whether \texttt{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.

\begin{section}{Distinguish Built-In Functions from Overloaded Functions}

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 22-12.

**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**

Code Analyzer has limited capabilities to check class definitions with superclasses. For example, Code Analyzer cannot always determine if the class is a handle class, but it can sometimes validate custom attributes used in a class if the attributes are inherited from a superclass. When analyzing class definitions, Code Analyzer tries to leverage information from the superclasses but often cannot get enough information to make a certain determination.

**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 22-14, includes the status of this setting.
Improve Code Readability

In this section...

“Indenting Code” on page 22-21
“Right-Side Text Limit Indicator” on page 22-23
“Code Folding — Expand and Collapse Code Constructs” on page 22-23

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.
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 \[ \text{Left, Center, Right} \].
- 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 ✧ or minus sign □ 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  

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.

![Tooltip Example](image)

**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 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 and Code Folding Enabled for Cells Only 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, illustrates the effects when code folding is enabled for both. Because the fold for section 3 (lines 11–13) overlaps the fold for function \texttt{foo} (lines 4–12), the Editor does not display the fold for section 3.
Code Folding Enabled for Cells Only
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 22-28
“Find and Replace Functions or Variables in the Current File” on page 22-28
“Automatically Rename All Functions or Variables in a File” on page 22-30
“Find and Replace Any Text” on page 22-32
“Find Text in Multiple File Names or Files” on page 22-32
“Function Alternative for Finding Text” on page 22-32
“Perform an Incremental Search in the Editor” on page 22-32

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.
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:

<table>
<thead>
<tr>
<th>Function or Variable Renamed</th>
<th>Example</th>
</tr>
</thead>
</table>
| 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.
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 22-33  
“Set Bookmarks” on page 22-36  
“Navigate Backward and Forward in Files” on page 22-36  
“Open a File or Variable from Within a File” on page 22-37

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.

<table>
<thead>
<tr>
<th>Go To</th>
<th>Steps</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line Number</td>
<td>1 On the Editor tab, in the Navigate section, click Go To.</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>2 Select Go to Line...</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 Specify the line to which you want to navigate.</td>
<td></td>
</tr>
<tr>
<td>Function definition</td>
<td>1 On the Editor tab, in the Navigate section, click Go To.</td>
<td>Includes local functions and nested functions</td>
</tr>
<tr>
<td></td>
<td>2 Under the heading Function, select the local function or nested function to which you want to navigate.</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>1 In the Current Folder browser, click the name of the file open in the Editor.</td>
<td>Functions list in order of appearance within your file.</td>
</tr>
<tr>
<td></td>
<td>2 Click the up arrow at the bottom of Current Folder browser to open the detail panel.</td>
<td></td>
</tr>
<tr>
<td>Go To</td>
<td>Steps</td>
<td>Notes</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------------------------------------------------------------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>Function reference</td>
<td>1  Click in any instance of the function name.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2  Press <strong>Alt+Up</strong> or <strong>Alt+Down</strong> to go to the next or previous function reference, respectively.</td>
<td><strong>Alt+Up</strong> and <strong>Alt+Down</strong> are the default keyboard shortcuts for the actions Go to Previous Underline or Highlight and Go to Next Underline or Highlight, respectively. For more information, see “Define Keyboard Shortcuts”.</td>
</tr>
<tr>
<td>Variable reference</td>
<td>1  Click in any instance of the variable name.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2  Press <strong>Alt+Up</strong> or <strong>Alt+Down</strong> to go to the next or previous variable reference, respectively.</td>
<td>For more information, see “Define Keyboard Shortcuts”.</td>
</tr>
<tr>
<td>Code Analyzer Message</td>
<td>Press <strong>Alt+Up</strong> or <strong>Alt+Down</strong> to go to the next or previous code analyzer message, respectively.</td>
<td></td>
</tr>
<tr>
<td>Code Section</td>
<td>1  On the <strong>Editor</strong> tab, in the <strong>Navigate</strong> section, click <strong>Go To</strong>.</td>
<td>For more information, see “Divide Your File into Code Sections”</td>
</tr>
<tr>
<td></td>
<td>2  Under <strong>Sections</strong>, select the title of the code section to which you want to navigate.</td>
<td></td>
</tr>
<tr>
<td>Go To</td>
<td>Steps</td>
<td>Notes</td>
</tr>
<tr>
<td>-------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td></td>
<td>1 In the Current Folder browser, click the name of the file that is open in the Editor.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 Click the up arrow ^ at the bottom of Current Folder browser to open the detail panel.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 In the detail panel, double-click the section icon ☰ corresponding to the title of the section to which you want to navigate.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Property</th>
<th>1 In the Current Folder browser, click the name of the file that is open in the Editor.</th>
<th>For more information, see “How to Use Properties”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 Click the up arrow ^ at the bottom of Current Folder browser to open the detail panel.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 On the detail panel, double-click the property icon ☰ corresponding to the name of the property to which you want to navigate.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method</th>
<th>1 In the Current Folder browser, click the name of the file that is open in the Editor.</th>
<th>For more information, see “How to Use Methods”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 Click the up arrow ^ at the bottom of Current Folder browser to open the detail panel.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 In the detail panel, double-click the icon ☞ corresponding to the name of the method to which you want to navigate.</td>
<td></td>
</tr>
</tbody>
</table>
### 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 ▶.

   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:

<table>
<thead>
<tr>
<th>Go To</th>
<th>Steps</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bookmark</td>
<td>1 On the Editor tab, in the Navigate section, click Go To ▶️.</td>
<td>For information on setting and clearing bookmarks, see “Set Bookmarks” on page 22-36.</td>
</tr>
<tr>
<td></td>
<td>2 Under Bookmarks, select the bookmark to which you want to navigate.</td>
<td></td>
</tr>
</tbody>
</table>
1. Click \( \rightarrow \).
2. Click \( \rightarrow \).
3. Edit a line or navigate to another line using the list of features described in “Navigate to a Specific Location” on page 22-33.

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 \( \rightarrow \) to return to line 4, and then to return to line 2.
4. Click \( \rightarrow \) to return to lines 4 and 6.
5. Click \( \rightarrow \) to return to line 1.
6. Edit at 3.

This interrupts the sequence. You can no longer use \( \rightarrow \) to return to lines 4 and 6.

You can, however, click \( \rightarrow \) 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.

<table>
<thead>
<tr>
<th>Item</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local function</td>
<td>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 open function on the selection, which opens the selection in the appropriate tool.</td>
</tr>
<tr>
<td>Text file</td>
<td>Opens in the Editor.</td>
</tr>
<tr>
<td>Item</td>
<td>Action</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-----------------------------------------------------</td>
</tr>
<tr>
<td>Figure file (<code>.fig</code>)</td>
<td>Opens in a figure window.</td>
</tr>
<tr>
<td>MATLAB variable that is in the current workspace</td>
<td>Opens in the Variables Editor.</td>
</tr>
<tr>
<td>Model</td>
<td>Opens in Simulink.</td>
</tr>
<tr>
<td>Other</td>
<td>If the selection is some other type, <strong>Open selection</strong> looks for a matching file in a private folder in the current folder and performs the appropriate action.</td>
</tr>
</tbody>
</table>
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.

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.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Split the screen horizontally.</td>
<td>Do either of the following:</td>
</tr>
<tr>
<td></td>
<td>• Right-click and, select <strong>Split Screen &gt; Top/Bottom</strong> from the Context Menu.</td>
</tr>
<tr>
<td></td>
<td>• If there is a vertical scroll bar, as shown in the illustration that follows, drag the splitter bar down.</td>
</tr>
<tr>
<td>Split the screen vertically.</td>
<td>Do either of the following:</td>
</tr>
<tr>
<td>Operation</td>
<td>Instructions</td>
</tr>
<tr>
<td>------------------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>• From the Context Menu, select <strong>Split Screen &gt; Left/Right.</strong></td>
</tr>
<tr>
<td></td>
<td>• 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.</td>
</tr>
<tr>
<td>Specify the active view</td>
<td>Do either of the following:</td>
</tr>
<tr>
<td></td>
<td>• From the Context Menu, select <strong>Split Screen &gt; Switch Focus.</strong></td>
</tr>
<tr>
<td></td>
<td>• Click in the view you want to make active.</td>
</tr>
<tr>
<td></td>
<td>Updates you make to the document in the active view are also visible in the other view.</td>
</tr>
<tr>
<td>Remove the splitter</td>
<td>Do one of the following:</td>
</tr>
<tr>
<td></td>
<td>• Double-click the splitter.</td>
</tr>
<tr>
<td></td>
<td>• From the Context Menu, <strong>Split Screen &gt; Off.</strong></td>
</tr>
</tbody>
</table>

![Diagram of splitting a window horizontally and vertically](image-url)
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 a file containing the strings TODO, FIXME, and NOTE. The search is case insensitive.

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.

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

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.

<table>
<thead>
<tr>
<th>Sample (Using Default Colors)</th>
<th>What the Color Indicates</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>create a file for output</code></td>
<td>Different types of language elements, such as keywords, comments, and strings appear in different colors. This is called <strong>syntax highlighting</strong>. See also, “Syntax Highlighting”</td>
</tr>
<tr>
<td><code>fid = fopen('testFile.txt', 'w');</code></td>
<td>Teal blue characters indicate variables with shared scope</td>
</tr>
<tr>
<td><code>for i = 1:10</code></td>
<td>Sky blue shading indicates function or variable names that match the name in which the cursor is currently placed. See also, “Check Variable Scope in Editor”</td>
</tr>
<tr>
<td><code>fprintf(fid,%6.2f \n,i);</code></td>
<td>Orange and red wavy underlines indicate warning and error conditions, respectively. Orange shading indicates coding issues that MATLAB can correct for you. See also, “Check Code for Errors and Warnings” on page 22-6</td>
</tr>
</tbody>
</table>
### Sample (Using Default Colors)

```matlab
%% Plot Sine Wave
% Calculate and plot a sine wave.
%% Calculate and Plot Sine Wave
% Define the range for x.
%% $0 \leq x \leq \pi$
%%
%% 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.
```

### What the Color Indicates

- **Yellow highlighting** indicates code sections, which:
  - Help you visually identify subsections of code
  - Enable you to publish and run subsections of code.

See also, “Divide Your File into Code Sections”

- **Red dots** represent breakpoints, which you use in debugging.
  - If you attempt to run your code, MATLAB stops at the first breakpoint it encounters.

See also, “Debugging Process and Features”

- **A gray vertical line** indicates the location of a particular column in the Editor that you can use to limit line widths.
  - The Editor does not enforce the limit.

See also, “Right-Side Text Limit Indicator” on page 22-23
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 22-15.
MATLAB Code Analyzer Report

In this section...

“Running the Code Analyzer Report” on page 22-47
“Changing Code Based on Code Analyzer Messages” on page 22-49
“Other Ways to Access Code Analyzer Messages” on page 22-50

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, `lengthofline.m`, you can change the current folder by running

   ```matlab
   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.
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”.

- 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 22-49.

- 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 22-16.

- 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 22-12.
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.
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.
Change Default Editor

In this section...

“Set Default Editor” on page 22-51
“Set Default Editor in '-nodisplay' mode” on page 22-51

Set Default Editor

To specify the default editor for MATLAB:

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. This file is typically found in your home directory (~):
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 ~/.Xdefaults

This assumes the .Xdefaults file is in your home directory.

For example, this code, executed from within MATLAB, opens foo in the emacs editor:

edit foo
Programming Utilities

- “Identify Program Dependencies” on page 23-2
- “Protect Your Source Code” on page 23-7
- “Create Hyperlinks that Run Functions” on page 23-10
- “Manage Toolboxes” on page 23-13
- “Create and Share Toolboxes” on page 23-15
**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.

<table>
<thead>
<tr>
<th>In this section...</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Simple Display of Program File Dependencies” on page 23-2</td>
</tr>
<tr>
<td>“Detailed Display of Program File Dependencies” on page 23-2</td>
</tr>
<tr>
<td>“Dependencies Within a Folder” on page 23-3</td>
</tr>
</tbody>
</table>

**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:

   ```matlab
   [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™:

```matlab
[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'
'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.
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.

<table>
<thead>
<tr>
<th><code>rational differential</code></th>
<th>toolbox : <code>\rf\rf\rf\zdadd.m</code></th>
</tr>
</thead>
<tbody>
<tr>
<td>toolbox : <code>\rf\rf\rf\etf.m</code></td>
<td></td>
</tr>
<tr>
<td>toolbox : <code>\rf\rf\rf\rf\model\cimeresp.m</code></td>
<td></td>
</tr>
<tr>
<td>toolbox : <code>\rf\rf\rf\cim\analyze.m</code></td>
<td></td>
</tr>
<tr>
<td>toolbox : <code>\signal\signal\ffcfilt.m</code></td>
<td></td>
</tr>
</tbody>
</table>

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, `frequesp.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.
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

```matlab
[out, out2, ...] = myfun(in1, in2, ...);
```

To invoke script `myscript.p`, type

```matlab
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:

```matlab
disp('<a href="matlab:a=3; b=4;c=hypot(a,b)">Hypotenuse</a>')</ndisp('a href="matlab:a=3; b=4;c=hypot(a,b)">Hypotenuse</a>'
```

Clicking the hyperlink executes the three commands following `matlab:`, resulting in

```matlab
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
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
??? 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:

```matlab
```

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 23-11
- “Run Multiple Functions” on page 23-11
- “Provide Command Options” on page 23-12
- “Include Special Characters” on page 23-12

## 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>')</n```

It displays this link in the Command Window:

[Generate magic square](matlab:magic(4))

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>')</n```

It displays this link in the Command Window:

[Plot x,y](matlab:x=0:1:8;y=sin(x);plot(x,y))

When you click the link, MATLAB runs this code:

```matlab
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>')
```
Manage Toolboxes

In this section...

“Install a Toolbox” on page 23-13
“View Toolbox Information” on page 23-13
“Uninstall Toolbox” on page 23-13

Install a Toolbox

To install toolbox:

1  In MATLAB, in the Current Folder browser, double-click the toolbox file (.mltbx) that you want to install. An Install Toolbox dialog box opens.
2  Click the Install button to proceed with the toolbox installation.

If the toolbox that you are installing includes any app installation files (.mlappinstall), MATLAB automatically installs those apps.

Upon successful installation, a notification box appears. Click the notification box to open the Manage Custom Toolboxes dialog box and to examine information about the toolbox.

View Toolbox Information

After installing a toolbox, you can review the toolbox details. To view the list of included files:

1  Open the Manage Custom Toolboxes dialog box. In the Resources section of the Home tab, select Manage Custom Toolboxes from the Add-Ons menu.
2  Click any installed toolbox to open its detail page.
3  Click the View File List expander.

Uninstall Toolbox

To uninstall a toolbox:

1  Open the Manage Custom Toolboxes dialog box. In the Resources section of the Home tab, select Manage Custom Toolboxes from the Add-Ons menu.
2 Locate the toolbox you want to remove and click **Uninstall**.

If the toolbox that you are uninstalling includes any app installation files (.mlappinstall), MATLAB automatically uninstalls those apps.

**Note:** When you uninstall a toolbox, MATLAB does not delete the .mltbx file.

**Related Examples**

- “Create and Share Toolboxes” on page 23-15
Create and Share Toolboxes

You can package MATLAB files to create a toolbox to share with others. These files can include MATLAB code, data, apps, examples, and documentation. When you create a toolbox, MATLAB generates a single installation file (.mltbx) that enables you or others to install your toolbox.

In this section...

“Create Toolbox” on page 23-15
“Share Toolbox” on page 23-18

Create Toolbox

To create a toolbox installation file:

1. In the Resources section of the Home tab, select Package a Toolbox from the Add-Ons menu.

2. In the Package a Toolbox dialog box, click the button and select your toolbox folder. It is good practice to create the toolbox package from the folder level above your toolbox folder. The .mltbx toolbox file contains information about the path settings for your toolbox files and folders. Any of the included folders and files that are on your path when you create the toolbox appear on their paths after the end users install the toolbox.

3. In the dialog box, add the following information about your toolbox.

<table>
<thead>
<tr>
<th>Toolbox Information Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toolbox Name</td>
<td>Enter the toolbox name, if necessary. By default, the toolbox name is the name of the toolbox folder. The Toolbox Name becomes the .mltbx file name.</td>
</tr>
<tr>
<td>Author Name,</td>
<td>Enter contact information for the toolbox author. Click Set as default contact to save the contact information.</td>
</tr>
</tbody>
</table>
### Toolbox Information Field

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Email, and Company</td>
<td></td>
</tr>
<tr>
<td>Toolbox Image</td>
<td>Click <strong>Select toolbox image</strong> to select an image that represents your toolbox.</td>
</tr>
<tr>
<td>Summary and Description</td>
<td>Enter the toolbox summary and description. It is good practice to keep the <strong>Summary</strong> text brief and to add detail to the <strong>Description</strong> text.</td>
</tr>
</tbody>
</table>

4. Review the toolbox contents to ensure MATLAB detects the expected components. The following sections of the Package a Toolbox dialog box appear after you select a toolbox folder.

<table>
<thead>
<tr>
<th>Package a Toolbox Dialog Box Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toolbox Files and Folders</td>
<td>List of the folders and files contained in your toolbox. The listed files and folders are only those that are located in the top level of the toolbox folder. You cannot navigate through the folders in the Toolbox Packaging dialog box. To exclude a file or folder from the toolbox, register it in the text file that is displayed when you click <strong>Exclude files and folders</strong>. It is good practice to exclude any source control files related to your toolbox.</td>
</tr>
<tr>
<td>Files and Products</td>
<td>List of required files that exist outside of the toolbox folder and any MathWorks products required by your toolbox. MATLAB checks for dependent files and automatically includes them in the toolbox. You can select these files to exclude them.</td>
</tr>
<tr>
<td>Examples, Apps, and Documentation</td>
<td>List of published MATLAB examples, installable apps, and custom documentation associated with your toolbox.</td>
</tr>
</tbody>
</table>

- For the Package a Toolbox tool to recognize examples, first publish them to HTML in MATLAB. For more information, see the `publish` function. Include the `.m` example file and the published output files in your toolbox folder. Do not specify an output folder when publishing your examples. For the Package a Toolbox tool to
To create different categories for your examples, place the examples in different subfolders within your toolbox folder. When you add your toolbox folder to the Package a Toolbox dialog box, MATLAB creates a `demos.xml` file to describe your examples, and takes the example subfolder name as the example category name. Alternatively, you can create your own `demos.xml` file. The `demos.xml` file allows recipients to access your examples through the **Supplemental Software** link at the bottom of the Help browser home page. For more information, see “Display Custom Examples”.

- For the Package a Toolbox tool to recognize apps, first package the app into a `.mlappinstall` file. For more information, see “Package Apps”.
- For the Package a Toolbox tool to recognize custom documentation, include an `info.xml` file to identify your documentation files. If you use the `builddocsearchdb` function to build the documentation database prior to packaging your toolbox, you can include the generated `helpsearch` subfolder in your toolbox. The `info.xml` file and the `helpsearch` folder allow recipients to access your documentation through the **Supplemental Software** link at the bottom of the Help browser home page. For more information, see “Display Custom Documentation”.

5 Click **Package** at the top of the Package a Toolbox dialog box. Packaging your toolbox generates a `.mltbx` file in your current MATLAB folder.

When you create a toolbox, MATLAB generates a `.prj` file that contains information about the toolbox and saves it frequently. It is good practice to save this associated `.prj` file so that you can quickly create future revisions of your toolbox.
Share Toolbox

To share your toolbox with others, give them the `.mltbx` file. All files you added when you packaged the toolbox are included in the `.mltbx` file. When the end users install your toolbox, they do not need to be concerned with the MATLAB path or other installation details. The `.mltbx` file manages these details for end users.

For information on installing, uninstalling, and viewing information about toolboxes, see “Manage Toolboxes” on page 23-13.

You can share your toolbox with others by attaching the `.mltbx` file to an email message, or using any other method you typically use to share files—such as uploading to MATLAB Central File Exchange.

---

**Note:** While `.mltbx` files can contain any files you specify, MATLAB Central File Exchange places additional limitations on submissions. Your toolbox cannot be submitted to File Exchange if it contains any of the following:

- MEX-files
- Other binary executable files, such as DLLs or ActiveX® controls. (Data and image files are typically acceptable.)

---

**See Also**

publish

**Related Examples**

- “Manage Toolboxes” on page 23-13
- “Display Custom Examples”
- “Package Apps”
- “Display Custom Documentation”
Software Development
Error Handling

- “Exception Handling in a MATLAB Application” on page 24-2
- “Capture Information About Exceptions” on page 24-5
- “Throw an Exception” on page 24-15
- “Respond to an Exception” on page 24-17
- “Clean Up When Functions Complete” on page 24-22
- “Issue Warnings and Errors” on page 24-28
- “ Suppress Warnings” on page 24-31
- “Restore Warnings” on page 24-34
- “Change How Warnings Display” on page 24-37
- “Use try/catch to Handle Errors” on page 24-39
Exception Handling in a MATLAB Application

In this section...

“Overview” on page 24-2
“Getting an Exception at the Command Line” on page 24-2
“Getting an Exception in Your Program Code” on page 24-3
“Generating a New Exception” on page 24-4

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” 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 24-5 describes how to acquire information about what caused the error, and “Respond to an Exception” on page 24-17 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 24-5 describes how to use an MException object to capture information about the error, and “Throw an Exception” on page 24-15 explains how to initiate the exception process.
Capture Information About Exceptions

In this section...

“Overview” on page 24-5
“The MException Class” on page 24-5
“Properties of the MException Class” on page 24-7
“Methods of the MException Class” on page 24-13

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 24-17 and “Throw an Exception” on page 24-15.

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 24-7 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

\[
\text{ME} = \text{MException}(\text{identifier}, \text{message})
\]

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 24-17 and “Throw an Exception” on page 24-15. 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 24-17 for more information on using try/catch).

