MATLAB®

The Language of Technical Computing

Computation

Visualization

Programming

External Interfaces

Version 6

The MathWorks

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Contents

1 Calling C and Fortran Programs from MATLAB

2 Creating C Language MEX-Files

3 Creating Fortran MEX-Files

4 Calling MATLAB from C and Fortran Programs

5 Calling Java from MATLAB

6 Importing and Exporting Data

7 COM and DDE Support

8 Serial Port I/O

1

Calling C and Fortran Programs from MATLAB

Although MATLAB® is a complete, self-contained environment for programming and manipulating data, it is often useful to interact with data and programs external to the MATLAB environment. MATLAB provides an interface to external programs written in the C and Fortran languages.

Introducing MEX-Files

You can call your own C or Fortran subroutines from MATLAB as if they were built-in functions. MATLAB callable C and Fortran programs are referred to as MEX-files. MEX-files are dynamically linked subroutines that the MATLAB interpreter can automatically load and execute.

MEX-files have several applications:

- Large pre-existing C and Fortran programs can be called from MATLAB without having to be rewritten as M-files.
- Bottleneck computations (usually `for`-loops) that do not run fast enough in MATLAB can be recoded in C or Fortran for efficiency.

MEX-files are not appropriate for all applications. MATLAB is a high-productivity system whose specialty is eliminating time-consuming, low-level programming in compiled languages like Fortran or C. In general, most programming should be done in MATLAB. Don't use the MEX facility unless your application requires it.

Using MEX-Files

MEX-files are subroutines produced from C or Fortran source code. They behave just like M-files and built-in functions. While M-files have a platform-independent extension, `.m`, MATLAB identifies MEX-files by platform-specific extensions. This table lists the platform-specific extensions for MEX-files.

Table 1-1: MEX-File Extensions

Platform	MEX-File Extension
Alpha	`mexaxp`
HP, Version 10.20	`mexhp7`
HP, Version 11.x	`mexhpux`
IBM RS/6000	`mexrs6`
Linux	`mexglx`
SGI, SGI64	`mexsg`

Table 1-1: MEX-File Extensions (Continued)

Platform	MEX-File Extension
Solaris	`mexsol`
Windows	`dll`

You can call MEX-files exactly as you would call any M-function. For example, a MEX-file called `conv2.mex` on your disk in the MATLAB `datafun` toolbox directory performs a 2-D convolution of matrices. `conv2.m` only contains the help text documentation. If you invoke the function `conv2` from inside MATLAB, the interpreter looks through the list of directories on the MATLAB search path. It scans each directory looking for the first occurrence of a file named `conv2` with the corresponding filename extension from the table or `.m`. When it finds one, it loads the file and executes it. MEX-files take precedence over M-files when like-named files exist in the same directory. However, help text documentation is still read from the `.m` file.

The Distinction Between mx and mex Prefixes

Routines in the API that are prefixed with `mx` allow you to create, access, manipulate, and destroy `mxArrays`. Routines prefixed with `mex` perform operations back in the MATLAB environment.

mx Routines

The array access and creation library provides a set of array access and creation routines for manipulating MATLAB arrays. These subroutines, which are fully documented in the online API reference pages, always start with the prefix `mx`. For example, `mxGetPi` retrieves the pointer to the imaginary data inside the array.

Although most of the routines in the array access and creation library let you manipulate the MATLAB array, there are two exceptions — the IEEE routines and memory management routines. For example, `mxGetNaN` returns a `double`, not an `mxArray`.

mex Routines

Routines that begin with the `mex` prefix perform operations back in the MATLAB environment. For example, the `mexEvalString` routine evaluates a string in the MATLAB workspace.

Note `mex` routines are only available in MEX-functions.

MATLAB Data

Before you can program MEX-files, you must understand how MATLAB represents the many data types it supports. This section discusses the following topics:

- "The MATLAB Array"
- "Data Storage"
- "Data Types in MATLAB"
- "Using Data Types"

The MATLAB Array

The MATLAB language works with only a single object type: the MATLAB array. All MATLAB variables, including scalars, vectors, matrices, strings, cell arrays, structures, and objects are stored as MATLAB arrays. In C, the MATLAB array is declared to be of type `mxArray`. The `mxArray` structure contains, among other things:

- Its type
- Its dimensions
- The data associated with this array
- If numeric, whether the variable is real or complex
- If sparse, its indices and nonzero maximum elements
- If a structure or object, the number of fields and field names

Data Storage

All MATLAB data is stored columnwise, which is how Fortran stores matrices. MATLAB uses this convention because it was originally written in Fortran. For example, given the matrix

```
a=['house'; 'floor'; 'porch']
a =
   house
   floor
   porch
```

its dimensions are

```
size(a)
ans =
     3     5
```

and its data is stored as

h	f	p	o	l	o	u	o	r	s	o	c	e	r	h

Data Types in MATLAB

Complex Double-Precision Matrices

The most common data type in MATLAB is the complex double-precision, nonsparse matrix. These matrices are of type `double` and have dimensions `m`-by-`n`, where `m` is the number of rows and `n` is the number of columns. The data is stored as two vectors of double-precision numbers – one contains the real data and one contains the imaginary data. The pointers to this data are referred to as `pr` (pointer to real data) and `pi` (pointer to imaginary data), respectively. A real-only, double-precision matrix is one whose `pi` is `NULL`.

Numeric Matrices

MATLAB also supports other types of numeric matrices. These are single-precision floating-point and 8-, 16-, and 32-bit integers, both signed and unsigned. The data is stored in two vectors in the same manner as double-precision matrices.

MATLAB Strings

MATLAB strings are of type `char` and are stored the same way as unsigned 16-bit integers except there is no imaginary data component. Unlike C, MATLAB strings are not null terminated.

Sparse Matrices

Sparse matrices have a different storage convention than full matrices in MATLAB. The parameters `pr` and `pi` are still arrays of double-precision numbers, but there are three additional parameters, `nzmax`, `ir`, and `jc`:

- nzmax is an integer that contains the length of ir, pr, and, if it exists, pi. It is the maximum possible number of nonzero elements in the sparse matrix.
- ir points to an integer array of length nzmax containing the row indices of the corresponding elements in pr and pi.
- jc points to an integer array of length N+1 that contains column index information. For j, in the range 0 ≤ j ≤ N-1, jc[j] is the index in ir and pr (and pi if it exists) of the first nonzero entry in the jth column and jc[j+1] - 1 index of the last nonzero entry. As a result, jc[N] is also equal to nnz, the number of nonzero entries in the matrix. If nnz is less than nzmax, then more nonzero entries can be inserted in the array without allocating additional storage.

Cell Arrays

Cell arrays are a collection of MATLAB arrays where each mxArray is referred to as a cell. This allows MATLAB arrays of different types to be stored together. Cell arrays are stored in a similar manner to numeric matrices, except the data portion contains a single vector of pointers to mxArrays. Members of this vector are called cells. Each cell can be of any supported data type, even another cell array.

Structures

A 1-by-1 structure is stored in the same manner as a 1-by-n cell array where n is the number of fields in the structure. Members of the data vector are called fields. Each field is associated with a name stored in the mxArray.

Objects

Objects are stored and accessed the same way as structures. In MATLAB, objects are named structures with registered methods. Outside MATLAB, an object is a structure that contains storage for an additional classname that identifies the name of the object.

Multidimensional Arrays

MATLAB arrays of any type can be multidimensional. A vector of integers is stored where each element is the size of the corresponding dimension. The storage of the data is the same as matrices.

Empty Arrays

MATLAB arrays of any type can be empty. An empty mxArray is one with at least one dimension equal to zero. For example, a double-precision mxArray of type double, where m and n equal 0 and pr is NULL, is an empty array.

Using Data Types

The six fundamental data types in MATLAB are double, char, logical, uint8, cell, and struct. You can write MEX-files, MAT-file applications, and engine applications in C that accept any data type supported by MATLAB. In Fortran, only the creation of double-precision n-by-m arrays and strings are supported. You can treat C and Fortran MEX-files, once compiled, exactly like M-functions.

The explore Example

There is an example MEX-file included with MATLAB, called explore, that identifies the data type of an input variable. The source file for this example is in the <matlab>/extern/examples/mex directory, where <matlab> represents the top-level directory where MATLAB is installed on your system.

Note In platform independent discussions that refer to directory paths, this book uses the UNIX convention. For example, a general reference to the mex directory is <matlab>/extern/examples/mex.

For example, typing

```
cd([matlabroot '/extern/examples/mex']);
x = 2;
explore(x);
```

produces this result

```
------------------------------------------------
Name: x
Dimensions: 1x1
Class Name: double
------------------------------------------------
   (1,1) = 2
```

`explore` accepts any data type. Try using `explore` with these examples.

```
explore([1 2 3 4 5])
explore 1 2 3 4 5
explore({1 2 3 4 5})
explore(int8([1 2 3 4 5]))
explore {1 2 3 4 5}
explore(sparse(eye(5)))
explore(struct('name', 'Joe Jones', 'ext', 7332))
explore(1, 2, 3, 4, 5)
```

Building MEX-Files

This section covers the following topics:

- "Compiler Requirements"
- "Testing Your Configuration on UNIX"
- "Testing Your Configuration on Windows"
- "Specifying an Options File"

Compiler Requirements

Your installed version of MATLAB contains all the tools you need to work with the API. MATLAB includes a C compiler for the PC called Lcc, but does not include a Fortran compiler. If you choose to use your own C compiler, it must be an ANSI C compiler. Also, if you are working on a Microsoft Windows platform, your compiler must be able to create 32-bit windows dynamically linked libraries (DLLs).

MATLAB supports many compilers and provides preconfigured files, called options files, designed specifically for these compilers. The Options Files table lists all supported compilers and their corresponding options files. The purpose of supporting this large collection of compilers is to provide you with the flexibility to use the tool of your choice. However, in many cases, you simply can use the provided Lcc compiler with your C code to produce your applications.

The MathWorks also maintains a list of compilers supported by MATLAB at the following location on the web: `http://www.mathworks.com/support/tech-notes/v5/1600/1601.shtml`.

Note The MathWorks provides an option (`setup`) for the `mex` script that lets you easily choose or switch your compiler.

The following sections contain configuration information for creating MEX-files on UNIX and Windows systems. More detailed information about the `mex` script is provided in "Custom Building MEX-Files" on page 1-19. In addition, there is a section on "Troubleshooting" on page 1-31, if you are having difficulties creating MEX-files.

Testing Your Configuration on UNIX

The quickest way to check if your system is set up properly to create MEX-files is by trying the actual process. There is C source code for an example, `yprime.c`, and its Fortran counterpart, `yprimef.F` and `yprimefg.F`, included in the `<matlab>/extern/examples/mex` directory, where `<matlab>` represents the top-level directory where MATLAB is installed on your system.

To compile and link the example source files, `yprime.c` or `yprimef.F` and `yprimefg.F`, on UNIX, you must first copy the file(s) to a local directory, and then change directory (`cd`) to that local directory.

At the MATLAB prompt, type

```
mex yprime.c
```

This uses the system compiler to create the MEX-file called `yprime` with the appropriate extension for your system.

You can now call `yprime` as if it were an M-function.

```
yprime(1,1:4)
ans =
     2.0000   8.9685   4.0000    -1.0947
```

To try the Fortran version of the sample program with your Fortran compiler, at the MATLAB prompt, type

```
mex yprimef.F yprimefg.F
```

In addition to running the `mex` script from the MATLAB prompt, you can also run the script from the system prompt.

Selecting a Compiler

To change your default compiler, you select a different options file. You can do this anytime by using the command

```
mex -setup

    Using the 'mex -setup' command selects an options file that is
    placed in ~/matlab and used by default for 'mex'. An options
    file in the current working directory or specified on the
    command line overrides the default options file in ~/matlab.
```

```
    Options files control which compiler to use, the compiler and
    link command options, and the runtime libraries to link
    against.

    To override the default options file, use the 'mex -f' command
    (see 'mex -help' for more information).

The options files available for mex are:

  1: <matlab>/bin/gccopts.sh :
        Template Options file for building gcc MEXfiles

  2: <matlab>/bin/mexopts.sh :
        Template Options file for building MEXfiles using the
         system ANSI compiler

Enter the number of the options file to use as your default options
file:
```

Select the proper options file for your system by entering its number and pressing **Return**. If an options file doesn't exist in your MATLAB directory, the system displays a message stating that the options file is being copied to your user-specific `matlab` directory. If an options file already exists in your `matlab` directory, the system prompts you to overwrite it.

Note The `setup` option creates a user-specific `matlab` directory in your individual home directory and copies the appropriate options file to the directory. (If the directory already exists, a new one is not created.) This `matlab` directory is used for your individual options files only; each user can have his or her own default options files (other MATLAB products may place options files in this directory). Do not confuse these user-specific `matlab` directories with the system `matlab` directory, where MATLAB is installed. To see the name of this directory on your machine, use the MATLAB command `prefdir`.

Using the setup option resets your default compiler so that the new compiler is used every time you use the `mex` script.

Testing Your Configuration on Windows

Before you can create MEX-files on the Windows platform, you must configure the default options file, `mexopts.bat`, for your compiler. The switch, `setup`, provides an easy way for you to configure the default options file. To configure or change the options file at anytime, run

```
mex -setup
```

from either the MATLAB or DOS command prompt.

Selecting a Compiler

MATLAB includes a C compiler, Lcc, that you can use to create C MEX-files. The `mex` script will use the Lcc compiler automatically if you do not have a C or C++ compiler of your own already installed on your system and you try to compile a C MEX-file. Naturally, if you need to compile Fortran programs, you must supply your own supported Fortran compiler.

The `mex` script uses the filename extension to determine the type of compiler to use for creating your MEX-files. For example,

```
mex test1.f
```

would use your Fortran compiler and

```
mex test2.c
```

would use your C compiler.

On Systems without a Compiler. If you do not have your own C or C++ compiler on your system, the `mex` utility automatically configures itself for the included Lcc compiler. So, to create a C MEX-file on these systems, you can simply enter

```
mex filename.c
```

This simple method of creating MEX-files works for the majority of users.

If using the included Lcc compiler satisfies your needs, you can skip ahead in this section to “Building the MEX-File on Windows” on page 1-15.

On Systems with a Compiler. On systems where there is a C, C++, or Fortran compiler, you can select which compiler you want to use. Once you choose your compiler, that compiler becomes your default compiler and you no longer have to select one when you compile MEX-files. To select a compiler or change to existing default compiler, use `mex  setup`.

This example shows the process of setting your default compiler to the Microsoft Visual C++ Version 6.0 compiler.

```
mex -setup

Please choose your compiler for building external interface (MEX)
files.

Would you like mex to locate installed compilers [y]/n? n

Select a compiler:
[1] Compaq Visual Fortran version 6.6
[2] Lcc C version 2.4
[3] Microsoft Visual C/C++ version 6.0

[0] None

Compiler: 3

Your machine has a Microsoft Visual C/C++ compiler located at
D:\Applications\Microsoft Visual Studio. Do you want to use this
compiler [y]/n? y

Please verify your choices:

Compiler: Microsoft Visual C/C++ 6.0
Location: C:\Program Files\Microsoft Visual Studio

Are these correct?([y]/n): y

The default options file:
"C:\WINNT\Profiles\username\ApplicationData\MathWorks\MATLAB\R13
\mexopts.bat" is being updated from ...
```

If the specified compiler cannot be located, you are given the message:

```
The default location for compiler-name is directory-name,
but that directory does not exist on this machine.

Use directory-name anyway [y]/n?
```

Using the `setup` option sets your default compiler so that the new compiler is used every time you use the `mex` script.

Building the MEX-File on Windows

There is example C source code, `yprime.c`, and its Fortran counterpart, `yprimef.f` and `yprimefg.f`, included in the `<matlab>\extern\examples\mex` directory, where `<matlab>` represents the top-level directory where MATLAB is installed on your system.

To compile and link the example source file on Windows, at the MATLAB prompt, type

```
cd([matlabroot '\extern\examples\mex'])
mex yprime.c
```

This should create the MEX-file called `yprime` with the `.DLL` extension, which corresponds to the Windows platform.

You can now call `yprime` as if it were an M-function.

```
yprime(1,1:4)
ans =
     2.0000   8.9685   4.0000    -1.0947
```

To try the Fortran version of the sample program with your Fortran compiler, switch to your Fortran compiler using `mex -setup`. Then, at the MATLAB prompt, type

```
cd([matlabroot '\extern\examples\mex'])
mex yprimef.f yprimefg.f
```

In addition to running the `mex` script from the MATLAB prompt, you can also run the script from the system prompt.

Specifying an Options File

You can use the `-f` option to specify an options file on either UNIX or Windows. To use the `-f` option, at the MATLAB prompt type

```
mex filename -f <optionsfile>
```

and specify the name of the options file along with its pathname. The Options Files table, below, contains a list of the options files included with MATLAB.

There are several situations when it may be necessary to specify an options file every time you use the `mex` script. These include:

- *(Windows and UNIX)* You want to use a different compiler (and not use the `-setup` option), or you want to compile MAT or engine stand-alone programs.
- *(UNIX)* You do not want to use the system C compiler.

Preconfigured Options Files

MATLAB includes some preconfigured options files that you can use with particular compilers. The Options Files table lists the compilers whose options files are included with this release of MATLAB.

Table 1-2: Options Files

Platform	Compiler	Options File
Windows	Borland C++, Version 5.0 & 5.2	`bccopts.bat`
	Borland C++Builder 3.0 (Borland C++, Version 5.3)	`bcc53opts.bat`
	Borland C++Builder 4.0 (Borland C++, Version 5.4)	`bcc54opts.bat`
	Borland C++Builder 5.0 (Borland C++, Version 5.5)	`bcc55opts.bat`
	Lcc C Compiler, bundled with MATLAB	`lccopts.bat`
	Microsoft C/C++, Version 5.0	`msvc50opts.bat`
	Microsoft C/C++, Version 6.0	`msvc60opts.bat`

Table 1-2: Options Files (Continued)

Platform	Compiler	Options File
	Watcom C/C++, Version 10.6	`watcopts.bat`
	Watcom C/C++, Version 11	`wat11copts.bat`
	DIGITAL Visual Fortran, Version 5.0	`df50opts.bat`
	Compaq Visual Fortran, Version 6.1	`df61opts.bat`
	Compaq Visual Fortran, Version 6.6	`df66opts.bat`
	Borland C, Version 5.0 & 5.2, for Engine and MAT stand-alone programs	`bccengmatopts.bat`
	Borland C, Version 5.3, for Engine and MAT stand-alone programs	`bcc53engmatopts.bat`
	Borland C, Version 5.4, for Engine and MAT stand-alone programs	`bcc54engmatopts.bat`
	Borland C, Version 5.5, for Engine and MAT stand-alone programs	`bcc55engmatopts.bat`
	Lcc C compiler for Engine and MAT stand-alone programs,	`lccengmatopts.bat`
	Microsoft Visual C for Engine and MAT stand-alone programs, Version 5.0	`msvc50engmatopts.bat`
	Microsoft Visual C for Engine and MAT stand-alone programs, Version 6.0	`msvc60engmatopts.bat`
	Watcom C for Engine and MAT stand-alone programs, Version 10.6	`watengmatopts.bat`

Table 1-2: Options Files (Continued)

Platform	Compiler	Options File
	Watcom C for Engine and MAT stand-alone programs, Version 11	`wat11engmatopts.bat`
	DIGITAL Visual Fortran for MAT stand-alone programs, Version 5.0	`df50engmatopts.bat`
	Compaq Visual Fortran for MAT stand-alone programs, Version 6.1	`df60engmatopts.bat`
UNIX	System ANSI Compiler	`mexopts.sh`
	GCC	`gccopts.sh`
	System ANSI Compiler for Engine stand-alone programs	`engopts.sh`
	System ANSI Compiler for MAT stand-alone programs	`matopts.sh`

An up-to-date list of options files is available from our FTP server, `ftp://ftp.mathworks.com/pub/tech-support/docexamples/apiguide/R12/bin`. For a list of all the compilers supported by MATLAB, access the MathWorks Technical Support Web site at `http://www.mathworks.com/support`.

Note The next section, "Custom Building MEX-Files" on page 1-19, contains specific information on how to modify options files for particular systems.

Custom Building MEX-Files

This section discusses in detail the process that the MEX-file build script uses. It covers the following topics:

- "Who Should Read This Chapter"
- "MEX Script Switches"
- "Default Options File on UNIX"
- "Default Options File on Windows"
- "Custom Building on UNIX"
- "Custom Building on Windows"

Who Should Read This Chapter

In general, the defaults that come with MATLAB should be sufficient for building most MEX-files. There are reasons that you might need more detailed information, such as:

- You want to use an Integrated Development Environment (IDE), rather than the provided script, to build MEX-files.
- You want to create a new options file, for example, to use a compiler that is not directly supported.
- You want to exercise more control over the build process than the script uses.

The script, in general, uses two stages (or three, for Microsoft Windows) to build MEX-files. These are the compile stage and the link stage. In between these two stages, Windows compilers must perform some additional steps to prepare for linking (the prelink stage).

MEX Script Switches

The `mex` script has a set of switches (also called options) that you can use to modify the link and compile stages. The MEX Script Switches table lists the available switches and their uses. Each switch is available on both UNIX and Windows unless otherwise noted.

For customizing the build process, you should modify the options file, which contains the compiler-specific flags corresponding to the general compile, prelink, and link steps required on your system. The options file consists of a series of variable assignments; each variable represents a different logical piece of the build process.

Table 1-3: MEX Script Switches

Switch	Function
`@<rsp_file>`	Include the contents of the text file `<rsp_file>` as command line arguments to the `mex` script.
`-argcheck`	Perform argument checking on MATLAB API functions (C functions only).
`-c`	Compile only; do not link.
`-D<name>[#<def>]`	Define C preprocessor macro `<name>` [as having value `<def>`]. (Note: UNIX also allows `-D<name>[=<def>]`.)
`-f <file>`	Use `<file>` as the options file; `<file>` is a full pathname if it is not in current directory.
`-g`	Build an executable with debugging symbols included.
`-h[elp]`	Help; lists the switches and their functions.
`-I<pathname>`	Include `<pathname>` in the compiler `include` search path.
`-inline`	Inlines matrix accessor functions (`mx*`). The generated MEX-function may not be compatible with future versions of MATLAB.
`-l<file>`	(UNIX) Link against library `lib<file>`.
`-L<pathname>`	(UNIX) Include `<pathname>` in the list of directories to search for libraries.

Table 1-3: MEX Script Switches (Continued)

Switch	Function
`<name>#<def>`	Override options file setting for variable `<name>`. This option is equivalent to `<ENV_VAR>#<val>`, which temporarily sets the environment variable `<ENV_VAR>` to `<val>` for the duration of the call to `mex`. `<val>` can refer to another environment variable by prepending the name of the variable with a `$`, e.g., `COMPFLAGS#"$COMPFLAGS -myswitch"`.
`<name>=<def>`	(UNIX) Override options file setting for variable `<name>`.
`-O`	Build an optimized executable.
`-outdir <name>`	Place all output files in directory `<name>`.
`-output <name>`	Create an executable named `<name>`. (An appropriate executable extension is automatically appended.)
`-setup`	Set up default options file. This switch should be the only argument passed.
`-U<name>`	Undefine C preprocessor macro `<name>`.
`-v`	Verbose; print all compiler and linker settings.
`-V5`	Compile MATLAB 5-compatible MEX-file.

Default Options File on UNIX

The default MEX options file provided with MATLAB is located in `<matlab>/bin`. The `mex` script searches for an options file called `mexopts.sh` in the following order:

- The current directory
- The directory returned by the `prefdir` function
- The directory specified by `[matlabroot '/bin']`

mex uses the first occurrence of the options file it finds. If no options file is found, mex displays an error message. You can directly specify the name of the options file using the -f switch.

For specific information on the default settings for the MATLAB supported compilers, you can examine the options file in fullfile(matlabroot, 'bin', 'mexopts.sh'), or you can invoke the mex script in verbose mode (-v). Verbose mode will print the exact compiler options, prelink commands (if appropriate), and linker options used in the build process for each compiler. "Custom Building on UNIX" on page 1-23 gives an overview of the high-level build process.

Default Options File on Windows

The default MEX options file is placed in your user profile directory after you configure your system by running mex -setup. The mex script searches for an options file called mexopts.bat in the following order:

- The current directory
- The user profile directory (returned by the prefdir function)
- The directory specified by [matlabroot '\bin\win32\mexopts']

mex uses the first occurrence of the options file it finds. If no options file is found, mex searches your machine for a supported C compiler and automatically configures itself to use that compiler. Also, during the configuration process, it copies the compiler's default options file to the user profile directory. If multiple compilers are found, you are prompted to select one.

For specific information on the default settings for the MATLAB supported compilers, you can examine the options file, mexopts.bat, or you can invoke the mex script in verbose mode (-v). Verbose mode will print the exact compiler options, prelink commands, if appropriate, and linker options used in the build process for each compiler. "Custom Building on Windows" on page 1-25 gives an overview of the high-level build process.

The User Profile Directory

The Windows user profile directory is a directory that contains user-specific information such as desktop appearance, recently used files, and **Start** menu items. The mex and mbuild utilities store their respective options files, mexopts.bat and compopts.bat, which are created during the setup process, in a subdirectory of your `user profile` directory, named `Application Data\MathWorks\MATLAB`.

Custom Building on UNIX

On UNIX systems, there are two stages in MEX-file building: compiling and linking.

Compile Stage

The compile stage must:

- Add `<matlab>/extern/include` to the list of directories in which to find header files (`-I<matlab>/extern/include`)
- Define the preprocessor macro `MATLAB_MEX_FILE` (`-DMATLAB_MEX_FILE`)
- (C MEX-files only) Compile the source file, which contains version information for the MEX-file, `<matlab>/extern/src/mexversion.c`

Link Stage

The link stage must:

- Instruct the linker to build a shared library
- Link all objects from compiled source files (including `mexversion.c`)
- (Fortran MEX-files only) Link in the precompiled versioning source file, `<matlab>/extern/lib/$Arch/version4.o`
- Export the symbols `mexFunction` and `mexVersion` (these symbols represent functions called by MATLAB)

For Fortran MEX-files, the symbols are all lower case and may have appended underscores. For specific information, invoke the `mex` script in verbose mode and examine the output.

Build Options

For customizing the build process, you should modify the options file. The options file contains the compiler-specific flags corresponding to the general steps outlined above. The options file consists of a series of variable assignments; each variable represents a different logical piece of the build process. The options files provided with MATLAB are located in `<matlab>/bin`.

The section, "Default Options File on UNIX" on page 1-21, describes how the mex script looks for an options file.

To aid in providing flexibility, there are two sets of options in the options file that can be turned on and off with switches to the mex script. These sets of options correspond to building in *debug mode* and building in *optimization mode*. They are represented by the variables DEBUGFLAGS and OPTIMFLAGS, respectively, one pair for each *driver* that is invoked (CDEBUGFLAGS for the C compiler, FDEBUGFLAGS for the Fortran compiler, and LDDEBUGFLAGS for the linker; similarly for the OPTIMFLAGS).

- If you build in optimization mode (the default), the mex script will include the OPTIMFLAGS options in the compile and link stages.
- If you build in debug mode, the mex script will include the DEBUGFLAGS options in the compile and link stages, but will not include the OPTIMFLAGS options.
- You can include both sets of options by specifying both the optimization and debugging flags to the mex script (-O and -g, respectively).

Aside from these special variables, the mex options file defines the executable invoked for each of the three modes (C compile, Fortran compile, link) and the flags for each stage. You can also provide explicit lists of libraries that must be linked in to all MEX-files containing source files of each language.

The variables can be summed up as follows.

Variable	C Compiler	Fortran Compiler	Linker
Executable	CC	FC	LD
Flags	CFLAGS	FFLAGS	LDFLAGS
Optimization	COPTIMFLAGS	FOPTIMFLAGS	LDOPTIMFLAGS
Debugging	CDEBUGFLAGS	FDEBUGFLAGS	LDDEBUGFLAGS
Additional libraries	CLIBS	FLIBS	----

For specifics on the default settings for these variables, you can:

- Examine the options file in `<matlab>/bin/mexopts.sh` (or the options file you are using), or
- Invoke the `mex` script in verbose mode

Custom Building on Windows

There are three stages to MEX-file building for both C and Fortran on Windows – compiling, prelinking, and linking.