```matlab
try
    surf
catch ME
   ME
end
```

Run this at the command line and MATLAB returns the contents of the MException object:

```plaintext
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:

```matlab
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,

```matlab
S = 'Accounts'; f1 = 'ClientName';
ME = MException('AcctError:Incomplete', ...
    'Field ''%s.%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:

```matlab
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 .
```
Error Handling

% Throw exception here

Catch the exception in variable ME and then examine the stack field:

```matlab
for k=1:length(ME.stack)
    ME.stack(k)
end
```

```plaintext
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:

```matlab
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):

```matlab
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.
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<td>Issue an exception, but omit the current stack frame from the stack field.</td>
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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 or try/catch 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:

Create an array, and an index into it with a logical array.

\[ A = [13 \quad 42; \quad 7 \quad 20]; \]
\[ \text{id}x = [1 \quad 0 \quad 1; \quad 0 \quad 1 \quad 0]; \]

Create an exception that provides general information about an error. Test the index array and add exceptions with more detailed information about the source of the failure.

\[
\text{% 1) Detect the error.}\n\text{try}\n\quad A(\text{id}x);\n\text{catch}\n\quad \text{\% 2) Construct an MException object to represent the error.}\n\quad \text{msgID} = 'MYFUN:BadIndex';\n\quad \text{msg} = 'Unable to index into array.';\n\quad \text{baseException} = \text{MException(msgID,msg)};\n\quad \text{\% 3) Store any information contributing to the error.}\n\text{try}\n\quad \text{assert(islogical(id)}, 'MYFUN:notLogical',...}
Error Handling

'Indexing array is not logical."

catch causeException
    baseException = addCause(baseException,causeException);
end

if any(size(idx) > size(A))
    msgID = 'MYFUN:incorrectSize';
    msg = 'Indexing array is too large.';
    causeException2 = MException(msgID,msg);
    baseException = addCause(baseException,causeException2);
end

% 4) Throw the exception to stop execution and display an error
% message.
throw(baseException)
end

Unable to index into array.

Caused by:
    Indexing array is not logical.
    Indexing array is too large.
Respond to an Exception

In this section...

“Overview” on page 24-17
“The try/catch Statement” on page 24-17
“Suggestions on How to Handle an Exception” on page 24-19

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\texttt{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\texttt{try/catch} block that catches any errors and handles them appropriately.

A\texttt{try/catch} statement looks something like the following pseudocode. It consists of two parts:

- A \texttt{try} block that includes all lines between the \texttt{try} and \texttt{catch} statements.
- A \texttt{catch} block that includes all lines of code between the \texttt{catch} and \texttt{end} statements.

\begin{verbatim}
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
\end{verbatim}
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:

```plaintext
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 24-5 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 24-5.

**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.

```matlab
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.
end
```
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 24-22
“Examples of Cleaning Up a Program Upon Exit” on page 24-23
“Retrieving Information About the Cleanup Routine” on page 24-25
“Using onCleanup Versus try/catch” on page 24-26
“onCleanup in Scripts” on page 24-27

**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:

```matlab
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.
Create a function handle for the cleanup routine.

At some point, generally early in your program code, insert a call to the onCleanup function, passing the function handle.

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.

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.

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
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 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('
   Opening the figure %s
', imageFile);
image(rgb);
pause(2);

% This is the cleanup routine.
function restore_env(fighandle, newpath)
Clean Up When Functions Complete

```
    disp '   Closing the figure'
    close(fighandle);
    pause(2)
    
    disp '   Restoring the path'
    rmpath(newpath);
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('
');
pause(2);

Run the modified function to see the output of the `functions` command and the contents of one of the `workspace` cells:

```matlab
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`:

```matlab
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`:

```matlab
function cleanupByFunc
    obj = onCleanup(@()...
        disp('   Executing cleanup tasks'));
    pause(10);
end
```

### `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

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### 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:

```matlab
warning('Input must be a string')
```

For example, you can insert a warning in your code to verify the software version:

```matlab
function warningExample1
    if ~strncmp(version, '7', 1)
        warning('You are using a version other than v7')
    end
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 24-28. 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:

```matlab
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

MException | lastwarn | warndlg | warning

Related Examples

- “Suppress Warnings” on page 24-31
- “Restore Warnings” on page 24-34
- “Capture Information About Exceptions” on page 24-5
- “Exception Handling in a MATLAB Application” on page 24-2

More About

- “Message Identifiers” on page 24-8
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:

```matlab
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:

```matlab
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:

```matlab
w = warning('query','last')
```

```matlab
w =
    identifier: 'MATLAB:rmpath:DirNotFound'
    state: 'on'
```

You can save the identifier field in the variable, `id`:

```matlab
id = w.identifier;
```

**Note:** `warning('query','last')` returns the last displayed warning. MATLAB only displays warning messages that have `state: 'on'` and a warning identifier.
Using the `lastwarn` function, you can retrieve the last warning message, regardless of its display state:

```matlab
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.

```matlab
warning('off',id)
rmpath('folderthatisnotonpath')
MATLAB displays no warning.

Turn the warning on, and try to remove a nonexistent path:

```matlab
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:

```matlab
warning('query','all')
```
warning

To enable all warnings and verify the state:

\[
\text{warning('on','all')} \\
\text{warning('query','all')}
\]

All warnings have the state 'on'.

To disable all warnings and verify the state, use this syntax:

\[
\text{warning('off','all')} \\
\text{warning}
\]

All warnings have the state 'off'.

**Related Examples**

- “Restore Warnings” on page 24-34
- “Change How Warnings Display” on page 24-37
**Error Handling**

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`:

```matlab
orig_state = warning;
```

To restore the original state after any warning modifications, use this syntax:

```matlab
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:

```matlab
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:

   ```matlab
   warning('query','Control:parameterNotSymmetric')
   ```

   The state of warning 'Control:parameterNotSymmetric' is 'on'.

2. Turn off the `Control:parameterNotSymmetric` warning:

   ```matlab
   orig_state = warning('off','Control:parameterNotSymmetric')
   ```

   ```matlab
   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:

```matlab
orig_state = warning('on','all');
```

2 Restore your warnings to the previous state:

```matlab
warning(orig_state)
```

See Also
onCleanup | warning

Related Examples

- “Suppress Warnings” on page 24-31
- “Clean Up When Functions Complete” on page 24-22
Change How Warnings Display

You can control how warnings appear in MATLAB by modifying two warning modes, verbose and backtrace.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>verbose</td>
<td>Display a message on how to suppress the warning.</td>
<td>off (terse)</td>
</tr>
<tr>
<td>backtrace</td>
<td>Display a stack trace after a warning is invoked.</td>
<td>on (enabled)</td>
</tr>
</tbody>
</table>

**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:

```matlab
warning on all
warning off backtrace
warning on verbose
```

Running a command that produces an error displays an extended message:

```matlab
rmpath('folderthatisnotonpath')
```

Warning: "folderthatisnotonpath" not found in path.
(Type "warning off MATLAB:rmpath: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

Optionally, you can capture more information about errors if a variable follows your `catch` statement:

```matlab
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 24-2.
```

**See Also**
MException | onCleanup
Program Scheduling

- “Use a MATLAB Timer Object” on page 25-2
- “Timer Callback Functions” on page 25-4
- “Handling Timer Queuing Conflicts” on page 25-9
Use a MATLAB Timer Object

In this section...

“Overview” on page 25-2
“Example: Displaying a Message” on page 25-3

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.
```

More About

- “Timer Callback Functions” on page 25-4
Timer Callback Functions

In this section...

“Associating Commands with Timer Object Events” on page 25-4
“Creating Callback Functions” on page 25-5
“Specifying the Value of Callback Function Properties” on page 25-7

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 25-7.

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 25-7.

function my_callback_fcn(obj, event, string_arg)

    txt1 = ' event occurred at ';
    txt2 = string_arg;
    end_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.

<table>
<thead>
<tr>
<th>Callback Function Syntax</th>
<th>How to Specify as a Property Value for Object t</th>
</tr>
</thead>
<tbody>
<tr>
<td>function myfile(obj, event)</td>
<td>t.StartFcn = @myfile</td>
</tr>
<tr>
<td>function myfile</td>
<td>t.StartFcn = @(<del>,</del>)myfile</td>
</tr>
<tr>
<td>function myfile(obj, event, arg1, arg2)</td>
<td>t.StartFcn = {@myfile, 5, 6}</td>
</tr>
</tbody>
</table>

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 25-6:

1. Create a timer object.

   ```matlab
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:

   ```matlab
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:

   ```matlab
t.StopFcn = { @my_callback_fcn, 'My stop message'};
```
Specify the value of the `TimerFcn` callback. The example specifies the MATLAB commands in a text string:

```matlab
t.TimerFcn = @(x,y)disp('Hello World!');
```

Start the timer object:

```matlab
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
```

Delete the timer object after you are finished with it.

```matlab
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:

<table>
<thead>
<tr>
<th>In this section...</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Drop Mode (Default)” on page 25-9</td>
</tr>
<tr>
<td>“Error Mode” on page 25-11</td>
</tr>
<tr>
<td>“Queue Mode” on page 25-12</td>
</tr>
</tbody>
</table>

**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**.

```matlab
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.

<table>
<thead>
<tr>
<th>Approximate Elapsed Time (Seconds)</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Start the first execution of the callback.</td>
</tr>
<tr>
<td>1</td>
<td>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.</td>
</tr>
<tr>
<td>1.6</td>
<td>Finish the first callback execution, and start the second. This action clears the execution queue.</td>
</tr>
<tr>
<td>2</td>
<td>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.</td>
</tr>
<tr>
<td>3</td>
<td>Attempt to start the fourth callback execution. The third callback is in the execution queue, so the timer drops this execution of the function.</td>
</tr>
<tr>
<td>3.2</td>
<td>Finish the second callback and start the third, clearing the execution queue.</td>
</tr>
<tr>
<td>4</td>
<td>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.</td>
</tr>
<tr>
<td>4.8</td>
<td>Finish the third execution and start the fourth instance, clearing the queue.</td>
</tr>
<tr>
<td>5</td>
<td>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.</td>
</tr>
<tr>
<td>6</td>
<td>Do nothing: the value of the TasksToExecute property is 5, and the fifth instance to run is in the queue.</td>
</tr>
<tr>
<td>6.4</td>
<td>Finish the fourth callback execution and start the fifth.</td>
</tr>
<tr>
<td>8</td>
<td>Finish the fifth callback execution.</td>
</tr>
</tbody>
</table>
**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'.

```matlab
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.

<table>
<thead>
<tr>
<th>Approximate Elapsed Time (Seconds)</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Start the first execution of the callback.</td>
</tr>
<tr>
<td>Approximate Elapsed Time (Seconds)</td>
<td>Action</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>1</td>
<td>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.</td>
</tr>
<tr>
<td>1.6</td>
<td>Finish the first callback execution, and start the second. This action clears the execution queue.</td>
</tr>
<tr>
<td>2</td>
<td>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.</td>
</tr>
<tr>
<td>3</td>
<td>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.</td>
</tr>
<tr>
<td>3.2</td>
<td>Finish the second callback and start the error handling function.</td>
</tr>
</tbody>
</table>

**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 26-2
• “Profiling for Improving Performance” on page 26-4
• “Determining Profiler Coverage” on page 26-25
• “Techniques for Improving Performance” on page 26-27
• “Vectorization” on page 26-31
Analyzing Your Program's Performance

In this section...

“Overview of Performance Timing Functions” on page 26-2
“Time Functions” on page 26-2
“Time Portions of Code” on page 26-2
“The cputime Function vs. tic/toc and timeit” on page 26-3

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**
tic | timeit | toc

**Related Examples**

- “Profiling for Improving Performance” on page 26-4
Profiling for Improving Performance

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 26-6

**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 26-11 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 26-13 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 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 26-6
- “Profiling a Graphical User Interface” on page 26-8
- “Profiling Statements from the Command Window” on page 26-8
- “Changing Fonts for the Profiler” on page 26-8
- “Troubleshooting” on page 26-9

For information about the reports generated by the Profiler, see “Profile Summary Report” on page 26-11 and “Profile Detail Report” on page 26-13.

**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 4.

On the Home tab, in the Code section, click Run and Time.

In the Command Window, type profile viewer.

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):

   \[ \text{[t,y]} = \text{ode23('lotka',}[0 \ 2],[20;20]) \]

• 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 4.

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 Profile 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 26-23.

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 26-11.

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**.

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 26-9
- “Multi-Core Processors — Setting for Most Accurate Profiling on Linux Systems” on page 26-10

**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
```
Profiling for Improving Performance

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 26-19.
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 26-13 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.

<table>
<thead>
<tr>
<th>Function Name</th>
<th>Calls</th>
<th>Total Time</th>
<th>Self Time*</th>
<th>Total Time Plot (dark band = self time)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ode23</td>
<td>1</td>
<td>0.085 s</td>
<td>0.060 s</td>
<td></td>
</tr>
<tr>
<td>workspacefunc</td>
<td>4</td>
<td>0.032 s</td>
<td>0.003 s</td>
<td></td>
</tr>
<tr>
<td>funfun\private\code\arguments</td>
<td>1</td>
<td>0.016 s</td>
<td>0.013 s</td>
<td></td>
</tr>
<tr>
<td>workspacefunc\getStatObjectJ</td>
<td>2</td>
<td>0.015 s</td>
<td>0.002 s</td>
<td></td>
</tr>
<tr>
<td>workspacefunc\getShortValueObjectJ</td>
<td>38</td>
<td>0.013 s</td>
<td>0.000 s</td>
<td></td>
</tr>
<tr>
<td>workspacefunc\getStatObjectM</td>
<td>1</td>
<td>0.012 s</td>
<td>0.002 s</td>
<td></td>
</tr>
<tr>
<td>workspacefunc\num2complex</td>
<td>64</td>
<td>0.010 s</td>
<td>0.003 s</td>
<td></td>
</tr>
<tr>
<td>workspacefunc\getShortValueObjectM</td>
<td>19</td>
<td>0.010 s</td>
<td>0.005 s</td>
<td></td>
</tr>
<tr>
<td>workspacefunc\getStatObjectM</td>
<td>38</td>
<td>0.008 s</td>
<td>0.002 s</td>
<td></td>
</tr>
<tr>
<td>odeget</td>
<td>1</td>
<td>0.005 s</td>
<td>0.005 s</td>
<td></td>
</tr>
<tr>
<td>funfun\private\code\finalize</td>
<td>1</td>
<td>0.005 s</td>
<td>0.005 s</td>
<td></td>
</tr>
<tr>
<td>workspacefunc\getAbstractValueSummaryJ</td>
<td>21</td>
<td>0.003 s</td>
<td>0.000 s</td>
<td></td>
</tr>
</tbody>
</table>

**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 26-14
- “Controlling the Contents of the Detail Report Display” on page 26-14
- “Profile Detail Report Header” on page 26-14
- “Parent Functions” on page 26-15
- “Busy Lines” on page 26-15
- “Child Functions” on page 26-16
- “Code Analyzer Results” on page 26-17
- “File Coverage” on page 26-18
- “Function Listing” on page 26-18

**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 26-6.
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.

```
<table>
<thead>
<tr>
<th>Function Name</th>
<th>Function Type</th>
<th>Calls</th>
</tr>
</thead>
<tbody>
<tr>
<td>ode23</td>
<td>M-function</td>
<td>1</td>
</tr>
</tbody>
</table>
```

**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.
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.
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.

<table>
<thead>
<tr>
<th>Line number</th>
<th>Message</th>
</tr>
</thead>
<tbody>
<tr>
<td>52</td>
<td>EXIST with two input arguments is generally faster and clearer than with one input argument.</td>
</tr>
<tr>
<td>80</td>
<td>EXIST with two input arguments is generally faster and clearer than with one input argument.</td>
</tr>
<tr>
<td>90</td>
<td>The value assigned to variable 'ME' might be unused.</td>
</tr>
</tbody>
</table>
**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.

<table>
<thead>
<tr>
<th>Coverage results</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>[Show coverage for parent directory]</td>
<td></td>
</tr>
<tr>
<td><strong>Total lines in function</strong></td>
<td>190</td>
</tr>
<tr>
<td><strong>Non-code lines (comments, blank lines)</strong></td>
<td>57</td>
</tr>
<tr>
<td><strong>Code lines (lines that can run)</strong></td>
<td>133</td>
</tr>
<tr>
<td><strong>Code lines that did run</strong></td>
<td>53</td>
</tr>
<tr>
<td><strong>Code lines that did not run</strong></td>
<td>80</td>
</tr>
<tr>
<td><strong>Coverage (did run/can run)</strong></td>
<td>39.85 %</td>
</tr>
</tbody>
</table>

**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 Profiler. 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 26-19
• “Accessing profile Function Results” on page 26-21
• “Saving profile Function Reports” on page 26-22
• “Using the profile Function to Change the Time Type Used by the Profiler” on page 26-23

Example: Using the profile Function

This example demonstrates how to run profile:

```plaintext
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 `lotkademo`, which runs a demonstration.

```matlab
[t,y] = ode23('lotka',[0 2],[20;20]);
```

3 Generate the profile report and display it in the Profiler window. This suspends `profile`.

```matlab
profile viewer
```

4 Restart `profile`, without clearing the existing statistics.

```matlab
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.

```matlab
profile off
```

6 To view the profile data, call `profile` specifying the `info` argument. The `profile` function returns data in a structure.

```matlab
p = profile('info')
```

```matlab
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`.

```matlab
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 Profile 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.
To change the timer back to using CPU time:

1. Close the Profiler, and if prompted, stop profiling.
2. Type the following in the Command Window:
   ```
   profile on -timer cpu
   ```
3. 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 26-4.
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).

Report for folder \my_MATLAB_files

<table>
<thead>
<tr>
<th>File</th>
<th>Coverage</th>
<th>Total time</th>
<th>Total lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>lengthofline2.m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>api2.m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>area.m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>basic matrix.m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>breakpoint.m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>collat2z.m</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Techniques for Improving Performance

In this section...

“Preallocating Arrays” on page 26-27
“Assigning Variables” on page 26-28
“Using Appropriate Logical Operators” on page 26-29
“Additional Tips on Improving Performance” on page 26-29

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.