Compile Stage

For the compile stage, a `mex` options file must:

- Set up paths to the compiler using the `COMPILER` (e.g., Watcom), `PATH`, `INCLUDE`, and `LIB` environment variables. If your compiler always has the environment variables set (e.g., in `AUTOEXEC.BAT`), you can remark them out in the options file.
- Define the name of the compiler, using the `COMPILER` environment variable, if needed.
- Define the compiler switches in the `COMPFLAGS` environment variable.
  - **a** The switch to create a DLL is required for MEX-files.
  - **b** For stand-alone programs, the switch to create an `exe` is required.
  - **c** The `-c` switch (compile only; do not link) is recommended.
  - **d** The switch to specify 8-byte alignment.
  - **e** Any other switch specific to the environment can be used.
- Define preprocessor `macro`, with `-D`, `MATLAB_MEX_FILE` is required.
- Set up optimizer switches and/or debug switches using `OPTIMFLAGS` and `DEBUGFLAGS`. These are mutually exclusive: the `OPTIMFLAGS` are the default, and the `DEBUGFLAGS` are used if you set the `-g` switch on the `mex` command line.

Prelink Stage

The prelink stage dynamically creates import libraries to import the required function into the MEX, MAT, or engine file. All MEX-files link against MATLAB only. MAT stand-alone programs link against `libmx.dll` (array access library) and `libmat.dll` (MAT-functions). Engine stand-alone programs link against `libmx.dll` (array access library) and `libeng.dll` for engine functions. MATLAB and each DLL have corresponding `.def` files of the same names located in the `<matlab>\extern\include` directory.

Link Stage

Finally, for the link stage, a `mex` options file must:

- Define the name of the linker in the `LINKER` environment variable.
- Define the `LINKFLAGS` environment variable that must contain:
  - The switch to create a DLL for MEX-files, or the switch to create an `exe` for stand-alone programs.
  - Export of the entry point to the MEX-file as `mexFunction` for C or `MEXFUNCTION@16` for DIGITAL Visual Fortran.
  - The import library(s) created in the `PRELINK_CMDS` stage.
  - Any other link switch specific to the compiler that can be used.
- Define the linking optimization switches and debugging switches in `LINKEROPTIMFLAGS` and `LINKDEBUGFLAGS`. As in the compile stage, these two are mutually exclusive: the default is optimization, and the `-g` switch invokes the debug switches.
- Define the link-file identifier in the `LINK_FILE` environment variable, if needed. For example, Watcom uses `file` to identify that the name following is a file and not a command.
- Define the link-library identifier in the `LINK_LIB` environment variable, if needed. For example, Watcom uses `library` to identify the name following is a library and not a command.
- Optionally, set up an output identifier and name with the output switch in the `NAME_OUTPUT` environment variable. The environment variable `MEX_NAME` contains the name of the first program in the command line. This must be set for `-output` to work. If this environment is not set, the compiler default is to use the name of the first program in the command line. Even if this is set, it can be overridden by specifying the `mex -output` switch.

Linking DLLs to MEX-Files

To link a DLL to a MEX-file, list the DLL's `.lib` file on the command line.

Versioning MEX-Files

The `mex` script can build your MEX-file with a resource file that contains versioning and other essential information. The resource file is called `mexversion.rc` and resides in the `extern\include` directory. To support versioning, there are two new commands in the options files, `RC_COMPILER` and `RC_LINKER`, to provide the resource compiler and linker commands. It is assumed that:

- If a compiler command is given, the compiled resource will be linked into the MEX-file using the standard link command.
- If a linker command is given, the resource file will be linked to the MEX-file after it is built using that command.

Compiling MEX-Files with the Microsoft Visual C++ IDE

Note This section provides information on how to compile MEX-files in the Microsoft Visual C++ (MSVC) IDE; it is not totally inclusive. This section assumes that you know how to use the IDE. If you need more information on using the MSVC IDE, refer to the corresponding Microsoft documentation.

To build MEX-files with the Microsoft Visual C++ integrated development environment:

1. Create a project and insert your MEX source and `mexversion.rc` into it.
2. Create a `.DEF` file to export the MEX entry point. For example

```
LIBRARY MYFILE.DLL
EXPORTS mexFunction              <-- for a C MEX-file
    or
EXPORTS _MEXFUNCTION@16          <-- for a Fortran MEX-file
```

3. Add the `.DEF` file to the project.

4 Locate the .LIB files for the compiler version you are using under matlabroot\extern\lib\win32\microsoft. For example, for version 6.0, these files are in the msvc60 subdirectory.

5 From this directory, add libmx.lib, libmex.lib, and libmat.lib to the library modules in the LINK settings option.

6 Add the MATLAB include directory, MATLAB\EXTERN\INCLUDE to the include path in the **Settings C/C++ Preprocessor** option.

7 Add MATLAB_MEX_FILE to the **C/C++ Preprocessor** option by selecting **Settings** from the **Build** menu, selecting **C/C++**, and then typing ,MATLAB_MEX_FILE after the last entry in the **Preprocessor definitions** field.

8 To debug the MEX-file using the IDE, put MATLAB.EXE in the **Settings Debug** option as the **Executable for debug session**.

If you are using a compiler other than the Microsoft Visual C/C++ compiler, the process for building MEX files is similar to that described above. In step 4, locate the .LIB files for the compiler you are using in a subdirectory of matlabroot\extern\lib\win32. For example, for version 5.4 of the Borland C/C++ compiler, look in matlabroot\extern\lib\win32\borland\bc54.

Using the Add-In for Visual Studio

The MathWorks provides a MATLAB add-in for the Visual Studio® development system that lets you work easily within Microsoft Visual C/C++ (MSVC). The MATLAB add-in for Visual Studio greatly simplifies using M-files in the MSVC environment. The add-in automates the integration of M-files into Visual C++ projects. It is fully integrated with the MSVC environment.

The add-in for Visual Studio is automatically installed on your system when you run either mbuild -setup or mex -setup and select Microsoft Visual C/C++ version 5 or 6. However, there are several steps you must follow in order to use the add-in:

1 To build MEX-files with the add-in for Visual Studio, run the following command at the MATLAB command prompt.

```
mex -setup
```

Follow the menus and choose either Microsoft Visual C/C++ 5.0 or 6.0. This configures `mex` to use the selected Microsoft compiler and also installs the necessary add-in files in your Microsoft Visual C/C++ directories.

2 To configure the MATLAB add-in for Visual Studio to work with Microsoft Visual C/C++:

   a Select **Tools** -> **Customize** from the MSVC menu.

   b Click on the **Add-ins and Macro Files** tab.

   c Check **MATLAB for Visual Studio** on the **Add-ins and Macro Files** list and click **Close**. The floating MATLAB add-in for Visual Studio toolbar appears. The checkmark directs MSVC to automatically load the add-in when you start MSVC again.

Configuring on Windows 98 and Windows ME Systems

Windows 98. To run the MATLAB add-in for Visual Studio on Windows 98 systems, add this line to your `config.sys` file.

```
shell=c:\command.com /e:32768 /p
```

Windows ME. To run the MATLAB add-in for Visual Studio on Windows ME systems, do the following:

1 Find `C:\windows\system\conagent.exe` in the Windows Explorer.

2 Right click on the `conagent.exe` icon.

3 Select **Properties** from the context menu. This brings up the **CONAGENT.EXE Properties** window.

4 Select the **Memory** tab in the **CONAGENT.EXE Properties** window.

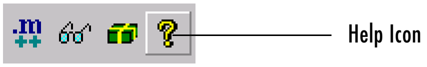
5 Set the **Initial Environment** field to 4096.

6 Click **Apply**.

7 Click **OK**.

For additional information on the MATLAB add-in for Visual Studio:

- See the `MATLABAddin.hlp` file in the `<matlab>\bin\win32` directory, or
- Click on the Help icon in the MATLAB add-in for Visual Studio toolbar.



Troubleshooting

This section explains how to troubleshoot some of the more common problems you may encounter. It addresses the following topics:

- "Configuration Issues"
- "Understanding MEX-File Problems"
- "Compiler and Platform-Specific Issues"
- "Memory Management Compatibility Issues"

Configuration Issues

This section focuses on some common problems that might occur when creating MEX-files.

Search Path Problem on Windows

Under Windows, if you move the MATLAB executable without reinstalling MATLAB, you may need to modify `mex.bat` to point to the new MATLAB location.

MATLAB Pathnames Containing Spaces on Windows

If you have problems building MEX-files on Windows and there is a space in any of the directory names within the MATLAB path, you need to either reinstall MATLAB into a pathname that contains no spaces or rename the directory that contains the space. For example, if you install MATLAB under the `Program Files` directory, you may have difficulty building MEX-files with certain C compilers. Also, if you install MATLAB in a directory such as `MATLAB V5.2`, you may have difficulty.

DLLs Not on Path on Windows

MATLAB will fail to load MEX-files if it cannot find all DLLs referenced by the MEX-file; the DLLs must be on the DOS path or in the same directory as the MEX-file. This is also true for third-party DLLs.

Internal Error When Using mex -setup (PC).

Some antivirus software packages may conflict with the mex -setup process or other mex commands. If you get an error message of the following form in response to a mex command,

```
mex.bat: internal error in sub get_compiler_info(): don't
recognize <string>
```

then you need to disable your antivirus software temporarily and reenter the command. After you have successfully run the mex operation, you can re-enable your antivirus software.

Alternatively, you can open a separate MS-DOS window and enter the mex command from that window.

General Configuration Problem

Make sure you followed the configuration steps for your platform described in this chapter. Also, refer to “Custom Building MEX-Files” on page 1-19 for additional information.

Understanding MEX-File Problems

This section contains information regarding common problems that occur when creating MEX-files. Use the figure, below, to help isolate these problems.

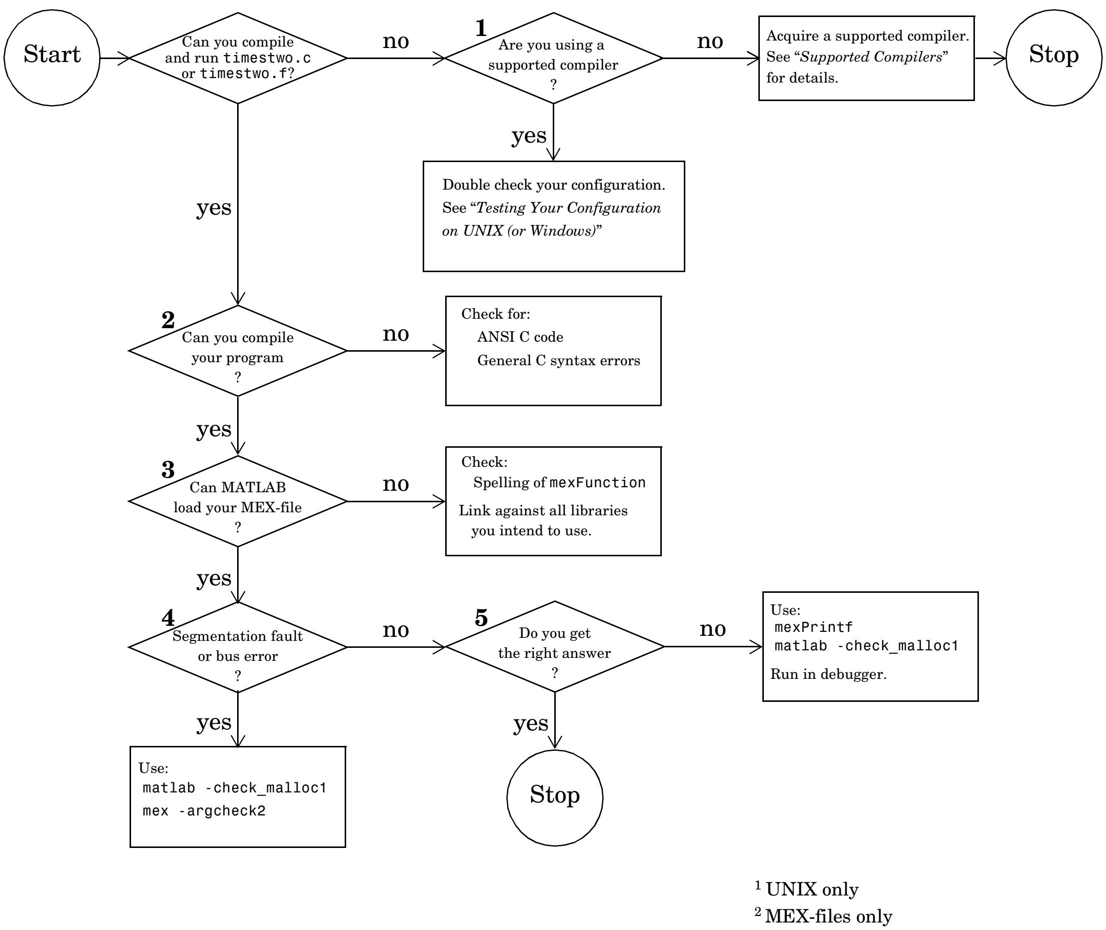


Figure 1-1: Troubleshooting MEX-File Creation Problems

Problems 1 through 5 refer to specific sections of the previous flowchart. For additional suggestions on resolving MEX build problems, access the MathWorks Technical Support Web site at `http://www.mathworks.com/support`.

Problem 1 - Compiling a MathWorks Program Fails

The most common configuration problem in creating C MEX-files on UNIX involves using a non-ANSI C compiler, or failing to pass to the compiler a flag that tells it to compile ANSI C code.

A reliable way of knowing if you have this type of configuration problem is if the header files supplied by The MathWorks generate a string of syntax errors when you try to compile your code. See "Building MEX-Files" on page 1-10 for information on selecting the appropriate options file or, if necessary, obtain an ANSI C compiler.

Problem 2 - Compiling Your Own Program Fails

A second way of generating a string of syntax errors occurs when you attempt to mix ANSI and non-ANSI C code. The MathWorks provides header and source files that are ANSI C compliant. Therefore, your C code must also be ANSI compliant.

Other common problems that can occur in any C program are neglecting to include all necessary header files, or neglecting to link against all required libraries.

Problem 3 - MEX-File Load Errors

If you receive an error of the form

```
Unable to load mex file:
??? Invalid MEX-file
```

MATLAB is unable to recognize your MEX-file as being valid.

MATLAB loads MEX-files by looking for the gateway routine, `mexFunction`. If you misspell the function name, MATLAB is not able to load your MEX-file and generates an error message. On Windows, check that you are exporting `mexFunction` correctly.

On some platforms, if you fail to link against required libraries, you may get an error when MATLAB loads your MEX-file rather than when you compile your

MEX-file. In such cases, you see a system error message referring to *unresolved symbols* or *unresolved references*. Be sure to link against the library that defines the function in question.

On Windows, MATLAB will fail to load MEX-files if it cannot find all DLLs referenced by the MEX-file; the DLLs must be on the path or in the same directory as the MEX-file. This is also true for third party DLLs.

Problem 4 - Segmentation Fault or Bus Error

If your MEX-file causes a segmentation violation or bus error, it means that the MEX-file has attempted to access protected, read-only, or unallocated memory. Since this is such a general category of programming errors, such problems are sometimes difficult to track down.

Segmentation violations do not always occur at the same point as the logical errors that cause them. If a program writes data to an unintended section of memory, an error may not occur until the program reads and interprets the corrupted data. Consequently, a segmentation violation or bus error can occur after the MEX-file finishes executing.

MATLAB provides three features to help you in troubleshooting problems of this nature. Listed in order of simplicity, they are:

- **Recompile your MEX-file with argument checking (C MEX-files only).** You can add a layer of error checking to your MEX-file by recompiling with the `mex` script flag `-argcheck`. This warns you about invalid arguments to both MATLAB MEX-file (`mex`) and matrix access (`mx`) API functions.

  Although your MEX-file will not run as efficiently as it can, this switch detects such errors as passing `null` pointers to API functions.
- **Run MATLAB with the -check_malloc option (UNIX only).** The MATLAB startup flag, `-check_malloc`, indicates that MATLAB should maintain additional memory checking information. When memory is freed, MATLAB checks to make sure that memory just before and just after this memory remains unwritten and that the memory has not been previously freed.

  If an error occurs, MATLAB reports the size of the allocated memory block. Using this information, you can track down where in your code this memory was allocated, and proceed accordingly.

Although using this flag prevents MATLAB from running as efficiently as it can, it detects such errors as writing past the end of a dimensioned array, or freeing previously freed memory.

- **Run MATLAB within a debugging environment.** This process is already described in the chapters on creating C and Fortran MEX-files, respectively.

Problem 5 - Program Generates Incorrect Results

If your program generates the wrong answer(s), there are several possible causes. First, there could be an error in the computational logic. Second, the program could be reading from an uninitialized section of memory. For example, reading the 11th element of a 10-element vector yields unpredictable results.

Another possibility for generating a wrong answer could be overwriting valid data due to memory mishandling. For example, writing to the 15th element of a 10-element vector might overwrite data in the adjacent variable in memory. This case can be handled in a similar manner as segmentation violations as described in Problem 4.

In all of these cases, you can use `mexPrintf` to examine data values at intermediate stages, or run MATLAB within a debugger to exploit all the tools the debugger provides.

Compiler and Platform-Specific Issues

This section refers to situations specific to particular compilers and platforms.

MEX-Files Created in Watcom IDE

If you use the Watcom IDE to create MEX-files and get unresolved references to API functions when linking against our libraries, check the argument passing convention. The Watcom IDE uses a default switch that passes parameters in registers. MATLAB requires that you pass parameters on the stack.

Memory Management Compatibility Issues

MATLAB now implicitly calls `mxDestroyArray`, the `mxArray` destructor, at the end of a MEX-file's execution on any `mxArrays` that are not returned in the left-hand side list (`plhs[]`). MATLAB issues a warning when it detects any misconstructed or improperly destructed `mxArrays`.

We highly recommend that you fix code in your MEX-files that produces any of the warnings discussed in the following sections. For additional information, see “Memory Management” on page 2-37 in Creating C Language MEX-Files.

Note Currently, the following warnings are enabled by default for backwards compatibility reasons. In future releases of MATLAB, the warnings will be disabled by default. The programmer will be responsible for enabling these warnings during the MEX-file development cycle.

Improperly Destroying an mxArray

You cannot use mxFree to destroy an mxArray.

Warning

```
Warning:  You are attempting to call mxFree on a <class-id> array.
The destructor for mxArrays is mxDestroyArray; please call this
instead. MATLAB will attempt to fix the problem and continue, but
this will result in memory faults in future releases.
```

Example That Causes Warning

In the following example, mxFree does not destroy the array object. This operation frees the structure header associated with the array, but MATLAB will still operate as if the array object needs to be destroyed. Thus MATLAB will try to destroy the array object, and in the process, attempt to free its structure header again.

```
mxArray *temp = mxCreateDoubleMatrix(1,1,mxREAL);
       ...
    mxFree(temp);  /* INCORRECT */
```

Solution

Call mxDestroyArray instead.

```
    mxDestroyArray(temp);  /* CORRECT */
```

Incorrectly Constructing a Cell or Structure mxArray

You cannot call `mxSetCell` or `mxSetField` variants with `prhs[]` as the member array.

Warning

```
Warning: You are attempting to use an array from another scope
(most likely an input argument) as a member of a cell array or
structure. You need to make a copy of the array first. MATLAB will
attempt to fix the problem and continue, but this will result in
memory faults in future releases.
```

Example That Causes Warning

In the following example, when the MEX-file returns, MATLAB will destroy the entire cell array. Since this includes the members of the cell, this will implicitly destroy the MEX-file's input arguments. This can cause several strange results, generally having to do with the corruption of the caller's workspace, if the right-hand side argument used is a temporary array (i.e., a literal or the result of an expression).

```
myfunction('hello')
/* myfunction is the name of your MEX-file and your code */
/* contains the following:    */

    mxArray *temp = mxCreateCellMatrix(1,1);
      ...
    mxSetCell(temp, 0, prhs[0]);  /* INCORRECT */
```

Solution

Make a copy of the right-hand side argument with `mxDuplicateArray` and use that copy as the argument to `mxSetCell` (or `mxSetField` variants); for example

```
mxSetCell(temp, 0, mxDuplicateArray(prhs[0]));  /* CORRECT */
```

Creating a Temporary mxArray with Improper Data

You cannot call `mxDestroyArray` on an `mxArray` whose data was not allocated by an API routine.

Warning

```
Warning: You have attempted to point the data of an array to a
block of memory not allocated through the MATLAB API. MATLAB will
attempt to fix the problem and continue, but this will result in
memory faults in future releases.
```

Example That Causes Warning

If you call `mxSetPr`, `mxSetPi`, `mxSetData`, or `mxSetImagData`, specifying memory that was not allocated by `mxCalloc`, `mxMalloc`, or `mxRealloc` as the intended data block (second argument), then when the MEX-file returns, MATLAB will attempt to free the pointer to real data and the pointer to imaginary data (if any). Thus MATLAB will attempt to free memory, in this example, from the program stack. This will cause the above warning when MATLAB attempts to reconcile its consistency checking information.

```
mxArray *temp = mxCreateDoubleMatrix(0,0,mxREAL);
   double data[5] = {1,2,3,4,5};
      ...
   mxSetM(temp,1); mxSetN(temp,5); mxSetPr(temp, data);
   /* INCORRECT */
```

Solution

Rather than use `mxSetPr` to set the data pointer, instead create the `mxArray` with the right size and use `memcpy` to copy the stack data into the buffer returned by `mxGetPr`.

```
    mxArray *temp = mxCreateDoubleMatrix(1,5,mxREAL);
    double data[5] = {1,2,3,4,5};
      ...
   memcpy(mxGetPr(temp), data, 5*sizeof(double));  /* CORRECT */
```

Potential Memory Leaks

Prior to Version 5.2, if you created an `mxArray` using one of the API creation routines and then you overwrote the pointer to the data using `mxSetPr`, MATLAB would still free the original memory. This is no longer the case.

For example,

```
pr = mxCalloc(5*5, sizeof(double));
... <load data into pr>
plhs[0] = mxCreateDoubleMatrix(5,5,mxREAL);
mxSetPr(plhs[0], pr);  /* INCORRECT */
```

will now leak 5*5*8 bytes of memory, where 8 bytes is the size of a `double`.

You can avoid that memory leak by changing the code

```
plhs[0] = mxCreateDoubleMatrix(5,5,mxREAL);
pr = mxGetPr(plhs[0]);
... <load data into pr>
```

or alternatively

```
pr = mxCalloc(5*5, sizeof(double));
... <load data into pr>
plhs[0] = mxCreateDoubleMatrix(5,5,mxREAL);
mxFree(mxGetPr(plhs[0]));
mxSetPr(plhs[0], pr);
```

Note that the first solution is more efficient.

Similar memory leaks can also occur when using `mxSetPi`, `mxSetData`, `mxSetImagData`, `mxSetIr`, or `mxSetJc`. You can address this issue as shown above to avoid such memory leaks.

MEX-Files Should Destroy Their Own Temporary Arrays

In general, we recommend that MEX-files destroy their own temporary arrays and clean up their own temporary memory. All `mxArrays` except those returned in the left-hand side list and those returned by `mexGetVariablePtr` may be safely destroyed. This approach is consistent with other MATLAB API applications (i.e., MAT-file applications, engine applications, and MATLAB Compiler generated applications, which do not have any automatic cleanup mechanism.)

Additional Information

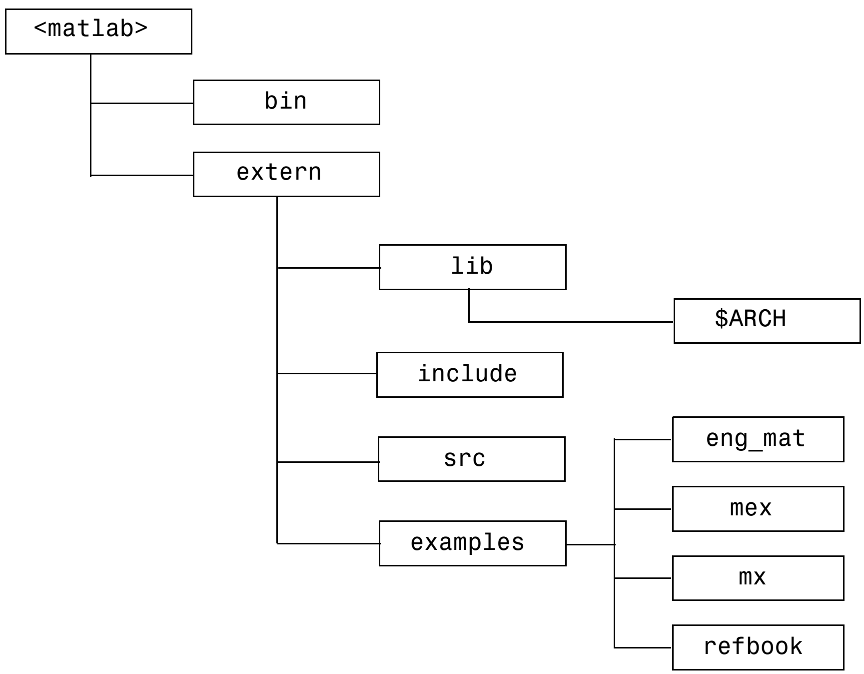
The following sections describe how to find additional information and assistance in building your applications. It covers the following topics:

- "Files and Directories - UNIX Systems"
- "Files and Directories - Windows Systems"
- "Examples"
- "Technical Support"

Files and Directories - UNIX Systems

This section describes the directory organization and purpose of the files associated with the MATLAB API on UNIX systems.

The following figure illustrates the directories in which the MATLAB API files are located. In the illustration, `<matlab>` symbolizes the top-level directory where MATLAB is installed on your system.



<matlab>/bin

The `<matlab>/bin` directory contains two files that are relevant for the MATLAB API.

`mex`	UNIX shell script that creates MEX-files from C or Fortran MEX-file source code.
`matlab`	UNIX shell script that initializes your environment and then invokes the MATLAB interpreter.

This directory also contains the preconfigured options files that the `mex` script uses with particular compilers. This table lists the options files.

Table 1-4: Preconfigured Options Files

Options File	Description
`engopts.sh`	Used with the `mex` script and the system C or Fortran compiler to compile engine applications
`gccopts.sh`	Used with the `mex` script and the GNU C (`gcc`) compiler to compile MEX-files
`matopts.sh`	Used with the `mex` script and the system C or Fortran compiler to compile MAT-file applications
`mexopts.sh`	Used with the `mex` script and the system ANSI C or Fortran compiler to compile MEX-files

<matlab>/extern/lib/$ARCH

The `<matlab>/extern/lib/`*`$ARCH`* directory contains libraries, where *`$ARCH`* specifies a particular UNIX platform. On some UNIX platforms, this directory contains two versions of this library. Library filenames ending with `.a` are static libraries and filenames ending with `.so` or `.sl` are shared libraries.

<matlab>/extern/include

The `<matlab>/extern/include` directory contains the header files for developing C and C++ applications that interface with MATLAB.

The relevant header files for the MATLAB API are:

`engine.h`	Header file for MATLAB engine programs. Contains function prototypes for engine routines.
`mat.h`	Header file for programs accessing MAT-files. Contains function prototypes for `mat` routines.
`matrix.h`	Header file containing a definition of the `mxArray` structure and function prototypes for matrix access routines.
`mex.h`	Header file for building MEX-files. Contains function prototypes for `mex` routines.

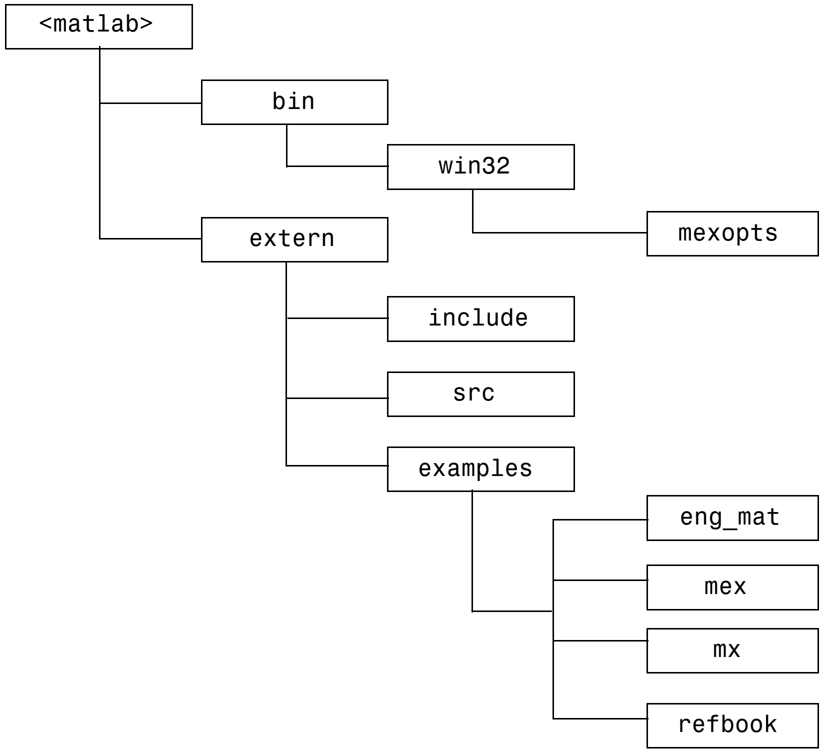
<matlab>/extern/src

The `<matlab>/extern/src` directory contains those C source files that are necessary to support certain MEX-file features such as argument checking and versioning.