```matlab
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.

```matlab
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

```matlab
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:

```matlab
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:

  ```matlab
  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.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp;,</td>
<td></td>
</tr>
<tr>
<td>&amp;&amp;,</td>
<td></td>
</tr>
</tbody>
</table>

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.

```matlab
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.

More About
• “Analyzing Your Program's Performance” on page 26-2
• “Profiling for Improving Performance” on page 26-4
• “Vectorization” on page 26-31
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:

```matlab
i = 0;
for t = 0:.01:10
    i = i + 1;
    y(i) = sin(t);
end
```

This is a vectorized version of the same code:

```matlab
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:

```matlab
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:

```matlab
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 26-32
- “Linear Indexing” on page 26-33
- “Logical Indexing” on page 26-34

**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 \( A \):

```matlab
A = 6:10;
A([3 5])
```

\( \text{ans} = \)
Multidimensional arrays or matrices use multiple index parameters for subscripted indexing.

\[
A = \begin{bmatrix}
11 & 12 & 13 \\
14 & 15 & 16 \\
17 & 18 & 19
\end{bmatrix}
\]

\[A(2:3,2:3)\]

\[
A =
\begin{bmatrix}
11 & 12 & 13 \\
14 & 15 & 16 \\
17 & 18 & 19
\end{bmatrix}
\]

\[\text{ans} = \begin{bmatrix}
15 & 16 \\
18 & 19
\end{bmatrix}\]

**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.

\[
A = \begin{bmatrix}
11 & 12 & 13; & 14 & 15 & 16; & 17 & 18 & 19
\end{bmatrix}
\]

\[A(6)\]
\[A([3, 1, 8])\]
\[A([3; 1; 8])\]

\[\text{ans} = 18\]

\[\text{ans} = \begin{bmatrix}
17 & 11 & 16
\end{bmatrix}\]

\[\text{ans} = \begin{bmatrix}
17 \\
11 \\
16
\end{bmatrix}\]
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:

```matlab
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:

```matlab
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:

```matlab
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:

```matlab
% 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:

```matlab
D = [-0.2 1.0 1.5 3.0 -1.0 4.2 3.14];
D >= 0
```

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

You can directly exploit the logical indexing power of MATLAB to select the valid cone volumes, \( V_{\text{good}} \), for which the corresponding elements of \( D \) are nonnegative:

```matlab
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:

```matlab
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 \texttt{inf} and \texttt{nan}. Logical operators \texttt{isinf} and \texttt{isnan} exist to help perform logical tests for these special values. For example, it is often useful to exclude NaN values from computations:

\[ x = [2 -1 0 3 \text{NaN} 2 \text{NaN} 11 4 \text{Inf}]; \]
\[ xvalid = x(~\text{isnan}(x)) \]
\[ xvalid = \]
\[ 2 \ -1 \ 0 \ 3 \ 2 \ 11 \ 4 \ \text{Inf} \]

\textbf{Note:} \texttt{Inf == Inf} returns true; however, \texttt{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:

\[ x = -2:0.2:2; \]
\[ y = -1.5:0.2:1.5; \]
\[ [X,Y] = \text{meshgrid}(x,y); \]
\[ F = X.*\exp(-X.^2-Y.^2); \]
Without \texttt{meshgrid}, you might need to write two \texttt{for} loops to iterate through vector combinations. The function \texttt{ndgrid} also creates number grids from vectors, but can construct grids beyond three dimensions. \texttt{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
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.

```matlab
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
 -13   -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. \texttt{NaN} always satisfies this condition. Finally, you can use logical indexing to choose the unique elements in the set:

\begin{verbatim}
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
\end{verbatim}

Alternatively, you could accomplish the same operation by using the \texttt{unique} function:

\begin{verbatim}
y=unique(x);
\end{verbatim}

However, the \texttt{unique} function might provide more functionality than is needed and slow down the execution of your code. Use the \texttt{tic} and \texttt{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 \texttt{x}, you can count the occurrences of an element in a vector. After the vector sorts, you can use the \texttt{find} function to determine the indices of zero values in \texttt{diff(x)} and to show where the elements change value. The difference between subsequent indices from the \texttt{find} function indicates the number of occurrences for a particular element:

\begin{verbatim}
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
\end{verbatim}

The \texttt{find} function does not return indices for \texttt{NaN} elements. You can count the number of \texttt{NaN} and \texttt{Inf} values using the \texttt{isnan} and \texttt{isinf} functions.

\begin{verbatim}
count_nans = sum(isnan(x(:)));
\end{verbatim}
count_infs = sum(isinf(x(:)));

## Functions Commonly Used in Vectorizing

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>all</td>
<td>Test to determine if all elements are nonzero</td>
</tr>
<tr>
<td>any</td>
<td>Test for any nonzeros</td>
</tr>
<tr>
<td>cumsum</td>
<td>Find cumulative sum</td>
</tr>
<tr>
<td>diff</td>
<td>Find differences and approximate derivatives</td>
</tr>
<tr>
<td>find</td>
<td>find indices and values of nonzero elements</td>
</tr>
<tr>
<td>ind2sub</td>
<td>Convert from linear index to subscripts</td>
</tr>
<tr>
<td>ipermute</td>
<td>Inverse permute dimensions of a multidimensional array</td>
</tr>
<tr>
<td>logical</td>
<td>Convert numeric values to logical</td>
</tr>
<tr>
<td>meshgrid</td>
<td>Generate X and Y arrays for 3-D plots</td>
</tr>
<tr>
<td>ndgrid</td>
<td>Generate arrays for multidimensional functions and interpolations</td>
</tr>
<tr>
<td>permute</td>
<td>Rearrange dimensions of a multidimensional array</td>
</tr>
<tr>
<td>prod</td>
<td>Find product of array elements</td>
</tr>
<tr>
<td>repmat</td>
<td>Replicate and tile an array</td>
</tr>
<tr>
<td>reshape</td>
<td>Change the shape of an array</td>
</tr>
<tr>
<td>shiftdim</td>
<td>Shift array dimensions</td>
</tr>
<tr>
<td>sort</td>
<td>Sort array elements in ascending or descending order</td>
</tr>
<tr>
<td>squeeze</td>
<td>Remove singleton dimensions from an array</td>
</tr>
<tr>
<td>sub2ind</td>
<td>Convert from subscripts to linear index</td>
</tr>
<tr>
<td>sum</td>
<td>find the sum of array elements</td>
</tr>
</tbody>
</table>

### More About
- “Techniques for Improving Performance” on page 26-27

### External Web Sites
- MathWorks Newsletter: Matrix Indexing in MATLAB
Memory Usage

- “Memory Allocation” on page 27-2
- “Memory Management Functions” on page 27-11
- “Strategies for Efficient Use of Memory” on page 27-14
- “Resolving “Out of Memory” Errors” on page 27-21
Memory Allocation

In this section...

“Memory Allocation for Arrays” on page 27-2
“Data Structures and Memory” on page 27-6

Memory Allocation for Arrays

The following topics 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 27-2
• “Copying Arrays” on page 27-3
• “Array Headers” on page 27-4
• “Function Arguments” on page 27-5

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 26-27.

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 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 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 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 (that is, 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 27-6.

**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 might 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 contains 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 an 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 might 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:

\[
\text{whos}
\]

<table>
<thead>
<tr>
<th>Name</th>
<th>Size</th>
<th>Bytes</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>1000x1000</td>
<td>8000000</td>
<td>double array</td>
</tr>
<tr>
<td>Y</td>
<td>1000x1000</td>
<td>4004000</td>
<td>double array (sparse)</td>
</tr>
</tbody>
</table>

**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:

\[
A = \{[]\}; \quad \% \text{Empty cell array}
\]

\[
\text{whos } A
\]

<table>
<thead>
<tr>
<th>Name</th>
<th>Size</th>
<th>Bytes</th>
<th>Class</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1x1</td>
<td>60</td>
<td>cell</td>
<td></td>
</tr>
</tbody>
</table>

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:

\[(\text{header} \times \text{number of cells}) + \text{data}\]

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:

```matlab
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
```

<table>
<thead>
<tr>
<th>Name</th>
<th>Size</th>
<th>Bytes</th>
<th>Class</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laptops</td>
<td>4x1</td>
<td>369</td>
<td>cell</td>
<td></td>
</tr>
</tbody>
</table>

**Structures**

```matlab
S.A = [];
B = whos('S');
B.bytes - 60
ans =
    64
```
Compute the memory needed for a structure array as follows:

32-bit systems: \( \text{fields} \times ((60 \times \text{array elements}) + 64) + \text{data} \)
64-bit systems: \( \text{fields} \times ((112 \times \text{array elements}) + 64) + \text{data} \)

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:

\[ 2 \times ((112 \times 20) + 64) = 2 \times (2240 + 64) = 4608 \text{ bytes} \]

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:

\[ (25+12) \text{ characters} \times 2 \text{ bytes per char} \times 20 \text{ elements} = 1480 \text{ bytes} \]

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:

```matlab
A = int8(ones(5,8,6));
B = single(1:500);
C = uint16(magic(30));
D = 'Company Name: MathWorks';
```

```matlab
s = struct('f1', A, 'f2', B, 'f3', C, 'f4', D);
```

```matlab
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 total physical memory (RAM) of the computer.
- `whos` shows how much memory MATLAB 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 (for example, MATLAB) until the application exits.

You can use the `save` and `load` functions 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.

```matlab
A = ones(10,10);
whos
```

<table>
<thead>
<tr>
<th>Name</th>
<th>Size</th>
<th>Bytes</th>
<th>Class</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10x10</td>
<td>800</td>
<td>double</td>
<td></td>
</tr>
</tbody>
</table>

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):

```matlab
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
```

<table>
<thead>
<tr>
<th>Name</th>
<th>Size</th>
<th>Bytes</th>
<th>Class</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>50000000x1</td>
<td>400000000</td>
<td>double</td>
<td></td>
</tr>
</tbody>
</table>

Create B and point it to A. 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:

```matlab
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 \texttt{B(1)} copies all of \texttt{A} to \texttt{B} and changes the value of \texttt{B(1)}. Memory used = 382MB (1097 MB – 715 MB). Now there are two copies of the data in memory, yet the output of \texttt{whos} does not change:

\texttt{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 27-14
“Using Appropriate Data Storage” on page 27-16
“How to Avoid Fragmenting Memory” on page 27-18
“Reclaiming Used Memory” on page 27-20

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`:

```matlab
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.

<table>
<thead>
<tr>
<th>Class (Data Type)</th>
<th>Bytes</th>
<th>Supported Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>single</td>
<td>4</td>
<td>Most math</td>
</tr>
</tbody>
</table>
### Strategies for Efficient Use of Memory

<table>
<thead>
<tr>
<th>Class (Data Type)</th>
<th>Bytes</th>
<th>Supported Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>double</td>
<td>8</td>
<td>All math</td>
</tr>
<tr>
<td>logical</td>
<td>1</td>
<td>Logical/conditional operations</td>
</tr>
<tr>
<td>int8, uint8</td>
<td>1</td>
<td>Arithmetic and some simple functions</td>
</tr>
<tr>
<td>int16, uint16</td>
<td>2</td>
<td>Arithmetic and some simple functions</td>
</tr>
<tr>
<td>int32, uint32</td>
<td>4</td>
<td>Arithmetic and some simple functions</td>
</tr>
<tr>
<td>int64, int64</td>
<td>8</td>
<td>Arithmetic and some simple functions</td>
</tr>
</tbody>
</table>

**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 “Array Headers” on page 27-4). 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,

```matlab
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 following example 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 might 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 26-27.

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 might not be able to reuse the space previously occupied by two 1 MB arrays when allocating space for a 2.3 MB array:

```matlab
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:

```matlab
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,

```matlab
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 27-21
“Setting the Process Limit” on page 27-21
“Disabling Java VM on Startup” on page 27-23
“Increasing System Swap Space” on page 27-23
“Using the 3GB Switch on Windows Systems” on page 27-24
“Freeing Up System Resources on Windows Systems” on page 27-24

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 available. When you see the Out of Memory message, use any of the techniques discussed under “Strategies for Efficient Use of Memory” on page 27-14 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 27-23, 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.

<table>
<thead>
<tr>
<th>Operating System</th>
<th>Process Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>32-bit Microsoft Windows XP, Windows Vista™, Windows 7 and higher</td>
<td>2 GB</td>
</tr>
<tr>
<td>32-bit Windows XP with 3 GB boot.ini switch or 32-bit Windows Vista or Windows 7 and higher with increaseuserva set (see later)</td>
<td>3 GB</td>
</tr>
<tr>
<td>64-bit Windows or Linux running 32-bit MATLAB</td>
<td>≤ 4 GB</td>
</tr>
<tr>
<td>64-bit Windows, Apple Mac, or Linux running 64-bit MATLAB</td>
<td>8 TB</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>memory Return Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MaxPossibleArrayBytes</td>
<td>Size of the largest single array MATLAB can currently create</td>
</tr>
<tr>
<td>MemAvailableAllArrays</td>
<td>Total size of the virtual address space available for data</td>
</tr>
<tr>
<td>MemUsedMATLAB</td>
<td>Total amount of memory used by the MATLAB process</td>
</tr>
</tbody>
</table>
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 \texttt{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 \texttt{-nojvm} to start MATLAB. This also increases the size of the largest contiguous block (and therefore the largest matrix) by about the same.

Using \texttt{-nojvm} comes with a penalty in that you lose many features that rely on the Java software, including the entire development environment.

Starting MATLAB with the \texttt{-nodesktop} option does not save any substantial amount of memory.

Shutting down other applications and services (for example, using \texttt{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.

\textbf{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, 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.

```matlab
[uview 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 28-2
- “Check Which Programs Have Help” on page 28-9
- “Create Help Summary Files — Contents.m” on page 28-12
- “Display Custom Documentation” on page 28-15
- “Display Custom Examples” on page 28-23
Create Help for Classes

In this section...

“Help Text from the doc Command” on page 28-2
“Custom Help Text” on page 28-3

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.

```matlab
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
end
```

```matlab
methods (Static)
    function myStaticMethod
        % Summary of myStaticMethod
    end
end
```
View the help text and the details from the class definition using the `doc` command.

```
doc someClass
```

**someClass**

**someClass** Summary of this class goes here
Detailed explanation goes here

**Class Details**
Sealed: false
Constructor load: false

**Constructor Summary**

<table>
<thead>
<tr>
<th>Constructor</th>
<th>Summary of constructor</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>someClass</code></td>
<td></td>
</tr>
</tbody>
</table>

**Property Summary**

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>First public property</td>
</tr>
<tr>
<td>Two</td>
<td>Second public property</td>
</tr>
</tbody>
</table>

**Method Summary**

<table>
<thead>
<tr>
<th>Method</th>
<th>Summary of myMethod</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>myMethod</code></td>
<td></td>
</tr>
<tr>
<td><code>myStaticMethod</code></td>
<td></td>
</tr>
</tbody>
</table>

**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 28-4
- “Methods” on page 28-5
- “Properties” on page 28-5
- “Enumerations” on page 28-6
• “Events” on page 28-7

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

Lists and descriptions of the properties and methods in the initial comment block are optional. If you include comment lines containing the class name 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.  

```matlab  
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.  

```matlab  
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`.

```matlab
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.

```matlab
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`.

```matlab
classdef myEnumeration
    enumeration
        uno,          % First enumeration
        % DOS - Second enumeration
        % The description for DOS has several
        % lines of text.
```
Create Help for Classes

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 a 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
View the help in the Command Window using the `help` command. Specify both the class name and event, separated by a dot.

```matlab
help hasEvents.Alpha
  Alpha -  First event

help hasEvents.Beta
  Beta -  Second event
  Additional text about second event.
```

**See Also**

`doc` | `help`

**More About**

- “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.

![Help Report](image)

**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.

<table>
<thead>
<tr>
<th>Help Report Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Show class methods</strong></td>
<td>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.</td>
</tr>
</tbody>
</table>
| **Show all help**      | Display all help text found in each file. If you also select individual help components, such as **Description**, then help text appears twice in the report for each file: once for the overall help text, and once for the component.  
If your program has the same name as other programs on the MATLAB search path, then the help command generates a list of those overloaded items. MATLAB automatically adds links to the help for those items. |
| **Description**        | Check for an initial, nonempty comment line in the file. This line is sometimes called the H1 line.                                           |
| **Examples**           | 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 **example**. The report displays that line and subsequent nonblank comment lines, along with the initial line number. |
| **See Also**           | Check for a line in the help that begins with the string **See also**. The report displays the text and the initial line number.  
If the programs listed after **See also** are on the search path, then the help command generates hyperlinks to the help for those programs. The Help Report indicates when a program in the **See also** line is not on the path. |
| **Copyright**          | Check for a comment line in the file that begins with the string **Copyright**. 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).  
The recommended practice is to include a range of years from the year you created the file to the current year. |
Related Examples

• “Add Help for Your Program”
• “Create Help Summary Files — Contents.m” on page 28-12
Create Help Summary Files — Contents.m

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 8.5 (R2015a) 02-Oct-2014

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
calendar. Follow these steps to create a file:

1. In the Current Folder browser, navigate to the folder that contains your program
   files.
2. Click 查, 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 查, 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 \\u. Instead, use an actual hard drive on your
system, or a mapped network drive.

The Contents Report performs the following checks.
<table>
<thead>
<tr>
<th>Check Whether the Contents.m File...</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exists</td>
<td>If there is no <code>Contents.m</code> file in the folder, you can create one from the report.</td>
</tr>
<tr>
<td>Includes all programs in the folder</td>
<td>Missing programs appear in gray highlights. You do not need to add programs that you do not want to expose to end users.</td>
</tr>
<tr>
<td>Incorrectly lists nonexistent files</td>
<td>Listed programs that are not in the folder appear in pink highlights.</td>
</tr>
<tr>
<td>Matches the program file descriptions</td>
<td>The report compares file descriptions in <code>Contents.m</code> with the first nonempty comment line in the corresponding file. Discrepancies appear in pink highlights. You can update either the program file or the <code>Contents.m</code> file.</td>
</tr>
<tr>
<td>Uses consistent spacing between file names and descriptions</td>
<td>Fix the alignment by clicking <strong>fix spacing</strong> at the top of the report.</td>
</tr>
</tbody>
</table>

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 28-15
“Identify Your Documentation — info.xml” on page 28-16
“Create a Table of Contents — helptoc.xml” on page 28-18
“Build a Search Database” on page 28-20
“Address Validation Errors for info.xml Files” on page 28-21

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 the 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
   - Outside the matlabroot folder
   - Outside any installed Hardware Support Package help 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”.

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 Help 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 right of the home page, under Supplemental Software, click the link to your help.

![Help browser screenshot](image)

Your help opens in the current window.

### Identify Your Documentation — `info.xml`

The `info.xml` file specifies the name to display for your documentation set. It also identifies where to find your HTML help files and the `helptoc.xml` file. 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:

```xml
<productinfo xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
```
The following table describes required elements of the info.xml file.

<table>
<thead>
<tr>
<th>XML Tag</th>
<th>Description</th>
<th>Value in Template</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;matlabrelease&gt;</td>
<td>Release of MATLAB</td>
<td>R2015a</td>
<td>Not displayed in the browser, but indicates when you added help files.</td>
</tr>
<tr>
<td>&lt;name&gt;</td>
<td>Title of toolbox</td>
<td>MyToolbox</td>
<td>The name of your toolbox that appears in the browser Contents pane.</td>
</tr>
<tr>
<td>&lt;type&gt;</td>
<td>Label for the toolbox</td>
<td>toolbox</td>
<td>Allowable values: matlab, toolbox, simulink, blockset, links_targets, other.</td>
</tr>
<tr>
<td>&lt;icon&gt;</td>
<td>Icon for the Start button</td>
<td></td>
<td>No longer used, but the &lt;icon&gt; element is required to parse the info.xml file.</td>
</tr>
<tr>
<td>&lt;help_location&gt;</td>
<td>Location of help files</td>
<td>html</td>
<td>Name of subfolder containing helptoc.xml and HTML help files you provide for your toolbox. If the help location is 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.</td>
</tr>
</tbody>
</table>
| <help_contents_icon>  | Icon to display in Contents pane | $toolbox/matlab/ icons/bookicon.gif | Ignored in MATLAB R2015a and later. If it appears in the info.xml file, the
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 lowercase 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. Then add the folder 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 that 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.
• An example, myexample.html.

Include file names and descriptions in a helptoc.xml file as follows:

```xml
<?xml version='1.0' encoding='utf-8'?>
<toc version="2.0">
    <tocitem target="mytoolbox.html">My Toolbox
        <tocitem target="funclist.html">Functions
            <tocitem target="firstfx.html">first</tocitem>
            <tocitem target="secondfx.html">second</tocitem>
            <tocitem target="thirdfx.html">third</tocitem>
        </tocitem>
    </tocitem>
    <tocitem target="myexample.html">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. Be sure that file and path names exactly match the names of the files and folders, including upper- and lowercase letters.