Files and Directories - Windows Systems

This section describes the directory organization and purpose of the files associated with the MATLAB API on Microsoft Windows systems.

The following figure illustrates the directories in which the MATLAB API files are located. In the illustration, <matlab> symbolizes the top-level directory where MATLAB is installed on your system.



<matlab>\bin\win32

The `<matlab>\bin\win32` directory contains the `mex.bat` batch file that builds C and Fortran files into MEX-files. Also, this directory contains `mex.pl`, which is a Perl script used by `mex.bat`.

<matlab>\bin\win32\mexopts

The `<matlab>\bin\win32\mexopts` directory contains the preconfigured options files that the `mex` script uses with particular compilers. See Table 1-2, Options Files, on page 1-16 for a complete list of the options files.

<matlab>\extern\include

The `<matlab>\extern\include` directory contains the header files for developing C and C++ applications that interface with MATLAB.

The relevant header files for the MATLAB API (MEX-files, engine, and MAT-files) are:

`engine.h`	Header file for MATLAB engine programs. Contains function prototypes for engine routines.
`mat.h`	Header file for programs accessing MAT-files. Contains function prototypes for `mat` routines.
`matrix.h`	Header file containing a definition of the `mxArray` structure and function prototypes for matrix access routines.
`mex.h`	Header file for building MEX-files. Contains function prototypes for `mex` routines.
`_*.def`	Files used by Borland compiler.
`*.def`	Files used by MSVC and Microsoft Fortran compilers.
`mexversion.rc`	Resource file for inserting versioning information into MEX-files.

<matlab>\extern\src

The `<matlab>\extern\src` directory contains files that are used for debugging MEX-files.

Examples

This book uses many examples to show how to write C and Fortran MEX-files.

Examples From the Text

The `refbook` subdirectory in the `extern/examples` directory contains the MEX-file examples (C and Fortran) that are used in this book, *External Interfaces*.

You can find the most recent versions of these examples using the anonymous FTP server locations

```
ftp://ftp.mathworks.com/pub/tech-support/docexamples/apiguide/R1
2/refbook
```

MEX Reference Examples

The `mex` subdirectory of `/extern/examples` directory contains MEX-file examples. It includes the examples described in the online External Interfaces/API reference pages for MEX interface functions (the functions beginning with the `mex` prefix).

You can find the most recent versions of these examples using the anonymous FTP server location

```
ftp://ftp.mathworks.com/pub/tech-support/docexamples/apiguide/R1
2/mex
```

MX Examples

The `mx` subdirectory of `extern/examples` contains examples for using the array access functions. Although you can use these functions in stand-alone programs, most of these are MEX-file examples. The exception is `mxSetAllocFcns.c`, since this function is available only to stand-alone programs.

You can find the most recent versions of these examples using the anonymous FTP server location

```
ftp://ftp.mathworks.com/pub/tech-support/docexamples/apiguide/R1
2/mx
```

Engine and MAT Examples

The `eng_mat` subdirectory in the `extern/examples` directory contains the MEX-file examples (C and Fortran) for using the MATLAB engine facility, as well as examples for reading and writing MATLAB data files (MAT-files). These examples are all stand-alone programs.

You can find the most recent versions of these examples using the anonymous FTP server locations

```
ftp://ftp.mathworks.com/pub/tech-support/docexamples/apiguide/R1
2/eng_mat
```

Technical Support

The MathWorks provides additional Technical Support through its web site. A few of the services provided are as follows:

- FAQ (Frequently Asked Questions)

This is a list of the most frequently asked questions received by our Technical Support staff, along with answers from the solutions database.

```
http://www.mathworks.com/support/index.shtml
```

- Solution Search Engine

This knowledge base on our web site includes thousands of solutions and links to Technical Notes and is updated several times each week.

```
http://www.mathworks.com/support/solutions/index.shtml
```

- Technical Notes

Technical notes are written by our Technical Support staff to address commonly asked questions.

```
http://www.mathworks.com/support/tech-notes/index.shtml
```

2

Creating C Language MEX-Files

This chapter describes how to write MEX-files in the C programming language. It discusses the MEX-file itself, how these C language files interact with MATLAB, how to pass and manipulate arguments of different data types, how to debug your MEX-file programs, and several other, more advanced topics.

C MEX-Files

C MEX-files are built by using the `mex` script to compile your C source code with additional calls to API routines.

The Components of a C MEX-File

The source code for a MEX-file consists of two distinct parts:

- A *computational routine* that contains the code for performing the computations that you want implemented in the MEX-file. Computations can be numerical computations as well as inputting and outputting data.
- A *gateway routine* that interfaces the computational routine with MATLAB by the entry point `mexFunction` and its parameters `prhs`, `nrhs`, `plhs`, `nlhs`, where `prhs` is an array of right-hand input arguments, `nrhs` is the number of right-hand input arguments, `plhs` is an array of left-hand output arguments, and `nlhs` is the number of left-hand output arguments. The gateway calls the computational routine as a subroutine.

In the gateway routine, you can access the data in the `mxArray` structure and then manipulate this data in your C computational subroutine. For example, the expression `mxGetPr(prhs[0])` returns a pointer of type `double *` to the real data in the `mxArray` pointed to by `prhs[0]`. You can then use this pointer like any other pointer of type `double *` in C. After calling your C computational routine from the gateway, you can set a pointer of type `mxArray` to the data it returns. MATLAB is then able to recognize the output from your computational routine as the output from the MEX-file.

The following C MEX Cycle figure shows how inputs enter a MEX-file, what functions the gateway routine performs, and how outputs return to MATLAB.

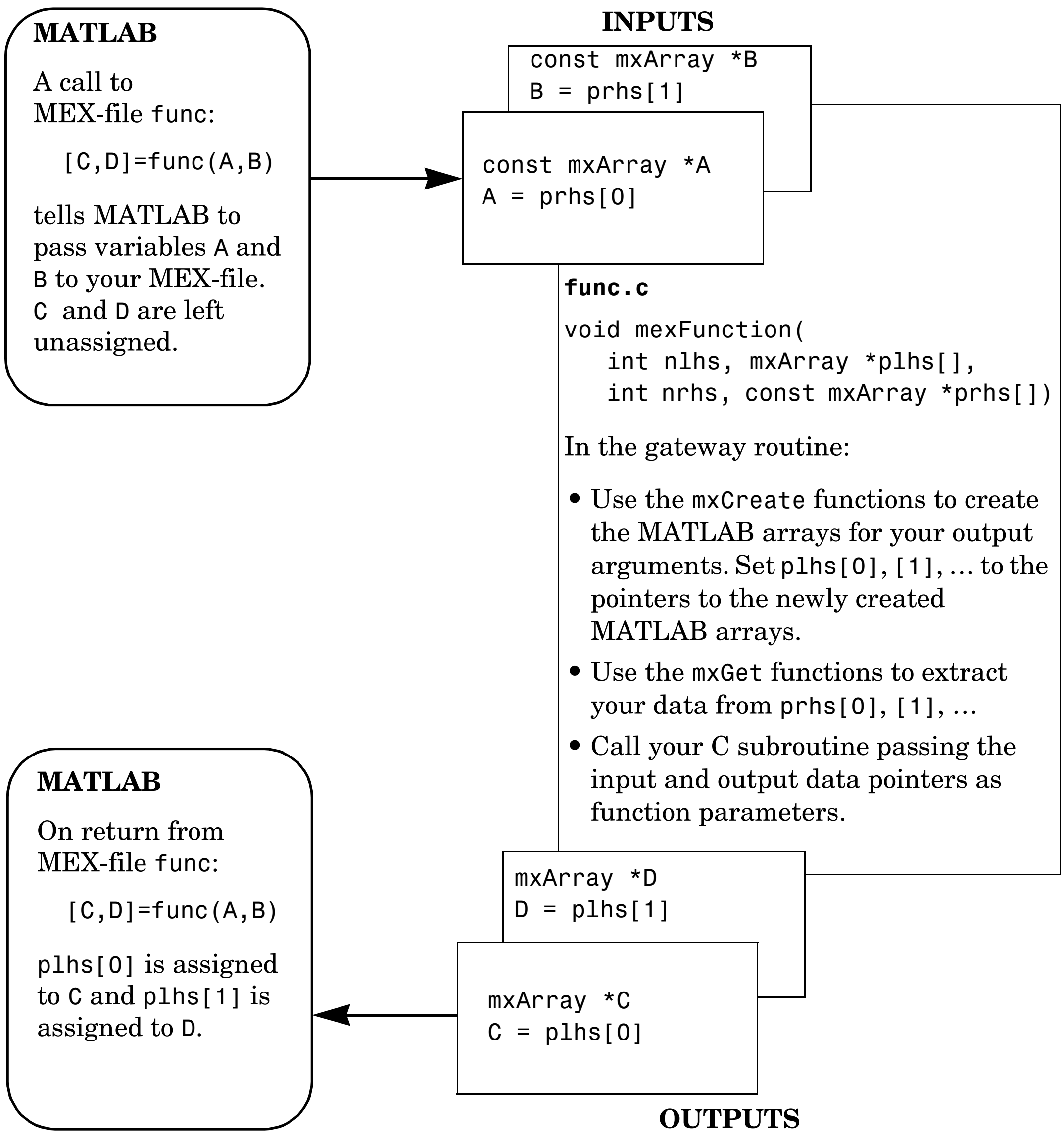


Figure 2-1: C MEX Cycle

Required Arguments to a MEX-File

The two components of the MEX-file may be separate or combined. In either case, the files must contain the `#include "mex.h"` header so that the entry point and interface routines are declared properly. The name of the gateway routine must always be `mexFunction` and must contain these parameters.

```
void mexFunction(
    int nlhs, mxArray *plhs[],
    int nrhs, const mxArray *prhs[])
{
   /* more C code ... */
```

The parameters `nlhs` and `nrhs` contain the number of left- and right-hand arguments with which the MEX-file is invoked. In the syntax of the MATLAB language, functions have the general form

```
[a,b,c, ] = fun(d,e,f, )
```

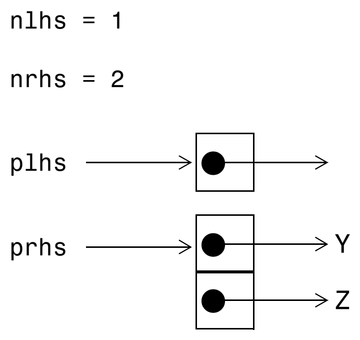
where the ellipsis ( ) denotes additional terms of the same format. The `a,b,c,` are left-hand arguments and the `d,e,f,` are right-hand arguments.

The parameters `plhs` and `prhs` are vectors that contain pointers to the left- and right-hand arguments of the MEX-file. Note that both are declared as containing type `mxArray *`, which means that the variables pointed at are MATLAB arrays. `prhs` is a length `nrhs` array of pointers to the right-hand side inputs to the MEX-file, and `plhs` is a length `nlhs` array that will contain pointers to the left-hand side outputs that your function generates.

For example, if you invoke a MEX-file from the MATLAB workspace with the command

```
x = fun(y,z);
```

the MATLAB interpreter calls `mexFunction` with the arguments



`plhs` is a 1-element C array where the single element is a `null` pointer. `prhs` is a 2-element C array where the first element is a pointer to an `mxArray` named `Y` and the second element is a pointer to an `mxArray` named `Z`.

The parameter `plhs` points at nothing because the output `x` is not created until the subroutine executes. It is the responsibility of the gateway routine to create an output array and to set a pointer to that array in `plhs[0]`. If `plhs[0]` is left unassigned, MATLAB prints a warning message stating that no output has been assigned.

Note It is possible to return an output value even if `nlhs = 0`. This corresponds to returning the result in the `ans` variable.

Examples of C MEX-Files

The following sections include information and examples describing how to pass and manipulate the different data types when working with MEX-files. These topics include

- "A First Example — Passing a Scalar"
- "Passing Strings"
- "Passing Two or More Inputs or Outputs"
- "Passing Structures and Cell Arrays"
- "Handling Complex Data"
- "Handling 8-,16-, and 32-Bit Data"
- "Manipulating Multidimensional Numerical Arrays"
- "Handling Sparse Arrays"
- "Calling Functions from C MEX-Files"

The MATLAB API provides a full set of routines that handle the various data types supported by MATLAB. For each data type there is a specific set of functions that you can use for data manipulation. The first example discusses the simple case of doubling a scalar. After that, the examples discuss how to pass in, manipulate, and pass back various data types, and how to handle multiple inputs and outputs. Finally, the sections discuss passing and manipulating various MATLAB data types.

Note You can find the most recent versions of the example programs at the anonymous FTP server

```
ftp://ftp.mathworks.com/pub/tech-support/docexamples/apiguide/R12/
refbook
```

A First Example — Passing a Scalar

Let's look at a simple example of C code and its MEX-file equivalent. Here is a C computational function that takes a scalar and doubles it.

```
#include <math.h>
void timestwo(double y[], double x[])
{
  y[0] = 2.0*x[0];
  return;
}
```

Below is the same function written in the MEX-file format.

```
/*
 * =============================================================
 * timestwo.c - example found in API guide
 *
 * Computational function that takes a scalar and doubles it.
 *
 * This is a MEX-file for MATLAB.
 * Copyright (c) 1984-2000 The MathWorks, Inc.
 * =============================================================
 */

/* $Revision: 1.8 $ */

#include "mex.h"

void timestwo(double y[], double x[])
{
  y[0] = 2.0*x[0];
}


void mexFunction(int nlhs, mxArray *plhs[], int nrhs,
                 const mxArray *prhs[])
{
  double *x, *y;
  int mrows, ncols;
```

```
    /* Check for proper number of arguments. */
    if (nrhs != 1) {
      mexErrMsgTxt("One input required.");
    } else if (nlhs > 1) {
      mexErrMsgTxt("Too many output arguments");
    }

    /* The input must be a noncomplex scalar double.*/
    mrows = mxGetM(prhs[0]);
    ncols = mxGetN(prhs[0]);
    if (!mxIsDouble(prhs[0]) || mxIsComplex(prhs[0]) ||
        !(mrows == 1 && ncols == 1)) {
      mexErrMsgTxt("Input must be a noncomplex scalar double.");
    }

    /* Create matrix for the return argument. */
    plhs[0] = mxCreateDoubleMatrix(mrows,ncols, mxREAL);

    /* Assign pointers to each input and output. */
    x = mxGetPr(prhs[0]);
    y = mxGetPr(plhs[0]);

    /* Call the timestwo subroutine. */
    timestwo(y,x);
  }
```

In C, function argument checking is done at compile time. In MATLAB, you can pass any number or type of arguments to your M-function, which is responsible for argument checking. This is also true for MEX-files. Your program must safely handle any number of input or output arguments of any supported type.

To compile and link this example source file at the MATLAB prompt, type

```
mex timestwo.c
```

This carries out the necessary steps to create the MEX-file called `timestwo` with an extension corresponding to the platform on which you're running. You can now call `timestwo` as if it were an M-function.

```
x = 2;
y = timestwo(x)
y =
     4
```

You can create and compile MEX-files in MATLAB or at your operating system's prompt. MATLAB uses `mex.m`, an M-file version of the `mex` script, and your operating system uses `mex.bat` on Windows and `mex.sh` on UNIX. In either case, typing

```
mex filename
```

at the prompt produces a compiled version of your MEX-file.

In the above example, scalars are viewed as 1-by-1 matrices. Alternatively, you can use a special API function called `mxGetScalar` that returns the values of scalars instead of pointers to copies of scalar variables. This is the alternative code (error checking has been omitted for brevity).

```
/*
 * =============================================================
 * timestwoalt.c - example found in API guide
 *
 * Use mxGetScalar to return the values of scalars instead of
 * pointers to copies of scalar variables.
 *
 * This is a MEX-file for MATLAB.
 * Copyright (c) 1984-2000 The MathWorks, Inc.
 * =============================================================
 */

/* $Revision: 1.5 $ */

#include "mex.h"

void timestwo_alt(double *y, double x)
{
  *y = 2.0*x;
}
```

```
void mexFunction(int nlhs, mxArray *plhs[],
                 int nrhs, const mxArray *prhs[])
{
  double *y;
  double x;

  /* Create a 1-by-1 matrix for the return argument. */
  plhs[0] = mxCreateDoubleMatrix(1, 1, mxREAL);

  /* Get the scalar value of the input x. */
  /* Note: mxGetScalar returns a value, not a pointer. */
  x = mxGetScalar(prhs[0]);

  /* Assign a pointer to the output. */
  y = mxGetPr(plhs[0]);

  /* Call the timestwo_alt subroutine. */
  timestwo_alt(y,x);
}
```

This example passes the input scalar `x` by value into the `timestwo_alt` subroutine, but passes the output scalar `y` by reference.

Passing Strings

Any MATLAB data type can be passed to and from MEX-files. For example, this C code accepts a string and returns the characters in reverse order.

```
/*
 * =============================================================
 * revord.c
 * Example for illustrating how to copy the string data from
 * MATLAB to a C-style string and back again.
 *
 * Takes a string and returns a string in reverse order.
 *
 * This is a MEX-file for MATLAB.
 * Copyright (c) 1984-2000 The MathWorks, Inc.
 * ============================================================
 */
```

```
/* $Revision: 1.10 $ */

#include "mex.h"

void revord(char *input_buf, int buflen, char *output_buf)
{
  int   i;

  /* Reverse the order of the input string. */
  for (i = 0; i < buflen-1; i++)
    *(output_buf+i) = *(input_buf+buflen-i-2);
}
```

In this example, the API function `mxCalloc` replaces `calloc`, the standard C function for dynamic memory allocation. `mxCalloc` allocates dynamic memory using the MATLAB memory manager and initializes it to zero. You must use `mxCalloc` in any situation where C would require the use of `calloc`. The same is true for `mxMalloc` and `mxRealloc`; use `mxMalloc` in any situation where C would require the use of `malloc` and use `mxRealloc` where C would require `realloc`.

Note MATLAB automatically frees up memory allocated with the `mx` allocation routines (`mxCalloc`, `mxMalloc`, `mxRealloc`) upon exiting your MEX-file. If you don't want this to happen, use the API function `mexMakeMemoryPersistent`.

Below is the gateway routine that calls the C computational routine `revord`.

```
void mexFunction(int nlhs, mxArray *plhs[],
                 int nrhs, const mxArray *prhs[])
{
  char *input_buf, *output_buf;
  int   buflen,status;

  /* Check for proper number of arguments. */
  if (nrhs != 1)
    mexErrMsgTxt("One input required.");
  else if (nlhs > 1)
    mexErrMsgTxt("Too many output arguments.");
```

```
    /* Input must be a string. */
    if (mxIsChar(prhs[0]) != 1)
      mexErrMsgTxt("Input must be a string.");

    /* Input must be a row vector. */
    if (mxGetM(prhs[0]) != 1)
      mexErrMsgTxt("Input must be a row vector.");

    /* Get the length of the input string. */
    buflen = (mxGetM(prhs[0]) * mxGetN(prhs[0])) + 1;

    /* Allocate memory for input and output strings. */
    input_buf = mxCalloc(buflen, sizeof(char));
    output_buf = mxCalloc(buflen, sizeof(char));

    /* Copy the string data from prhs[0] into a C string
     * input_buf. If the string array contains several rows,
     * they are copied, one column at a time, into one long
     * string array. */
    status = mxGetString(prhs[0], input_buf, buflen);
    if (status != 0)
      mexWarnMsgTxt("Not enough space. String is truncated.");

    /* Call the C subroutine. */
    revord(input_buf, buflen, output_buf);

    /* Set C-style string output_buf to MATLAB mexFunction output*/
    plhs[0] = mxCreateString(output_buf);
    return;
  }
```

The gateway routine allocates memory for the input and output strings. Since these are C strings, they need to be one greater than the number of elements in the MATLAB string. Next the MATLAB string is copied to the input string. Both the input and output strings are passed to the computational subroutine (`revord`), which loads the output in reverse order. Note that the output buffer is a valid null-terminated C string because `mxCalloc` initializes the memory to 0. The API function `mxCreateString` then creates a MATLAB string from the

C string, output_buf. Finally, plhs[0], the left-hand side return argument to MATLAB, is set to the MATLAB array you just created.

By isolating variables of type mxArray from the computational subroutine, you can avoid having to make significant changes to your original C code.

In this example, typing

```
x = 'hello world';
y = revord(x)
```

produces

```
The string to convert is 'hello world'.
y =
dlrow olleh
```

Passing Two or More Inputs or Outputs

The plhs[] and prhs[] parameters are vectors that contain pointers to each left-hand side (output) variable and each right-hand side (input) variable, respectively. Accordingly, plhs[0] contains a pointer to the first left-hand side argument, plhs[1] contains a pointer to the second left-hand side argument, and so on. Likewise, prhs[0] contains a pointer to the first right-hand side argument, prhs[1] points to the second, and so on.

This example, xtimesy, multiplies an input scalar by an input scalar or matrix and outputs a matrix. For example, using xtimesy with two scalars gives

```
x = 7;
y = 7;
z = xtimesy(x,y)

z =
     49
```

Using xtimesy with a scalar and a matrix gives

```
x = 9;
y = ones(3);
z = xtimesy(x,y)
```

```
z =
     9     9     9
     9     9     9
     9     9     9
```

This is the corresponding MEX-file C code.

```
/*
 * =============================================================
 * xtimesy.c - example found in API guide
 *
 * Multiplies an input scalar times an input matrix and outputs a
 * matrix.
 *
 * This is a MEX-file for MATLAB.
 * Copyright (c) 1984-2000 The MathWorks, Inc.
 * =============================================================
 */

/* $Revision: 1.10 $ */

#include "mex.h"

void xtimesy(double x, double *y, double *z, int m, int n)
{
  int i,j,count = 0;

  for (i = 0; i < n; i++) {
    for (j = 0; j < m; j++) {
      *(z+count) = x * *(y+count);
      count++;
    }
  }
}
```

```
/* The gateway routine */
void mexFunction(int nlhs, mxArray *plhs[],
                 int nrhs, const mxArray *prhs[])
{
  double *y, *z;
  double x;
  int status,mrows,ncols;

  /*  Check for proper number of arguments. */
  /* NOTE: You do not need an else statement when using
     mexErrMsgTxt within an if statement. It will never
     get to the else statement if mexErrMsgTxt is executed.
     (mexErrMsgTxt breaks you out of the MEX-file.)
  */
  if (nrhs != 2)
    mexErrMsgTxt("Two inputs required.");
  if (nlhs != 1)
    mexErrMsgTxt("One output required.");

  /* Check to make sure the first input argument is a scalar. */
  if (!mxIsDouble(prhs[0]) || mxIsComplex(prhs[0]) ||
      mxGetN(prhs[0])*mxGetM(prhs[0]) != 1) {
    mexErrMsgTxt("Input x must be a scalar.");
  }

  /* Get the scalar input x. */
  x = mxGetScalar(prhs[0]);

  /* Create a pointer to the input matrix y. */
  y = mxGetPr(prhs[1]);

  /* Get the dimensions of the matrix input y. */
  mrows = mxGetM(prhs[1]);
  ncols = mxGetN(prhs[1]);

  /* Set the output pointer to the output matrix. */
  plhs[0] = mxCreateDoubleMatrix(mrows,ncols, mxREAL);

  /* Create a C pointer to a copy of the output matrix. */
  z = mxGetPr(plhs[0]);
```

```
    /* Call the C subroutine. */
    xtimesy(x,y,z,mrows,ncols);
  }
```

As this example shows, creating MEX-file gateways that handle multiple inputs and outputs is straightforward. All you need to do is keep track of which indices of the vectors `prhs` and `plhs` correspond to the input and output arguments of your function. In the example above, the input variable `x` corresponds to `prhs[0]` and the input variable `y` to `prhs[1]`.

Note that `mxGetScalar` returns the value of `x` rather than a pointer to `x`. This is just an alternative way of handling scalars. You could treat `x` as a 1-by-1 matrix and use `mxGetPr` to return a pointer to `x`.

Passing Structures and Cell Arrays

Passing structures and cell arrays into MEX-files is just like passing any other data types, except the data itself is of type `mxArray`. In practice, this means that `mxGetField` (for structures) and `mxGetCell` (for cell arrays) return pointers of type `mxArray`. You can then treat the pointers like any other pointers of type `mxArray`, but if you want to pass the data contained in the `mxArray` to a C routine, you must use an API function such as `mxGetData` to access it.

This example takes an m-by-n structure matrix as input and returns a new 1-by-1 structure that contains these fields:

- String input generates an m-by-n cell array
- Numeric input (noncomplex, scalar values) generates an m-by-n vector of numbers with the same class ID as the input, for example `int`, `double`, and so on.

```
/*
 * =============================================================
 * phonebook.c
 * Example for illustrating how to manipulate structure and cell
 * array
 *
 * Takes a (MxN) structure matrix and returns a new structure
 * (1x1) containing corresponding fields:for string input, it
 * will be (MxN) cell array; and for numeric (noncomplex, scalar)
 * input, it will be (MxN) vector of numbers with the same
```

```
 * classID as input, such as int, double etc..
 *
 * This is a MEX-file for MATLAB.
 * Copyright (c) 1984-2000 The MathWorks, Inc.
 * =============================================================
 */

/* $Revision: 1.6 $ */

#include "mex.h"
#include "string.h"

#define MAXCHARS 80   /* max length of string contained in each
                         field */

/* The gateway routine.  */
void mexFunction(int nlhs, mxArray *plhs[],
                 int nrhs, const mxArray *prhs[])
{
  const char **fnames;       /* pointers to field names */
  const int  *dims;
  mxArray    *tmp, *fout;
  char       *pdata;
  int        ifield, jstruct, *classIDflags;
  int        NStructElems, nfields, ndim;

  /* Check proper input and output */
  if (nrhs != 1)
    mexErrMsgTxt("One input required.");
  else if (nlhs > 1)
    mexErrMsgTxt("Too many output arguments.");
  else if (!mxIsStruct(prhs[0]))
    mexErrMsgTxt("Input must be a structure.");

  /* Get input arguments */
  nfields = mxGetNumberOfFields(prhs[0]);
  NStructElems = mxGetNumberOfElements(prhs[0]);

  /* Allocate memory  for storing classIDflags */
  classIDflags = mxCalloc(nfields, sizeof(int));
```

```
/* Check empty field, proper data type, and data type
    consistency; get classID for each field. */
for (ifield = 0; ifield < nfields; ifield++) {
  for (jstruct = 0; jstruct < NStructElems; jstruct++) {
    tmp = mxGetFieldByNumber(prhs[0], jstruct, ifield);
    if (tmp == NULL) {
      mexPrintf("%s%d\t%s%d\n",
          "FIELD:", ifield+1, "STRUCT INDEX :", jstruct+1);
      mexErrMsgTxt("Above field is empty!");
    }
    if (jstruct == 0) {
      if ((!mxIsChar(tmp) && !mxIsNumeric(tmp)) ||
          mxIsSparse(tmp)) {
        mexPrintf("%s%d\t%s%d\n",
            "FIELD:", ifield+1, "STRUCT INDEX :", jstruct+1);
        mexErrMsgTxt("Above field must have either "
            "string or numeric non-sparse data.");
      }
      classIDflags[ifield] = mxGetClassID(tmp);
    } else {
      if (mxGetClassID(tmp) != classIDflags[ifield]) {
        mexPrintf("%s%d\t%s%d\n",
            "FIELD:", ifield+1, "STRUCT INDEX :", jstruct+1);
       mexErrMsgTxt("Inconsistent data type in above field!");
      }
      else if (!mxIsChar(tmp) && ((mxIsComplex(tmp) ||
          mxGetNumberOfElements(tmp) != 1))) {
        mexPrintf("%s%d\t%s%d\n",
            "FIELD:", ifield+1, "STRUCT INDEX :", jstruct+1);
        mexErrMsgTxt("Numeric data in above field "
            "must be scalar and noncomplex!");
      }
    }
  }
}

/* Allocate memory  for storing pointers */
fnames = mxCalloc(nfields, sizeof(*fnames));
```

```
  /* Get field name pointers */
  for (ifield = 0; ifield < nfields; ifield++) {
    fnames[ifield] = mxGetFieldNameByNumber(prhs[0],ifield);
  }

  /* Create a 1x1 struct matrix for output */
  plhs[0] = mxCreateStructMatrix(1, 1, nfields, fnames);
  mxFree(fnames);
  ndim = mxGetNumberOfDimensions(prhs[0]);
  dims = mxGetDimensions(prhs[0]);
  for (ifield = 0; ifield < nfields; ifield++) {
    /* Create cell/numeric array */
    if (classIDflags[ifield] == mxCHAR_CLASS) {
      fout = mxCreateCellArray(ndim, dims);
    } else {
      fout = mxCreateNumericArray(ndim, dims,
          classIDflags[ifield], mxREAL);
      pdata = mxGetData(fout);
    }

    /* Copy data from input structure array */
    for (jstruct = 0; jstruct < NStructElems; jstruct++) {
      tmp = mxGetFieldByNumber(prhs[0],jstruct,ifield);
      if (mxIsChar(tmp)) {
        mxSetCell(fout, jstruct, mxDuplicateArray(tmp));
      } else {
        size_t     sizebuf;
        sizebuf = mxGetElementSize(tmp);
        memcpy(pdata, mxGetData(tmp), sizebuf);
        pdata += sizebuf;
      }
    }

    /* Set each field in output structure */
    mxSetFieldByNumber(plhs[0], 0, ifield, fout);
  }
  mxFree(classIDflags);
  return;
}
```

To see how this program works, enter this structure.

```
friends(1).name = 'Jordan Robert';
friends(1).phone = 3386;
friends(2).name = 'Mary Smith';
friends(2).phone = 3912;
friends(3).name = 'Stacy Flora';
friends(3).phone = 3238;
friends(4).name = 'Harry Alpert';
friends(4).phone = 3077;
```

The results of this input are

```
phonebook(friends)

ans =
     name: {1x4 cell  }
    phone: [3386 3912 3238 3077]
```

Handling Complex Data

Complex data from MATLAB is separated into real and imaginary parts. The MATLAB API provides two functions, `mxGetPr` and `mxGetPi`, that return pointers (of type `double *`) to the real and imaginary parts of your data.

This example takes two complex row vectors and convolves them.

```
/*
 * =============================================================
 * convec.c
 * Example for illustrating how to pass complex data
 * from MATLAB to C and back again
 *
 * Convolves two complex input vectors.
 *
 * This is a MEX-file for MATLAB.
 * Copyright (c) 1984-2000 The MathWorks, Inc.
 * =============================================================
 */

/* $Revision: 1.8 $ */
```

```
#include "mex.h"

/* Computational subroutine */
void convec(double *xr, double *xi, int nx, double *yr,
            double *yi, int ny, double *zr, double *zi)
{
  int i,j;

  zr[0] = 0.0;
  zi[0] = 0.0;
  /* Perform the convolution of the complex vectors. */
  for (i = 0; i < nx; i++) {
    for (j = 0; j < ny; j++) {
      *(zr+i+j) = *(zr+i+j) + *(xr+i) * *(yr+j) - *(xi+i)
          * *(yi+j);
      *(zi+i+j) = *(zi+i+j) + *(xr+i) * *(yi+j) + *(xi+i)
          * *(yr+j);
    }
  }
}
```

Below is the gateway routine that calls this complex convolution.

```
/* The gateway routine. */
void mexFunction(int nlhs, mxArray *plhs[],
                 int nrhs, const mxArray *prhs[])
{
  double  *xr, *xi, *yr, *yi, *zr, *zi;
  int     rows, cols, nx, ny;

  /* Check for the proper number of arguments. */
  if (nrhs != 2)
    mexErrMsgTxt("Two inputs required.");
  if (nlhs > 1)
    mexErrMsgTxt("Too many output arguments.");

  /* Check that both inputs are row vectors. */
  if (mxGetM(prhs[0]) != 1 || mxGetM(prhs[1]) != 1)
    mexErrMsgTxt("Both inputs must be row vectors.");
  rows = 1;
```

```
  /* Check that both inputs are complex. */
  if (!mxIsComplex(prhs[0]) || !mxIsComplex(prhs[1]))
    mexErrMsgTxt("Inputs must be complex.\n");

  /* Get the length of each input vector. */
  nx = mxGetN(prhs[0]);
  ny = mxGetN(prhs[1]);

  /* Get pointers to real and imaginary parts of the inputs. */
  xr = mxGetPr(prhs[0]);
  xi = mxGetPi(prhs[0]);
  yr = mxGetPr(prhs[1]);
  yi = mxGetPi(prhs[1]);

  /* Create a new array and set the output pointer to it. */
  cols = nx + ny - 1;
  plhs[0] = mxCreateDoubleMatrix(rows, cols, mxCOMPLEX);
  zr = mxGetPr(plhs[0]);
  zi = mxGetPi(plhs[0]);

  /* Call the C subroutine. */
  convec(xr, xi, nx, yr, yi, ny, zr, zi);

  return;
}
```

Entering these numbers at the MATLAB prompt

```
x = [3.000 - 1.000i, 4.000 + 2.000i, 7.000 - 3.000i];
y = [8.000 - 6.000i, 12.000 + 16.000i, 40.000 - 42.000i];
```

and invoking the new MEX-file

```
z = convec(x,y)
```

results in

```
z =
   1.0e+02 *
```

```
Columns 1 through 4

0.1800 - 0.2600i 0.9600 + 0.2800i 1.3200 - 1.4400i 3.7600 - 0.1200i

Column 5

1.5400 - 4.1400i
```

which agrees with the results that the built-in MATLAB function `conv.m` produces.

Handling 8-,16-, and 32-Bit Data

You can create and manipulate signed and unsigned 8-, 16-, and 32-bit data from within your MEX-files. The MATLAB API provides a set of functions that support these data types. The API function `mxCreateNumericArray` constructs an unpopulated N-dimensional numeric array with a specified data size. Refer to the entry for `mxClassID` in the online reference pages for a discussion of how the MATLAB API represents these data types.

Once you have created an unpopulated MATLAB array of a specified data type, you can access the data using `mxGetData` and `mxGetImagData`. These two functions return pointers to the real and imaginary data. You can perform arithmetic on data of 8-, 16- or 32-bit precision in MEX-files and return the result to MATLAB, which will recognize the correct data class. Although from within MATLAB it is not currently possible to perform arithmetic or to call MATLAB functions that perform data manipulation on data of 8-, 16-, or 32-bit precision, you can display the data at the MATLAB prompt and save it in a MAT-file.

This example constructs a 2-by-2 matrix with unsigned 16-bit integers, doubles each element, and returns both matrices to MATLAB.

```
/*
 * =============================================================
 * doubleelement.c - Example found in API Guide
 *
 * Constructs a 2-by-2 matrix with unsigned 16-bit integers,
 * doubles each element, and returns the matrix.
 *
```

```
 * This is a MEX-file for MATLAB.
 * Copyright (c) 1984-2000 The MathWorks, Inc.
 * ============================================================
 */

/* $Revision: 1.9 $ */

#include <string.h> /* Needed for memcpy() */
#include "mex.h"

#define NDIMS 2
#define TOTAL_ELEMENTS 4

/* The computational subroutine */
void dbl_elem(unsigned short *x)
{
  unsigned short scalar=2;
  int i,j;

  for (i=0; i<2; i++) {
    for (j=0; j<2; j++) {
      *(x+i+j) = scalar * *(x+i+j);
    }
  }
}


/* The gateway routine */
void mexFunction(int nlhs, mxArray *plhs[],
                 int nrhs, const mxArray *prhs[])
{
  const int dims[]={2,2};
  unsigned char *start_of_pr;
  unsigned short data[]={1,2,3,4};
  int bytes_to_copy;

  /* Call the computational subroutine. */
  dbl_elem(data);
```

```
    /* Create a 2-by-2 array of unsigned 16-bit integers. */
    plhs[0] = mxCreateNumericArray(NDIMS,dims,mxUINT16_CLASS,
                                   mxREAL);

    /* Populate the real part of the created array. */
    start_of_pr = (unsigned char *)mxGetData(plhs[0]);
    bytes_to_copy = TOTAL_ELEMENTS * mxGetElementSize(plhs[0]);
    memcpy(start_of_pr, data, bytes_to_copy);
  }
```

At the MATLAB prompt, entering

```
doubleelement
```

produces

```
ans =
     2     6
     8     4
```

The output of this function is a 2-by-2 matrix populated with unsigned 16-bit integers. You can view the contents of this matrix in MATLAB, but you cannot manipulate the data in any fashion.

Manipulating Multidimensional Numerical Arrays

You can manipulate multidimensional numerical arrays by using `mxGetData` and `mxGetImagData` to return pointers to the real and imaginary parts of the data stored in the original multidimensional array. This example takes an N-dimensional array of doubles and returns the indices for the nonzero elements in the array.

```
/*
 * =============================================================
 * findnz.c
 * Example for illustrating how to handle N-dimensional arrays in
 * a MEX-file. NOTE: MATLAB uses 1-based indexing, C uses 0-based
 * indexing.
 *
 * Takes an N-dimensional array of doubles and returns the indices
 * for the non-zero elements in the array. findnz works
 * differently than the FIND command in MATLAB in that it returns
```

```
 * all the indices in one output variable, where the column
 * element contains the index for that dimension.
 *
 *
 * This is a MEX-file for MATLAB.
 * Copyright (c) 1984-2000 by The MathWorks, Inc.
 * =============================================================
 */

/* $Revision: 1.5 $ */

#include "mex.h"

/* If you are using a compiler that equates NaN to zero, you must
 * compile this example using the flag -DNAN_EQUALS_ZERO. For
 * example:
 *
 *     mex -DNAN_EQUALS_ZERO findnz.c
 *
 * This will correctly define the IsNonZero macro for your
   compiler. */

#if NAN_EQUALS_ZERO
#define IsNonZero(d) ((d) != 0.0 || mxIsNaN(d))
#else
#define IsNonZero(d) ((d) != 0.0)
#endif

void mexFunction(int nlhs, mxArray *plhs[],
                 int nrhs, const mxArray *prhs[])
{
  /* Declare variables. */
  int elements, j, number_of_dims, cmplx;
  int nnz = 0, count = 0;
  double *pr, *pi, *pind;
  const int  *dim_array;
```

```
/* Check for proper number of input and output arguments. */
if (nrhs != 1) {
  mexErrMsgTxt("One input argument required.");
}
if (nlhs > 1) {
  mexErrMsgTxt("Too many output arguments.");
}

/* Check data type of input argument. */
if (!(mxIsDouble(prhs[0]))) {
  mexErrMsgTxt("Input array must be of type double.");
}

/* Get the number of elements in the input argument. */
elements = mxGetNumberOfElements(prhs[0]);

/* Get the data. */
pr = (double *)mxGetPr(prhs[0]);
pi = (double *)mxGetPi(prhs[0]);
cmplx = ((pi == NULL) ? 0 : 1);

/* Count the number of non-zero elements to be able to allocate
   the correct size for output variable. */
for (j = 0; j < elements; j++) {
  if (IsNonZero(pr[j]) || (cmplx && IsNonZero(pi[j]))) {
    nnz++;
  }
}

/* Get the number of dimensions in the input argument.
   Allocate the space for the return argument */
number_of_dims = mxGetNumberOfDimensions(prhs[0]);
plhs[0] = mxCreateDoubleMatrix(nnz, number_of_dims, mxREAL);
pind = mxGetPr(plhs[0]);

/* Get the number of dimensions in the input argument. */
dim_array = mxGetDimensions(prhs[0]);
```

```
    /* Fill in the indices to return to MATLAB. This loops through
     * the elements and checks for non-zero values. If it finds a
     * non-zero value, it then calculates the corresponding MATLAB
     * indices and assigns them into the output array. The 1 is added
     * to the calculated index because MATLAB is 1-based and C is
     * 0-based. */
    for (j = 0; j < elements; j++) {
      if (IsNonZero(pr[j]) || (cmplx && IsNonZero(pi[j]))) {
        int temp = j;
        int k;
        for (k = 0; k < number_of_dims; k++) {
          pind[nnz*k+count] = ((temp % (dim_array[k])) + 1);
          temp /= dim_array[k];
        }
        count++;
      }
    }
  }
```

Entering a sample matrix at the MATLAB prompt gives

```
matrix = [ 3 0 9 0; 0 8 2 4; 0 9 2 4; 3 0 9 3; 9 9 2 0]
matrix =
     3     0     9     0
     0     8     2     4
     0     9     2     4
     3     0     9     3
     9     9     2     0
```

This example determines the position of all nonzero elements in the matrix. Running the MEX-file on this matrix produces

```
nz = findnz(matrix)
nz =
     1     1
     4     1
     5     1
     2     2
     3     2
     5     2
     1     3
```

```
2     3
3     3
4     3
5     3
2     4
3     4
4     4
```

Handling Sparse Arrays

The MATLAB API provides a set of functions that allow you to create and manipulate sparse arrays from within your MEX-files. These API routines access and manipulate `ir` and `jc`, two of the parameters associated with sparse arrays. For more information on how MATLAB stores sparse arrays, refer to the section, "The MATLAB Array" on page 1-5.

This example illustrates how to populate a sparse matrix.

```
/*
 * =============================================================
 * fulltosparse.c
 * This example demonstrates how to populate a sparse
 * matrix.  For the purpose of this example, you must pass in a
 * non-sparse 2-dimensional argument of type double.
 *
 * Comment: You might want to modify this MEX-file so that you can
 * use it to read large sparse data sets into MATLAB.
 *
 * This is a MEX-file for MATLAB.
 * Copyright (c) 1984-2000 The MathWorks, Inc.
 * =============================================================
 */

/* $Revision: 1.5 $ */

#include <math.h> /* Needed for the ceil() prototype. */
#include "mex.h"

/* If you are using a compiler that equates NaN to be zero, you
 * must compile this example using the flag  -DNAN_EQUALS_ZERO.
 * For example:
```

```
 *
 *     mex -DNAN_EQUALS_ZERO fulltosparse.c
 *
 * This will correctly define the IsNonZero macro for your C
 * compiler.
 */

#if defined(NAN_EQUALS_ZERO)
#define IsNonZero(d) ((d) != 0.0 || mxIsNaN(d))
#else
#define IsNonZero(d) ((d) != 0.0)
#endif

void mexFunction(
        int nlhs,       mxArray *plhs[],
        int nrhs, const mxArray *prhs[]
        )
{
  /* Declare variables. */
  int j,k,m,n,nzmax,*irs,*jcs,cmplx,isfull;
  double *pr,*pi,*si,*sr;
  double percent_sparse;

  /* Check for proper number of input and output arguments. */
  if (nrhs != 1) {
    mexErrMsgTxt("One input argument required.");
  }
  if (nlhs > 1) {
    mexErrMsgTxt("Too many output arguments.");
  }

  /* Check data type of input argument. */
  if (!(mxIsDouble(prhs[0]))) {
    mexErrMsgTxt("Input argument must be of type double.");
  }

  if (mxGetNumberOfDimensions(prhs[0]) != 2) {
    mexErrMsgTxt("Input argument must be two dimensional\n");
  }
```

```
/* Get the size and pointers to input data. */
m  = mxGetM(prhs[0]);
n  = mxGetN(prhs[0]);
pr = mxGetPr(prhs[0]);
pi = mxGetPi(prhs[0]);
cmplx = (pi == NULL ? 0 : 1);

/* Allocate space for sparse matrix.
 * NOTE:  Assume at most 20% of the data is sparse.  Use ceil
 * to cause it to round up.
 */

percent_sparse = 0.2;
nzmax = (int)ceil((double)m*(double)n*percent_sparse);

plhs[0] = mxCreateSparse(m,n,nzmax,cmplx);
sr  = mxGetPr(plhs[0]);
si  = mxGetPi(plhs[0]);
irs = mxGetIr(plhs[0]);
jcs = mxGetJc(plhs[0]);

/* Copy nonzeros. */
k = 0;
isfull = 0;
for (j = 0; (j < n); j++) {
  int i;
  jcs[j] = k;
  for (i = 0; (i < m); i++) {
    if (IsNonZero(pr[i]) || (cmplx && IsNonZero(pi[i]))) {

      /* Check to see if non-zero element will fit in
       * allocated output array.  If not, increase
       * percent_sparse by 10%, recalculate nzmax, and augment
       * the sparse array.
       */
      if (k >= nzmax) {
        int oldnzmax = nzmax;
        percent_sparse += 0.1;
        nzmax = (int)ceil((double)m*(double)n*percent_sparse);
```

```
          /* Make sure nzmax increases atleast by 1. */
          if (oldnzmax == nzmax)
            nzmax++;

          mxSetNzmax(plhs[0], nzmax);
          mxSetPr(plhs[0], mxRealloc(sr, nzmax*sizeof(double)));
          if (si != NULL)
          mxSetPi(plhs[0], mxRealloc(si, nzmax*sizeof(double)));
          mxSetIr(plhs[0], mxRealloc(irs, nzmax*sizeof(int)));

          sr  = mxGetPr(plhs[0]);
          si  = mxGetPi(plhs[0]);
          irs = mxGetIr(plhs[0]);
        }
        sr[k] = pr[i];
        if (cmplx) {
          si[k] = pi[i];
        }
        irs[k] = i;
        k++;
      }
    }
    pr += m;
    pi += m;
  }
  jcs[n] = k;
}
```

At the MATLAB prompt, entering

```
full = eye(5)
full =
     1     0     0     0     0
     0     1     0     0     0
     0     0     1     0     0
     0     0     0     1     0
     0     0     0     0     1
```

creates a full, 5-by-5 identity matrix. Using `fulltosparse` on the full matrix produces the corresponding sparse matrix.

```
spar = fulltosparse(full)
spar =
   (1,1)        1
   (2,2)        1
   (3,3)        1
   (4,4)        1
   (5,5)        1
```

Calling Functions from C MEX-Files

It is possible to call MATLAB functions, operators, M-files, and other MEX-files from within your C source code by using the API function `mexCallMATLAB`. This example creates an `mxArray`, passes various pointers to a subfunction to acquire data, and calls `mexCallMATLAB` to calculate the sine function and plot the results.

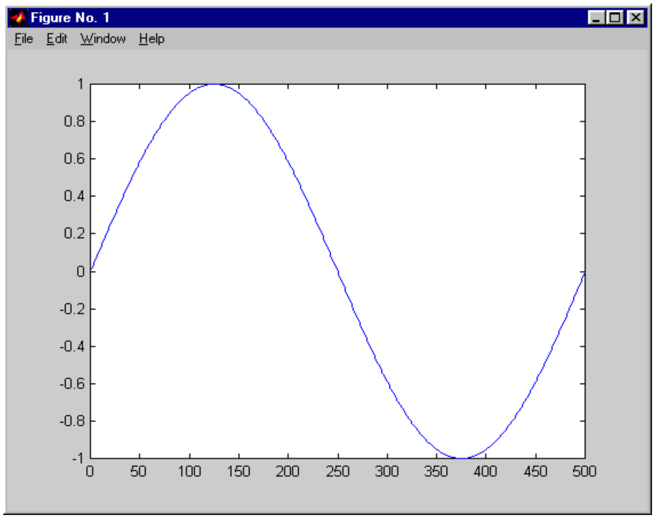
```
/*
 * =============================================================
 * sincall.c
 *
 * Example for illustrating how to use mexCallMATLAB
 *
 * Creates an mxArray and passes its associated pointers (in
 * this demo, only pointer to its real part, pointer to number of
 * rows, pointer to number of columns) to subfunction fill() to
 * get data filled up, then calls mexCallMATLAB to calculate sin
 * function and plot the result.
 *
 * This is a MEX-file for MATLAB.
 * Copyright (c) 1984-2000 The MathWorks, Inc.
 * =============================================================
 */

/* $Revision: 1.4 $ */

#include "mex.h"
#define MAX 1000
```

```
/* Subroutine for filling up data */
void fill(double *pr, int *pm, int *pn, int max)
{
  int i;

  /* You can fill up to max elements, so (*pr) <= max. */
  *pm = max/2;
  *pn = 1;
  for (i = 0; i < (*pm); i++)
    pr[i] = i * (4*3.14159/max);
}

/* The gateway routine */
void mexFunction(int nlhs, mxArray *plhs[],
                 int nrhs, const mxArray *prhs[])
{
  int     m, n, max = MAX;
  mxArray *rhs[1], *lhs[1];

  rhs[0] = mxCreateDoubleMatrix(max, 1, mxREAL);

  /* Pass the pointers and let fill() fill up data. */
  fill(mxGetPr(rhs[0]), &m, &n, MAX);
  mxSetM(rhs[0], m);
  mxSetN(rhs[0], n);

  /* Get the sin wave and plot it. */
  mexCallMATLAB(1, lhs, 1, rhs, "sin");
  mexCallMATLAB(0, NULL, 1, lhs, "plot");

  /* Clean up allocated memory. */
  mxDestroyArray(rhs[0]);
  mxDestroyArray(lhs[0]);

  return;
}
```

Running this example

```
sincall
```

displays the results



Note It is possible to generate an object of type mxUNKNOWN_CLASS using `mexCallMATLAB`. See the example below.

The following example creates an M-file that returns two variables but only assigns one of them a value.

```
function [a,b] = foo[c]
a = 2*c;
```

MATLAB displays the following warning message.

```
Warning: One or more output arguments not assigned during call to
'foo'.
```

If you then call `foo` using `mexCallMATLAB`, the unassigned output variable will now be of type `mxUNKNOWN_CLASS`.

Advanced Topics

These sections cover advanced features of MEX-files that you can use when your applications require sophisticated MEX-files.

Help Files

Because the MATLAB interpreter chooses the MEX-file when both an M-file and a MEX-file with the same name are encountered in the same directory, it is possible to use M-files for documenting the behavior of your MEX-files. The MATLAB `help` command will automatically find and display the appropriate M-file when help is requested and the interpreter will find and execute the corresponding MEX-file when the function is invoked.

Linking Multiple Files

It is possible to combine several object files and to use object file libraries when building MEX-files. To do so, simply list the additional files with their full extension, separated by spaces. For example, on the PC

```
mex circle.c square.obj rectangle.c shapes.lib
```

is a legal command that operates on the `.c`, `.obj`, and `.lib` files to create a MEX-file called `circle.dll`, where `dll` is the extension corresponding to the MEX-file type on the PC. The name of the resulting MEX-file is taken from the first file in the list.

You may find it useful to use a software development tool like `MAKE` to manage MEX-file projects involving multiple source files. Simply create a `MAKEFILE` that contains a rule for producing object files from each of your source files and then invoke `mex` to combine your object files into a MEX-file. This way you can ensure that your source files are recompiled only when necessary.

Note On UNIX, you must use the `-cxx` switch to the `mex` script if you are linking C++ objects.

Workspace for MEX-File Functions

Unlike M-file functions, MEX-file functions do not have their own variable workspace. MEX-file functions operate in the caller's workspace.

`mexEvalString` evaluates the string in the caller's workspace. In addition, you can use the `mexGetVariable` and `mexPutVariable` routines to get and put variables into the caller's workspace.

Memory Management

Memory management within MEX-files is not unlike memory management for regular C or Fortran applications. However, there are special considerations because the MEX-file must exist within the context of a larger application, i.e., MATLAB itself.

Automatic Cleanup of Temporary Arrays

When a MEX-file returns to MATLAB, it gives to MATLAB the results of its computations in the form of the left-hand side arguments – the `mxArrays` contained within the `plhs[]` list. Any `mxArrays` created by the MEX-file that are not in this list are automatically destroyed. In addition, any memory allocated with `mxCalloc`, `mxMalloc`, or `mxRealloc` during the MEX-file's execution is automatically freed.

In general, we recommend that MEX-files destroy their own temporary arrays and free their own dynamically allocated memory. It is more efficient for the MEX-file to perform this cleanup than to rely on the automatic mechanism. However, there are several circumstances in which the MEX-file will not reach its normal return statement. The normal return will not be reached if:

- A call to `mexErrMsgTxt` occurs.
- A call to `mexCallMATLAB` occurs and the function being called creates an error. (A MEX-file can trap such errors by using `mexSetTrapFlag`, but not all MEX-files would necessarily need to trap errors.)
- The user interrupts the MEX-file's execution using **Ctrl-C**.
- The MEX-file runs out of memory. When this happens, the MATLAB out-of-memory handler will immediately terminate the MEX-file.

A careful MEX-file programmer can ensure safe cleanup of all temporary arrays and memory before returning in the first two cases, but not in the last two cases. In the last two cases, the automatic cleanup mechanism is necessary to prevent memory leaks.

Persistent Arrays

You can exempt an array, or a piece of memory, from the MATLAB automatic cleanup by calling `mexMakeArrayPersistent` or `mexMakeMemoryPersistent`. However, if a MEX-file creates such persistent objects, there is a danger that a memory leak could occur if the MEX-file is cleared before the persistent object is properly destroyed. In order to prevent this from happening, a MEX-file that creates persistent objects should register a function, using `mexAtExit`, which will dispose of the objects. (You can use a `mexAtExit` function to dispose of other resources as well; for example, you can use `mexAtExit` to close an open file.)

For example, here is a simple MEX-file that creates a persistent array and properly disposes of it.

```
#include "mex.h"

static int initialized = 0;
static mxArray *persistent_array_ptr = NULL;

void cleanup(void) {
    mexPrintf("MEX-file is terminating, destroying array\n");
    mxDestroyArray(persistent_array_ptr);
}

void mexFunction(int nlhs,
    mxArray *plhs[],
    int nrhs,
    const mxArray *prhs[])
{
  if (!initialized) {
    mexPrintf("MEX-file initializing, creating array\n");

    /* Create persistent array and register its cleanup. */
    persistent_array_ptr = mxCreateDoubleMatrix(1, 1, mxREAL);
    mexMakeArrayPersistent(persistent_array_ptr);
    mexAtExit(cleanup);
    initialized = 1;
```

```
      /* Set the data of the array to some interesting value. */
      *mxGetPr(persistent_array_ptr) = 1.0;
    } else {
      mexPrintf("MEX-file executing; value of first array
          element is %g\n", *mxGetPr(persistent_array_ptr));
    }
  }
```

Hybrid Arrays

Functions such as `mxSetPr`, `mxSetData`, and `mxSetCell` allow the direct placement of memory pieces into an `mxArray`. `mxDestroyArray` will destroy these pieces along with the entire array. Because of this, it is possible to create an array that cannot be destroyed, i.e., an array on which it is not safe to call `mxDestroyArray`. Such an array is called a *hybrid* array, because it contains both destroyable and nondestroyable components.

For example, it is not legal to call `mxFree` (or the ANSI `free()` function, for that matter) on automatic variables. Therefore, in the following code fragment, `pArray` is a hybrid array.

```
mxArray *pArray = mxCreateDoubleMatrix(0, 0, mxREAL);
double data[10];

mxSetPr(pArray, data);
mxSetM(pArray, 1);
mxSetN(pArray, 10);
```

Another example of a hybrid array is a cell array or structure, one of whose children is a read-only array (an array with the `const` qualifier, such as one of the inputs to the MEX-file). The array cannot be destroyed because the input to the MEX-file would also be destroyed.

Because hybrid arrays cannot be destroyed, they cannot be cleaned up by the automatic mechanism outlined in "Automatic Cleanup of Temporary Arrays" on page 2-37. As described in that section, the automatic cleanup mechanism is the only way to destroy temporary arrays in case of a user interrupt. Therefore, *temporary hybrid arrays are illegal* and may cause your MEX-file to crash.

Although persistent hybrid arrays are viable, we recommend avoiding their use wherever possible.

Using LAPACK and BLAS Functions

LAPACK is a large, multiauthor Fortran subroutine library that MATLAB uses for numerical linear algebra. BLAS, which stands for Basic Linear Algebra Subroutines, is used by MATLAB to speed up matrix multiplication and the LAPACK routines themselves. The functions provided by LAPACK and BLAS can also be called directly from within your C MEX-files.