The elements in the previous helptoc.xml and info.xml files correspond to the following display in the browser.

![Contents](image_url)

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
Custom Help and Documentation

Template for helptoc.xml

A complete template for helptoc.xml files is located in an examples folder included with the MATLAB documentation. The template includes <tocitem> elements for all standard content types, such as Getting Started, User Guide, and Release Notes. 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, also referred to as a search index, using the builddocsearchdb function. When using this function, specify the complete path to the folder that contains your HTML files.

For example, suppose that your HTML files are in C:\MATLAB\MyToolbox\html. This command creates a searchable database:

builddocsearchdb('C:\MATLAB\MyToolbox\html')

builddocsearchdb creates a subfolder of C:\MATLAB\MyToolbox\html named helpsearch-v3, which contains the database files.

You can search for terms in your toolbox from the Search Documentation field.

Beginning with MATLAB R2014b, you can maintain search indexes side by side. For instance, if you already have a search index for MATLAB R2014a or earlier, run builddocsearchdb against your help files using MATLAB R2014b. Then, when you
run any MATLAB release, the help browser automatically uses the appropriate index for searching your documentation database.

**Address Validation Errors for info.xml Files**

- “About XML File Validation” on page 28-21
- “Entities Missing or Out of Order in info.xml” on page 28-21
- “Unrelated info.xml File” on page 28-21
- “Invalid Constructs in info.xml File” on page 28-22
- “Outdated info.xml File for a MathWorks Product” on page 28-22

**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 28-16.
```

**Unrelated info.xml File**

Suppose that 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. Alternatively, 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 xml schema validator. For more information about the structure of the info.xml file, consult its schema, 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. Alternatively, 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 28-23
“Elements of the demos.xml File” on page 28-24

How to Display Examples

To display examples such as videos, published program scripts, or other files that illustrate the use of your programs in the MATLAB help browser, follow these steps:

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”.

2. Create a `demos.xml` file that describes the name, type, and display information for your examples.

For example, suppose that 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
<?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>
  <demosection>
    <label>First Section</label>
    <demoitem>
      <label>My Example Title</label>
      <type>M-file</type>
      <source>my_example</source>
    </demoitem>
  </demosection>
</demos>
```
<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>
</demosection>
</demos>

**Note:** `<demosection>` elements are optional.

3 View your examples.

- In the Help browser, navigate to the home page.
- At the bottom of the page, under *Supplemental Software* click the link for your example.

Your example opens in the main help window.

### Elements of the demos.xml File

- “General Information in `<demos>`” on page 28-24
- “Categories Using `<demosection>`” on page 28-25
- “Information About Each Example in `<demoitem>`” on page 28-25

### 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.

<table>
<thead>
<tr>
<th>XML Tag</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>&lt;name&gt;</code></td>
<td>Name of your toolbox or collection of examples.</td>
</tr>
<tr>
<td><code>&lt;type&gt;</code></td>
<td>Possible values are <code>matlab</code>, <code>simulink</code>, <code>toolbox</code>, or <code>blockset</code>.</td>
</tr>
<tr>
<td><code>&lt;icon&gt;</code></td>
<td>Ignored in MATLAB R2015a and later. In previous releases, this icon was the icon for your example. In those releases, you can use a standard icon,</td>
</tr>
</tbody>
</table>
Display Custom Examples

<table>
<thead>
<tr>
<th>XML Tag</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>HelpIcon.DEMOS</td>
<td>Or, you can provide a custom icon by specifying a path to the icon relative to the location of the demos.xml file.</td>
</tr>
<tr>
<td>&lt;description&gt;</td>
<td>The description that appears on the main page for your examples.</td>
</tr>
<tr>
<td>&lt;website&gt;</td>
<td>(Optional) Link to a website. For example, MathWorks examples include a link to the product page at <a href="http://www.mathworks.com">http://www.mathworks.com</a>.</td>
</tr>
</tbody>
</table>

Categories Using <demosection>

Optionally, 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>

<table>
<thead>
<tr>
<th>XML Tag</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;label&gt;</td>
<td>Defines the title to display in the browser.</td>
</tr>
<tr>
<td>&lt;type&gt;</td>
<td>Possible values are M-file, model, M-GUI, video, or other.</td>
</tr>
<tr>
<td></td>
<td>Typically, if you published your example using the publish function, the appropriate &lt;type&gt; is M-file.</td>
</tr>
<tr>
<td>&lt;source&gt;</td>
<td>If &lt;type&gt; is M-file, model, M-GUI, then &lt;source&gt; is the name of the associated .m file or model file, with no extension. Otherwise, do not include a &lt;source&gt; element, but include a &lt;callback&gt; element.</td>
</tr>
<tr>
<td>&lt;file&gt;</td>
<td>Use this element only for examples with a &lt;type&gt; 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 demos.xml.</td>
</tr>
<tr>
<td>&lt;callback&gt;</td>
<td>Use this element only for examples with a &lt;type&gt; value of video or other to specify an executable file or a MATLAB command to run the example.</td>
</tr>
<tr>
<td>XML Tag</td>
<td>Notes</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>&lt;dependency&gt;</td>
<td>(Optional) Specifies other products required to run the example, such as another toolbox. The text must match a product name specified in an info.xml file that is on the search path or in the current folder.</td>
</tr>
</tbody>
</table>
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.

- “About MathWorks Source Control Integration” on page 29-3
- “Select or Disable Source Control System” on page 29-4
- “Create New Repository” on page 29-5
- “Review Changes in Source Control” on page 29-7
- “Mark Files for Addition to Source Control” on page 29-8
- “Resolve Source Control Conflicts” on page 29-9
- “Commit Modified Files to Source Control” on page 29-13
- “Revert Changes in Source Control” on page 29-14
- “Set Up SVN Source Control” on page 29-15
- “Check Out from SVN Repository” on page 29-21
- “Update SVN File Status and Revision” on page 29-25
- “Get SVN File Locks” on page 29-26
- “Set Up Git Source Control” on page 29-27
- “Clone from Git Repository” on page 29-31
- “Update Git File Status and Revision” on page 29-33
- “Branch and Merge with Git” on page 29-34
- “Push and Fetch with Git” on page 29-38
- “MSSCCI Source Control Interface” on page 29-40
- “Set Up MSSCCI Source Control” on page 29-41
- “Check Files In and Out from MSSCCI Source Control” on page 29-48
- “Additional MSSCCI Source Control Actions” on page 29-51
• “Access MSSCCI Source Control from Editors” on page 29-58
• “Troubleshoot MSSCCI Source Control Problems” on page 29-59
About MathWorks Source Control Integration

You can use MATLAB to work with files under source control. You can perform operations such as update, commit, merge changes, and view revision history directly from the Current Folder browser.

MATLAB integrates with:

- Subversion® (SVN)
- Git™

MATLAB also has interfaces to MSSCCI source control systems. However, this interfaces is not integrated with the Current Folder browser. If you are just starting to use source control in MATLAB, use a source control system that is part of the MathWorks source control integration, such as SVN or Git, to take full advantage of built-in capabilities with the Current Folder browser.

To use source control in your project, use any of these workflows:

- Retrieve files from an existing repository. See “Check Out from SVN Repository” on page 29-21 or “Clone from Git Repository” on page 29-31.
- Add source control to a folder. See “Create New Repository” on page 29-5.
- Add new files in a folder already under source control. See “Mark Files for Addition to Source Control” on page 29-8.
Select or Disable Source Control System

Select Source Control System

If you are just starting to use source control in MATLAB, select a source control system that is part of the MathWorks source control integration with the Current Folder browser, such as Subversion or Git. Doing so enables you to take advantage of the built-in nature of the integration. MathWorks source control integration is on by default.

1. On the Home tab, in the Environment section, click Preferences.
2. In the preferences dialog box, navigate to the MATLAB > General > Source Control pane.
3. To use the MathWorks source control integration, which is accessible through the Current Folder browser, select Enable MathWorks source control integration. Use this option for source control systems such as Subversion and Git. This is the default option, unless you previously set up source control with MATLAB.

Alternatively, on Microsoft Windows, to use a Microsoft Source Control Interface (MSSCCI) system, select Enable Microsoft Source Control Interface (MSSCCI) and choose your installed source control system from the list. On a UNIX platform, to use another source control system, such as CVS or RCS, select Enable other source control system and choose your source control system from the list. These source control systems are not integrated with the MATLAB Current Folder browser.

Disable Source Control

When you disable source control, MATLAB does not destroy repository information. For example, it does not remove the .svn folder. You can put the folder back under source control by enabling the source control integration again.

1. On the Home tab, in the Environment section, click Preferences.
2. In the Preferences dialog box, in the MATLAB > General > Source Control pane, select None.
Create New Repository

You can use MATLAB to add source control to files in a folder. If you want to add version control to your files without sharing with another user, it is quickest to create a local Git repository in your sandbox.

For SVN, check that your sandbox folder is on a local hard disk. Using a network folder with SVN is slow and unreliable.

Before using source control, you must register binary files with your source control tools to avoid corruption. See “Register Binary Files with SVN” on page 29-16 or “Register Binary Files with Git” on page 29-29.

Tip To check out an existing SVN repository, see “Check Out from SVN Repository” on page 29-21. To clone an existing remote Git repository, see “Clone from Git Repository” on page 29-31.

1 Right-click in the white space (any blank area) of the MATLAB Current Folder browser. Select Source Control > Manage Files.

2 In the Manage Files Using Source Control dialog box, in the Source control integration list:
   - For an SVN repository, select Built-In SVN Integration.
   - For a Git repository, select Git.

3 Click the Change button to open the Specify SVN Repository URL dialog box if you are using SVN or the Select a Repository dialog box if you are using Git.

4 Click the Create a repository button to create a repository on disk.

5 Select an empty folder or create a new folder in which you want to create the repository and click Select Folder to create the repository.

   For SVN, the URL of the new repository is in the Repository URL box, and the trunk folder is selected. Specify file:// URLs and create new repositories for single users only. For multiple users, see “Share a Subversion Repository” on page 29-20.

6 In the Specify SVN Repository URL (SVN) or Select a Repository (Git), click Validate to check the path to the selected repository, and then click OK.
If your SVN repository has a file URL, a warning appears that file URLs are for single users. Click **OK** to continue.

7 In the Manage Files Using Source Control dialog box, choose the location for your sandbox, and then click **Retrieve**.

You need some additional setup steps if you want to merge branches with Git. See “Install Command-Line Git Client” on page 29-28.

After integrity checks are complete, you can commit the first version of your files to the new repository.

**Related Examples**

- “Set Up SVN Source Control” on page 29-15
- “Set Up Git Source Control” on page 29-27
- “Check Out from SVN Repository” on page 29-21
- “Clone from Git Repository” on page 29-31
- “Commit Modified Files to Source Control” on page 29-13
Review Changes in Source Control

The files under source control that you have changed display the Modified File symbol □ in the Current Folder browser. Right-click the file in the Current Folder browser, select Source Control, and select:

- **Show Revisions** to open the File Revisions dialog box and browse the history of a file. You can view information about who previously committed the file, when they committed it, and the log messages. You can select multiple files and view revision history for each file.
- **Compare to Revision** to open a dialog box where you can select the revision you want to compare. You can select multiple files and select a revision to compare against for each file. Click Compare to run comparisons and view reports.
- **Compare to Ancestor** to run a comparison with the last checked-out version in the sandbox (SVN) or against the local repository (Git). The Comparison Tool displays a report.

If you need to update the status of the modified files, see “Update SVN File Status and Revision” on page 29-25 or “Update Git File Status and Revision” on page 29-33.

**Related Examples**
- “Resolve Source Control Conflicts” on page 29-9
- “Commit Modified Files to Source Control” on page 29-13
- “Revert Changes in Source Control” on page 29-14
Mark Files for Addition to Source Control

When you create a new file in a folder under source control, the Not Under Source Control symbol appears in the status column of the Current Folder browser. To add a file to source control, right-click the file in the Current Folder browser, and select Source Control and then the Add option appropriate to your source control system. For example, select Add to Git or Add to SVN.

When the file is marked for addition to source control, the symbol changes to Added.
Resolve Source Control Conflicts

Examining and Resolving Conflicts

If you and another user change the same file in different sandboxes or on different branches, a conflict message appears when you try to commit your modified files. Follow the procedure “Resolve Conflicts” on page 29-9 to extract conflict markers if necessary, compare the differences causing the conflict, and resolve the conflict.

To resolve conflicts you can:

• Use the Comparison Tool to merge changes between revisions.
• Decide to overwrite one set of changes with the other.
• Make changes manually by editing files.

For details on using the Comparison Tool to merge changes, see “Merge Text Files” on page 29-10.

After you are satisfied with the file that is marked conflicted, you can mark the conflict resolved and commit the file.

Resolve Conflicts

1 Look for conflicted files in the Current Folder browser.
2 Check the source control status column (SVN or Git) for files with a red warning symbol ☢, which indicates a conflict.
3 Right-click the conflicted file and select Source Control > View Conflicts to compare versions.
4 If the file contains conflict markers, the View Conflicts dialog box reports that you need to extract the conflict markers before you can compare the conflicts.

Leave the default option to copy the “mine” revision over the conflicted file. Leave the Compare extracted files check box selected. Click Extract.
5 Examine the conflict. A comparison report opens that shows the differences between the conflicted files.

With SVN, the comparison shows the differences between the file and the version of the file in conflict.
With Git, the comparison shows the differences between the file on your branch and the branch you want to merge into.

6 Use the Comparison Tool report to determine how to resolve the conflict.

You can use the Comparison Tool to merge changes between revisions, as described in “Merge Text Files” on page 29-10.

7 When you have resolved the changes and want to commit the version in your sandbox, in the Current Folder browser, right-click the file and select Source Control > Mark Conflict Resolved.

With Git, the Branch status in the Source Control Details dialog box changes from MERGING to SAFE.

8 Commit the modified files.

**Merge Text Files**

When comparing text files, you can merge changes from one file to the other. Merging changes is useful when resolving conflicts between different versions of files.

If you see conflict markers in a text comparison report like this:

```bash
<<<<<<< .mine
```

then extract the conflict markers before merging, as described in “Extract Conflict Markers” on page 29-11.

**Tip** When comparing a file to another version in source control, by default the right file is the version in your sandbox and the left file is either a temporary copy of the previous version or another version causing a conflict (e.g., `filename_theirs`). You can swap the position of the files, so be sure to observe the file paths of the left and right file at the top of the comparison report. Merge differences from the temporary copy to the version in your sandbox to resolve conflicts.

1 In the Comparison Tool report, select a difference in the report and click **Merge**. The selected difference is copied from the left file to the right file.

Merged differences display gray row highlighting and a green merge arrow.
Resolve Source Control Conflicts

1. The merged file name at the top of the report displays with an asterisk (*filename.m*) to show you that the file contains unsaved changes.

2. Click **Save Merged File** to save the file in your sandbox. To resolve conflicts, save the merged file over the conflicted file.

3. If you want to inspect the files in the editor, click the line number links in the report.

   **Note:** If you make any further changes in the editor, the comparison report does not update to reflect changes and report links can become incorrect.

4. When you have resolved the changes mark them as conflict resolved. Right-click the file in the Current Folder browser and select **Source Control > Mark Conflict Resolved**.

**Extract Conflict Markers**

- “What Are Conflict Markers?” on page 29-11
- “Extract Conflict Markers” on page 29-12

**What Are Conflict Markers?**

Source control tools can insert conflict markers in files that you have not registered as binary (e.g., text files). You can use MATLAB to extract the conflict markers and compare the files causing the conflict. This process helps you to decide how to resolve the conflict.

**Caution** Register files with source control tools to prevent them from inserting conflict markers and corrupting files. See “Register Binary Files with SVN” on page 29-16 or “Register Binary Files with Git” on page 29-29. If your files already contain conflict markers, the MATLAB tools can help you to resolve the conflict.

Conflict markers have the following form:

```matlab
<<<<<<<<<<<["mine" file descriptor]
["mine" file content]
=======
["theirs" file content]
```
If you try to open a file containing conflict markers, the Conflict Markers Found dialog box opens. Follow the prompts to fix the file by extracting the conflict markers. After you extract the conflict markers, resolve the conflicts as described in “Examining and Resolving Conflicts” on page 29-9.

To view the conflict markers, in the Conflict Markers Found dialog box, click **Load File**. Do not try to load files, because MATLAB does not recognize conflict markers. Instead, click **Fix File** to extract the conflict markers.

MATLAB checks only conflicted files for conflict markers.

**Extract Conflict Markers**

When you open a conflicted file or select **View Conflicts**, MATLAB checks files for conflict markers and offers to extract the conflict markers. MATLAB checks only conflicted files for conflict markers.

However, some files that are not marked as conflicted can still contain conflict markers. This can happen if you or another user marked a conflict resolved without removing the conflict markers and then committed the file. If you see conflict markers in a file that is not marked conflicted, you can extract the conflict markers.

1. In the Current Folder browser, right-click the file, and select **Source Control > Extract Conflict Markers to File**.
2. In the Extract Conflict Markers to File dialog box, leave the default option to copy “mine” file version over the conflicted file. Leave the **Compare extracted files** check box selected. Click **Extract**.
3. Use the Comparison Tool report as usual to continue to resolve the conflict.
Commit Modified Files to Source Control

Before you commit modified files, review changes and mark any new files for addition into source control. The files under source control that you can commit to a repository display the Added to Source Control symbol + or the Modified File symbol ■ in the Current Folder browser.

1 If you are using SVN, in the Current Folder browser select the files you want to commit. Right-click and select Source Control > Commit Selection to SVN Repository. To commit all modified or added files, right-click in the Current Folder browser and select Source Control > Commit All to SVN Repository. This commits the changes to your repository.

If you are using Git, to commit all modified or added files to the repository, right-click in the Current Folder browser, and select Source Control > Commit All to Git Repository. This commits the changes to your local repository. To commit to the remote repository, see “Push and Fetch with Git” on page 29-38.

2 Enter comments in the dialog box, and click Submit.

3 A message appears if you cannot commit because the repository has moved ahead. Before you can commit the file, you must update the revision up to the current HEAD revision.

   • If you are using SVN source control, right-click the white space in the Current Folder browser or right-click a file. Select Source Control > Update from SVN.
   • If you are using Git source control, right-click in the Current Folder browser. Select Source Control > Fetch.

Resolve any conflicts before you commit.

Related Examples

• “Mark Files for Addition to Source Control” on page 29-8
• “Review Changes in Source Control” on page 29-7
• “Resolve Source Control Conflicts” on page 29-9
• “Update SVN File Status and Revision” on page 29-25
• “Update Git File Status and Revision” on page 29-33
• “Push and Fetch with Git” on page 29-38
Revert Changes in Source Control

**Revert Local Changes**

With SVN, if you want to roll back local changes in a file, right-click the file and select **Source Control > Revert Local Changes and Release Locks**. This command releases locks and reverts to the version in the last sandbox update (that is, the last version you synchronized or retrieved from the repository). If your file is not locked, the menu option is **Source Control > Revert Local Changes**. To abandon all local changes, select all the files in the Current Folder browser before you select the command.

With Git, right-click a file and select **Source Control > Revert Local Changes**. To remove all local changes, right-click a blank space in the Current Folder browser and select **Source Control > Manage Branches**. In the Manage Branches dialog box, click **Revert to Head**.

**Revert a File to a Specified Revision**

1 Right-click a file in the Current Folder browser and select **Source Control > Revert using SVN** or **Revert using Git**.

2 In the Revert Files dialog box, choose a revision to revert to. Select a revision to view information about the change such as the author, date, and log message.

3 Click **Revert**.

If you revert a file to an earlier revision and then make changes, you cannot commit the file until you resolve the conflict with the repository history.

**Related Examples**

- “Resolve Source Control Conflicts” on page 29-9
Set Up SVN Source Control

MATLAB provides built-in SVN integration for use with Subversion (SVN) sandboxes and repositories. Because the implementation is built in to MATLAB, you do not need to install SVN. The built-in SVN integration supports secure logins. This integration ignores any existing SVN installation.