This section explains how to write and build MEX-files that call LAPACK and BLAS functions. It provides information on

Specifying the Function Name

When calling an LAPACK or BLAS function, some platforms require an underscore character following the function name in the call statement.

On the PC, IBM_RS, and HP platforms, use the function name alone, with no trailing underscore. For example, to call the LAPACK `dgemm` function, use

```
dgemm (arg1, arg2, ..., argn);
```

On the SGI, LINUX, Solaris, Alpha, and Macintosh platforms, add the underscore after the function name. For example, to call `dgemm` on any of these platforms, use

```
dgemm_ (arg1, arg2, ..., argn);
```

Calling LAPACK and BLAS Functions from C

Since the LAPACK and BLAS functions are written in Fortran, arguments passed to and from these functions must be passed by reference. The following example calls dgemm, passing all arguments by reference. An ampersand (&) precedes each argument unless that argument is already a reference.

```
#include "mex.h"

void mexFunction(int nlhs, mxArray *plhs[], int nrhs, mxArray
*prhs[])
{
  double *A, *B, *C, one = 1.0, zero = 0.0;
  int m,n,p;
  char *chn = "N";

  A = mxGetPr(prhs[0]);
  B = mxGetPr(prhs[1]);
  m = mxGetM(prhs[0]);
  p = mxGetN(prhs[0]);
  n = mxGetN(prhs[1]);

  if (p != mxGetM(prhs[1])) {
    mexErrMsgTxt("Inner dimensions of matrix multiply do not
        match");
  }

  plhs[0] = mxCreateDoubleMatrix(m, n, mxREAL);
  C = mxGetPr(plhs[0]);

  /* Pass all arguments to Fortran by reference */
  dgemm (chn, chn, &m, &n, &p, &one, A, &m, B, &p, &zero, C, &m);
}
```

Handling Complex Numbers

MATLAB stores complex numbers differently than Fortran. MATLAB stores the real and imaginary parts of a complex number in separate, equal length vectors, pr and pi. Fortran stores the same number in one location with the real and imaginary parts interleaved.

As a result, complex variables exchanged between MATLAB and the Fortran functions in LAPACK and BLAS are incompatible. MATLAB provides conversion routines that change the storage format of complex numbers to address this incompatibility.

Input Arguments. For all complex variables passed as input arguments to a Fortran function, you need to convert the storage of the MATLAB variable to be compatible with the Fortran function. Use the `mat2fort` function for this. See the example that follows.

Output Arguments. For all complex variables passed as output arguments to a Fortran function, you need to do the following:

1. When allocating storage for the complex variable, allocate a real variable with twice as much space as you would for a MATLAB variable of the same size. You need to do this because the returned variable uses the Fortran format, which takes twice the space. See the allocation of `zout` in the example that follows.

2. Once the variable is returned to MATLAB, convert its storage so that it is compatible with MATLAB. Use the `fort2mat` function for this.

Example – Passing Complex Variables. The example below shows how to call an LAPACK function from MATLAB, passing complex `prhs[0]` as input and receiving complex `plhs[0]` as output. Temporary variables `zin` and `zout` are used to hold `prhs[0]` and `plhs[0]` in Fortran format.

```
#include "mex.h"
#include "fort.h"      /* defines mat2fort and fort2mat */

void mexFunction(int nlhs, mxArray *plhs[], int nrhs, mxArray
*prhs[])
{
  int lda, n;
  double *zin, *zout;
  lda = mxGetM(prhs[0]);
  n = mxGetN(prhs[0]);

  /* Convert input to Fortran format */
  zin = mat2fort(prhs[0], lda, n);

 /* Allocate a real, complex, lda-by-n variable to store output */
  zout = mxCalloc(2*lda*n, sizeof(double));
```

```
    /* Call complex LAPACK function */
    zlapack_function(zin, &lda, &n, zout);

    /* Convert output to MATLAB format */
    plhs[0] = fort2mat(zout, lda, lda, n);

    /* Free intermediate Fortran format arrays */
    mxFree(zin);
    mxFree(zout);
  }
```

Preserving Input Values from Modification

Many LAPACK and BLAS functions modify the values of arguments passed in to them. It is advisable to make a copy of arguments that can be modified prior to passing them to the function. For complex inputs, this point is moot since the `mat2fort` version of the input is a new piece of memory, but for real data this is not the case.

The following example calls an LAPACK function that modifies the first input argument. The code in this example makes a copy of `prhs[0]`, and then passes the copy to the LAPACK function to preserve the contents of `prhs[0]`.

```
/* lapack_function modifies A so make a copy of the input */
m = mxGetM(prhs[0]);
n = mxGetN(prhs[0]);
A = mxCalloc(m*n, sizeof(double));

/* Copy mxGetPr(prhs[0]) into A */
temp = mxGetPr(prhs[0]);
for (k = 0; k < m*n; k++) {
   A[k] = temp[k];
   }

/* lapack_function does not modify B so it is OK to use the input
directly */
B = mxGetPr(prhs[1]);
lapack_function(A, B);       /* modifies A but not B */

/* Free A when you are done with it */
mxFree(A);
```

Building the C MEX-File

The examples in this section show how to compile and link a C MEX file, `myCmexFile.c`, on the platforms supported by MATLAB. In each example, the term `<matlab>` stands for the MATLAB root directory.

Building on the PC. If you build your C MEX-file on a PC or IBM_RS platform, you need to explicitly specify a library file to link with.

On the PC, use this command if you are using the Lcc compiler that ships with MATLAB:

```
mex myCmexFile.c <matlab>/extern/lib/win32/lcc/libmwlapack.lib
```

Or, use this command if you are using Microsoft Visual C++ as your C compiler:

```
mex myCmexFile.c
<matlab>/extern/lib/win32/microsoft/msvc60/libmwlapack.lib
```

Building on IBM_RS. For IBM_RS, use the following syntax.

```
mex myCmexFile.c -L<matlab>/bin/ibm_rs -lmwlapack
```

Building on Other Platforms. On all other platforms, you can build your MEX-file as you would any other C MEX-file. For example,

```
mex myCmexFile.c
```

MEX-Files That Perform Complex Number Conversion. MATLAB supplies the files `fort.c` and `fort.h`, which provide routines for conversion between MATLAB and FORTRAN complex data structures. These files define the `mat2fort` and `fort2mat` routines mentioned previously under "Handling Complex Numbers" on page 2-41.

If your program uses these routines, then you need to:

1. Include the `fort.h` file in your program, using, `#include "fort.h"`. See the example above.

2. Build the `fort.c` file with your program. Specify the pathname, `<matlab>/extern/examples/refbook` for both `fort.c` and `fort.h` in the build command, (where `<matlab>` stands for the MATLAB root directory).

On the PC, use either one of the following.

```
mex myCmexFile.c <matlab>/extern/examples/refbook/fort.c
-I<matlab>/extern/examples/refbook
<matlab>/extern/lib/win32/microsoft/msvc60/libmwlapack.lib
```

```
mex myCmexFile.c <matlab>/extern/examples/refbook/fort.c
-I<matlab>/extern/examples/refbook
<matlab>/extern/lib/win32/lcc/libmwlapack.lib
```

For IBM_RS, use

```
mex myCmexFile.c <matlab>/extern/examples/refbook/fort.c
-I<matlab>/extern/examples/refbook -L<matlab>/bin/ibm_rs
-lmwlapack
```

For all other platforms, use

```
mex myCmexFile.c <matlab>/extern/examples/refbook/fort.c
-I<matlab>/extern/examples/refbook
```

Example – Symmetric Indefinite Factorization Using LAPACK

You will find an example C MEX-file that calls two LAPACK functions in the directory `<matlab>/extern/examples/refbook`, where `<matlab>` stands for the MATLAB root directory. There are two versions of this file:

- `utdu_slv.c` – calls functions `zhesvx` and `dsysvx`, and thus is compatible with the PC, HP, and IBM platforms.
- `utdu_slv_.c` – calls functions `zhesvx_` and `dsysvx_`, and thus is compatible with the SGI, LINUX, Solaris, and Alpha platforms.

Calling LAPACK and BLAS Functions from Fortran

You can make calls to the LAPACK and BLAS functions used by MATLAB from your Fortran MEX files. The following is an example program that takes two matrices and multiplies them by calling the LAPACK routine, `dgemm`:

```
      subroutine mexFunction(nlhs, plhs, nrhs, prhs)
      integer plhs(*), prhs(*)
      integer nlhs, nrhs
      integer mxcreatedoublematrix, mxgetpr
      integer mxgetm, mxgetn
      integer m, n, p
```

```
      integer A, B, C
      double precision one, zero, ar, br
      character ch1, ch2

      ch1 = 'N'
      ch2 = 'N'
      one = 1.0
      zero = 0.0

      A = mxgetpr(prhs(1))
      B = mxgetpr(prhs(2))
      m = mxgetm(prhs(1))
      p = mxgetn(prhs(1))
      n = mxgetn(prhs(2))

      plhs(1) = mxcreatedoublematrix(m, n, 0.0)
      C = mxgetpr(plhs(1))
      call mxcopyptrtoreal8(A, ar, 1)
      call mxcopyptrtoreal8(B, br, 1)

      call dgemm (ch1, ch2, m, n, p, one, %val(A), m,
     +            %val(B), p, zero, %val(C), m)

      return
      end
```

Building the Fortran MEX-File

The examples in this section show how to compile and link a Fortran MEX file, `myFortranmexFile.F`, on the platforms supported by MATLAB. In each example, the term `<matlab>` stands for the MATLAB root directory.

Building on the PC. On the PC, using Visual Fortran, you will have to link against a library called `libdflapack.lib`:

```
mex  v myFortranMexFile.F
<matlab>/extern/lib/win32/digital/df60/libdflapack.lib
```

Building on IBM_RS. On the IBM_RS, invoke

```
mex myFortranMexFile.F -L<matlab>/bin/ibm_rs -lmwlapack
```

Building on Other UNIX Platforms. On the UNIX platforms (except IBM_RS), you create the MEX file as follows:

```
mex  v myFortranMexFile.F
```

Debugging C Language MEX-Files

On most platforms, it is now possible to debug MEX-files while they are running within MATLAB. Complete source code debugging, including setting breakpoints, examining variables, and stepping through the source code line-by-line, is now available.

Note The section entitled, "Troubleshooting" on page 1-31, provides additional information on isolating problems with MEX-files.

To debug a MEX-file from within MATLAB, you must first compile the MEX-file with the `-g` option to `mex`.

```
mex -g filename.c
```

Debugging on UNIX

You need to start MATLAB from within a debugger. To do this, specify the name of the debugger you want to use with the `-D` option when starting MATLAB.

This example shows how to debug `yprime.c` on Solaris using `dbx`, the UNIX debugger.

```
unix> mex -g yprime.c
unix> matlab -Ddbx
<dbx> stop dlopen <matlab>/extern/examples/mex/yprime.mexsol
```

Once the debugger loads MATLAB into memory, you can start it by issuing a `run` command.

```
<dbx> run
```

Now, run the MEX-file that you want to debug as you would ordinarily do (either directly or by means of some other function or script). Before executing the MEX-file, you will be returned to the debugger.

```
>> yprime(1,1:4)
<dbx> stop in `yprime.mexsol`mexFunction
```

Note The tick marks used are back ticks (`` ` ``), not single quotes (`'`).

You may need to tell the debugger where the MEX-file was loaded or the name of the MEX-file, in which case MATLAB will display the appropriate command for you to use. At this point, you are ready to start debugging. You can list the source code for your MEX-file and set breakpoints in it. It is often convenient to set one at `mexFunction` so that you stop at the beginning of the gateway routine. To proceed from the breakpoint, issue a `continue` command to the debugger.

```
<dbx> cont
```

Once you hit one of your breakpoints, you can make full use of any facilities that your debugger provides to examine variables, display memory, or inspect registers. Refer to the documentation provided with your debugger for information on its use.

Note For information on debugging on other UNIX platforms, access the MathWorks Technical Support Web site at `http://www.mathworks.com/support`.

Debugging on Windows

The following sections provide instructions on how to debug on Microsoft Windows systems using various compilers.

Microsoft Compiler

If you are using the Microsoft compiler:

1 Start the Microsoft Visual Studio (Version 5 or 6) by typing at the DOS prompt

   msdev *`filename`*.dll

2 In the Microsoft environment, from the **Project** menu, select **Settings**. In the window that opens, select the **Debug** tab. This options window contains edit boxes. In the edit box labeled **Executable for debug session**, enter the full path to where MATLAB resides. All other edit boxes should be empty.

3 Open the source files and set a break point on the desired line of code by right-clicking with your mouse on the line of code.

4 From the **Build** menu, select **Debug**, and click **Go**.

5 You will now be able to run your MEX-file in MATLAB and use the Microsoft debugging environment. For more information on how to debug in the Microsoft environment, see the Microsoft Development Studio or Microsoft Visual Studio documentation.

Watcom Compiler

If you are using the Watcom compiler:

1 Start the debugger by typing on the DOS command line

```
WDW
```

2 The Watcom Debugger starts and a **New Program** window opens. In this window type the full path to MATLAB. For example,

```
c:\matlab\bin\matlab.exe
```

Then click **OK**.

3 From the **Break** menu, select **On Image Load** and type the name of your MEX-file DLL in capital letters. For example,

```
YPRIME
```

Then select **ADD** and click **OK** to close the window.

4 From the **Run** menu, select **GO**. This should start MATLAB.

5 When MATLAB starts, in the command window change directories to where your MEX-file resides and run your MEX-file. If a message similar to the following appears, ignore the message and click **OK**.

```
LDR: Automatic DLL Relocation in matlab.exe
LDR: DLL filename.dll base <number> relocated due to collision
with matlab.exe
```

6 Open the file you want to debug and set breakpoints in the source code.

3

Creating Fortran MEX-Files

This chapter describes how to write MEX-files in the Fortran programming language. It discusses the MEX-file itself, how these Fortran language files interact with MATLAB, how to pass and manipulate arguments of different data types, how to debug your MEX-file programs, and several other, more advanced topics.

Fortran MEX-Files

Fortran MEX-files are built by using the `mex` script to compile your Fortran source code with additional calls to API routines.

MEX-files in Fortran, like their C counterparts, can create any data type supported by MATLAB. You can treat Fortran MEX-files, once compiled, exactly like M-functions.

The Components of a Fortran MEX-File

This section discusses the specific elements needed in a Fortran MEX-file. The source code for a Fortran MEX-file, like the C MEX-file, consists of two distinct parts:

- A *computational routine* that contains the code for performing the computations that you want implemented in the MEX-file. Computations can be numerical computations as well as inputting and outputting data.
- A *gateway routine* that interfaces the computational routine with MATLAB by the entry point `mexFunction` and its parameters `prhs`, `nrhs`, `plhs`, `nlhs`, where `prhs` is an array of right-hand input arguments, `nrhs` is the number of right-hand input arguments, `plhs` is an array of left-hand output arguments, and `nlhs` is the number of left-hand output arguments. The gateway calls the computational routine as a subroutine.

The computational and gateway routines may be separate or combined. The following figure, Fortran MEX Cycle, shows how inputs enter an API function, what functions the gateway routine performs, and how output returns to MATLAB.

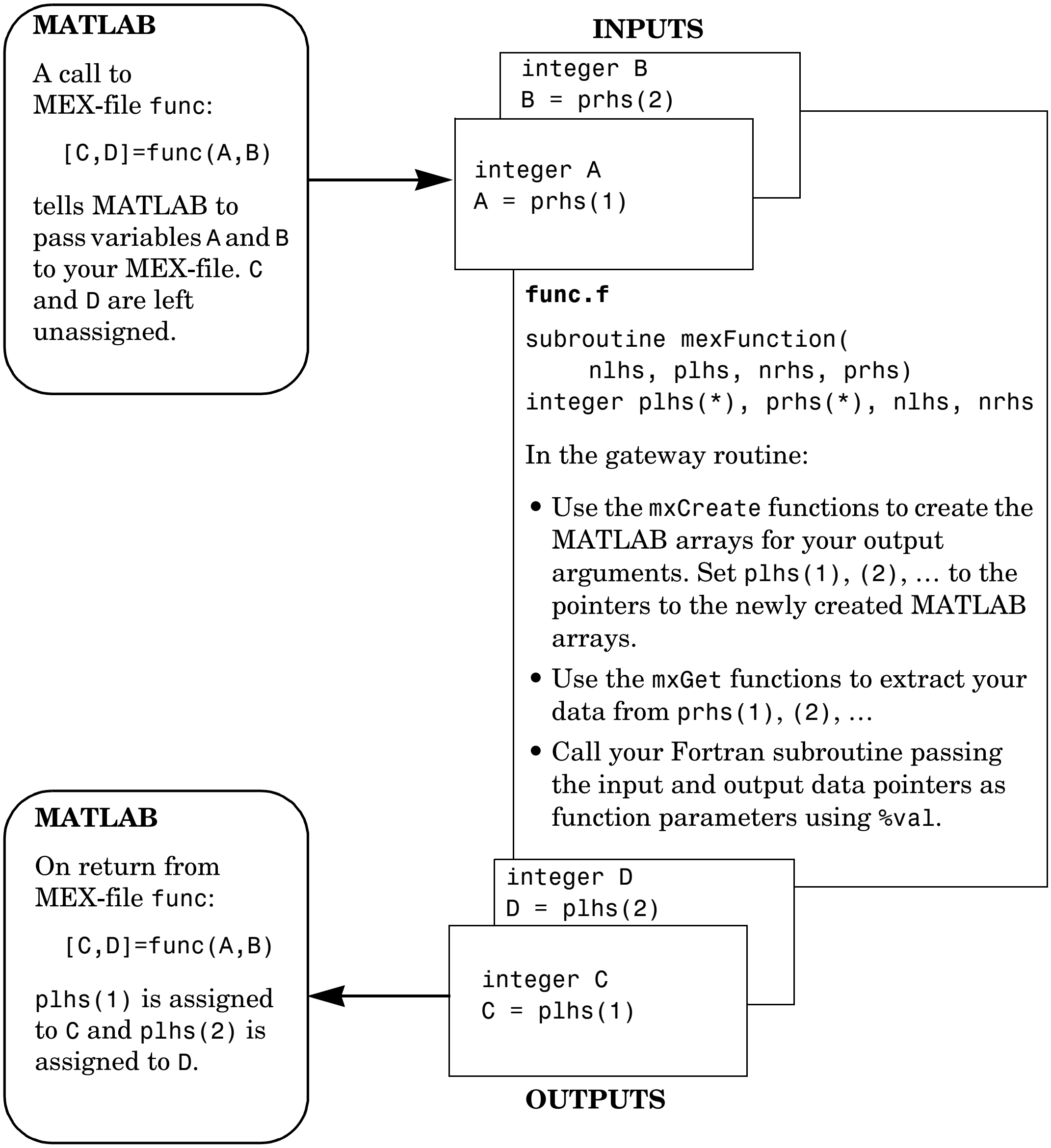


Figure 3-1: Fortran MEX Cycle

The Pointer Concept

The MATLAB API works with a unique data type, the mxArray. Because there is no way to create a new data type in Fortran, MATLAB passes a special identifier, called a pointer, to a Fortran program. You can get information about an mxArray by passing this pointer to various API functions called Access Routines. These access routines allow you to get a native Fortran data type containing exactly the information you want, i.e., the size of the mxArray, whether or not it is a string, or its data contents.

There are several implications when using pointers in Fortran:

- The %val construct.

  If your Fortran compiler supports the %val construct, then there is one type of pointer you can use without requiring an access routine, namely a pointer to data (i.e., the pointer returned by mxGetPr or mxGetPi). You can use %val to pass this pointer's contents to a subroutine, where it is declared as a Fortran double-precision matrix.

  If your Fortran compiler does not support the %val construct, you must use the mxCopy__ routines (e.g., mxCopyPtrToReal8) to access the contents of the pointer. For more information about the %val construct and an example, see the section, "The %val Construct" on page 3-7.

- Variable declarations.

  To use pointers properly, you must declare them to be the correct size. On DEC Alpha machines, all pointers should be declared as integer*8. On all other platforms, pointers should be declared as integer*4.

  If your Fortran compiler supports preprocessing with the C preprocessor, you can use the preprocessing stage to map pointers to the appropriate declaration. In UNIX, see the examples ending with .F in the examples directory for a possible approach.

Caution Declaring a pointer to be the incorrect size may cause your program to crash.

The Gateway Routine

The entry point to the gateway subroutine must be named `mexFunction` and must contain these parameters.

```
subroutine mexFunction(nlhs, plhs, nrhs, prhs)
integer plhs(*), prhs(*)
integer nlhs, nrhs
```

Note Fortran is case-insensitive. This document uses mixed-case function names for ease of reading.

In a Fortran MEX-file, the parameters `nlhs` and `nrhs` contain the number of left- and right-hand arguments with which the MEX-file is invoked. `prhs` is a length `nrhs` array that contains pointers to the right-hand side inputs to the MEX-file, and `plhs` is a length `nlhs` array that contains pointers to the left-hand side outputs that your Fortran function generates.

In the syntax of the MATLAB language, functions have the general form

```
[a,b,c, ] = fun(d,e,f, )
```

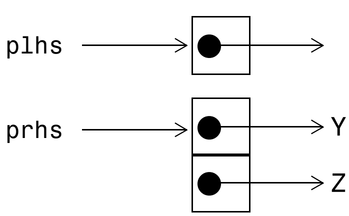
where the ellipsis ( ) denotes additional terms of the same format. The `a,b,c,` are left-hand arguments and the `d,e,f,` are right-hand arguments.

As an example of the gateway routine, consider invoking a MEX-file from the MATLAB workspace with the command

```
x = fun(y,z);
```

the MATLAB interpreter calls `mexFunction` with the arguments

```
nlhs = 1

nrhs = 2
```



plhs is a 1-element C array where the single element is a null pointer. prhs is a 2-element C array where the first element is a pointer to an mxArray named Y and the second element is a pointer to an mxArray named Z.

The parameter plhs points at nothing because the output x is not created until the subroutine executes. It is the responsibility of the gateway routine to create an output array and to set a pointer to that array in plhs(1). If plhs(1) is left unassigned, MATLAB prints a warning message stating that no output has been assigned.

Note It is possible to return an output value even if nlhs = 0. This corresponds to returning the result in the ans variable.

The gateway routine should validate the input arguments and call mexErrMsgTxt if anything is amiss. This step includes checking the number, type, and size of the input arrays as well as examining the number of output arrays. The examples included later in this section illustrate this technique.

The mx functions provide a set of access methods (subroutines) for manipulating MATLAB arrays. These functions are fully documented in the online API reference pages. The mx prefix is shorthand for mxArray and it means that the function enables you to access and/or manipulate some of the information in the MATLAB array. For example, mxGetPr gets the real data from the MATLAB array. Additional routines are provided for transferring data between MATLAB arrays and Fortran arrays.

The gateway routine must call mxCreateDoubleMatrix, mxCreateSparse, or mxCreateString to create MATLAB arrays of the required sizes in which to return the results. The return values from these calls should be assigned to the appropriate elements of plhs.

The gateway routine may call mxCalloc to allocate temporary work arrays for the computational routine if it needs them.

The gateway routine should call the computational routine to perform the desired calculations or operations. There are a number of additional routines that MEX-files can use. These routines are distinguished by the initial characters mex, as in mexCallMATLAB and mexErrMsgTxt.

When a MEX-file completes its task, it returns control to MATLAB. Any MATLAB arrays that are created by the MEX-file that are not returned to MATLAB through the left-hand side arguments are automatically destroyed.

The %val Construct

The `%val` construct is supported by most, but not all, Fortran compilers. DIGITAL Visual Fortran *does* support the construct. `%val` causes the value of the variable, rather than the address of the variable, to be passed to the subroutine. If you are using a Fortran compiler that does not support the `%val` construct, you must copy the array values into a temporary true Fortran array using special routines. For example, consider a gateway routine that calls its computational routine, `yprime`, by

```
call yprime(%val(yp), %val(t), %val(y))
```

If your Fortran compiler does not support the `%val` construct, you would replace the call to the computational subroutine with

```
C Copy array pointers to local arrays.
       call mxCopyPtrToReal8(t, tr, 1)
       call mxCopyPtrToReal8(y, yr, 4)
C
C Call the computational subroutine.
       call yprime(ypr, tr, yr)
C
C Copy local array to output array pointer.
       call mxCopyReal8ToPtr(ypr, yp, 4)
```

You must also add the following declaration line to the top of the gateway routine.

```
real*8 ypr(4), tr, yr(4)
```

Note that if you use `mxCopyPtrToReal8` or any of the other `mxCopy__` routines, the size of the arrays declared in the Fortran gateway routine must be greater than or equal to the size of the inputs to the MEX-file coming in from MATLAB. Otherwise `mxCopyPtrToReal8` will not work correctly.

Examples of Fortran MEX-Files

The following sections include information and examples describing how to pass and manipulate the different data types when working with MEX-files. These topics include:

- "A First Example — Passing a Scalar"
- "Passing Strings"
- "Passing Arrays of Strings"
- "Passing Matrices"
- "Passing Two or More Inputs or Outputs"
- "Handling Complex Data"
- "Dynamically Allocating Memory"
- "Handling Sparse Matrices"
- "Calling Functions from Fortran MEX-Files"

The MATLAB API provides a set of routines for Fortran that handle double-precision data and strings in MATLAB. For each data type, there is a specific set of functions that you can use for data manipulation.

Note to UNIX Users The example Fortran files in the directory `<matlab>/extern/examples/refbook` have extensions `.F` and `.f`. The distinction between these extensions is that the `.F` files need to be preprocessed.

Note You can find the most recent versions of the example programs from this chapter at the anonymous FTP server,

```
ftp://ftp.mathworks.com/pub/tech-support/docexamples/apiguide/R12/
refbook
```

A First Example — Passing a Scalar

Let's look at a simple example of Fortran code and its MEX-file equivalent. Here is a Fortran computational routine that takes a scalar and doubles it.

```
      subroutine timestwo(y, x)
      real*8 x, y
C
      y = 2.0 * x
      return
      end
```

Below is the same function written in the MEX-file format.

```
C================================================================
C     timestwo.f
C     Multiply the input argument by 2.
C
C     This is a MEX-file for MATLAB.
C     Copyright (c) 1984-2000 The MathWorks, Inc.
C     $Revision: 1.12 $
C================================================================

C     Computational subroutine
      subroutine timestwo(y, x)
      real*8 x, y

      y = 2.0 * x
      return
      end


C     The gateway routine
      subroutine mexFunction(nlhs, plhs, nrhs, prhs)
C----------------------------------------------------------------
C     (pointer) Replace integer by integer*8 on the DEC Alpha
C     64-bit platform.

      integer plhs(*), prhs(*)
      integer mxGetPr, mxCreateDoubleMatrix
      integer x_pr, y_pr
C----------------------------------------------------------------
```

```
      integer nlhs, nrhs
      integer mxGetM, mxGetN, mxIsNumeric
      integer m, n, size
      real*8 x, y

C     Check for proper number of arguments.
      if(nrhs .ne. 1) then
         call mexErrMsgTxt('One input required.')
      elseif(nlhs .ne. 1) then
         call mexErrMsgTxt('One output required.')
      endif

C     Get the size of the input array.
      m = mxGetM(prhs(1))
      n = mxGetN(prhs(1))
      size = m*n

C     Check to ensure the input is a number.
      if(mxIsNumeric(prhs(1)) .eq. 0) then
         call mexErrMsgTxt('Input must be a number.')
      endif

C     Create matrix for the return argument.
      plhs(1) = mxCreateDoubleMatrix(m, n, 0)
      x_pr = mxGetPr(prhs(1))
      y_pr = mxGetPr(plhs(1))
      call mxCopyPtrToReal8(x_pr, x, size)

C     Call the computational subroutine.
      call timestwo(y, x)

C     Load the data into y_pr, which is the output to MATLAB.
      call mxCopyReal8ToPtr(y, y_pr, size)

      return
      end
```

To compile and link this example source file, at the MATLAB prompt type

```
mex timestwo.f
```

This carries out the necessary steps to create the MEX-file called `timestwo` with an extension corresponding to the machine type on which you're running. You can now call `timestwo` as if it were an M-function.

```
x = 2;
y = timestwo(x)
y =
     4
```

Passing Strings

Passing strings from MATLAB to a Fortran MEX-file is straightforward. This program accepts a string and returns the characters in reverse order.

```
C==============================================================
C     revord.f
C     Example for illustrating how to copy string data from
C     MATLAB to a Fortran-style string and back again.
C
C     Takes a string and returns a string in reverse order.
C
C     This is a MEX-file for MATLAB.
C     Copyright (c) 1984-2000 The MathWorks, Inc.
C     $Revision: 1.14 $
C==============================================================

C     Computational subroutine
      subroutine revord(input_buf, strlen, output_buf)
      character  input_buf(*), output_buf(*)
      integer i, strlen

      do 10 i=1,strlen
         output_buf(i) = input_buf(strlen-i+1)
 10   continue
      return
      end
```

Below is the gateway routine that calls the computational routine.

```
C     The gateway routine
      subroutine mexFunction(nlhs, plhs, nrhs, prhs)
C---------------------------------------------------------------
C     (pointer) Replace integer by integer*8 on the DEC Alpha
C     platform.

      integer plhs(*), prhs(*)
      integer mxCreateString, mxGetString
C---------------------------------------------------------------

      integer nlhs, nrhs
      integer  mxGetM, mxGetN, mxIsChar
      integer  status, strlen
      character*100 input_buf, output_buf

C     Check for proper number of arguments.
      if (nrhs .ne. 1) then
         call mexErrMsgTxt('One input required.')
      elseif (nlhs .gt. 1) then
         call mexErrMsgTxt('Too many output arguments.')

C     The input  must be a string.
      elseif(mxIsChar(prhs(1)) .ne. 1) then
         call mexErrMsgTxt('Input must be a string.')

C     The input must be a row vector.
      elseif (mxGetM(prhs(1)) .ne. 1) then
         call mexErrMsgTxt('Input must be a row vector.')
      endif

C     Get the length of the input string.
      strlen = mxGetM(prhs(1))*mxGetN(prhs(1))

C     Get the string contents (dereference the input integer).
      status = mxGetString(prhs(1), input_buf, 100)

C     Check if mxGetString is successful.
      if (status .ne. 0) then
```

```
         call mexErrMsgTxt('String length must be less than 100.')
       endif

C     Initialize outbuf_buf to blanks. This is necessary on some
C      compilers.

       output_buf = ' '

C      Call the computational subroutine.
       call revord(input_buf, strlen, output_buf)

C      Set output_buf to MATLAB mexFunction output.
       plhs(1) = mxCreateString(output_buf)

       return
       end
```

After checking for the correct number of inputs, this MEX-file gateway routine verifies that the input was either a row or column vector string. It then finds the size of the string and places the string into a Fortran character array. Note that in the case of character strings, it is not necessary to copy the data into a Fortran character array by using `mxCopyPtrToCharacter`. In fact, `mxCopyPtrToCharacter` works only with MAT-files. For more information about MAT-files, see Chapter 6, "Importing and Exporting Data."