In this section...

“SVN Source Control Options” on page 29-15
“Register Binary Files with SVN” on page 29-16
“Standard Repository Structure” on page 29-19
“Tag Versions of Files” on page 29-19
“Enforce Locking Files Before Editing” on page 29-19
“Share a Subversion Repository” on page 29-20

SVN Source Control Options

To use the version of SVN provided with MATLAB, when you retrieve a file from source control, select **Built-In SVN Integration** in the **Source control integration** list. For instructions, see “Check Out from SVN Repository” on page 29-21. When you create a new sandbox using the MATLAB built-in SVN integration, the new sandbox uses the latest version of SVN provided by MATLAB.

**Caution** Before using source control, you must register binary files with the source control tools to avoid corruption. See “Register Binary Files with SVN” on page 29-16.

If you need to use a version of SVN other than the built-in version, you can create a repository using the **Command-Line SVN Integration (compatibility mode)** **Source control integration** option, but you must also install a command-line SVN client.

Command-line SVN integration communicates with any Subversion (SVN) client that supports the command-line interface. With **Command-Line SVN Integration (compatibility mode)**, if you try to rename a file or folder to a name that contains an @ character, an error occurs because command-line SVN treats all characters after the @ symbol as a peg revision value.
Register Binary Files with SVN

If you use third-party source control tools, you must register your MATLAB and Simulink file extensions such as `.mat`, `.mdl`, and `.slx` as binary formats. If you do not register the extensions, these tools can corrupt your files when you submit them by changing end-of-line characters, expanding tokens, substituting keywords, or attempting to automerge. Corruption can occur whether you use the source control tools outside of MATLAB or if you try submitting files from MATLAB without first registering your file formats.

Also check that other file extensions are registered as binary to avoid corruption at check-in. Check and register files such as `.mdlp`, `.slxp`, `.sldd`, `.p`, MEX-files, `.xlsx`, `.jpg`, `.pdf`, `.docx`, etc.

You must register binary files if you use any version of SVN, including the built-in SVN integration provided by MATLAB. If you do not register your extensions as binary, SVN might add annotations to conflicted MATLAB files and attempt automerge. To avoid this problem when using SVN, register file extensions.

1 Locate your SVN config file. Look for the file in these locations:
   - `C:\Users\myusername\AppData\Roaming\Subversion\config` or `C:\Documents and Settings\myusername\Application Data\Subversion\config` on Windows
   - `~/.subversion` on Linux or Mac OS X

2 If you do not find a config file, create a new one. See “Create SVN Config File” on page 29-16.

3 If you find an existing config file, you have previously installed SVN. Edit the config file. See “Update Existing SVN Config File” on page 29-17.

Create SVN Config File

1 If you do not find an SVN config file, create a text file containing these lines:

```
[miscellany]
enable-auto-props = yes
/auto-props*
.mdl = svn:mime-type=application/octet-stream
.mat = svn:mime-type=application/octet-stream
.slx = svn:mime-type= application/octet-stream
```
2 Check for other file types you use that you also need to register as binary to avoid corruption at check-in. Check for files such as .mat, .mdlp, .slxp, .p, MEX-files (.mexa64, .mexmaci64, .mexw32, .mexw64), .xlsx, .jpg, .pdf, .docx, etc. Add a line to the config file for each file type you need. Examples:

* .mdlp  = svn:mime-type=application/octet-stream
* .slxp  = svn:mime-type=application/octet-stream
* .sldd  = svn:mime-type=application/octet-stream
* .p     = svn:mime-type=application/octet-stream
* .mexa64 = svn:mime-type=application/octet-stream
* .mexw64 = svn:mime-type=application/octet-stream
* .mexmaci64 = svn:mime-type=application/octet-stream
* .xlsx  = svn:mime-type=application/octet-stream
* .docx  = svn:mime-type=application/octet-stream
* .pdf   = svn:mime-type=application/octet-stream
* .jpg   = svn:mime-type=application/octet-stream
* .png   = svn:mime-type=application/octet-stream

3 Name the file config and save it in the appropriate location:

- C:\Users\myusername\AppData\Roaming\Subversion\config or C:\Documents and Settings\myusername\Application Data\Subversion\config on Windows
- ~/.subversion on Linux or Mac OS X.

After you create the SVN config file, SVN treats new files with these extensions as binary. If you already have binary files in repositories, see “Register Files Already in Repositories” on page 29-18.

**Update Existing SVN Config File**

If you find an existing config file, you have previously installed SVN. Edit the config file to register files as binary.

1 Edit the config file in a text editor.

2 Locate the [miscellany] section, and verify the following line enables auto-props with yes:

   enable-auto-props = yes

Ensure that this line is not commented (that is, that it does not start with #). Config files can contain example lines that are commented out. If there is a # character at the beginning of the line, delete it.
3 Locate the `[auto-props]` section. Ensure that `[auto-props]` is not commented. If there is a `#` character at the beginning, delete it.

4 Add the following lines at the end of the `[auto-props]` section:

```plaintext
*.mdl = svn:mime-type= application/octet-stream
*.mat = svn:mime-type=application/octet-stream
*.slx = svn:mime-type= application/octet-stream
```

These lines prevent SVN from adding annotations to MATLAB and Simulink files on conflict and from automerging.

5 Check for other file types you use that you also need to register as binary to avoid corruption at check-in. Check for files such as `.mdlp`, `.slxp`, `.p`, MEX-files (`.mexa64`, `.mexmaci64`, `.mexw32`, `.mexw64`), `.xlsx`, `.jpg`, `.pdf`, `.docx`, etc. Add a line to the `config` file for each file type you use. Examples:

```plaintext
*.mdlp  = svn:mime-type=application/octet-stream
*.slxp  = svn:mime-type=application/octet-stream
*.sldd  = svn:mime-type=application/octet-stream
*.p     = svn:mime-type=application/octet-stream
*.mexa64 = svn:mime-type=application/octet-stream
*.mexw32 = svn:mime-type=application/octet-stream
*.mexw64 = svn:mime-type=application/octet-stream
*.mexmaci64 = svn:mime-type=application/octet-stream
*.xlsx  = svn:mime-type=application/octet-stream
*.docx  = svn:mime-type=application/octet-stream
*.pdf   = svn:mime-type=application/octet-stream
*.jpg   = svn:mime-type=application/octet-stream
*.png   = svn:mime-type=application/octet-stream
```

6 Save the `config` file.

After you create or update the SVN `config` file, SVN treats new files as binary. If you already have files in repositories, register them as described in “Register Files Already in Repositories” on page 29-18.

**Register Files Already in Repositories**

*Caution* Changing your SVN `config` file does not affect files already committed to an SVN repository. If a file is not registered as binary, use `svn propset` to manually register the files as binary.
To manually register a file in a repository as binary, use the following command with command-line SVN:

```
svn propset svn:mime-type application/octet-stream binaryfilename
```

**Standard Repository Structure**

Create your repository with the standard tags, trunk, and branches folders, and check out files from trunk. The Subversion project recommends this structure. See the Web page:

```
```

If you use MATLAB to create an SVN repository, it creates the standard repository structure. To enable tagging, the repository must have the standard trunk/ and tags/ folders. After you create a repository with this structure, you can click Tag in the Source Control context menu to add tags to all of your files. For more information, see “Tag Versions of Files” on page 29-19.

**Tag Versions of Files**

With SVN, you can use tags to identify specific revisions of all files. To use tags with SVN, you need the standard folder structure in your repository and you need to check out your files from trunk. See “Standard Repository Structure” on page 29-19.

1. Right-click in the Current Folder browser, and select Source Control > Tag.
2. Specify the tag text and click Submit. The tag is added to every file in the folder. Errors appear if you do not have a tags folder in your repository.

---

**Note:** You can retrieve a tagged version of your files from source control, but you cannot tag them again with a new tag. You must check out from trunk to create new tags.

---

**Enforce Locking Files Before Editing**

To require that users remember to get a lock on files before editing, configure SVN to make files with specified extensions read only. When your files are read only, you need to select Get File Lock before you can edit them. This setting prevents editing of files without getting the file lock. When the file has a lock, other users know the file is being edited, and you can avoid merge issues.
To make files with a .m extension read only, add this property to your SVN config file in the [auto-props] section:

`*.m = svn:needs-lock=yes`

To locate your SVN config file, see “Register Binary Files with SVN” on page 29-16.

Re-create the sandbox for the configuration to take effect.

With this setting, you need to select **Get File Lock** before you can edit files with a .m extension. See “Get SVN File Locks” on page 29-26.

**Share a Subversion Repository**

You can specify a repository location using the file:// protocol. However, Subversion documentation strongly recommends that only a single user access a repository directly via file:// URLs. See the Web page:


---

**Caution**

Do not allow multiple users to access a repository directly via file:// URLs or you risk corrupting the repository. Use file:// URLs only for single-user repositories.

Be aware of this caution if you use MATLAB to create a repository. MATLAB uses the file:// protocol. Creating new repositories is provided for local, single-user access only, for testing and debugging. Accessing a repository via file:// URLs is slower than using a server.

When you want to share a repository, you need to set up a server. You can use svnserv or the Apache™ SVN module. See the Web page references:


**Related Examples**

- “Check Out from SVN Repository” on page 29-21
Check Out from SVN Repository

Create a new local copy of a repository by retrieving files from source control.

1. Right-click in the white space (any blank area) in the Current Folder browser and select Source Control > Manage Files.

2. In the Manage Files Using Source Control dialog box, select the source control interface from the Source control integration list. To use SVN, leave the default Built-In SVN Integration.

3. Click Change to browse for and validate the repository path. (If you know your repository location, you can paste it into the Repository Path box and proceed to step 8.)

4. In the Specify Repository URL dialog box, specify the repository URL by entering a URL in the box, using the list of recent repositories, or by using the Generate URL from folder button.

Caution Use file:// URLs only for single-user repositories. For more information, see “Share a Subversion Repository” on page 29-20.

5. Click Validate to check the repository path.

If the path is invalid, check the URL against your source control repository browser.
If you see an authentication dialog box for your repository, enter login information to continue.

If necessary, select a deeper folder in the repository tree. You might want to check out from \texttt{trunk} or from a branch folder under \texttt{tags}, if your repository contains tagged versions of files. You can check out from a branch, but the built-in SVN integration does not support branch merging. Use an external tool such as TortoiseSVN to perform branch merging. The example shows \texttt{trunk} selected, and the Selected URL displays at the bottom of the dialog box. The retriever uses this URL when you click \texttt{OK}.

When you have finished specifying the URL path you want to retrieve, click \texttt{OK}.

In the Manage Files Using Source Control dialog box, select the sandbox folder where you want to put the retrieved files, and click \texttt{Retrieve}.

\textbf{Caution} Use local sandbox folders. Using a network folder with SVN slows source control operations.
Check Out from SVN Repository

The Manage Files Using Source Control dialog box displays messages as it retrieves the files from source control.

**Note:** To update an existing sandbox from source control, see “Update SVN File Status and Revision” on page 29-25.

Retrieve Tagged Version of Repository

To use tags with SVN, you need the standard folder structure in your repository. For more information, see “Standard Repository Structure” on page 29-19.

1. Right-click in the white space in the Current Folder browser, and select **Source Control > Manage Files**.

2. In the Manage Files Using Source Control dialog box, select the source control interface from the **Source control integration** list. To use SVN, leave the default **Built-In SVN Integration**.
3 Click **Change** to select the Repository Path that you want to retrieve files from.

4 In the Specify Repository URL dialog box:
   
   - Select a recent repository from the **Repository URL** list, or click the **Generate URL from folder** button to browse for the repository location.
   - Click **Validate** to show the repository browser.
   - Expand the **tags** folder in the repository tree, and select the tag version you want. Navigate up a level in the repository if the URL contains the **trunk**.
   - Click **OK** to continue and return to the Manage Files Using Source Control dialog box.

5 Select the sandbox folder to receive the tagged files. You must use an empty sandbox folder or specify a new folder.

6 Click **Retrieve**.

**Related Examples**

- “Set Up SVN Source Control” on page 29-15
- “Update SVN File Status and Revision” on page 29-25
Update SVN File Status and Revision

In this section...

“Refresh Status of Files” on page 29-25
“Update Revisions of Files” on page 29-25

Refresh Status of Files

To refresh the source control status of files, select one or more files in the Current Folder browser, right-click and select **Source Control > Refresh SVN status.**

To refresh the status of all files in a folder, right-click the white space of the Current Folder browser and select **Source Control > Refresh SVN status.**

**Note:** For SVN, refreshing the source control status does not contact the repository. To get the latest revisions, see “Update Revisions of Files” on page 29-25.

Update Revisions of Files

To update the local copies of selected files, select one or more files in the Current Folder browser, right-click and select **Source Control > Update from SVN.**

To update all files in a folder, right-click the white space of the Current Folder browser and select **Source Control > Update from SVN.**

Related Examples

- “Check Out from SVN Repository” on page 29-21
- “Review Changes in Source Control” on page 29-7
Get SVN File Locks

It is good practice to get a file lock before editing a file. The lock tells other users that the file is being edited, and you can avoid merge issues. When you set up source control, you can configure SVN to make files with certain extensions read only. Users must get a lock on these read-only files before editing.

In the Current Folder browser, select the files you want to check out. Right-click the selected files and select **Source Control > Get File Lock**. A lock symbol appears in the source control status column. Other users cannot see the lock symbol in their sandboxes, but they cannot get a file lock or check in a change when you have the lock.

**Related Examples**
- “Enforce Locking Files Before Editing” on page 29-19
Set Up Git Source Control

In this section...

“About Git Source Control” on page 29-27
“Install Command-Line Git Client” on page 29-28
“Register Binary Files with Git” on page 29-29

About Git Source Control

Git integration with MATLAB provides distributed source control with support for creating and merging branches. Git is a distributed source control tool, so you can commit changes to a local repository and later synchronize with other remote repositories.

Git supports distributed development because every sandbox contains a complete repository. The full revision history of every file is saved locally. This enables working offline, because you do not need to contact remote repositories for every local edit and commit, only when pushing batches of changes. In addition, you can create your own branches and commit local edits. Doing so is fast, and you do not need to merge with other changes on each commit.

Capabilities of Git source control:

- Branch management
- Local full revision history
- Local access that is quicker than remote access
- Offline working
- Tracking of file names and contents separately
- Enforcing of change logs for tracing accountability
- Integration of batches of changes when ready

These capabilities do not suit every situation. If your project is not appropriate for offline working or your repository is too large for a full local revision history, for example, Git is not the ideal source control. In addition, if you need to enforce locking of files before editing, Git does not have this ability. In that situation, SVN is the better choice.

When you use Git in MATLAB, you can:
• Create local Git repositories.
• Fetch files from remote Git repositories.
• Create and switch branches.
• Merge branches locally.
• Commit locally.
• Push files to remote Git repositories.

This diagram represents the distributed Git workflow.

Install Command-Line Git Client

If you want to use Git to merge branches in MATLAB, you must also install a command-line Git client. You can use other Git functionality without any additional installation. After you have installed a command-line Git client and registered your files as binary, you can use the merging features of Git in MATLAB.

On Windows:

1. Download the Git installer and run it. You can find command-line Git at:

   http://msysgit.github.io/
2 In the section on adjusting your PATH, choose the install option to **Use Git from the Windows Command Prompt**. This option adds Git to your PATH variable, so that MATLAB can communicate with Git.

3 In the section on configuring the line ending conversions, choose the option **Checkout as-is, commit as-is** to avoid converting any line endings in files.

4 To avoid corrupting binary files, before using Git to merge branches, register the binary files.

On Linux, Git is available for most distributions. Install Git for your distribution. For example, on Debian®, install Git by entering:

```
sudo apt-get install git
```

On Mac, on Mavericks (10.9) or above, try to run `git` from the Terminal. If you do not have Git installed already, it will prompt you to install Xcode Command Line Tools. For more options, see [http://git-scm.com/doc](http://git-scm.com/doc).

**Register Binary Files with Git**

If you use third-party source control tools, you must register your MATLAB and Simulink file extensions such as `.mat`, `.mdl`, and `.slx` as binary formats. If you do not register the extensions, these tools can corrupt your files when you submit them by changing end-of-line characters, expanding tokens, substituting keywords, or attempting to automerge. Corruption can occur whether you use the source control tools outside of MATLAB or if you try submitting files from MATLAB without first registering your file formats.

Also check that other file extensions are registered as binary to avoid corruption at check-in. Check and register files such as `.mdlp`, `.s1xp`, `.s1dd`, `.p`, MEX-files, `.xls`, `.jpg`, `.pdf`, `.docx`, etc.

After you install a command-line Git client, you can prevent Git from corrupting your files by inserting conflict markers. To do so, edit your `gitattributes` file to register binary files. For details, see:

[http://git-scm.com/docs/gitattributes](http://git-scm.com/docs/gitattributes)

1 If you do not already have one in your sandbox folder, create a text file with the name `gitattributes`.

2 Add these lines to the `gitattributes` file:
* .mat -crlf -diff –merge
* .p -crlf -diff –merge
* .slx -crlf -diff –merge
* .mdl -crlf -diff –merge

These lines specify not to try automatic line feed, diff, and merge attempts for these types of files.

3 Check for other file types you use that you also need to register as binary to avoid corruption at check-in. Check for files such as .mdl, .slx, MEX-files (.mexa64, .mexmaci64, .mexw32, .mexw64), .xlsx, .jpg, .pdf, .docx, etc. Add a line to the attributes file for each file type you need.

Examples:

* .mdlp -crlf -diff –merge
* .slxp -crlf -diff –merge
* .sldd -crlf -diff –merge
* .mexa64 -crlf -diff –merge
* .mexw32 -crlf -diff –merge
* .mexw64 -crlf -diff –merge
* .mexmaci64 -crlf -diff –merge
* .xlsx -crlf -diff –merge
* .docx -crlf -diff –merge
* .pdf -crlf -diff –merge
* .jpg -crlf -diff –merge
* .png -crlf -diff –merge

4 Restart MATLAB so you can start using the Git client.

Related Examples

• “Clone from Git Repository” on page 29-31
Clone from Git Repository

Clone a remote Git repository to retrieve repository files.

1. Right-click in the white space (any blank area) in the Current Folder browser, and select Source Control > Manage Files.

2. In the Manage Files Using Source Control dialog box, select Git from the Source control integration list.

3. Click Change to browse for and validate the repository path. (If you know your repository location, you can paste it into the Repository Path box and proceed to step 7.)

4. In the Select a Repository dialog box, specify the repository path by entering the path in the box, using the list of recent repositories, or by using the Browse to a Git repository on disk button.

5. Click Validate to check the repository path.

   If the path is invalid, check it against your source control repository browser.

6. If you see an authentication dialog box for your repository, enter login information to continue.

7. When you have finished specifying the path you want to retrieve, click OK.
8 In the Manage Files Using Source Control dialog box, select the sandbox folder where you want to put the retrieved files, and click **Retrieve**.

**Related Examples**

- “Set Up Git Source Control” on page 29-27
- “Update Git File Status and Revision” on page 29-33
- “Branch and Merge with Git” on page 29-34
Update Git File Status and Revision

In this section...

“Refresh Status of Files” on page 29-33
“Update Revisions of Files” on page 29-33

Refresh Status of Files

To refresh the source control status of files, select one or more files in the Current Folder browser, right-click and select Source Control > Refresh Git status.

To refresh the status of all files in the repository, right-click the white space of the Current Folder browser and select Source Control > Refresh Git status.

Update Revisions of Files

To update all files in a repository, right-click in the Current Folder browser and select Source Control > Fetch.

Caution Ensure you have registered binary files with Git before using Fetch. If you do not, conflict markers can corrupt your files. For more information, see “Register Binary Files with Git” on page 29-29.

After clicking Fetch, you need to merge in the origin changes to your local branches. For next steps, see “Push and Fetch with Git” on page 29-38.

Related Examples

• “Clone from Git Repository” on page 29-31
• “Review Changes in Source Control” on page 29-7
Branch and Merge with Git

Create Branch

1. From within your Git repository folder, right-click the white space of the Current Folder browser and select Source Control > Manage Branches. In the Manage Branches dialog box, you can view, switch, create, and merge branches.