For an input string

```
x = 'hello world';
```

typing

```
y = revord(x)
```

produces

```
y =
dlrow olleh
```

Passing Arrays of Strings

Passing arrays of strings adds a slight complication to the example in the previous section, "Passing Strings". Because MATLAB stores elements of a matrix by column instead of by row, it is essential that the size of the string array be correctly defined in the Fortran MEX-file. The key point is that the row and column sizes as defined in MATLAB must be reversed in the Fortran MEX-file. Consequently, when returning to MATLAB, the output matrix must be transposed.

This example places a string array/character matrix into MATLAB as output arguments rather than placing it directly into the workspace. Inside MATLAB, call this function by typing

```
passstr;
```

You will get the matrix `mystring` of size 5-by-15. There are some manipulations that need to be done here. The original string matrix is of the size 5-by-15. Because of the way MATLAB reads and orients elements in matrices, the size of the matrix must be defined as `M=15` and `N=5` from the MEX-file. After the matrix is put into MATLAB, the matrix must be transposed.

```
C==============================================================
C     passstr.f
C     Example for illustrating how to pass a character matrix
C     from Fortran to MATLAB.
C
C     Passes a string array/character matrix into MATLAB as
C     output arguments rather than placing it directly into the
C     workspace.
C
C     This is a MEX-file for MATLAB.
C     Copyright (c) 1984-2000 The MathWorks, Inc.
C     $Revision: 1.11 $
C==============================================================

C     The gateway routine
      subroutine mexFunction(nlhs, plhs, nrhs, prhs)
C--------------------------------------------------------------
C     (pointer) Replace integer by integer*8 on the DEC Alpha
C     platform.

      integer plhs(*), prhs(*)
      integer p_str, mxCreateString
C--------------------------------------------------------------
```

```
      integer nlhs, nrhs
      integer i
      character*75 thestring
      character*15 string(5)

C     Create the string to passed into MATLAB.
      string(1) = 'MATLAB         '
      string(2) = 'The Scientific '
      string(3) = 'Computing      '
      string(4) = 'Environment    '
      string(5) = '   by TMW, Inc.'

C     Concatenate the set of 5 strings into a long string.
      thestring = string(1)
      do 10 i=2,6
         thestring = thestring(:((i-1)*15)) // string(i)
 10   continue

C     Create the string matrix to be passed into MATLAB.
C     Set the matrix size to be M=15 and N=5.
      p_str = mxcreatestring(thestring)
      call mxSetM(p_str, 15)
      call mxSetN(p_str, 5)

C     Transpose the resulting matrix in MATLAB.
      call mexCallMATLAB(1, plhs, 1, p_str, 'transpose')

      return
      end
```

Typing

```
passstr
```

at the MATLAB prompt produces this result

```
ans =

MATLAB
The Scientific
Computing
```

```
Environment
   by TMW, Inc.
```

Passing Matrices

In MATLAB, you can pass matrices into and out of MEX-files written in Fortran. You can manipulate the MATLAB arrays by using `mxGetPr` and `mxGetPi` to assign pointers to the real and imaginary parts of the data stored in the MATLAB arrays. You can create new MATLAB arrays from within your MEX-file by using `mxCreateDoubleMatrix`.

This example takes a real 2-by-3 matrix and squares each element.

```
C================================================================
C     matsq.f
C
C     Squares the input matrix
C
C     This is a MEX-file for MATLAB.
C     Copyright (c) 1984-2000 The MathWorks, Inc.
C     $Revision: 1.13 $
C================================================================

C     Computational subroutine
      subroutine matsq(y, x, m, n)
      real*8 x(m,n), y(m,n)
      integer m, n
C
      do 20 i=1,m
         do 10 j=1,n
            y(i,j)= x(i,j)**2
 10      continue
 20   continue
      return
      end


C     The gateway routine
      subroutine mexFunction(nlhs, plhs, nrhs, prhs)

C----------------------------------------------------------------
```

```
C     (pointer) Replace integer by integer*8 on the DEC Alpha
C     64-bit platform

      integer plhs(*), prhs(*)
      integer mxCreateDoubleMatrix, mxGetPr
      integer x_pr, y_pr
C----------------------------------------------------------------

      integer nlhs, nrhs
      integer mxGetM, mxGetN, mxIsNumeric
      integer m, n, size
      real*8  x(1000), y(1000)

C     Check for proper number of arguments.
      if(nrhs .ne. 1) then
         call mexErrMsgTxt('One input required.')
      elseif(nlhs .ne. 1) then
         call mexErrMsgTxt('One output required.')
      endif

C     Get the size of the input array.
      m = mxGetM(prhs(1))
      n = mxGetN(prhs(1))
      size = m*n

C     Column * row should be smaller than 1000.
      if(size.gt.1000) then
         call mexErrMsgTxt('Row * column must be <= 1000.')
      endif

C     Check to ensure the array is numeric (not strings).
      if(mxIsNumeric(prhs(1)) .eq. 0) then
         call mexErrMsgTxt('Input must be a numeric array.')
      endif

C     Create matrix for the return argument.
      plhs(1) = mxCreateDoubleMatrix(m, n, 0)
      x_pr = mxGetPr(prhs(1))
      y_pr = mxGetPr(plhs(1))
      call mxCopyPtrToReal8(x_pr, x, size)
```

```
C     Call the computational subroutine.
      call matsq(y, x, m, n)

C     Load the data into y_pr, which is the output to MATLAB.
      call mxCopyReal8ToPtr(y, y_pr, size)

      return
      end
```

After performing error checking to ensure that the correct number of inputs and outputs was assigned to the gateway subroutine and to verify the input was in fact a numeric matrix, `matsq.f` creates a matrix for the argument returned from the computational subroutine. The input matrix data is then copied to a Fortran matrix by using `mxCopyPtrToReal8`. Now the computational subroutine can be called, and the return argument can then be placed into `y_pr`, the pointer to the output, using `mxCopyReal8ToPtr`.

For a 2-by-3 real matrix

```
x = [1 2 3; 4 5 6];
```

typing

```
y = matsq(x)
```

produces this result

```
y =
     1      4      9
    16     25     36
```

Passing Two or More Inputs or Outputs

The `plhs` and `prhs` parameters are vectors that contain pointers to each left-hand side (output) variable and right-hand side (input) variable. Accordingly, `plhs(1)` contains a pointer to the first left-hand side argument, `plhs(2)` contains a pointer to the second left-hand side argument, and so on. Likewise, `prhs(1)` contains a pointer to the first right-hand side argument, `prhs(2)` points to the second, and so on.

This routine multiplies an input scalar times an input scalar or matrix.

```
C================================================================
C     xtimesy.f
C
C     Multiply the first input by the second input.
C
C     This is a MEX file for MATLAB.
C     Copyright (c) 1984-2000 The MathWorks, Inc.
C     $Revision: 1.12 $
C================================================================

C     Computational subroutine
      subroutine xtimesy(x, y, z, m, n)
      real*8  x, y(3,3), z(3,3)
      integer m, n
      do 20 i=1,m
         do 10 j=1,n
            z(i,j) = x*y(i,j)
 10      continue
 20   continue
      return
      end


C     The gateway routine
      subroutine mexFunction(nlhs, plhs, nrhs, prhs)
C----------------------------------------------------------------
C     (pointer) Replace integer by integer*8 on the DEC Alpha
C     64-bit platform

      integer plhs(*), prhs(*)
      integer mxCreateDoubleMatrix
      integer x_pr, y_pr, z_pr
C----------------------------------------------------------------

      integer nlhs, nrhs
      integer m, n, size
      integer mxGetM, mxGetN, mxIsNumeric
      real*8  x, y(3,3), z(3,3)
```

```
C     Check for proper number of arguments.
      if (nrhs .ne. 2) then
         call mexErrMsgTxt('Two inputs required.')
      elseif (nlhs .ne. 1) then
         call mexErrMsgTxt('One output required.')
      endif

C     Check to see both inputs are numeric.
      if (mxIsNumeric(prhs(1)) .ne. 1) then
         call mexErrMsgTxt('Input #1 is not a numeric.')
      elseif (mxIsNumeric(prhs(2)) .ne. 1) then
         call mexErrMsgTxt('Input #2 is not a numeric array.')
      endif

C     Check that input #1 is a scalar.
      m = mxGetM(prhs(1))
      n = mxGetN(prhs(1))
      if(n .ne. 1 .or. m .ne. 1) then
         call mexErrMsgTxt('Input #1 is not a scalar.')
      endif

C     Get the size of the input matrix.
      m = mxGetM(prhs(2))
      n = mxGetN(prhs(2))
      size = m*n

C     Create matrix for the return argument.
      plhs(1) = mxCreateDoubleMatrix(m, n, 0)
      x_pr = mxGetPr(prhs(1))
      y_pr = mxGetPr(prhs(2))
      z_pr = mxGetPr(plhs(1))

C     Load the data into Fortran arrays.
      call mxCopyPtrToReal8(x_pr, x, 1)
      call mxCopyPtrToReal8(y_pr, y, size)

C     Call the computational subroutine.
      call xtimesy(x, y, z, m, n)
```

```
C     Load the output into a MATLAB array.
      call mxCopyReal8ToPtr(z, z_pr, size)

      return
      end
```

As this example shows, creating MEX-file gateways that handle multiple inputs and outputs is straightforward. All you need to do is keep track of which indices of the vectors `prhs` and `plhs` correspond to which input and output arguments of your function. In this example, the input variable `x` corresponds to `prhs(1)` and the input variable `y` to `prhs(2)`.

For an input scalar `x` and a real 3-by-3 matrix,

```
x = 3; y = ones(3);
```

typing

```
z = xtimesy(x, y)
```

yields this result

```
z =
     3     3     3
     3     3     3
     3     3     3
```

Handling Complex Data

MATLAB stores complex double-precision data as two vectors of numbers — one contains the real data and one contains the imaginary data. The API provides two functions, `mxCopyPtrToComplex16` and `mxCopyComplex16ToPtr`, which allow you to copy the MATLAB data to a native `complex*16` Fortran array.

This example takes two complex vectors (of length 3) and convolves them.

```
C================================================================
C     convec.f
C     Example for illustrating how to pass complex data from
C     MATLAB to FORTRAN (using COMPLEX data type) and back
C     again.
C
C     Convolves two complex input vectors.
```

```
C
C     This is a MEX-file for MATLAB.
C     Copyright (c) 1984-2000 The MathWorks, Inc.
C     $Revision: 1.15 $
C================================================================

C     Computational subroutine
      subroutine convec(x, y, z, nx, ny)
      complex*16 x(*), y(*), z(*)
      integer nx, ny

C     Initialize the output array
      do 10 i=1,nx+ny-1
         z(i) = (0.0,0.0)
 10   continue

      do 30 i=1,nx
         do 20 j=1,ny
            z(i+j-1) = z(i+j-1) + x(i) * y(j)
 20      continue
 30   continue
      return
      end


C     The gateway routine.
      subroutine mexFunction(nlhs, plhs, nrhs, prhs)
C----------------------------------------------------------------
C     (pointer) Replace integer by integer*8 on the DEC Alpha
C     64-bit platform.

      integer plhs(*), prhs(*)
      integer mxGetPr, mxGetPi, mxCreateDoubleMatrix
C----------------------------------------------------------------

      integer nlhs, nrhs
      integer mx, nx, my, ny, nz
      integer mxGetM, mxGetN, mxIsComplex
      complex*16 x(100), y(100), z(199)
```

```
C     Check for proper number of arguments.
      if (nrhs .ne. 2) then
         call mexErrMsgTxt('Two inputs required.')
      elseif (nlhs .gt. 1) then
         call mexErrMsgTxt('Too many output arguments.')
      endif

C     Check that inputs are both row vectors.
      mx = mxGetM(prhs(1))
      nx = mxGetN(prhs(1))
      my = mxGetM(prhs(2))
      ny = mxGetN(prhs(2))
      nz = nx+ny-1

C     Only handle row vector input.
      if(mx .ne. 1 .or. my .ne. 1) then
         call mexErrMsgTxt('Both inputs must be row vector.')

C     Check sizes of the two inputs.
      elseif(nx .gt. 100 .or. ny .gt. 100) then
         call mexErrMsgTxt('Inputs must have less than 100
                             elements.')

C     Check to see both inputs are complex.
      elseif ((mxIsComplex(prhs(1)) .ne. 1) .or.
     +        (mxIsComplex(prhs(2)) .ne. 1)) then
         call mexErrMsgTxt('Inputs must be complex.')
      endif

C     Create the output array.
      plhs(1) = mxCreateDoubleMatrix(1, nz, 1)

C     Load the data into Fortran arrays(native COMPLEX data).
      call mxCopyPtrToComplex16(mxGetPr(prhs(1)),
                                   mxGetPi(prhs(1)), x, nx)
      call mxCopyPtrToComplex16(mxGetPr(prhs(2)),
                                   mxGetPi(prhs(2)), y, ny)

C     Call the computational subroutine.
      call convec(x, y, z, nx, ny)
```

```
C     Load the output into a MATLAB array.
      call mxCopyComplex16ToPtr(z, mxGetPr(plhs(1)),
                                   mxGetPi(plhs(1)), nz)
      return
      end
```

Entering these numbers at the MATLAB prompt

```
x = [3 - 1i, 4 + 2i, 7 - 3i]

x =

   3.0000 - 1.0000i   4.0000 + 2.0000i   7.0000 - 3.0000i

y = [8 - 6i, 12 + 16i, 40 - 42i]

y =

   8.0000 - 6.0000i  12.0000 +16.0000i  40.0000 -42.0000i
```

and invoking the new MEX-file

```
z = convec(x, y)
```

results in

```
z =

   1.0e+02 *

  Columns 1 through 4

   0.1800 - 0.2600i   0.9600 + 0.2800i   1.3200 - 1.4400i
   3.7600 - 0.1200i

  Column 5

   1.5400 - 4.1400i
```

which agrees with the results the built-in MATLAB function `conv.m` produces.

Dynamically Allocating Memory

It is possible to allocate memory dynamically in a Fortran MEX-file, but you must use `%val` to do it. This example takes an input matrix of real data and doubles each of its elements.

```
C=============================================================
C     dblmat.f
C     Example for illustrating how to use %val.
C     Doubles the input matrix. The demo only handles real part
C     of input.
C
C     NOTE: If your Fortran compiler does not support %val,
C     use mxCopy_routine.
C     NOTE: The subroutine compute() is in the file called
C     compute.f.
C
C     This is a MEX-file for MATLAB.
C     Copyright (c) 1984-2000 The MathWorks, Inc.
C     $Revision: 1.13 $
C=============================================================

C     The gateway subroutine
      subroutine mexfunction(nlhs, plhs, nrhs, prhs)
C-------------------------------------------------------------
C     (pointer) Replace integer by integer*8 on the DEC Alpha
C     64-bit platform

      integer plhs(*), prhs(*)
      integer pr_in, pr_out
      integer mxGetPr, mxCreateDoubleMatrix
C-------------------------------------------------------------

      integer nlhs, nrhs, mxGetM, mxGetN
      integer m_in, n_in, size

      if(nrhs .ne. 1) then
         call mexErrMsgTxt('One input required.')
      endif
      if(nlhs .gt. 1) then
         call mexErrMsgTxt('Less than one output required.')
```

```
      endif

      m_in = mxGetM(prhs(1))
      n_in = mxGetN(prhs(1))
      size = m_in * n_in
      pr_in = mxGetPr(prhs(1))
      plhs(1) = mxCreateDoubleMatrix(m_in, n_in, 0)
      pr_out = mxGetPr(plhs(1))

C     Call the computational routine.
      call compute(%val(pr_out), %val(pr_in), size)

      return
      end
```

This is the subroutine that `dblmat` calls to double the input matrix.

```
C=================================================================
C     compute.f
C
C     This subroutine doubles the input matrix. Your version of
C     compute() may do whaveter you would like it to do.
C
C     This is a MEX-file for MATLAB.
C     Copyright (c) 1984-2000 The MathWorks, Inc.
C     $Revision: 1.3 $
C=================================================================

C     Computational subroutine
      subroutine compute(out_mat, in_mat, size)
      integer size, i
      real*8  out_mat(*), in_mat(*)

      do 10 i=1,size
         out_mat(i) = 2*in_mat(i)
 10   continue

      return
      end
```

For an input 2-by-3 matrix

```
x = [1 2 3; 4 5 6];
```

typing

```
y = dblmat(x)
```

yields

```
y =
     2     4     6
     8    10    12
```

Note The `dblmat.f` example, as well as `fulltosparse.f` and `sincall.f`, are split into two parts, the gateway and the computational subroutine, because of restrictions in some compilers.

Handling Sparse Matrices

The MATLAB API provides a set of functions that allow you to create and manipulate sparse matrices from within your MEX-files. There are special parameters associated with sparse matrices, namely `ir`, `jc`, and `nzmax`. For information on how to use these parameters and how MATLAB stores sparse matrices in general, refer to the section on “The MATLAB Array” on page 1-5.

Note Sparse array indexing is zero-based, not one-based.

This example illustrates how to populate a sparse matrix.

```
C===============================================================
C     fulltosparse.f
C     Example for illustrating how to populate a sparse matrix.
C     For the purpose of this example, you must pass in a
C     non-sparse 2-dimensional argument of type real double.
C
C     NOTE: The subroutine loadsparse() is in the file called
C     loadsparse.f.
```

```
C
C     This is a MEX-file for MATLAB.
C     Copyright (c) 1984-2000 The MathWorks, Inc.
C     $Revision: 1.6 $
C================================================================

C     The gateway routine.
      subroutine mexFunction(nlhs, plhs, nrhs, prhs)
C----------------------------------------------------------------
C     (pointer) Replace integer by integer*8 on the DEC Alpha
C     64-bit platform

      integer plhs(*), prhs(*)
      integer mxGetPr, mxCreateSparse, mxGetIr, mxGetJc
      integer pr, sr, irs, jcs
C----------------------------------------------------------------

      integer nlhs, nrhs
      integer m, n, nzmax
      integer mxGetM, mxGetN, mxIsComplex, mxIsDouble
      integer loadsparse

C     Check for proper number of arguments.
      if (nrhs .ne. 1) then
         call mexErrMsgTxt('One input argument required.')
      endif
      if (nlhs .gt. 1) then
         call mexErrMsgTxt('Too many output arguments.')
      endif

C     Check data type of input argument.
      if (mxIsDouble(prhs(1)) .eq. 0) then
       call mexErrMsgTxt('Input argument must be of type double.')
      endif
      if (mxIsComplex(prhs(1)) .eq. 1) then
         call mexErrMsgTxt('Input argument must be real only')
      endif

C     Get the size and pointers to input data.
      m = mxGetM(prhs(1))
```

```
      n = mxGetN(prhs(1))
      pr = mxGetPr(prhs(1))

C     Allocate space.
C     NOTE: Assume at most 20% of the data is sparse.
      nzmax = dble(m*n) *.20 + .5

C    NOTE: The maximum number of non-zero elements cannot be less
C     than the number of columns in the matrix.
      if (n .gt. nzmax) then
         nzmax = n
      endif

      plhs(1) = mxCreateSparse(m,n,nzmax,0)
      sr = mxGetPr(plhs(1))
      irs = mxGetIr(plhs(1))
      jcs = mxGetJc(plhs(1))

C     Load the sparse data.
      if (loadsparse(%val(pr), %val(sr), %val(irs), %val(jcs),
     +m,n,nzmax) .eq. 1) then
       call mexPrintf('Truncating output, input is > 20%% sparse')
      endif
      return
      end
```

This is the subroutine that `fulltosparse` calls to fill the `mxArray` with the sparse data.

```
C================================================================
C     loadsparse.f
C    This is the subfunction called by fulltosparse that fills the
C     mxArray with the sparse data.  Your version of
C     loadsparse can operate however you would like it to on the
C     data.
C
C     This is a MEX-file for MATLAB.
C     Copyright (c) 1984-2000 The MathWorks, Inc.
C     $Revision: 1.4 $
C================================================================
```

```
C     Load sparse data subroutine.
      function loadsparse(a, b, ir, jc, m, n, nzmax)
      integer nzmax, m, n
      integer ir(*), jc(*)
      real*8 a(*), b(*)
      integer i, j, k

C     Copy nonzeros.
      k = 1
      do 100 j=1,n
C        NOTE: Sparse indexing is zero based.
         jc(j) = k-1
         do 200 i=1,m
            if (a((j-1)*m+i).ne. 0.0) then
               if (k .gt. nzmax) then
                  jc(n+1) = nzmax
                  loadsparse = 1
                  goto 300
               endif
               b(k) = a((j-1)*m+i)
C              NOTE: Sparse indexing is zero based.
               ir(k) = i-1
               k = k+1
            endif
 200     continue
 100  continue
C     NOTE: Sparse indexing is zero based.
      jc(n+1) = k-1
      loadsparse = 0
 300  return
      end
```

At the MATLAB prompt, entering

```
full = eye(5)
full =
     1     0     0     0     0
     0     1     0     0     0
     0     0     1     0     0
     0     0     0     1     0
     0     0     0     0     1
```

creates a full, 5-by-5 identity matrix. Using `fulltosparse` on the full matrix produces the corresponding sparse matrix.

```
spar = fulltosparse(full)
spar =
   (1,1)        1
   (2,2)        1
   (3,3)        1
   (4,4)        1
   (5,5)        1
```

Calling Functions from Fortran MEX-Files

It's possible to call MATLAB functions, operators, M-files, and even other MEX-files from within your Fortran source code by using the API function `mexCallMATLAB`. This example creates an `mxArray`, passes various pointers to a subfunction to acquire data, and calls `mexCallMATLAB` to calculate the sine function and plot the results.

```
C===============================================================
C     sincall.f
C
C     Example for illustrating how to use mexCallMATLAB.
C
C     Creates an mxArray and passes its associated pointers (in
C     this demo, only pointer to its real part, pointer to number
C     of rows, pointer to number of columns) to subfunction fill()
C     to get data filled up, then calls mexCallMATLAB to calculate
C     sin function and plot the result.
C
C     NOTE: The subfunction fill() is in the file called fill.f.
C
C     This is a MEX-file for MATLAB.
C     Copyright (c) 1984-2000 The MathWorks, Inc.
C     $Revision: 1.10 $
C ==============================================================
```

```
C     The gateway routine
      subroutine mexFunction(nlhs, plhs, nrhs, prhs)
C-----------------------------------------------------------------
C     (pointer) Replace integer by integer*8 on the DEC Alpha
C     64-bit platform

      integer plhs(*), prhs(*)
      integer rhs(1), lhs(1)
      integer mxGetPr, mxCreateDoubleMatrix
C-----------------------------------------------------------------

      integer nlhs, nrhs
      integer m, n, max

C     initializition
      m = 1
      n = 1
      max = 1000

      rhs(1) = mxCreateDoubleMatrix(max, 1, 0)

C     Pass the pointer and variable and let fill() fill up data.
      call fill(%val(mxGetPr(rhs(1))), m, n, max)
      call mxSetM(rhs(1), m)
      call mxSetN(rhs(1), n)

      call mexCallMATLAB(1, lhs, 1, rhs, 'sin')
      call mexCallMATLAB(0, NULL, 1, lhs, 'plot')

C     Clean up the unfreed memory after calling mexCallMATLAB.
      call mxDestroyArray(rhs(1))
      call mxDestroyArray(lhs(1))

      return
      end
```

This is the subroutine that `sincall` calls to fill the mxArray with data.

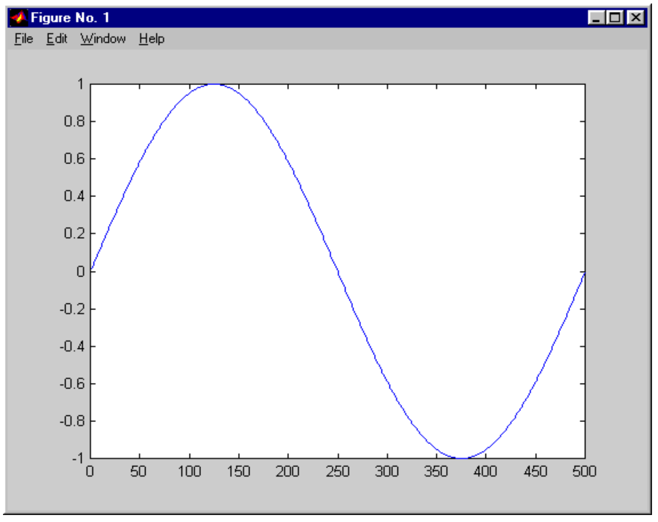
```
C=====================================================================
C     fill.f
C     This is the subfunction called by sincall that fills the
C     mxArray with data. Your version of fill can load your data
C     however you would like.
C
C     This is a MEX-file for MATLAB.
C     Copyright (c) 1984-2000 The MathWorks, Inc.
C     $Revision: 1.3 $
C=====================================================================

C     Subroutine for filling up data.
      subroutine fill(pr, m, n, max)
      real*8  pr(*)
      integer i, m, n, max

      m = max/2
      n = 1
      do 10 i=1,m
 10      pr(i) = i*(4*3.1415926/max)

      return
      end
```

It is possible to use `mexCallMATLAB` (or any other API routine) from within your computational Fortran subroutine. Note that you can only call most MATLAB functions with double-precision data. M-functions that perform computations, like `eig`, will not work correctly with data that is not double precision.

Running this example

```
sincall
```

displays the results



Note It is possible to generate an object of type `mxUNKNOWN_CLASS` using `mexCallMATLAB`. See the example below.

The following example creates an M-file that returns two variables but only assigns one of them a value.

```
function [a,b]=foo[c]
a=2*c;
```

MATLAB displays the following warning message.

```
Warning: One or more output arguments not assigned during call to
'foo'.
```

If you then call `foo` using `mexCallMATLAB`, the unassigned output variable will now be of type `mxUNKNOWN_CLASS`.

Advanced Topics

These sections cover advanced features of MEX-files that you can use when your applications require sophisticated MEX-files.

Help Files

Because the MATLAB interpreter chooses the MEX-file when both an M-file and a MEX-file with the same name are encountered in the same directory, it is possible to use M-files for documenting the behavior of your MEX-files. The MATLAB `help` command will automatically find and display the appropriate M-file when help is requested and the interpreter will find and execute the corresponding MEX-file when the function is actually invoked.

Linking Multiple Files

You can combine several source files when building MEX-files. For example,

```
mex circle.f square.o rectangle.f shapes.o
```

is a legal command that operates on the `.f` and `.o` files to create a MEX-file called `circle.`*`ext`*, where *`ext`* is the extension corresponding to the MEX-file type. The name of the resulting MEX-file is taken from the first file in the list.

You may find it useful to use a software development tool like `MAKE` to manage MEX-file projects involving multiple source files. Simply create a `MAKEFILE` that contains a rule for producing object files from each of your source files and then invoke `mex` to combine your object files into a MEX-file. This way you can ensure that your source files are recompiled only when necessary.

Note On UNIX, you must use the `-fortran` switch to the `mex` script if you are linking Fortran objects.

Workspace for MEX-File Functions

Unlike M-file functions, MEX-file functions do not have their own variable workspace. `mexEvalString` evaluates the string in the caller's workspace. In addition, you can use the `mexGetMatrix` and `mexPutMatrix` routines to get and put variables into the caller's workspace.

Memory Management

MATLAB now implicitly destroys (by calling `mxDestroyArray`) any arrays created by a MEX-file that are not returned in the left-hand side list (`plhs()`). Consequently, any misconstructed arrays left over at the end of a MEX-file's execution have the potential to cause memory errors.

In general, we recommend that MEX-files destroy their own temporary arrays and clean up their own temporary memory. For additional information on memory management techniques, see the sections "Memory Management" on page 2-37 and "Memory Management Compatibility Issues" on page 1-36.

Debugging Fortran Language MEX-Files

On most platforms, it is now possible to debug MEX-files while they are running within MATLAB. Complete source code debugging, including setting breakpoints, examining variables, and stepping through the source code line-by-line, is now available.

Note The section on “Troubleshooting” on page 1-31 provides additional information on isolating problems with MEX-files.

To debug a MEX-file from within MATLAB, you must first compile the MEX-file with the `-g` option to `mex`.

```
mex -g filename.f
```

Debugging on UNIX

You must start MATLAB from within a debugger. To do this, specify the name of the debugger you want to use with the `-D` option when starting MATLAB. For example, to use `dbx`, the UNIX debugger, type

```
matlab -Ddbx
```

Once the debugger loads MATLAB into memory, you can start it by issuing a `run` command. Now, from within MATLAB, enable MEX-file debugging by typing

```
dbmex on
```

at the MATLAB prompt. Then run the MEX-file you want to debug as you would ordinarily (either directly or by means of some other function or script). Before executing the MEX-file, you will be returned to the debugger.

You may need to tell the debugger where the MEX-file was loaded or the name of the MEX-file, in which case MATLAB will display the appropriate command for you to use. At this point, you are ready to start debugging. You can list the source code for your MEX-file and set break points in it. It is often convenient to set one at mexFunction so that you stop at the beginning of the gateway routine.

Note The name `mexFunction` may be slightly altered by the compiler (i.e., it may have an underscore appended). To determine how this symbol appears in a given MEX-file, use the UNIX command

```
nm <MEX-file> | grep -i mexfunction
```

To proceed from the breakpoint, issue a `continue` command to the debugger.

Once you hit one of your breakpoints, you can make full use of any facilities your debugger provides to examine variables, display memory, or inspect registers. Refer to the documentation provided with your debugger for information on its use.

If you are at the MATLAB prompt and want to return control to the debugger, you can issue the command

```
dbmex stop
```

which allows you to gain access to the debugger so you can set additional breakpoints or examine source code. To resume execution, issue a `continue` command to the debugger.

Debugging on Windows

Compaq Visual Fortran

If you are using the Compaq (or DIGITAL) Visual Fortran compiler, you use the Microsoft debugging environment to debug your program.

1. Start the Microsoft Visual Studio by typing at the DOS prompt

   msdev *filename*.dll

2. In the Microsoft environment, from the **Project** menu, select **Settings**. In the window that opens, select the **Debug** tab. This options window contains edit boxes. In the edit box labeled **Executable for debug session**, enter the full path where MATLAB resides. All other edit boxes should be empty.

3. Open the source files and set a break point on the desired line of code by right-clicking with your mouse on the line of code.

4 From the **Build** menu, select **Debug**, and click **Go**.

5 You will now be able to run your MEX-file in MATLAB and use the Microsoft debugging environment. For more information on how to debug in the Microsoft environment, see the Microsoft Development Studio documentation.

4

Calling MATLAB from C and Fortran Programs

The MATLAB engine library is a set of routines that allows you to call MATLAB from your own programs, thereby employing MATLAB as a computation engine. MATLAB engine programs are C or Fortran programs that communicate with a separate MATLAB process via pipes, on UNIX, and through a Component Object Model (COM) interface, on Windows. There is a library of functions provided with MATLAB that allows you to start and end the MATLAB process, send data to and from MATLAB, and send commands to be processed in MATLAB.

Using the MATLAB Engine

Some of the things you can do with the MATLAB engine are:

- Call a math routine, for example, to invert an array or to compute an FFT from your own program. When employed in this manner, MATLAB is a powerful and programmable mathematical subroutine library.
- Build an entire system for a specific task, for example, radar signature analysis or gas chromatography, where the front end (GUI) is programmed in C and the back end (analysis) is programmed in MATLAB, thereby shortening development time.

The MATLAB engine operates by running in the background as a separate process from your own program. This offers several advantages:

- On UNIX, the MATLAB engine can run on your machine, or on any other UNIX machine on your network, including machines of a different architecture. Thus you could implement a user interface on your workstation and perform the computations on a faster machine located elsewhere on your network. The description of the `engOpen` function offers further information.
- Instead of requiring that all of MATLAB be linked to your program (a substantial amount of code), only a small engine communication library is needed.

The Engine Library

The engine library contains the following routines for controlling the MATLAB computation engine. Their names all begin with the three-letter prefix `eng`. These tables list all the available engine functions and their purposes.

C Engine Routines

Function	Purpose
`engOpen`	Start up MATLAB engine
`engClose`	Shut down MATLAB engine
`engGetVariable`	Get a MATLAB array from the MATLAB engine

C Engine Routines

Function	Purpose
`engPutVariable`	Send a MATLAB array to the MATLAB engine
`engEvalString`	Execute a MATLAB command
`engOutputBuffer`	Create a buffer to store MATLAB text output
`engOpenSingleUse`	Start a MATLAB engine session for single, nonshared use
`engGetVisible`	Determine visibility of MATLAB engine session
`engSetVisible`	Show or hide MATLAB engine session

Fortran Engine Routines

Function	Purpose
`engOpen`	Start up MATLAB engine
`engClose`	Shut down MATLAB engine
`engGetVariable`	Get a MATLAB array from the MATLAB engine
`engPutVariable`	Send a MATLAB array to the MATLAB engine
`engEvalString`	Execute a MATLAB command
`engOutputBuffer`	Create a buffer to store MATLAB text output

The MATLAB engine also uses the `mx` prefixed API routines discussed in Chapter 2, "Creating C Language MEX-Files" and Chapter 3, "Creating Fortran MEX-Files."

Communicating with MATLAB

On UNIX, the engine library communicates with the MATLAB engine using pipes, and, if needed, `rsh` for remote execution. On Microsoft Windows, the engine library communicates with MATLAB using a Component Object Model () interface. Chapter 7, "COM and DDE Support" contains a detailed description of COM.

GUI-Intensive Applications

If you have graphical user interface (GUI) intensive applications that execute a lot of callbacks through the MATLAB engine, you should force these callbacks to be evaluated in the context of the base workspace. Use `evalin` to specify that the base workspace is to be used in evaluating the callback expression, as follows.

```
engEvalString(ep, "evalin('base', expression)")
```

Specifying the base workspace in this manner ensures that MATLAB will process the callback correctly and return results for that call.

This does not apply to computational applications that do not execute callbacks.

Examples of Calling Engine Functions

This section contains examples that illustrate how to call engine functions from C and Fortran programs. The examples cover the following topics:

- "Calling MATLAB From a C Application"
- "Calling MATLAB From a Fortran Application"
- "Attaching to an Existing MATLAB Session"

It is important to understand the sequence of steps you must follow when using the engine functions. For example, before using `engPutVariable`, you must create the matrix and populate it.

After reviewing these examples, follow the instructions in "Compiling and Linking Engine Programs" on page 4-16 to build the application and test it. By building and running the application, you will ensure that your system is properly configured for engine applications.

Calling MATLAB From a C Application

This program, `engdemo.c`, illustrates how to call the engine functions from a stand-alone C program. For the Windows version of this program, see `engwindemo.c` in the `<matlab>\extern\examples\eng_mat` directory. Engine examples, like the MAT-file examples, are located in the `eng_mat` directory.

```
/*
 * engdemo.c
 *
 * This is a simple program that illustrates how to call the
 * MATLAB engine functions from a C program.
 *
 * Copyright (c) 1984-2000 The MathWorks, Inc.
 * Revision: 1.8 $
 */
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include "engine.h"
#define  BUFSIZE 256
```

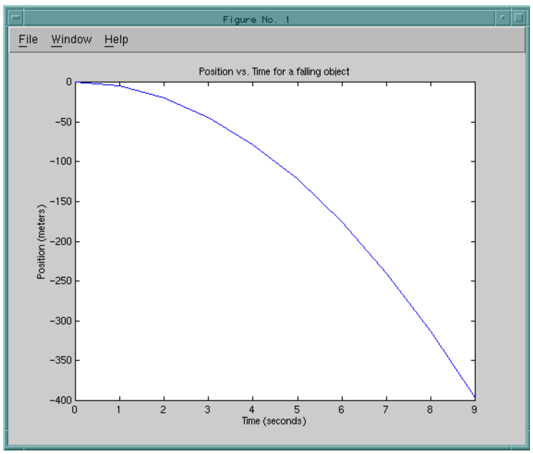
```
int main()

{
   Engine *ep;
   mxArray *T = NULL, *result = NULL;
   char buffer[BUFSIZE];
   double time[10] = {0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0,
                      8.0, 9.0};
   /*
    * Start the MATLAB engine locally by executing the string
    * "matlab".
    *
    * To start the session on a remote host, use the name of
    * the host as the string rather than \0.
    *
    * For more complicated cases, use any string with whitespace,
    * and that string will be executed literally to start MATLAB.
    */
   if (!(ep = engOpen("\0"))) {
      fprintf(stderr, "\nCan't start MATLAB engine\n");
      return EXIT_FAILURE;
   }

   /*
    * PART I
    *
    * For the first half of this demonstration, we will send data
    * to MATLAB, analyze the data, and plot the result.
    */

   /*
    * Create a variable for our data.
    */
   T = mxCreateDoubleMatrix(1, 10, mxREAL);
   memcpy((void *)mxGetPr(T), (void *)time, sizeof(time));

   /*
    * Place the variable T into the MATLAB workspace.
    */
   engPutVariable(ep, "T", T);
```

```
/*
 * Evaluate a function of time, distance = (1/2)g.*t.^2
 * (g is the acceleration due to gravity).
 */
engEvalString(ep, "D = .5.*(-9.8).*T.^2;");

/*
 * Plot the result.
 */
engEvalString(ep, "plot(T,D);");
engEvalString(ep, "title('Position vs. Time for a falling
               object');");
engEvalString(ep, "xlabel('Time (seconds)');");
engEvalString(ep, "ylabel('Position (meters)');");

/*
 * Use fgetc() to make sure that we pause long enough to be
 * able to see the plot.
 */
printf("Hit return to continue\n\n");
fgetc(stdin);

/*
 * We're done for Part I! Free memory, close MATLAB engine.
 */
printf("Done for Part I.\n");
mxDestroyArray(T);
engEvalString(ep, "close;");

/*
 * PART II
 *
 * For the second half of this demonstration, we will request
 * a MATLAB string, which should define a variable X.  MATLAB
 * will evaluate the string and create the variable.  We
 * will then recover the variable, and determine its type.
 */

/*
```

```
 * Use engOutputBuffer to capture MATLAB output, so we can
 * echo it back.
 */

engOutputBuffer(ep, buffer, BUFSIZE);
while (result == NULL) {
   char str[BUFSIZE];

   /*
    * Get a string input from the user.
    */
   printf("Enter a MATLAB command to evaluate.  This command
           should\n");
   printf("create a variable X.  This program will then
           determine\n");
   printf("what kind of variable you created.\n");
   printf("For example: X = 1:5\n");
   printf(">> ");

   fgets(str, BUFSIZE-1, stdin);

   /*
    * Evaluate input with engEvalString.
    */
   engEvalString(ep, str);

   /*
    * Echo the output from the command.  First two characters
    * are always the double prompt (>>).
    */
   printf("%s", buffer+2);

   /*
    * Get result of computation.
    */
   printf("\nRetrieving X...\n");
   if ((result = engGetVariable(ep,"X")) == NULL)
      printf("Oops! You didn't create a variable X.\n\n");
   else {
      printf("X is class %s\t\n", mxGetClassName(result));
```

```
        }
    }

    /*
     * We're done! Free memory, close MATLAB engine and exit.
     */
    printf("Done!\n");
    mxDestroyArray(result);
    engClose(ep);

    return EXIT_SUCCESS;
}
```

The first part of this program launches MATLAB and sends it data. MATLAB then analyzes the data and plots the results.



The program then continues with

```
Press Return to continue
```

Pressing **Return** continues the program.

```
Done for Part I.
Enter a MATLAB command to evaluate.  This command should
create a variable X.  This program will then determine
what kind of variable you created.
For example: X = 1:5
```

Entering `X = 17.5` continues the program execution.

```
X = 17.5

X =

   17.5000


Retrieving X...
X is class double
Done!
```

Finally, the program frees memory, closes the MATLAB engine, and exits.

Calling MATLAB From a Fortran Application

This program, `fengdemo.f`, illustrates how to call the engine functions from a stand-alone Fortran program.

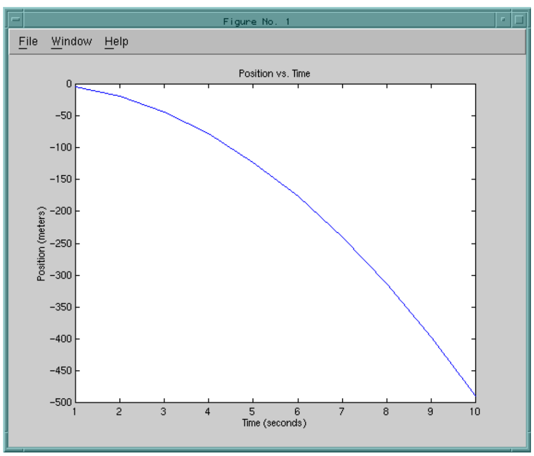
```
C==============================================================
C     fengdemo.f
C
C     This program illustrates how to call the MATLAB
C     Engine functions from a Fortran program.
C
C Copyright (c) 1984-2000 by The MathWorks, Inc.
C $Revision: 1.9 $
C==============================================================

      program main
C--------------------------------------------------------------
C     (pointer) Replace integer by integer*8 on the DEC Alpha
C     64-bit platform

      integer engOpen, engGetVariable, mxCreateDoubleMatrix
      integer mxGetPr
      integer ep, T, D
C--------------------------------------------------------------
```

```
C     Other variable declarations here
      double precision time(10), dist(10)
      integer engPutVariable, engEvalString, engClose
      integer temp, status
      data time / 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0,
     &            9.0, 10.0 /

      ep = engOpen('matlab ')

      if (ep .eq. 0) then
         write(6,*) 'Can''t start MATLAB engine'
         stop
      endif

      T = mxCreateDoubleMatrix(1, 10, 0)
      call mxCopyReal8ToPtr(time, mxGetPr(T), 10)
C
C     Place the variable T into the MATLAB workspace.
C
      status = engPutVariable(ep, 'T', T)

      if (status .ne. 0) then
         write(6,*) 'engPutVariable failed'
         stop
      endif
C
C     Evaluate a function of time, distance = (1/2)g.*t.^2
C     (g is the acceleration due to gravity).
C
      if (engEvalString(ep, 'D = .5.*(-9.8).*T.^2;') .ne. 0) then
         write(6,*) 'engEvalString failed'
         stop
      endif
C
C     Plot the result.
C
      if (engEvalString(ep, 'plot(T,D);') .ne. 0) then
         write(6,*) 'engEvalString failed'
         stop
      endif
```

```
      if (engEvalString(ep, 'title(''Position vs. Time'')')
      .ne. 0) then
         write(6,*) 'engEvalString failed'
         stop
      endif

      if (engEvalString(ep, 'xlabel(''Time (seconds)'')')
      .ne. 0) then
         write(6,*) 'engEvalString failed'
         stop
      endif
      if (engEvalString(ep, 'ylabel(''Position (meters)'')')
      .ne. 0) then
         write(6,*) 'engEvalString failed'
         stop
      endif
C
C     Read from console to make sure that we pause long enough to
C     be able to see the plot.
C
      print *, 'Type 0 <return> to Exit'
      print *, 'Type 1 <return> to continue'

      read(*,*) temp

      if (temp.eq.0) then
         print *, 'EXIT!'
         stop
      end if

      if (engEvalString(ep, 'close;') .ne. 0) then
         write(6,*) 'engEvalString failed'
         stop
      endif

      D = engGetVariable(ep, 'D')
      call mxCopyPtrToReal8(mxGetPr(D), dist, 10)
      print *, 'MATLAB computed the following distances:'
      print *, '  time(s)  distance(m)'
```

```
      do 10 i=1,10
         print 20, time(i), dist(i)
 20      format(' ', G10.3, G10.3)
 10   continue

      call mxDestroyArray(T)
      call mxDestroyArray(D)
      status = engClose(ep)

      if (status .ne. 0) then
         write(6,*) 'engClose failed'
         stop
      endif

      stop
      end
```

Executing this program launches MATLAB, sends it data, and plots the results.



The program continues with

```
Type 0 <return> to Exit
Type 1 <return> to continue
```

Entering 1 at the prompt continues the program execution.

```
1
 MATLAB computed the following distances:
   time(s)  distance(m)
   1.00     -4.90
   2.00     -19.6
   3.00     -44.1
   4.00     -78.4
   5.00     -123.
   6.00     -176.
   7.00     -240.
   8.00     -314.
   9.00     -397.
   10.0     -490.
```

Finally, the program frees memory, closes the MATLAB engine, and exits.

Attaching to an Existing MATLAB Session

You can make a MATLAB engine program attach to a MATLAB session that is already running by starting the MATLAB session with `/Automation` in the command line. When you make a call to `engOpen`, it will then connect to this existing session. You should only call `engOpen` once, as any `engOpen` calls will now connect to this one MATLAB session.

The `/Automation` option also causes the command window to be minimized. You must open it manually.

Note For more information on the `/Automation` command line argument, see "Additional Automation Server Information" on page 7-41. For information about the Component Object Model interfaces used by MATLAB, see "Introducing MATLAB COM Integration" on page 7-2.

For example:

1 Shut down any MATLAB sessions.

2 From the **Start** button on the Windows menu bar, click **Run**.

3 In the **Open** field, type

```
d:\matlab\bin\win32\matlab.exe /Automation
```

where `d:\matlab\bin\win32` represents the path to the MATLAB executable.

4 Click **OK**. This starts MATLAB.

5 In MATLAB, change directories to `$MATLAB/extern/examples/eng_mat`, where `$MATLAB` is the MATLAB root directory.

6 Compile the `engwindemo.c` example.

7 Run the `engwindemo` program by typing at the MATLAB prompt

```
!engwindemo
```

This does not start another MATLAB session, but rather uses the MATLAB session that is already open.

Note On the UNIX platform, you cannot make a MATLAB engine program use a MATLAB session that is already running.

Compiling and Linking Engine Programs

To produce an executable version of an engine program, you must compile it and link it with the appropriate library. This section describes the steps required to compile and link engine programs on UNIX and Windows systems. It begins by looking at a special consideration for compilers that do not mask floating-point exceptions. Topics covered are:

- "Masking Floating-Point Exceptions"
- "Compiling and Linking on UNIX"
- "Compiling and Linking on Windows"

Masking Floating-Point Exceptions

Certain mathematical operations can result in nonfinite values. For example, division by zero results in the nonfinite IEEE value, `inf`. A floating-point exception occurs when such an operation is performed. Because MATLAB uses an IEEE model that supports nonfinite values such as `inf` and `NaN`, MATLAB disables, or *masks*, floating-point exceptions.

Some compilers do not mask floating-point exceptions by default. This causes engine programs built with such compilers to terminate when a floating-point exception occurs. Consequently, you need to take special precautions when using these compilers to mask floating-point exceptions so that your engine application will perform properly.

Note MATLAB based applications should never get floating-point exceptions. If you do get a floating-point exception, verify that any third party libraries that you link against do not enable floating-point exception handling.

The only compiler and platform on which you need to mask floating-point exceptions is the Borland C++ compiler on Windows.

Borland C++ Compiler on Windows

To mask floating-point exceptions when using the Borland C++ compiler on the Windows platform, you must add some code to your program. Include the following at the beginning of your `main()` or `WinMain()` function, before any calls to MATLAB API functions.

```
#include <float.h>
    .
    .
    .
_control87(MCW_EM,MCW_EM);
    .
    .
    .
```

Compiling and Linking on UNIX

Under UNIX at runtime, you must tell the system where the API shared libraries reside. These sections provide the necessary UNIX commands depending on your shell and system architecture.

Setting Runtime Library Path

In C shell, the command to set the library path is

```
setenv LD_LIBRARY_PATH
<matlab>/extern/lib/$Arch:$LD_LIBRARY_PATH
```

In Bourne shell, the commands to set the library path are

```
LD_LIBRARY_PATH=<matlab>/extern/lib/$Arch:$LD_LIBRARY_PATH
export LD_LIBRARY_PATH
```

where `<matlab>` is the MATLAB root directory and `$Arch` is your system architecture (`alpha`, `glnx86`, `sgi`, `sol2`, `hp700`, or `ibm_rs`).

Note that the environment variable (LD_LIBRARY_PATH in this example) varies on several platforms. This table lists the different environment variable names you should use on these systems.

Environment Variable Names

Architecture	Environment Variable
HP700	SHLIB_PATH
IBM RS/6000	LIBPATH

It is convenient to place these commands in a startup script such as ~/.cshrc for C shell or ~/.profile for Bourne shell.

Compiling and Linking

MATLAB provides an options file, engopts.sh, that lets you use the mex script to easily compile and link engine applications. For example, to compile and link the engdemo.c example, you can use

```
mex -f <matlab>/bin/engopts.sh <pathname>/engdemo.c
```

where <pathname> specifies the complete path to the specified file.

If you need to modify the options file for your particular compiler or platform, use the -v switch to view the current compiler and linker settings and then make the appropriate changes in a local copy of the engopts.sh file.

Compiling and Linking on Windows

To compile and link engine programs, use the mex script with an engine options file. Table 1-2, Options Files, on page 1-16 lists the engine options files included in this release. All of these options files are located in <matlab>\bin\win32\mexopts.

As an example, to compile and link the stand-alone engine application engwindemo.c on Windows using MSVC (Version 5.0), use

```
mex -f <matlab>\bin\win32\mexopts\msvc50engmatopts.bat ...
<pathname>\engwindemo.c
```

where <pathname> specifies the complete path to the specified file. If you need to modify the options file for your particular compiler, use the -v switch to view the current compiler and linker settings and then make the appropriate changes in the options file.

5

Calling Java from MATLAB

This chapter describes how to use the MATLAB interface to Java classes and objects. This MATLAB capability enables you to conveniently bring Java classes into the MATLAB environment, to construct objects from those classes, to call methods on the Java objects, and to save Java objects for later reloading — all accomplished with MATLAB functions and commands.

Using Java from MATLAB: An Overview

Java Interface Is Integral to MATLAB

Every installation of MATLAB includes a Java Virtual Machine (JVM), so that you can use the Java interpreter via MATLAB commands, and you can create and run programs that create and access Java objects. For information on MATLAB installation, see the MATLAB installation documentation for your platform.

Benefits of the MATLAB Java Interface

The MATLAB Java interface enables you to:

- Access Java API (application programming interface) class packages that support essential activities such as I/O and networking. For example, the `URL` class provides convenient access to resources on the internet
- Access third-party Java classes
- Easily construct Java objects in MATLAB
- Call Java object methods, using either Java or MATLAB syntax
- Pass data between MATLAB variables and Java objects

Who Should Use the MATLAB Java Interface

The MATLAB Java interface is intended for all MATLAB users who want to take advantage of the special capabilities of the Java programming language. For example:

- You need to access, from MATLAB, the capabilities of available Java classes.
- You are familiar with object-oriented programming in Java or in another language, such as C++.
- You are familiar with MATLAB object-oriented classes, or with MATLAB MEX-files.

To Learn More About Java Programming

For a complete description of the Java language and for guidance in object-oriented software design and programming, you'll need to consult outside resources. For example, these recently published books may be helpful:

- *Java in a Nutshell* (Second Edition), by David Flanagan
- *Teach Yourself Java in 21 Days*, by Lemay and Perkins

Another place to find information is the JavaSoft Web site.

```
http://www.javasoft.com
```

For other suggestions on object-oriented programming resources, see:

- *Object Oriented Software Construction*, by Bertrand Meyer
- *Object Oriented Analysis and Design with Applications*, by Grady Booch

Platform Support for the Java Virtual Machine

To find out which version of the Java Virtual Machine (JVM) is being used by MATLAB on your platform, type the following at the MATLAB prompt.

```
version -java
```

Bringing Java Classes into MATLAB

You can draw from an extensive collection of existing Java classes or create your own class definitions to use with MATLAB. This section explains how to go about finding the class definitions that you need or how to create classes of your own design. Once you have the classes you need, defined in either individual `.class` files, packages, or Java Archive files, you will see how to make them available within the MATLAB environment.

This section addresses the following topics:

Sources of Java Classes

There are three main sources of Java classes that you can use in MATLAB:

- **Java built-in classes**

  The Java language includes general-purpose class packages, such as `java.awt`. See your Java language documentation for descriptions of these packages.
- **Third-party classes**

  There are a number of packages of special-purpose Java classes that you can use.
- **User-defined classes**

  You can define new Java classes or subclasses of existing classes. You need to use a Java development environment to do this, as explained in the following section.

Defining New Java Classes

To define new Java classes and subclasses of existing classes, you must use a Java development environment, external to MATLAB, that supports Java version 1.1. You can download the development kit that supports the version

1.1.8 Java Virtual Machine from the web site at Sun Microsystems, (`http://www.java.sun.com/jdk/`). The Sun site also provides documentation for the Java language and classes that you will need for development.

After you create class definitions in `.java` files, use your Java compiler to produce `.class` files from them. The next step is to make the class definitions in those `.class` files available for you to use in MATLAB.

Making Java Classes Available to MATLAB

To make your third-party and user-defined Java classes available in MATLAB, place them on your MATLAB path by adding their locations to the file `classpath.txt`. For more information on `classpath.txt`, see "Finding and Editing classpath.txt" on page 5-6.

Making Individual (Unpackaged) Classes Available

To make individual classes (classes not part of a package) available in MATLAB, add to `classpath.txt` an entry containing the full path to the directory you want to use for the `.class` file(s).

For example, to make available your compiled Java classes in the file `d:\work\javaclasses\test.class`, add the following entry to your `classpath.txt` file.

```
d:\work\javaclasses
```

Making Entire Packages Available

To access one or more classes belonging to a package, you need to make the entire package available to MATLAB. Do this by adding to `classpath.txt` the full path to the *parent directory of the highest-level directory* of the package path. This directory is the first component in the package name.

For example, if your Java class package `com.mw.tbx.ini has` its classes in directory `d:\work\com\mw\tbx\ini`, add the following entry to your `classpath.txt.`

```
d:\work
```

Making Classes in a JAR File Available

You can use the `jar` (Java Archive) tool to create a JAR file, containing multiple Java classes and packages in a compressed ZIP format. For information on `jar` and JAR files, consult your Java development documentation or the JavaSoft web site. See also “To Learn More About Java Programming” on page 5-2.