Tip You can inspect information about each commit node. Select a node in the Branch Browser diagram to view the author, date, commit message, and changed files.

The Branch Browser in this figure shows an example branch history.
2 Select a source for the new branch. Click a node in the Branch Browser diagram, or enter a unique identifier in the Source text box. You can enter a tag, branch name, or a unique prefix of the SHA1 hash (for example, 73c637 to identify a specific commit). Leave the default to create a branch from the head of the current branch.

3 Enter a name in the Branch name text box and click Create.

4 To work on the files on your new branch, switch your project to the branch.
In the **Branches** drop-down list, select the branch you want to switch to and click **Switch**.

5 Close the Manage Branches dialog box and work on the files on your branch.

For next steps, see “Push and Fetch with Git” on page 29-38.

**Switch Branch**

1 From within your Git repository folder, right-click the white space of the Current Folder browser and select **Source Control > Manage Branches**.

2 In the Manage Branches dialog box, in the **Branches** drop-down list, select the branch you want to and click **Switch**.

3 Close the Manage Branches dialog box and work on the files on your branch.

**Merge Branches**

Before you can merge branches, you must install command-line Git on your system path and register binary files to prevent Git from inserting conflict markers. See “Install Command-Line Git Client” on page 29-28.

1 From within your Git repository folder, right-click the white space of the Current Folder browser and select **Source Control** and **Manage Branches**.

2 In the Manage Branches dialog box, from the **Branches** drop-down list, select a branch you want to merge into the current branch, and click **Merge**.

3 Close the Manage Branches dialog box and work on the files on your branch.

If the branch merge causes a conflict that Git cannot resolve automatically, an error dialog box reports that automatic merge failed. Resolve the conflicts before proceeding.

**Keep Your Version**

1 To keep your version of the file, right-click the file and select **Mark Conflict Resolved**.

2 Click **Commit Modified Files** to commit your change that marks the conflict resolved.

**Compare Branch Versions**

If you merge a branch and there is a conflict in a file, Git marks the file as conflicted and does not modify the contents. Right-click the file and select **Source Control > View**
Conflicts. A comparison report opens that shows the differences between the file on your branch and the branch you want to merge into. Decide how to resolve the conflict. See “Resolve Source Control Conflicts” on page 29-9.

Revert to Head

1. From within your Git repository folder, right-click the white space of the Current Folder browser and select Source Control > Manage Branches.
2. In the Manage Branches dialog box, click Revert to Head to remove all local changes.

Delete Branches

1. In the Manage Branches dialog box under Branch Browser, expand the Branches drop-down list, and select the branch you want to delete.
2. On the far right, click the down arrow and select Delete Branch.

Caution  You cannot undo branch deletion.

Related Examples

- “Set Up Git Source Control” on page 29-27
- “Push and Fetch with Git” on page 29-38
- “Resolve Source Control Conflicts” on page 29-9
Push and Fetch with Git

Use this workflow to work with a remote repository. With Git, there is a two-step workflow: commit local changes, and then push to the remote repository. In MATLAB, the only access to the remote repository is through the **Push** and **Fetch** menu options. All other actions, such as **Compare to Ancestor** and **Commit**, use the local repository. This diagram represents the Git workflow.

**Push**

To commit all changes to the local repository, right-click the white space of the Current Folder browser and select **Source Control > Commit All to Git Repository**.

To send local commits to the remote repository, right-click in the Current Folder browser and select **Source Control > Push**. A message appears if you cannot push your changes directly because the repository has moved on. Right-click in the Current Folder browser and select **Source Control > Fetch** to fetch all changes from the remote repository. Merge branches and resolve conflicts, and then you can push your changes.

Using Git, you cannot add empty folders to source control, so you cannot select **Push** and then clone an empty folder. You can create an empty folder in MATLAB, but if you push changes and then sync a new sandbox, then the empty folder does not appear in the
new sandbox. To push empty folders to the repository for other users to sync, create a `gitignore` file in the folder and then push your changes.

**Fetch**

To fetch changes from the remote repository, right-click in the Current Folder browser and select **Source Control > Fetch**. Fetch updates all of the origin branches in the local repository. Your sandbox files do not change. You need to merge in the origin changes to your local branches.

For example, if you are on the master branch, get all changes from the master branch in the remote repository.

1. Right-click in the Current Folder browser and select **Source Control > Fetch**
2. Right-click in the Current Folder browser and select **Source Control > Manage Branches**.
3. In the Manage Branches dialog box, select `origin/master` in the **Branches** list, and click **Merge**.

The origin branch changes merge into the master branch in your sandbox.

**Related Examples**

- “Branch and Merge with Git” on page 29-34
- “Resolve Source Control Conflicts” on page 29-9
MSSCCI Source Control Interface

If you are a new user to source control, it is recommended that you select a source control system that is part of the MathWorks source control integration with the Current Folder browser, such as Subversion or Git. For more information, see SVN and Git “Source Control Integration” topics.

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 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® 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 MSSCCI Source Control from Editors” on page 29-58.
Set Up MSSCCI Source Control

If you are a new user to source control, it is recommended that you select a source control system that is part of the MathWorks source control integration with the Current Folder browser, such as Subversion or Git. For more information, see SVN and Git “Source Control Integration” topics.

In this section...

| “Create Projects in Source Control System” on page 29-41 |
| “Specify Source Control System with MATLAB Software” on page 29-43 |
| “Register Source Control Project with MATLAB Software” on page 29-44 |
| “Add Files to Source Control” on page 29-46 |

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.

![Set Working Folder 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.

**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 29-43.

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**.
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.
Check Files In and Out from MSSCCI Source Control

If you are a new user to source control, it is recommended that you select a source control system that is part of the MathWorks source control integration with the Current Folder browser, such as Subversion or Git. For more information, see SVN and Git “Source Control Integration” topics.

In this section...

“Check Files Into Source Control” on page 29-48
“Check Files Out of Source Control” on page 29-48
“Undoing the Checkout” on page 29-49

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 MSSCCI Source Control” on page 29-41.

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.

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.

**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.

![Undo checkout dialog box](image)

3 Click **OK**.
Additional MSSCCI Source Control Actions

If you are a new user to source control, it is recommended that you select a source control system that is part of the MathWorks source control integration with the Current Folder browser, such as Subversion or Git. For more information, see SVN and Git “Source Control Integration” topics.

In this section...

| “Getting the Latest Version of Files for Viewing or Compiling” on page 29-51 |
| “Removing Files from the Source Control System” on page 29-52 |
| “Showing File History” on page 29-53 |
| “Comparing the Working Copy of a File to the Latest Version in Source Control” on page 29-54 |
| “Viewing Source Control Properties of a File” on page 29-56 |
| “Starting the Source Control System” on page 29-56 |

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.
You can now open the file to view it, run the file, or check out the file for editing.

### 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**.
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.
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.
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.

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.
2. 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.
Access MSSCCI Source Control from Editors

If you are a new user to source control, it is recommended that you select a source control system that is part of the MathWorks source control integration with the Current Folder browser, such as Subversion or Git. For more information, see SVN and Git “Source Control Integration” topics.

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 29-44.
Troubleshoot MSSCCI Source Control Problems

If you are a new user to source control, it is recommended that you select a source control system that is part of the MathWorks source control integration with the Current Folder browser, such as Subversion or Git. For more information, see SVN and Git “Source Control Integration” topics.

**In this section...**

- “Source Control Error: Provider Not Present or Not Installed Properly” on page 29-59
- “Restriction Against @ Character” on page 29-60
- “Add to Source Control Is the Only Action Available” on page 29-60
- “More Solutions for Source Control Problems” on page 29-60

**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, 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\SccServerPath
```

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 Control, 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 29-44. You can then perform source control actions for all files in that project (folder).

**More Solutions for Source Control Problems**

Unit Testing

- “Write Script-Based Unit Tests” on page 30-2
- “Write Function-Based Unit Tests” on page 30-9
- “Write Simple Test Case Using Functions” on page 30-13
- “Write Test Using Setup and Teardown Functions” on page 30-18
- “Author Class-Based Unit Tests in MATLAB” on page 30-24
- “Write Simple Test Case Using Classes” on page 30-28
- “Write Setup and Teardown Code Using Classes” on page 30-32
- “Types of Qualifications” on page 30-36
- “Tag Unit Tests” on page 30-39
- “Write Tests Using Shared Fixtures” on page 30-44
- “Create Basic Custom Fixture” on page 30-48
- “Create Advanced Custom Fixture” on page 30-51
- “Create Basic Parameterized Test” on page 30-58
- “Create Advanced Parameterized Test” on page 30-64
- “Create Simple Test Suites” on page 30-72
- “Run Tests for Various Workflows” on page 30-75
- “Add Plugin to Test Runner” on page 30-79
- “Write Plugins to Extend TestRunner” on page 30-82
- “Create Custom Plugin” on page 30-86
- “Write Plugin to Save Diagnostic Details” on page 30-92
- “Analyze Test Case Results” on page 30-97
- “Analyze Failed Test Results” on page 30-100
- “Dynamically Filtered Tests” on page 30-103
Write Script-Based Unit Tests

This example shows how to write a script that tests a function that you create. The example function computes the angles of a right triangle, and you create a script-based unit test to test the function.

Create rightTri Function to Test

Create this function in a file, rightTri.m, in your current MATLAB® folder. This function takes lengths of two sides of a triangle as input and returns the three angles of the corresponding right triangle. The input sides are the two shorter edges of the triangle, not the hypotenuse.

```matlab
function angles = rightTri(sides)

A = atand(sides(1)/sides(2));
B = atand(sides(2)/sides(1));
hypotenuse = sides(1)/sind(A);
C = asind(hypotenuse*sind(A)/sides(1));

angles = [A B C];
end
```

Create Test Script

In your working folder, create a new script, rightTriTest.m. Each unit test checks a different output of the rightTri function. A test script must adhere to the following conventions:

- The name of the script file must start or end with the word 'test', which is case-insensitive.
- Place each unit test into a separate section of the script file. Each section begins with two percent signs (%), and the text that follows on the same line becomes the name of the test element. If no text follows the %, MATLAB assigns a name to the test. If MATLAB encounters a test failure, it still runs remaining tests.
- In a test script, the shared variable section consists of any code that appears before the first explicit code section (the first line beginning with %). Tests share the variables that you define in this section. Within a test, you can modify the values of
these variables. However, in subsequent tests, the value is reset to the value defined in the shared variables section.

• In the shared variables section (first code section), define any preconditions necessary for your tests. If the inputs or outputs do not meet this precondition, MATLAB does not run any of the tests. MATLAB marks the tests as failed and incomplete.

• When a script is run as a test, variables defined in one test are not accessible within other tests unless they are defined in the shared variables section (first code section). Similarly, variables defined in other workspaces are not accessible to the tests.

• If the script file does not include any code sections, MATLAB generates a single test element from the full contents of the script file. The name of the test element is the same as the script file name. In this case, if MATLAB encounters a failed test, it halts execution of the entire script.

In rightTriTest.m, write four tests to test the output of rightTri. Use the assert function to test the different conditions. In the shared variables section, define four triangle geometries and define a precondition that the rightTri function returns a right triangle.

```matlab
% test triangles
tri = [7 9];
triIso = [4 4];
tri306090 = [2 2*sqrt(3)];
triSkewed = [1 1500];

% preconditions
angles = rightTri(tri);
assert(angles(3) == 90,'Fundamental problem: rightTri not producing right triangle')

% Test 1: sum of angles
angles = rightTri(tri);
assert(sum(angles) == 180)

angles = rightTri(triIso);
assert(sum(angles) == 180)

angles = rightTri(tri306090);
assert(sum(angles) == 180)

angles = rightTri(triSkewed);
assert(sum(angles) == 180)
```
Test 1 tests the summation of the triangle angles. If the summation is not equal to 180 degrees, assert throws an error.

Test 2 tests that if two sides are equal, the corresponding angles are equal. If the non-right angles are not both equal to 45 degrees, the assert function throws an error.

Test 3 tests that if the triangle sides are 1 and $\sqrt{3}$, the angles are 30, 60, and 90 degrees. If this condition is not true, assert throws an error.

Test 4 tests the small-angle approximation. The small-angle approximation states that for small angles the sine of the angle in radians is approximately equal to the angle. If it is not true, assert throws an error.

**Run Tests**

Execute the runtests function to run the four tests in rightTriTest.m. The runtests function executes each test in each code section individually. If Test 1 fails, MATLAB still runs the remaining tests. If you execute rightTriTest as a script instead of by using runtests, MATLAB halts execution of the entire script if it encounters a failed assertion. Additionally, when you run tests using the runtests function, MATLAB provides informative test diagnostics.

result = runtests('rightTriTest');
The test for the 30-60-90 triangle and the test for the small-angle approximation fail in the comparison of floating-point numbers. Typically, when you compare floating-point values, you specify a tolerance for the comparison. In Test 3 and Test 4, MATLAB throws an error at the failed assertion and does not complete the test. Therefore, the test is marked as both Failed and Incomplete.

To provide diagnostic information (Error Details) that is more informative than 'Assertion failed' (Test 3), consider passing a message string to the assert function (as in Test 4). Or you can also consider using function-based unit tests.
**Revise Test to Use Tolerance**

Save `rightTriTest.m` as `rightTriTolTest.m`, and revise Test 3 and Test 4 to use a tolerance. In Test 3 and Test 4, instead of asserting that the angles are equal to an expected value, assert that the difference between the actual and expected values is less than or equal to a specified tolerance. Define the tolerance in the shared variables section of the test script so it is accessible to both tests.

For script-based unit tests, manually verify that the difference between two values is less than a specified tolerance. If instead you write a function-based unit test, you can access built-in constraints to specify a tolerance when comparing floating-point values.

```matlab
% test triangles
tri = [7 9];
triIso = [4 4];
tri306090 = [2 2*sqrt(3)];
triSkewed = [1 1500];

define an absolute tolerance
tol = 1e-10;

% preconditions
angles = rightTri(tri);
assert(angles(3) == 90,'Fundamental problem: rightTri not producing right triangle')

% Test 1: sum of angles
angles = rightTri(tri);
assert(sum(angles) == 180)
angles = rightTri(triIso);
assert(sum(angles) == 180)
angles = rightTri(tri306090);
assert(sum(angles) == 180)
angles = rightTri(triSkewed);
assert(sum(angles) == 180)

% Test 2: isosceles triangles
angles = rightTri(triIso);
assert(angles(1) == 45)
assert(angles(1) == angles(2))
```
%% Test 3: 30-60-90 triangle
angles = rightTri(tri306090);
assert(abs(angles(1)-30) <= tol)
assert(abs(angles(2)-60) <= tol)
assert(abs(angles(3)-90) <= tol)

%% Test 4: Small angle approximation
angles = rightTri(triSkewed);
smallAngle = (pi/180)*angles(1); % radians
approx = sin(smallAngle);
assert(abs(approx-smallAngle) <= tol, 'Problem with small angle approximation')

Rerun the tests.
result = runtests('rightTriTolTest');

Running rightTriTolTest
....
Done rightTriTolTest

All the tests pass.

Create a table of test results.

rt = table(result)

rt =

<table>
<thead>
<tr>
<th>Name</th>
<th>Passed</th>
<th>Failed</th>
<th>Incomplete</th>
</tr>
</thead>
<tbody>
<tr>
<td>'rightTriTolTest/Test1_SumOfAngles'</td>
<td>true</td>
<td>false</td>
<td>false</td>
</tr>
<tr>
<td>'rightTriTolTest/Test2_IsoscelesTriangles'</td>
<td>true</td>
<td>false</td>
<td>false</td>
</tr>
<tr>
<td>'rightTriTolTest/Test3_30_60_90Triangle'</td>
<td>true</td>
<td>false</td>
<td>false</td>
</tr>
<tr>
<td>'rightTriTolTest/Test4_SmallAngleApproximation'</td>
<td>true</td>
<td>false</td>
<td>false</td>
</tr>
</tbody>
</table>

See Also
assert | runtests
Related Examples

• “Write Function-Based Unit Tests” on page 30-9
Write Function-Based Unit Tests

In this section...

“Create Test Function” on page 30-9
“Run the Tests” on page 30-12
“Analyze the Results” on page 30-12

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 30-13 and “Types of Qualifications” on page 30-36. This is a typical example of skeletal local-test functions.

```
function testFunctionOne(testCase)
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 30-18.

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.

```matlab
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.

```matlab
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 \texttt{runtests} command with your MATLAB test file as input. For example:

\begin{verbatim}
results = runtests('exampleTest.m')
\end{verbatim}

Alternatively, you can run tests using the \texttt{run} function.

\begin{verbatim}
results = run(exampleTest)
\end{verbatim}

For more information on running tests see the \texttt{runtests} reference page and “Run Tests for Various Workflows” on page 30-75.

Analyze the Results

To analyze the test results, examine the output structure from \texttt{runtests} or \texttt{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 30-97 and “Analyze Failed Test Results” on page 30-100.

See Also

\texttt{functiontests} | \texttt{localfunctions} | \texttt{runtests}

Related Examples

- “Write Simple Test Case Using Functions” on page 30-13
- “Write Test Using Setup and Teardown Functions” on page 30-18
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.

```matlab
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.

```matlab
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.

```matlab
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.

```matlab
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(localfuntions);
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.

```matlab
results = runtests('solverTest.m')
```

Running `solverTest`

```
Verification failed in solverTest/testImaginarySolution.

Framework Diagnostic:
verifyEqual failed.
--> Complexity does not match.

Actual Complexity:
   Real
Expected Complexity:
   Complex

Actual Value:
   -1   -1
Expected Value:
   -1.000000000000000 + 3.000000000000000i -1.000000000000000 - 3.000000000000000i

Stack Information:
In C:\work\solverTest.m (testImaginarySolution) at 14
```

Done `solverTest`

```
Failure Summary:

<table>
<thead>
<tr>
<th>Name</th>
<th>Failed</th>
<th>Incomplete</th>
<th>Reason(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>solverTest/testImaginarySolution</td>
<td>X</td>
<td></td>
<td>Failed by verification.</td>
</tr>
</tbody>
</table>
```
results =

1x2 TestResult array with properties:

Name
Passed
Failed
Incomplete
Duration

Totals:
1 Passed, 1 Failed, 0 Incomplete.
0.043751 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

More About
• “Write Function-Based Unit Tests” on page 30-9
• “Types of Qualifications” on page 30-36
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.

```matlab
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.

```matlab
function f = createFigure
f = figure;
ax = axes('Parent', f);
cylinder(ax,10)
h = findobj(ax,'Type','surface');
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.

```matlab
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, `verifyLessThanOrEqual` and `verifyGreaterThanOrEqual`, 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 = testCase.TestData.Axes.XLim;
    verifyLessThanOrEqual(testCase, xlim(1), -10,...
        'Minimum x-limit was not small enough')
    verifyGreaterThanOrEqual(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 = h.FaceColor;
    verifyEqual(testCase, co, [1 0 0], 'FaceColor is incorrect')
end

Now the axesPropertiesTest.m file is complete with a main function, 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.
The fresh fixture teardown closes the figure.
The fresh fixture setup opens the saved figure and finds the handles.
The `surfaceColorTest` test is run.
The fresh fixture teardown closes the figure.
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.

```matlab
results = runtests('axesPropertiesTest.m')
```

Running `axesPropertiesTest`
..
Done `axesPropertiesTest`
```
results =
```
```
1x2 TestResult array with properties:

<table>
<thead>
<tr>
<th>Name</th>
<th>Passed</th>
<th>Failed</th>
<th>Incomplete</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Totals:
2 Passed, 0 Failed, 0 Incomplete.
1.6127 seconds testing time.

Create Table of Test Results

To access functionality available to tables, create one from the `TestResult` object.

```matlab
rt = table(results)
```

```matlab
rt =
```
```
```

<table>
<thead>
<tr>
<th>Name</th>
<th>Passed</th>
<th>Failed</th>
<th>Incomplete</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Export test results to an Excel® spreadsheet.

\[
\text{writetable(rt,'myTestResults.xls')}
\]

Sort the test results by increasing duration.

\[
\text{sortrows(rt,'Duration')}
\]

\[
\begin{array}{cccc}
\text{Name} & \text{Passed} & \text{Failed} & \text{Incomplete} & \text{Duration} \\
\hline
\text{axesPropertiesTest/surfaceColorTest} & \text{true} & \text{false} & \text{false} & 0.76662 \\
\text{axesPropertiesTest/testDefaultXLim} & \text{true} & \text{false} & \text{false} & 0.84605 \\
\end{array}
\]

**See Also**

- `matlab.unittest.constraints`
- `matlab.unittest.test.fixtures`

**More About**

- “Write Function-Based Unit Tests” on page 30-9
- “Types of Qualifications” on page 30-36
Author Class-Based Unit Tests in MATLAB

To test a MATLAB program, write a unit test using qualifications that are methods for testing values and responding to failures.

In this section...

“The Test Class Definition” on page 30-24
“The Unit Tests” on page 30-24
“Additional Features for Advanced Test Classes” on page 30-26

The Test Class Definition

A test class must inherit from `matlab.unittest.TestCase` and contain a methods block with the Test attribute. The methods block contains functions, each of which is a unit test. A general, basic class definition follows.

```matlab
classdef MyComponentTest < matlab.unittest.TestCase
    methods (Test)
    % includes unit test functions
    end
end
```

The Unit Tests

A unit test is a method that determines the correctness of a unit of software. Each unit test is contained within a methods block. The function must accept a `TestCase` instance as an input.

```matlab
classdef MyComponentTest < matlab.unittest.TestCase
    methods (Test)
    % Test Function
    function testASolution(testCase)
        % Exercise function under test
        % act = the value from the function under test
    end
end
```
%% Verify using test qualification
% exp = your expected value
% testCase.<qualification method>(act,exp);
end
Qualifications are methods for testing values and responding to failures. This table lists the types of qualifications.

<table>
<thead>
<tr>
<th>Qualification</th>
<th>Description</th>
<th>MATLAB Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verifiable</td>
<td>Use this qualification to produce and record failures without throwing an exception. The remaining tests run to completion.</td>
<td>matlab.unittest.qualifications.Verifiable</td>
</tr>
<tr>
<td>Assumable</td>
<td>Use this qualification to ensure that a test runs only when certain preconditions are satisfied. However, running the test without satisfying the preconditions does not produce a test failure. When an assumption failure occurs, the testing framework marks the test as filtered.</td>
<td>matlab.unittest.qualifications.Assumable</td>
</tr>
<tr>
<td>Assertable</td>
<td>Use this qualification to ensure that the preconditions of the current test are met.</td>
<td>matlab.unittest.qualifications.Assertable</td>
</tr>
<tr>
<td>Fatal Assertable</td>
<td>Use this qualification when the failure at the assertion point renders the remainder of the current test method invalid or the state is unrecoverable.</td>
<td>matlab.unittest.qualifications.FatalAssertable</td>
</tr>
</tbody>
</table>

The MATLAB Unit Testing Framework provides approximately 25 qualification methods for each type of qualification. For example, use `verifyClass` or `assertClass` to test
that a value is of an expected class, and use `assumeTrue` or `fatalAssertTrue` to test if the actual value is true. For a summary of qualification methods, see “Types of Qualifications” on page 30-36.

Often, each unit test function obtains an actual value by exercising the code that you are testing and defines the associated expected value. For example, if you are testing the `plus` function, the actual value might be `plus(2,3)` and the expected value 5. Within the test function, you pass the actual and expected values to a qualification method. For example:

```matlab
testCase.verifyEqual(plus(2,3),5)
```

For an example of a basic unit test, see “Write Simple Test Case Using Classes” on page 30-28.

**Additional Features for Advanced Test Classes**

The MATLAB Unit Testing Framework includes several features for authoring more advanced test classes:

- Setup and teardown methods blocks to implicitly set up the pretest state of the system and return it to the original state after running the tests. For an example of a test class with setup and teardown code, see “Write Setup and Teardown Code Using Classes” on page 30-32.
- Advanced qualification features, including actual value proxies, test diagnostics, and a constraint interface. For more information, see `matlab.unittest.constraints` and `matlab.unittest.diagnostics`.
- Parameterized tests to combine and execute tests on the specified lists of parameters. For more information, see “Create Basic Parameterized Test” on page 30-58 and “Create Advanced Parameterized Test” on page 30-64.
- Ready-to-use fixtures for handling the setup and teardown of frequently used testing actions and for sharing fixtures between classes. For more information, see `matlab.unittest.fixtures` and “Write Tests Using Shared Fixtures” on page 30-44.
- Ability to create custom test fixtures. For more information see “Create Basic Custom Fixture” on page 30-48 and “Create Advanced Custom Fixture” on page 30-51.

**Related Examples**

- “Write Simple Test Case Using Classes” on page 30-28
• “Write Setup and Teardown Code Using Classes” on page 30-32
• “Create Simple Test Suites” on page 30-72
• “Run Tests for Various Workflows” on page 30-75
• “Analyze Test Case Results” on page 30-97
• “Analyze Failed Test Results” on page 30-100
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.

```matlab
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.

```matlab
classdef SolverTest < matlab.unittest.TestCase
    methods (Test)
      end
    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.

```matlab
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.

```matlab
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

**Run Tests in SolverTest Test Case**

Run all the tests in the SolverTest class definition file.

```matlab
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.
0.77015 seconds testing time.

Run Single Test Method

To run the single test, testRealSolution:

```matlab
testCase = SolverTest;
res = run(testCase,'testRealSolution')
```

Running SolverTest
.
Done SolverTest
__________

res =

TestResult with properties:

    Name: 'SolverTest/testRealSolution'
    Passed: 1
    Failed: 0
    Incomplete: 0
    Duration: 0.0085

Totals:
1 Passed, 0 Failed, 0 Incomplete.
0.0085028 seconds testing time.

Related Examples

- “Author Class-Based Unit Tests in MATLAB” on page 30-24
- “Write Setup and Teardown Code Using Classes” on page 30-32
- “Analyze Test Case Results” on page 30-97
- “Create Simple Test Suites” on page 30-72
Write Setup and Teardown Code Using Classes

In this section...

“Test Fixtures” on page 30-32
“Test Case with Method-Level Setup Code” on page 30-32
“Test Case with Class-Level Setup Code” on page 30-33

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.

The testing framework guarantees that `TestMethodSetup` and `TestClassSetup` methods of superclasses are executed before those in subclasses.

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. As discussed previously, you should try to define teardown activities with the `addTeardown` method. However, for illustrative purposes, this example shows the implementation of a `TestMethodTeardown` block.

```matlab
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 = testCase.TestFigure.CurrentPoint;
    testCase.verifyEqual(cp, [0 0], ...
                       'Default current point is incorrect')
  end

  function defaultCurrentObject(testCase)
    import matlab.unittest.constraints.IsEmpty
    co = 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. Typically, you set up the path using a PathFixture. this example performs the setup and teardown activities manually for illustrative purposes.

classdef BankAccountTest < matlab.unittest.TestCase
    % Tests the BankAccount class.
    methods (TestClassSetup)
        function addBankAccountClassToPath(testCase)
            p = path;
            testCase.addTeardown(@path,p);
            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 testDeposit(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

See Also
matlab.unittest.TestCase | addTeardown

Related Examples
• “Author Class-Based Unit Tests in MATLAB” on page 30-24
• “Write Simple Test Case Using Classes” on page 30-28
## 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.

<table>
<thead>
<tr>
<th>Type of Test</th>
<th>Verification</th>
<th>Assumption</th>
<th>Assertion</th>
<th>Fatal Assertion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value is true.</td>
<td>verifyTrue</td>
<td>assumeTrue</td>
<td>assertTrue</td>
<td>fatalAssertTrue</td>
</tr>
<tr>
<td>Value is false.</td>
<td>verifyFalse</td>
<td>assumeFalse</td>
<td>assertFalse</td>
<td>fatalAssertFalse</td>
</tr>
<tr>
<td>Value is equal to specified value.</td>
<td>verifyEqual</td>
<td>assumeEqual</td>
<td>assertEqual</td>
<td>fatalAssertEqual</td>
</tr>
<tr>
<td>Value is not equal to specified value.</td>
<td>verifyNotEqual</td>
<td>assumeNotEqual</td>
<td>assertNotEqual</td>
<td>fatalAssertNotEqual</td>
</tr>
<tr>
<td>Two values are handles to same instance.</td>
<td>verifySameHand</td>
<td>assumeSameHand</td>
<td>assertSameHand</td>
<td>fatalAssertSameHandle</td>
</tr>
<tr>
<td>Value is not handle to specified instance.</td>
<td>verifyNotSameHa</td>
<td>assumeNotSameHs</td>
<td>assertNotSameHs</td>
<td>fatalAssertNotSameHandle</td>
</tr>
<tr>
<td>Function returns true when evaluated.</td>
<td>verifyReturnsTrue</td>
<td>assumeReturnsTrue</td>
<td>assertReturnsTrue</td>
<td>fatalAssertReturnsTrue</td>
</tr>
<tr>
<td>Test produces unconditional failure.</td>
<td>verifyFail</td>
<td>assumeFail</td>
<td>assertFail</td>
<td>fatalAssertFail</td>
</tr>
<tr>
<td>Type of Test</td>
<td>Verification</td>
<td>Assumption</td>
<td>Assertion</td>
<td>Fatal Assertion</td>
</tr>
<tr>
<td>--------------------------------------------------</td>
<td>----------------------</td>
<td>---------------------</td>
<td>--------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>Value meets given constraint.</td>
<td>verifyThat</td>
<td>assumeThat</td>
<td>assertThat</td>
<td>fatalAssertThat</td>
</tr>
<tr>
<td>Value is greater than specified value.</td>
<td>verifyGreaterThan</td>
<td>assumeGreaterThan</td>
<td>assertGreaterThan</td>
<td>fatalAssertGreaterThan</td>
</tr>
<tr>
<td>Value is greater than or equal to specified value.</td>
<td>verifyGreaterThan</td>
<td>assumeGreaterThan</td>
<td>assertGreaterThan</td>
<td>fatalAssertGreaterThan</td>
</tr>
<tr>
<td>Value is less than specified value.</td>
<td>verifyLessThan</td>
<td>assumeLessThan</td>
<td>assertLessThan</td>
<td>fatalAssertLessThan</td>
</tr>
<tr>
<td>Value is less than or equal to specified value.</td>
<td>verifyLessThanOrEqualTo</td>
<td>assumeLessThanOrEqualTo</td>
<td>assertLessThanOrEqualTo</td>
<td>fatalAssertLessThanOrEqualTo</td>
</tr>
<tr>
<td>Value is exact specified class.</td>
<td>verifyClass</td>
<td>assumeClass</td>
<td>assertClass</td>
<td>fatalAssertClass</td>
</tr>
<tr>
<td>Value is object of specified type.</td>
<td>verifyInstanceOf</td>
<td>assumeInstanceOf</td>
<td>assertInstanceOf</td>
<td>fatalAssertInstanceOf</td>
</tr>
<tr>
<td>Value is empty.</td>
<td>verifyEmpty</td>
<td>assumeEmpty</td>
<td>assertEmpty</td>
<td>fatalAssertEmpty</td>
</tr>
<tr>
<td>Value is not empty.</td>
<td>verifyNotEmpty</td>
<td>assumeNotEmpty</td>
<td>assertNotEmpty</td>
<td>fatalAssertNotEmpty</td>
</tr>
<tr>
<td>Value has specified size.</td>
<td>verifySize</td>
<td>assumeSize</td>
<td>assertSize</td>
<td>fatalAssertSize</td>
</tr>
<tr>
<td>Value has specified length.</td>
<td>verifyLength</td>
<td>assumeLength</td>
<td>assertLength</td>
<td>fatalAssertLength</td>
</tr>
<tr>
<td>Value has specified element count.</td>
<td>verifyNumElements</td>
<td>assumeNumElements</td>
<td>assertNumElements</td>
<td>fatalAssertNumElements</td>
</tr>
<tr>
<td>String contains specified string.</td>
<td>verifySubstring</td>
<td>assumeSubstring</td>
<td>assertSubstring</td>
<td>fatalAssertSubstring</td>
</tr>
<tr>
<td>String matches specified regular expression.</td>
<td>verifyMatches</td>
<td>assumeMatches</td>
<td>assertMatches</td>
<td>fatalAssertMatches</td>
</tr>
<tr>
<td>Type of Test</td>
<td>Verification</td>
<td>Assumption</td>
<td>Assertion</td>
<td>Fatal Assertion</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>---------------</td>
<td>---------------</td>
<td>--------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Function throws specified exception.</td>
<td>verifyError</td>
<td>assumeError</td>
<td>assertError</td>
<td>fatalAssertError</td>
</tr>
<tr>
<td>Function issues specified warning.</td>
<td>verifyWarning</td>
<td>assumeWarning</td>
<td>assertWarning</td>
<td>fatalAssertWarning</td>
</tr>
<tr>
<td>Function issues no warnings.</td>
<td>verifyWarningF</td>
<td>assumeWarningF</td>
<td>assertWarningF</td>
<td>fatalAssertWarningFree</td>
</tr>
</tbody>
</table>

**See Also**
Assertable | Assumable | FatalAssertable | matlab.unittest.qualifications | Verifiable
Tag Unit Tests

You can use test tags to group tests into categories and then run tests with specified tags. Typical test tags identify a particular feature or describe the type of test.

<table>
<thead>
<tr>
<th>In this section...</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Tag Tests” on page 30-39</td>
</tr>
<tr>
<td>“Select and Run Tests” on page 30-40</td>
</tr>
</tbody>
</table>

Tag Tests

To define test tags, use a cell array of meaningful strings. For example, TestTags = {'Unit'} or TestTags = {'Unit','FeatureA'}.

- To tag individual tests, use the TestTags method attribute.
- To tag all the tests within a class, use the TestTags class attribute. If you use the TestTags class attribute in a superclass, tests in the subclasses inherit the tags.

This sample test class, `ExampleTagTest`, uses the TestTags method attribute to tag individual tests.

```matlab
classdef ExampleTagTest < matlab.unittest.TestCase
    methods (Test)
        function testA (testCase)
            % test code
        end
    end
    methods (Test, TestTags = {'Unit'})
        function testB (testCase)
            % test code
        end
        function testC (testCase)
            % test code
        end
    end
    methods (Test, TestTags = {'Unit','FeatureA'})
        function testD (testCase)
            % test code
        end
    end
end
```
Several of the tests in class ExampleTagTest are tagged. For example, testD is tagged with 'Unit' and 'FeatureA'. One test, testA, is not tagged.

This sample test class, ExampleTagClassTest, uses a TestTags class attribute to tag all the tests within the class, and a TestTags method attribute to add tags to individual tests.

classdef (TestTags = {'FeatureB'}) ...  
    ExampleTagClassTest < matlab.unittest.TestCase
    methods (Test)  
        function testF (testCase)  
            % test code  
        end  
    end
    methods (Test, TestTags = {'FeatureC', 'System'})  
        function testG (testCase)  
            % test code  
        end  
    end
    methods (Test, TestTags = {'System', 'FeatureA'})  
        function testH (testCase)  
            % test code  
        end  
    end
end

each test in class ExampleTagClassTest is tagged with 'FeatureB'. Additionally, individual tests are tagged with various tags including 'FeatureA', 'FeatureC', and 'System'.

Select and Run Tests

There are three ways of selecting and running tagged tests:

• “Run Selected Tests Using runtests” on page 30-41
• “Select Tests Using TestSuite Methods” on page 30-41
• “Select Tests Using HasTag Selector” on page 30-42

**Run Selected Tests Using runtests**

Use the `runtests` function to select and run tests without explicitly creating a test suite. Select and run all the tests from `ExampleTagTest` and `ExampleTagClassTest` that include the 'FeatureA' tag.

```matlab
results = runtests({'ExampleTagTest','ExampleTagClassTest'},'Tag','FeatureA');
```

Running `ExampleTagTest` .
Done `ExampleTagTest`

Running `ExampleTagClassTest` .
Done `ExampleTagClassTest`

`runtests` selected and ran three tests.

Display the results in a table.

```matlab
table(results)
```

```
ans =

<table>
<thead>
<tr>
<th>Name</th>
<th>Passed</th>
<th>Failed</th>
<th>Incomplete</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>'ExampleTagTest/testE'</td>
<td>true</td>
<td>false</td>
<td>false</td>
<td>0.00032102</td>
</tr>
<tr>
<td>'ExampleTagTest/testD'</td>
<td>true</td>
<td>false</td>
<td>false</td>
<td>0.00010879</td>
</tr>
<tr>
<td>'ExampleTagClassTest/testH'</td>
<td>true</td>
<td>false</td>
<td>false</td>
<td>0.00028554</td>
</tr>
</tbody>
</table>
```

The selected tests are `testE` and `testD` from `ExampleTagTest`, and `testH` from `ExampleTagClassTest`.

**Select Tests Using TestSuite Methods**

Create a suite of tests from the `ExampleTagTest` class that are tagged with 'FeatureA'.

```matlab
import matlab.unittest.TestSuite
sA = TestSuite.fromClass('ExampleTagTest','Tag','FeatureA');
```
Create a suite of tests from the `ExampleTagClassTest` class that are tagged with 'FeatureC'.

```matlab
sB = TestSuite.fromFile('ExampleTagClassTest.m','Tag','FeatureC');
```

Concatenate the suite and view the names of the tests.

```matlab
suite = [sA sB];
{suite.Name}'
```

```
ans =
    'ExampleTagTest/testE'
    'ExampleTagTest/testD'
    'ExampleTagClassTest/testG'
```

**Select Tests Using HasTag Selector**

Create a suite of all the tests from the `ExampleTagTest` and `ExampleTagClassTest` classes.

```matlab
import matlab.unittest.selectors.HasTag
sA = TestSuite.fromClass('ExampleTagTest');
sB = TestSuite.fromFile('ExampleTagClassTest.m');
suite = [sA sB];
```

Select all the tests that do not have tags.

```matlab
s1 = suite.selectIf(~HasTag)
```

```
s1 =
    Test with properties:
        Name: 'ExampleTagTest/testA'
        Parameterization: []
        SharedTestFixtures: []
        Tags: {0x1 cell}

    Tests Include:
        0 Parameterizations, 0 Shared Test Fixture Classes, 0 Tags.
```

Select all the tests with the 'Unit' tag and display their names.

```matlab
s2 = suite.selectIf(HasTag('Unit'));
```
Select all the tests with the 'FeatureB' or 'System' tag using a constraint.

```matlab
import matlab.unittest.constraints.IsEqualTo
constraint = IsEqualTo('FeatureB') | IsEqualTo('System');
s3 = suite.selectIf(HasTag(constraint));
{s3.Name}'
ans =
    'ExampleTagTest/testE'
    'ExampleTagClassTest/testH'
    'ExampleTagClassTest/testG'
    'ExampleTagClassTest/testF'
```

See Also
- `matlab.unittest.selectors.HasTag`
- `matlab.unittest.TestSuite`
- `matlab.unittest.TestCase`
- `matlab.unittest.constraints`
- `runtests`
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,...
```
Write Tests Using Shared Fixtures

(x^2 + 1) + (5x + 2) = x^2 + 5x + 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) * (5x + 2) = 5x^3 + 2x^2 + 15x + 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

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```matlab
function testDeposit(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

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.

```matlab
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_oop\examples' to
__________

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
matlab.unittest.fixtures | PathFixture | TestCase
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.unittestfixtures.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.unittestfixtures.Fixture
    properties (Access=private)
        OriginalFormat
    end
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

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 30-51
• “Write Tests Using Shared Fixtures” on page 30-44
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.

```matlab
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.

```matlab
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.

```matlab
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
    end
function setup(fixture)
    originalUserName = getenv('UserName');
    fixture.testEmpty(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

methods (Access=protected)
    function bool = isCompatible(fixture, other)
        bool = strcmp(fixture.UserName, other.UserName);
    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.

```matlab
classdef (SharedTestFixtures={...
    UserNameEnvironmentVariableFixture('David')}) ...
    testA < matlab.unittest.TestCase
    methods (Test)
    function t1(~)
        fprintf(1, 'Current UserName: "%s", getenv('UserName'))
    end
end
```

Create testB.m as follows.

```matlab
classdef (SharedTestFixtures={...
    UserNameEnvironmentVariableFixture('Andy')}) ...
    testB < matlab.unittest.TestCase
    methods (Test)
    function t1(~)
        fprintf(1, 'Current UserName: "%s", getenv('UserName'))
    end
end
```

Create testC.m as follows.

```matlab
classdef (SharedTestFixtures={...
    UserNameEnvironmentVariableFixture('Andy')}) ...
    testC < matlab.unittest.TestCase
    methods (Test)
    function t1(~)
        fprintf(1, 'Current UserName: "%s", getenv('UserName'))
    end
end
```

At the command prompt, run the tests.

```matlab
runtests({'testA','testB','testC'});
```
Setting up UserNameEnvironmentVariableFixture
Done setting up UserNameEnvironmentVariableFixture: Set the UserName environment variable to "David".

Running testA
Current UserName: "David".
Done testA

Tearing down UserNameEnvironmentVariableFixture
Done tearing down UserNameEnvironmentVariableFixture: Restored the UserName environment variable to "Kim".

Setting up UserNameEnvironmentVariableFixture
Done setting up UserNameEnvironmentVariableFixture: Set the UserName environment variable to "Andy".

Running testB
Current UserName: "Andy".
Done testB

Running testC
Current UserName: "Andy".
Done testC

Tearing down UserNameEnvironmentVariableFixture
Done tearing down UserNameEnvironmentVariableFixture: Restored the UserName environment variable to "Kim".

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

    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 30-48
• “Write Tests Using Shared Fixtures” on page 30-44
Create Basic Parameterized Test

This example shows how to create a basic parameterized test.

Create Function to Test

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.

```matlab
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.

```matlab
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.

```matlab
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.

```matlab
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 testRemainPixels 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'.

```matlab
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.

```matlab
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);
```
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

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)'

30-61
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`.

```matlab
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 30-64
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.

<table>
<thead>
<tr>
<th>Parameterization Level</th>
<th>Method Attribute</th>
<th>Property Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test level</td>
<td>Test</td>
<td>TestParameter</td>
</tr>
<tr>
<td>Method setup level</td>
<td>TestMethodSetup</td>
<td>MethodSetupParameter</td>
</tr>
<tr>
<td>Class setup level</td>
<td>TestClassSetup</td>
<td>ClassSetupParameter</td>
</tr>
</tbody>
</table>

At each test level, you can use the ParameterCombination method attribute to specify the test parameterization.

<table>
<thead>
<tr>
<th>ParameterCombination Attribute</th>
<th>Method Invocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>'exhaustive' (default)</td>
<td>Methods are invoked for all combinations of parameters. The test framework uses this default combination if you do not specify the ParameterCombination attribute.</td>
</tr>
<tr>
<td>'sequential'</td>
<td>Methods are invoked with corresponding values from each parameter. Each parameter must contain the same number of values.</td>
</tr>
<tr>
<td>'pairwise'</td>
<td>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.</td>
</tr>
</tbody>
</table>

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.

```matlab
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.

```matlab
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.

```matlab
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 testRepeatble 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.

```matlab
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 givenTestClassSetup 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**

```matlab
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

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

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
SharedTestFixture
Tags

Tests Include:
17 Unique Parameterizations, 0 Shared Test Fixture Classes, 0 Tags.

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=single)

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  Tags

Tests Include:
    9 Unique Parameterizations, 0 Shared Test Fixture Classes, 0 Tags.

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=small)'
'TestRand[generator=combRecursive]/[seed=value2]testRepeatable(dim1=small,dim2=small,dim3=small)'
'TestRand[generator=combRecursive]/[seed=value3]testRepeatable(dim1=small,dim2=small,dim3=small)'
'TestRand[generator=multFibonacci]/[seed=value1]testRepeatable(dim1=small,dim2=small,dim3=small)'
'TestRand[generator=multFibonacci]/[seed=value2]testRepeatable(dim1=small,dim2=small,dim3=small)'
'TestRand[generator=multFibonacci]/[seed=value3]testRepeatable(dim1=small,dim2=small,dim3=small)'

Run the test suite.

suite3.run;
Running TestRand
............
Done TestRand

Run All Double Precision Tests

At the command prompt, run all the test elements from TestRand.m that use the parameter name 'double'.

runtests('TestRand','ParameterName','double');
Running TestRand
............
............
............
............
............
............
............
.
Done TestRand

See Also
matlab.unittest.TestSuite | matlab.unittest.TestCase | matlab.unittest.selectors

Related Examples
• “Create Basic Parameterized Test” on page 30-58
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.

```matlab
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.

```matlab
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
```
Create Simple Test Suites

end
end
end

Import TestSuite Class

At the command prompt, add the `matlab.unittest.TestSuite` class to the current import list.

```matlab
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.

```matlab
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.

```matlab
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`

```matlab
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 30-28
Run Tests for Various Workflows

In this section...

“Set Up Example Tests” on page 30-75
“Run All Tests in Class or Function” on page 30-75
“Run Single Test in Class or Function” on page 30-76
“Run Test Suites by Name” on page 30-76
“Run Test Suites from Test Array” on page 30-77
“Run Tests with Customized Test Runner” on page 30-77

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”.

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.

```matlab
% 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.

```matlab
% 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 singleTestCase 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 \texttt{pwd} as input to the \texttt{runtests} function.

\begin{verbatim}
runtests(pwd);
\end{verbatim}

Alternatively, you can explicitly create \texttt{Test} arrays and use the \texttt{run} method to run them.

\section*{Run Test Suites from Test Array}

You can explicitly create \texttt{Test} arrays and use the \texttt{run} method in the \texttt{TestSuite} class to run them. Using this approach, you explicitly define \texttt{TestSuite} objects and, therefore, can examine the contents. The \texttt{runtests} function does not return the \texttt{TestSuite} object.

\begin{verbatim}
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);
\end{verbatim}

Since the suite is explicitly defined, it is easy for you to perform further analysis on the suite, such as rerunning failed tests.

\begin{verbatim}
failedTests = fullSuite([result.Failed]);
result2 = run(failedTests);
\end{verbatim}

\section*{Run Tests with Customized Test Runner}

You can specialize the test running by defining a custom test runner and adding plugins. The \texttt{run} method of the \texttt{TestRunner} class operates on a \texttt{TestSuite} object.

\begin{verbatim}
import matlab.unittest.TestRunner
import matlab.unittest.TestSuite
import matlab.unittest.plugins.TestRunProgressPlugin

% Generate TestSuite.
s1 = TestSuite.fromClass('DocPolynomTest');
s2 = TestSuite.fromFile('axesPropertiesTest.m');
suite = [s1 s2];
\end{verbatim}
% Create silent test runner.
runner = TestRunner.withNoPlugins;

% Add plugin to display test progress.
runner.addPlugin(TestRunProgressPlugin.withVerbosity(2))

% Run tests using customized runner.
result = run(runner,[suite]);

See Also
matlab.unittest.TestCase.run | matlab.unittest.TestSuite.run | matlab.unittest.TestRunner.run | runtests
Add Plugin to Test Runner

This example shows how to add a plugin to the test runner. The `matlab.unittest.plugins.TestRunProgressPlugin` 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)
            p = path;
            testCase.addTeardown(@path,p);
            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 testDeposit(testCase)
            b = BankAccount(1234, 100);
            b.deposit(25);
            testCase.verifyEqual(b.AccountBalance, 125);
        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

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, TestRunProgressPlugin.

import matlab.unittest.plugins.TestRunProgressPlugin
Add Plugin to Test Runner

```matlab
runner.addPlugin(TestRunProgressPlugin.withVerbosity(2))
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 30-82
“Extending Test Level Plugin Methods” on page 30-83
“Extending Test Class Level Plugin Methods” on page 30-83
“Extending Test Suite Level Plugin Methods” on page 30-84

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.

<table>
<thead>
<tr>
<th>Type of Method</th>
<th>Test Level Falls Within Scope of runTest</th>
</tr>
</thead>
<tbody>
<tr>
<td>creation method</td>
<td>createTestMethodInstance</td>
</tr>
<tr>
<td>setup method</td>
<td>setupTestMethod</td>
</tr>
<tr>
<td>run method</td>
<td>runTestMethod</td>
</tr>
<tr>
<td>teardown method</td>
<td>teardownTestMethod</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Type of Method</th>
<th>Test Class Level Falls Within Scope of runTestClass</th>
</tr>
</thead>
<tbody>
<tr>
<td>creation method</td>
<td>createTestClassInstance</td>
</tr>
<tr>
<td>setup method</td>
<td>setupTestClass</td>
</tr>
<tr>
<td>run method</td>
<td>runTest</td>
</tr>
<tr>
<td>teardown method</td>
<td>tearDownTestClass</td>
</tr>
</tbody>
</table>

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 theTestClassSetup 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. These methods fall within the scope of `runTestSuite`.

<table>
<thead>
<tr>
<th>Type of Method</th>
<th>Test Level Falls Within Scope of <code>runTestSuite</code></th>
</tr>
</thead>
<tbody>
<tr>
<td>creation method</td>
<td><code>createSharedTestFixture</code></td>
</tr>
<tr>
<td>setup method</td>
<td><code>setupSharedTestFixture</code></td>
</tr>
<tr>
<td>run method</td>
<td><code>runTestClass</code></td>
</tr>
<tr>
<td>teardown method</td>
<td><code>teardownSharedTestFixture</code></td>
</tr>
</tbody>
</table>

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`
Write Plugins to Extend TestRunner

| matlab.unittest.TestRunner | matlab.unittest.fixtures.Fixture | addlistener

**Related Examples**

- “Create Custom Plugin” on page 30-86
- “Write Plugin to Save Diagnostic Details” on page 30-92
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.

```matlab
properties
    NumPassingAssertions = 0;
    NumFailingAssertions = 0;
end
```

Extend Running of TestSuite

Implement the runTestSuite method in a methods block with protected access.

```matlab
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
```

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.

```matlab
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

**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.

```matlab
methods (Access = protected)
  function runTest(plugin, pluginData)
    fprintf('### Running test: %s
', 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.

```matlab
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
', repmat('_', 1, 30))
    fprintf('Total Assertions: %d
', ...
      plugin.NumPassingAssertions + plugin.NumFailingAssertions)
    fprintf('	%d Passed, %d Failed
', ...
      plugin.NumPassingAssertions, plugin.NumFailingAssertions)
  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

        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

Create Example Test Class

In your working folder, create the file `ExampleTest.m` containing the following test class.

```matlab
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

Related Examples
• “Write Plugins to Extend TestRunner” on page 30-82
• “Write Plugin to Save Diagnostic Details” on page 30-92
Write Plugin to Save Diagnostic Details

This example shows how to create a custom plugin to save diagnostic details. The plugin listens for test failures and saves diagnostic information so you can access it after the framework completes the tests.

Create Plugin

In a file in your working folder, create a class, myPlugin, that inherits from the matlab.unittest.plugins.TestRunnerPlugin class. In the plugin class:

- Define a FailedTestData property on the plugin that stores information from failed tests.
- Override the default createTestMethodInstance method of TestRunnerPlugin to listen for assertion, fatal assertion, and verification failures, and to record relevant information.
- Override the default runTestSuite method of TestRunnerPlugin to initialize the FailedTestData property value. If you do not initialize value of the property, each time you run the tests using the same test runner, failed test information is appended to the FailedTestData property.
- Define a helper function, recordData, to save information about the test failure as a table.

The plugin saves information contained in the PluginData and QualificationEventData objects. It also saves the type of failure and timestamp.

```matlab
classdef DiagnosticRecorderPlugin < matlab.unittest.plugins.TestRunnerPlugin
    properties
        FailedTestData
    end

    methods (Access = protected)
        function runTestSuite(plugin, pluginData)
            plugin.FailedTestData = [];
            runTestSuite@...
                matlab.unittest.plugins.TestRunnerPlugin(plugin, pluginData);
        end

        function testCase = createTestMethodInstance(plugin, pluginData)
            testCase = createTestMethodInstance@...
```
Write Plugin to Save Diagnostic Details

matlab.unittest.plugins.TestRunnerPlugin(plugin, pluginData);

testName = pluginData.Name;
testCase.addlistener('AssertionFailed', ...
    @(-,event)plugin.recordData(event,testName, 'Assertion'));
testCase.addlistener('FatalAssertionFailed', ...
    @(-,event)plugin.recordData(event,testName, 'Fatal Assertion'));
testCase.addlistener('VerificationFailed', ...
    @(-,event)plugin.recordData(event,testName, 'Verification'));
end
end
end

methods (Access = private)
    function recordData(plugin,eventData,name,failureType)
        s.Name = {name};
        s.Type = {failureType};
        s.TestDiagnostics = eventData.TestDiagnosticResult;
        s.FrameworkDiagnostics = eventData.FrameworkDiagnosticResult;
        s.Stack = eventData.Stack;
        s.Timestamp = datetime;

        plugin.FailedTestData = [plugin.FailedTestData; struct2table(s)];
    end
end
end

Create 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)
            testCase.assertGreaterThan(5,10)
        end

        function testTwo(testCase)
            wrongAnswer = 'wrong';
            testCase.verifyEmpty(wrongAnswer,'Not Empty')
            testCase.verifyClass(wrongAnswer,'double','Not double')
        end

        function testThree(testCase)
            testCase.assertEqual(7*2,13,'Values not equal')
        end
    end
end
### Add Plugin to Test Runner and Run Tests

At the command prompt, create a test suite from the `ExampleTest` class, and create a test runner.

```matlab
import matlab.unittest.TestSuite
import matlab.unittest.TestRunner

suite = TestSuite.fromClass(?ExampleTest);
runner = TestRunner.withNoPlugins;
```

Create an instance of `myPlugin` and add it to the test runner. Run the tests.

```matlab
p = DiagnosticRecorderPlugin;
runner.addPlugin(p);
result = runner.run(suite);
```

With the failed fatal assertion, the framework throws an error, and the test runner does not return a `TestResult` object. However, the `DiagnosticRecorderPlugin` stores information about the tests preceding and including the test with the failed assertion.

### Inspect Diagnostic Information

At the command prompt, view information about the failed tests. The information is saved in the `FailedTestData` property of the plugin.

```matlab
T = p.FailedTestData
```

T =

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>TestDiagnostics</th>
<th>FrameworkDiagnostics</th>
</tr>
</thead>
</table>

The fatal assertion failure in `testFour` causes the framework to halt and throw an error. In this example, there are no subsequent tests. If there was a subsequent test, the framework would not run it.
There are many options to archive or post-process this information. For example, you can save the variable as a MAT-file or use `writetable` to write the table to various file types, such as `.txt`, `.csv`, or `.xls`.

View the stack information for the third test failure

```
T.Stack(3)
```

```
ans =

    file: 'C:\Work\ExampleTest.m'
    name: 'ExampleTest.testTwo'
    line: 9
```

Display the diagnostics that the framework displayed for the fifth test failure.

```
celldisp(T.FrameworkDiagnostics(5))
```

```
ans{1} =

    fatalAssertEqual failed.
--> The values are not equal using "isequaln".
--> Failure table:
     Index  Actual  Expected  Error  RelativeError
         ___    _____    ________    _____    __________________
          1      5        6        -1       -0.166666666666667

Actual double:
  5
Expected double:
  6
```

See Also

- `matlab.unittest.plugins.TestRunnerPlugin`
- `matlab.unittest.TestCase`
- `matlab.unittest.TestRunner`
- `addlistener`
Related Examples

- “Write Plugins to Extend TestRunner” on page 30-82
- “Create Custom Plugin” on page 30-86
**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.

```matlab
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.

```matlab
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: 0.0064

    Totals:
        1 Passed, 0 Failed, 0 Incomplete.
0.0063833 seconds testing time.

**Create Table of Test Results**

To access functionality available to tables, create one from the `TestResult` object.

```matlab
rt = table(result)
rt =

<table>
<thead>
<tr>
<th>Name</th>
<th>Passed</th>
<th>Failed</th>
<th>Incomplete</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>'SolverTest/testRealSolution'</td>
<td>true</td>
<td>false</td>
<td>false</td>
<td>0.0063833</td>
</tr>
<tr>
<td>'SolverTest/testImaginarySolution'</td>
<td>true</td>
<td>false</td>
<td>false</td>
<td>0.0051785</td>
</tr>
</tbody>
</table>
```

Sort the test results by duration.

```matlab
sortrows(rt,'Duration')
an =

<table>
<thead>
<tr>
<th>Name</th>
<th>Passed</th>
<th>Failed</th>
<th>Incomplete</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>'SolverTest/testImaginarySolution'</td>
<td>true</td>
<td>false</td>
<td>false</td>
<td>0.0051785</td>
</tr>
<tr>
<td>'SolverTest/testRealSolution'</td>
<td>true</td>
<td>false</td>
<td>false</td>
<td>0.0063833</td>
</tr>
</tbody>
</table>
```

Export test results to a CSV file.

```matlab
writetable(rt,'myTestResults.csv','QuoteStrings',true)
```

**Related Examples**

- “Write Simple Test Case Using Classes” on page 30-28
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].

```matlab
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.

```matlab
quadTests = matlab.unittest.TestSuite.fromClass(?SolverTest);
result1 = run(quadTests);
```

Running SolverTest

```
================================================================================
Verification failed in SolverTest/testBadRealSolution.
```

Framework Diagnostic:

```
verifyEqual failed.
--> The values are not equal using "isequaln".
--> Failure table:

<table>
<thead>
<tr>
<th>Index</th>
<th>Actual</th>
<th>Expected</th>
<th>Error</th>
<th>RelativeError</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-1</td>
<td>2</td>
<td>-3</td>
<td>-1.5</td>
</tr>
<tr>
<td>2</td>
<td>-2</td>
<td>1</td>
<td>-3</td>
<td>-3</td>
</tr>
</tbody>
</table>
```

Actual Value:

-1 -2

Expected Value:

2 1
------------------
Stack Information:  
------------------  
In C:\work\SolverTest.m (SolverTest.testBadRealSolution) at 19  
--------------------------------------------------------------------------------  
.  
Done SolverTest  
__________  

Failure Summary:  

<table>
<thead>
<tr>
<th>Name</th>
<th>Failed</th>
<th>Incomplete</th>
<th>Reason(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SolverTest/testBadRealSolution</td>
<td>X</td>
<td></td>
<td>Failed by verification.</td>
</tr>
</tbody>
</table>

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 30-103
“Method Setup and Teardown Code” on page 30-106
“Class Setup and Teardown Code” on page 30-108

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.

```matlab
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.

```matlab
    ts = matlab.unittest.TestSuite.fromClass(ExampleTest);
    res = ts.run;
```

Running ExampleTest.

ExampleTest/testB was filtered.

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:

<table>
<thead>
<tr>
<th>Name</th>
<th>Failed</th>
<th>Incomplete</th>
<th>Reason(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ExampleTest/testB</td>
<td>X</td>
<td></td>
<td>Filtered by assumption.</td>
</tr>
<tr>
<td>ExampleTest/testC</td>
<td>X</td>
<td></td>
<td>Failed by verification.</td>
</tr>
</tbody>
</table>

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:
Method Setup and Teardown Code

If an assumption failure is encountered inside a Test Case 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.

```matlab
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
```

Updated ExampleTest Class Definition

```matlab
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

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:

<table>
<thead>
<tr>
<th>Name</th>
<th>Failed</th>
<th>Incomplete</th>
<th>Reason(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ExampleTest/testA</td>
<td>X</td>
<td></td>
<td>Filtered by assumption.</td>
</tr>
<tr>
<td>ExampleTest/testB</td>
<td>X</td>
<td></td>
<td>Filtered by assumption.</td>
</tr>
<tr>
<td>ExampleTest/testC</td>
<td>X</td>
<td></td>
<td>Filtered by assumption.</td>
</tr>
</tbody>
</table>

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.

```matlab
methods(TestClassSetup)
    function setupClass(testCase)
        testCase.assumeEqual(1,0)
        % remaining test code is not exercised
    end
end
```

**Updated ExampleTest Class Definition**

```matlab
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:

<table>
<thead>
<tr>
<th>Name</th>
<th>Failed</th>
<th>Incomplete</th>
<th>Reason(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ExampleTest/testA</td>
<td>X</td>
<td></td>
<td>Filtered by assumption.</td>
</tr>
</tbody>
</table>

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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