To make the contents of a JAR file available for use in MATLAB, add to `classpath.txt` the full path, *including full filename*, for the JAR file.

Note Note that the `classpath.txt` requirement for JAR files is different than that for `.class` files and packages, for which you do not specify any filename.

For example, to make available the JAR file `e:\java\classes\utilpkg.jar`, add the following to your `classpath.txt`.

```
e:\java\classes\utilpkg.jar
```

Finding and Editing classpath.txt

To make your Java classes available, you can edit the default `classpath.txt`, which is in the directory `toolbox/local`. Or, you can copy the default `classpath.txt` from this directory to your own startup directory where the changes you make to it do not affect anyone else.

To find the `classpath.txt` that is used by your MATLAB environment, use the MATLAB `which` function.

```
which classpath.txt
```

To edit either the default file or the copy you have made in your own directory, enter the following command in MATLAB.

```
edit classpath.txt
```

MATLAB reads `classpath.txt` only upon startup. So, if you edit `classpath.txt` or change your `.class` files while MATLAB is running, you must restart MATLAB to put those changes into effect.

Loading Java Class Definitions

Normally, MATLAB loads a Java class automatically when your code first uses it, (for example, when you call its constructor). However, there is one exception that you should be aware of.

When you use the `which` function on methods defined by Java classes, the function only acts on the classes currently loaded into the MATLAB working environment. In contrast, `which` always operates on MATLAB classes, whether or not they are loaded.

Determining Which Classes Are Loaded

At any time during a MATLAB session, you can obtain a listing of all the Java classes that are currently loaded. To do so, you use the `inmem` function, in the following form.

```
[M,X,J] = inmem
```

This function returns the list of Java classes in output argument `J`. (It also returns in `M` the names of all currently loaded M-files, and in `X` the names of all currently loaded MEX-files.)

Here's a sample of output from the `inmem` function.

```
[m,x,j] = inmem
m =
   'isequal'
   'isunix'
   'fullfile'
   'filesep'
   .
   .
   .
   'matlabrc'
x =
   'getprofl'
j =
   'java.awt.Frame'
   'com.mathworks.ide.desktop.MLDesktop'
```

Simplifying Java Class Names

Your MATLAB commands can refer to any Java class by its fully qualified name, which includes its package name. For example, the following are fully qualified names:

- `java.lang.String`
- `java.util.Enumeration`

A fully qualified name can be rather long, making commands and functions, such as constructors, cumbersome to edit and to read. You can refer to classes by the class name alone (without a package name) if you, first, import the fully qualified name into MATLAB.

The `import` command has the following forms.

```
import pkg_name.*                 % Import all classes in package
import pkg_name1.* pkg_name2.*  % Import multiple packages
import class_name                 % Import one class
import                            % Display current import list
L = import                        % Return current import list
```

MATLAB adds all classes that you `import` to a list called the *import list*. You can see what classes are on that list by typing `import`, without any arguments. Your code can refer to any class on the list by class name alone.

When called from a function, `import` adds the specified classes to the import list in effect for that function. When invoked at the command prompt, `import` uses the base import list for your MATLAB environment.

For example, suppose a function contains the following statements.

```
import java.lang.String
import java.util.* java.awt.*
import java.util.Enumeration
```

Code that follows the `import` statements above can now refer to the `String`, `Frame`, and `Enumeration` classes without using the package names.

```
str = String('hello');     % Create java.lang.String object
frm = Frame;               % Create java.awt.Frame object
methods Enumeration        % List java.util.Enumeration methods
```

To `clear` the list of imported Java classes, invoke the command

```
clear import
```

Creating and Using Java Objects

In MATLAB, you create a Java object by calling one of the constructors of that class. You then use commands and programming statements to perform operations on these objects. You can also save your Java objects to a MAT-file and, in subsequent sessions, reload them into MATLAB.

This section addresses the following topics:

Constructing Java Objects

You construct Java objects in MATLAB by calling the Java class constructor, which has the same name as the class. For example, the following constructor creates a `Frame` object with the title `'Frame A'` and the other properties with their default values.

```
frame = java.awt.Frame('Frame A');
```

Displaying the new object `frame` shows the following.

```
frame =
java.awt.Frame[frame0,0,0,0x0,invalid,hidden,layout=
java.awt.BorderLayout,resizable,title=Frame A]
```

All of the programming examples in this chapter contain Java object constructors. For example, the sample code for Reading a URL creates a `java.net.URL` object with the constructor

```
url = java.net.URL(...
     'http://archive.ncsa.uiuc.edu/demoweb/')
```

Using the javaObject Function

Under certain circumstances, you may need to use the `javaObject` function to construct a Java object. The following syntax invokes the Java constructor for class, `class_name`, with the argument list that matches `x1,...,xn`, and returns a new object, `J`.

```
J = javaObject('class_name',x1,...,xn);
```

For example, to construct and return a Java object of class `java.lang.String`, you use

```
strObj = javaObject('java.lang.String','hello');
```

Using the `javaObject` function enables you to:

- Use classes that have names that exceed the maximum length of a MATLAB identifier. (Call the `namelengthmax` function to obtain the maximum identifier length.)
- Specify the class for an object at run-time, for example, as input from an application user

The default MATLAB constructor syntax requires that no segment of the input class name be longer than `namelengthmax` characters. (A *class name segment* is any portion of the class name before, between, or after a dot. For example, there are three segments in class, `java.lang.String`.) Any class name segment that exceeds `namelengthmax` characters is truncated by MATLAB. In the rare case where you need to use a class name of this length, you must use `javaObject` to instantiate the class.

The `javaObject` function also allows you to specify the Java class for the object being constructed at run-time. In this situation, you call `javaObject` with a string variable in place of the class name argument.

```
class  = 'java.lang.String';
text = 'hello';
strObj = javaObject(class, text);
```

In the usual case, when the class to instantiate is known at development time, it is more convenient to use the MATLAB constructor syntax. For example, to create a `java.lang.String` object, you would use

```
strObj = java.lang.String('hello');
```

Note Typically, you will not need to use `javaObject`. The default MATLAB syntax for instantiating a Java class is somewhat simpler and is preferable for most applications. Use `javaObject` primarily for the two cases described above.

Java Objects Are References in MATLAB

In MATLAB, Java objects are *references* and do not adhere to MATLAB copy-on-assignment and pass-by-value rules. For example,

```
origFrame = java.awt.Frame;
setSize(origFrame, 800, 400);
newFrameRef = origFrame;
```

In the second statement above, the variable `newFrameRef` is a second reference to `origFrame`, not a copy of the object. In any code following the example above, any change to the object at `newFrameRef` also changes the object at `origFrame`. This effect occurs whether the object is changed by MATLAB code, or by Java code.

The following example shows that `origFrame` and `newFrameRef` are both references to the same entity. When the size of the frame is changed via one reference (`newFrameRef`), the change is reflected through the other reference (`origFrame`), as well.

```
setSize(newFrameRef, 1000, 800);

getSize(origFrame)
ans =
java.awt.Dimension[width=1000,height=800]
```

Concatenating Java Objects

You can concatenate Java objects in the same way that you concatenate native MATLAB data types. You use either the `cat` function or the square bracket operators to tell MATLAB to assemble the enclosed objects into a single object.

Concatenating Objects of the Same Class

If all of the objects being operated on are of the same Java class, then the concatenation of those objects produces an array of objects from the same class.

In the following example, the `cat` function concatenates two objects of the class `java.awt.Point`. The class of the result is also `java.awt.Point`.

```
point1 = java.awt.Point(24,127);
point2 = java.awt.Point(114,29);

cat(1, point1, point2)
ans =
java.awt.Point[]:
    [1x1 java.awt.Point]
    [1x1 java.awt.Point]
```

Concatenating Objects of Unlike Classes

When you concatenate objects of unlike classes, MATLAB finds one class from which all of the input objects inherit, and makes the output an instance of this class. MATLAB selects the lowest common parent in the Java class hierarchy as the output class.

For example, concatenating objects of `java.lang.Byte`, `java.lang.Integer`, and `java.lang.Double` yields an object of `java.lang.Number`, since this is the common parent to the three input classes.

```
byte = java.lang.Byte(127);
integer = java.lang.Integer(52);
double = java.lang.Double(7.8);

[byte; integer; double]

ans =
java.lang.Number[]:
    [   127]
    [    52]
    [7.8000]
```

If there is no common, lower level parent, then the resultant class is `java.lang.Object`, which is the root of the entire Java class hierarchy.

```
byte = java.lang.Byte(127);
point = java.awt.Point(24,127);

[byte; point]

ans =
java.lang.Object[]:
    [               127]
    [1x1 java.awt.Point]
```

Saving and Loading Java Objects to MAT-Files

Use the MATLAB `save` function to save a Java object to a MAT-file. Use the `load` function to load it back into MATLAB from that MAT-file. To save a Java object to a MAT-file, and to load the object from the MAT-file, make sure that the object and its class meet all of the following criteria:

- The class implements the Serializable interface (part of the Java API), either directly or by inheriting it from a parent class. Any embedded or otherwise referenced objects must also implement Serializable.
- The definition of the class is not changed between saving and loading the object. Any change to the data fields or methods of a class prevents the loading (deserialization) of an object that was constructed with the old class definition.
- Either the class does not have any transient data fields, or the values in transient data fields of the object to be saved are not significant. Values in transient data fields are never saved with the object.

If you define your own Java classes, or subclasses of existing classes, you can follow the criteria above to enable objects of the class to be saved and loaded in MATLAB. For details on defining classes to support serialization, consult your Java development documentation. (See also “To Learn More About Java Programming” on page 5-2).

Finding the Public Data Fields of an Object

To list the public fields that belong to a Java object, use the `fieldnames` function, which takes either of these forms.

```
names = fieldnames(obj)
names = fieldnames(obj,'-full')
```

Calling `fieldnames` without `'-full'` returns the names of all the data fields (including inherited) on the object. With the `'-full'` qualifier, `fieldnames` returns the full description of the data fields defined for the object, including type, attributes, and inheritance information.

Suppose, for example, that you constructed a `Frame` object with

```
frame = java.awt.Frame;
```

To obtain the full description of the data fields on `frame`, you could use the command

```
fieldnames(frame,'-full')
```

Sample output from this command follows.

```
ans =
'static final int WIDTH
    % Inherited from java.awt.image.ImageObserver'
'static final int HEIGHT
    % Inherited from java.awt.image.ImageObserver'
[1x74 char]
'static final int SOMEBITS
    % Inherited from java.awt.image.ImageObserver'
'static final int FRAMEBITS
    % Inherited from java.awt.image.ImageObserver'
'static final int ALLBITS
    % Inherited from java.awt.image.ImageObserver'
'static final int ERROR
    % Inherited from java.awt.image.ImageObserver'
'static final int ABORT
    % Inherited from java.awt.image.ImageObserver'
'static final float TOP_ALIGNMENT
    % Inherited from java.awt.Component'
'static final float CENTER_ALIGNMENT
    % Inherited from java.awt.Component'
```

```
'static final float BOTTOM_ALIGNMENT
    % Inherited from java.awt.Component'
'static final float LEFT_ALIGNMENT
    % Inherited from java.awt.Component'
'static final float RIGHT_ALIGNMENT
    % Inherited from java.awt.Component'
.
.
.
```

Accessing Private and Public Data

Java API classes provide accessor methods you can use to read from and, where allowed, to modify *private* data fields. These are sometimes referred to as *get* and *set* methods, respectively.

Some Java classes have *public* data fields, which your code can read or modify directly. To access these fields, use the syntax `object.field`.

Examples

The `java.awt.Frame` class provides an example of access to both private and public data fields. This class has the read accessor method `getSize`, which returns a `java.awt.Dimension` object. The `Dimension` object has data fields `height` and `width`, which are public and therefore directly accessible. The following example shows MATLAB commands accessing this data.

```
frame = java.awt.Frame;
frameDim = getSize(frame);
height = frameDim.height;
frameDim.width = 42;
```

The programming examples in this chapter also contain calls to data field accessors. For instance, the sample code for “Example – Finding an Internet Protocol Address” on page 5-66 uses calls to accessors on a `java.net.InetAddress` object.

```
hostname = address.getHostName;
ipaddress = address.getHostAddress;
```

Accessing Data from a Static Field

In Java, a static data field is a field that applies to an entire class of objects. Static fields are most commonly accessed in relation to the class name itself in Java. For example, the code below accesses the `WIDTH` field of the `Frame` class by referring to it in relation to the package and class names, `java.awt.Frame`, rather than an object instance.

```
width = java.awt.Frame.WIDTH;
```

In MATLAB, you can use that same syntax. Or you can refer to the `WIDTH` field in relation to an instance of the class. The example shown here creates an instance of `java.awt.Frame` called `frameObj`, and then accesses the `WIDTH` field using the name `frameObj` rather than the package and class names.

```
frame = java.awt.Frame('Frame A');

width = frame.WIDTH
width =
     1
```

Assigning to a Static Field

You can assign values to static Java fields by using a static `set` method of the class, or by making the assignment in reference to an instance of the class. For more information, see the previous section, "Accessing Data from a Static Field". You can assign `value` to the field `staticFieldName` in the example below by referring to this field in reference to an instance of the class.

```
objectName = java.className;
objectName.staticFieldName = value;
```

Note MATLAB does not allow assignment to static fields using the class name itself.

Determining the Class of an Object

To find the class of a Java object, use the query form of the MATLAB function, `class`. After execution of the following example, `frameClass` contains the name of the package and class that Java object `frame` instantiates.

```
frameClass = class(frame)
frameClass =
java.awt.Frame
```

Because this form of `class` also works on MATLAB objects, it does not, in itself, tell you whether it is a Java class. To determine the type of class, use the `isjava` function, which has the form

```
x = isjava(obj)
```

`isjava` returns `1` if `obj` is Java, and `0` if it is not.

```
isjava(frame)
ans =
     1
```

To find out whether or not an object is an instance of a specified class, use the `isa` function, which has the form

```
x = isa(obj, 'class_name')
```

`isa` returns `1` if `obj` is an instance of the class named '*class_name*', and `0` if it is not. Note that '*class_name*' can be a MATLAB built-in or user-defined class, as well as a Java class.

```
isa(frame, 'java.awt.Frame')
ans =
     1
```

Invoking Methods on Java Objects

This section explains how to invoke an object's methods in MATLAB. It also covers how to obtain information related to the methods that you're using and how MATLAB handles certain types of nonstandard situations.

This section addresses the following topics:

Using Java and MATLAB Calling Syntax

To call methods on Java objects, you can use the Java syntax

```
object.method(arg1,...,argn)
```

In the following example, `frame` is the `java.awt.Frame` object created above, and `getTitle` and `setTitle` are methods of that object.

```
frame.setTitle('Sample Frame')

title = frame.getTitle
title =
Sample Frame
```

Alternatively, you can call Java object (nonstatic) methods with the MATLAB syntax

```
method(object, arg1,...,argn)
```

With MATLAB syntax, the `java.awt.Frame` example above becomes

```
setTitle(frame, 'Sample Frame')

title = getTitle(frame)
title =
Sample Frame
```

All of the programming examples in this chapter contain invocations of Java object methods. For example, the code for Reading a URL contains a call, using MATLAB syntax, to the `openStream` method on a `java.net.URL` object, `url`.

```
is = openStream(url)
```

In another example, the code for "Example – Creating and Using a Phone Book" on page 5-73 contains a call, using Java syntax, to the `load` method on a `java.utils.Properties` object, `pb_htable`.

```
pb_htable.load(FIS);
```

Using the javaMethod Function on Nonstatic Methods

Under certain circumstances, you may need to use the `javaMethod` function to call a Java method. The following syntax invokes the method, `method_name`, on Java object `J` with the argument list that matches `x1,...,xn`. This returns the value `X`.

```
X = javaMethod('method_name',J,x1,...,xn);
```

For example, to call the `startsWith` method on a `java.lang.String` object passing one argument, use

```
gAddress = java.lang.String('Four score and seven years ago');
str = java.lang.String('Four score');

javaMethod('startsWith', gAddress, str)
ans =
     1
```

Using the `javaMethod` function enables you to

- Use methods that have names that exceed the maximum length of a MATLAB identifier. (Call the `namelengthmax` function to obtain the maximum identifier length.)
- Specify the method you want to invoke at run-time, for example, as input from an application user.

The only way to invoke a method whose name is longer than `namelengthmax` characters is to use `javaMethod`. The Java and MATLAB calling syntax does not accept method names of this length.

With javaMethod, you can also specify the method to be invoked at run-time. In this situation, your code calls javaMethod with a string variable in place of the method_name argument. When you use javaMethod to invoke a static method, you can also use a string variable in place of the class name argument.

Note Typically, you will not need to use javaMethod. The default MATLAB syntax for invoking a Java method is somewhat simpler and is preferable for most applications. Use javaMethod primarily for the two cases described above.

Invoking Static Methods on Java Classes

To invoke a static method on a Java class, use the Java invocation syntax

```
class.method(arg1,...,argn)
```

For example, call the isNaN static method on the java.lang.Double class.

```
java.lang.Double.isNaN(2.2)
```

Alternatively, you can apply static method names to instances of a class. In this example, the isNaN static method is referenced in relation to the dblObject instance of the java.lang.Double class.

```
dblObject = java.lang.Double(2.2);

dblObject.isNaN
ans =
     0
```

Several of the programming examples in this chapter contain examples of static method invocation. For example, the code for Communicating Through a Serial Port contains a call to static method getPortIdentifier on Java class javax.comm.CommPortIdentifier.

```
commPort =
javax.comm.CommPortIdentifier.getPortIdentifier('COM1');
```

Using the javaMethod Function on Static Methods

The javaMethod function was introduced in section “Using the javaMethod Function on Nonstatic Methods” on page 5-19. You can also use this function to call static methods.

The following syntax invokes the static method, method_name, in class, class_name, with the argument list that matches x1,...,xn. This returns the value X.

```
X = javaMethod('method_name','class_name',x1,...,xn);
```

For example, to call the static isNaN method of the java.lang.Double class on a double value of 2.2, you use

```
javaMethod('isNaN','java.lang.Double',2.2);
```

Using the javaMethod function to call static methods enables you to:

- Use methods that have names that exceed the maximum length of a MATLAB identifier. (Call the namelengthmax function to obtain the maximum identifier length.)
- Specify method and class names at run-time, for example, as input from an application user

Obtaining Information About Methods

MATLAB offers several functions to help obtain information related to the Java methods you are working with. You can request a list of all of the methods that are implemented by any class. The list may be accompanied by other method information such as argument types and exceptions. You can also request a listing of every Java class that you loaded into MATLAB that implements a specified method.

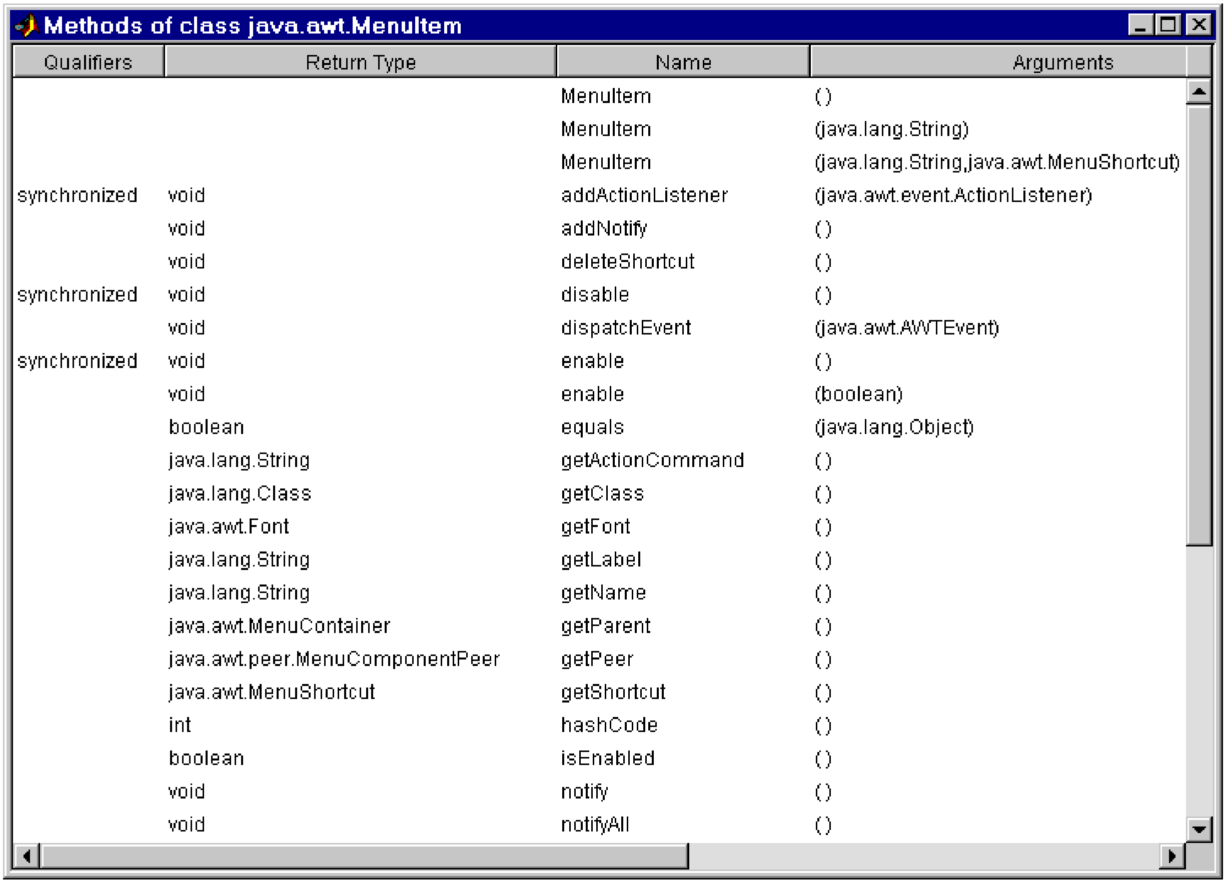
Methodsview: Displaying a Listing of Java Methods

If you want to know what methods are implemented by a particular Java (or MATLAB) class, use the methodsview function in MATLAB. Specify the class name (along with its package name, for Java classes) in the command line. If you have imported the package that defines this class, then the class name alone will suffice.

The following command lists information on all methods in the `java.awt.MenuItem` class.

```
methodsview java.awt.MenuItem
```

A new window appears, listing one row of information for each method in the class. This is what the `methodsview` display looks like. The fieldnames shown at the top of the window are described following the figure.


Methods of class java.awt.MenuItem

Qualifiers	Return Type	Name	Arguments
		MenuItem	()
		MenuItem	(java.lang.String)
		MenuItem	(java.lang.String,java.awt.MenuShortcut)
synchronized	void	addActionListener	(java.awt.event.ActionListener)
	void	addNotify	()
	void	deleteShortcut	()
synchronized	void	disable	()
	void	dispatchEvent	(java.awt.AWTEvent)
synchronized	void	enable	()
	void	enable	(boolean)
	boolean	equals	(java.lang.Object)
	java.lang.String	getActionCommand	()
	java.lang.Class	getClass	()
	java.awt.Font	getFont	()
	java.lang.String	getLabel	()
	java.lang.String	getName	()
	java.awt.MenuContainer	getParent	()
	java.awt.peer.MenuComponentPeer	getPeer	()
	java.awt.MenuShortcut	getShortcut	()
	int	hashCode	()
	boolean	isEnabled	()
	void	notify	()
	void	notifyAll	()

Each row in the window displays up to six fields of information describing the method. The table below lists the fields displayed in the `methodsview` window along with a description and examples of each field type.

Table 5-1: Fields Displayed in the Methodsview Window

Field Name	Description	Examples
Qualifiers	Method type qualifiers	abstract, synchronized
Return Type	Data type returned by the method	`void`, `java.lang.String`
Name	Method name	`addActionListener`, `dispatchEvent`
Arguments	Arguments passed to method	`boolean`, `java.lang.Object`
Other	Other relevant information	throws `java.io.IOException`
Parent	Parent of the specified class	`java.awt.MenuComponent`

Using the Methods Function on Java Classes

In addition to `methodsview`, the MATLAB `methods` function, that returns information on methods of MATLAB classes, will also work on Java classes. You can use any of the following forms of this command.

```
methods class_name
methods class_name -full
n = methods('class_name')
n = methods('class_name','-full')
```

Use `methods` without the `'-full'` qualifier to return the names of all the methods (including inherited methods) of the class. Names of overloaded methods are listed only once.

With the `'-full'` qualifier, `methods` returns a listing of the method names (including inherited methods) along with attributes, argument lists, and inheritance information on each. Each overloaded method is listed separately.

For example, display a full description of all methods of the `java.awt.Dimension` object.

```
methods java.awt.Dimension -full

Methods for class java.awt.Dimension:
Dimension()
Dimension(java.awt.Dimension)
Dimension(int,int)
java.lang.Class getClass()  % Inherited from java.lang.Object
int hashCode()  % Inherited from java.lang.Object
boolean equals(java.lang.Object)
java.lang.String toString()
void notify()  % Inherited from java.lang.Object
void notifyAll()  % Inherited from java.lang.Object
void wait(long) throws java.lang.InterruptedException
   % Inherited from java.lang.Object
void wait(long,int) throws java.lang.InterruptedException
   % Inherited from java.lang.Object
void wait() throws java.lang.InterruptedException
   % Inherited from java.lang.Object
java.awt.Dimension getSize()
void setSize(java.awt.Dimension)
void setSize(int,int)
```

Determining What Classes Define a Method

You can use the `which` function to display the fully qualified name (package and class name) of a method implemented by a *loaded* Java class. With the `-all` qualifier, the `which` function finds all classes with a method of the name specified.

Suppose, for example, that you want to find the package and class name for the `concat` method, with the `String` class currently loaded. Use the command

```
which concat
java.lang.String.concat  % String method
```

If the `java.lang.String` class has not been loaded, the same `which` command would give the output

```
which concat
concat not found.
```

If you use `which -all` for the method `equals`, with the `String` and `java.awt.Frame` classes loaded, you see the following display.

```
which -all equals
java.lang.String.equals                      % String method
java.awt.Frame.equals                        % Frame method
com.mathworks.ide.desktop.MLDesktop.equals   % MLDesktop method
```

The `which` function operates differently on Java classes than it does on MATLAB classes. MATLAB classes are always displayed by `which`, whether or not they are loaded. This is not true for Java classes. You can find out which Java classes are currently loaded by using the command `[m,x,j]=inmem`, described in “Determining Which Classes Are Loaded” on page 5-7.

For a description of how Java classes are loaded, see “Making Java Classes Available to MATLAB” on page 5-5.

Java Methods That Affect MATLAB Commands

MATLAB commands that operate on Java objects and arrays make use of the methods that are implemented within, or inherited by, these objects’ classes. There are some MATLAB commands that you can alter somewhat in behavior by changing the Java methods that they rely on.

Changing the Effect of disp and display

You can use the `disp` function to display the value of a variable or an expression in MATLAB. Terminating a command line without a semicolon also calls the `disp` function. You can also use `disp` to display a Java object in MATLAB.

When `disp` operates on a Java object, MATLAB formats the output using the `toString` method of the class to which the object belongs. If the class does not implement this method, then an inherited `toString` method is used. If no intermediate ancestor classes define this method, it uses the `toString` method defined by the `java.lang.Object` class. You can override inherited `toString` methods in classes that you create by implementing such a method within your class definition. In this way, you can change the way MATLAB displays information regarding the objects of the class.

Changing the Effect of isequal

The MATLAB `isequal` function compares two or more arrays for equality in type, size, and contents. This function can also be used to test Java objects for equality.

When you compare two Java objects using `isequal`, MATLAB performs the comparison using the Java method, `equals`. MATLAB first determines the class of the objects specified in the command, and then uses the `equals` method implemented by that class. If it is not implemented in this class, then an inherited `equals` method is used. This will be the `equals` method defined by the `java.lang.Object` class if no intermediate ancestor classes define this method.

You can override inherited `equals` methods in classes that you create by implementing such a method within your class definition. In this way, you can change the way MATLAB performs comparison of the members of this class.

Changing the Effect of double and char

You can also define your own Java methods `toDouble` and `toChar` to change the output of the MATLAB `double` and `char` functions. For more information, see the sections entitled "Converting to the MATLAB double Data Type" and "Converting to the MATLAB char Data Type" on page 5-58.

How MATLAB Handles Undefined Methods

If your MATLAB command invokes a nonexistent method on a Java object, MATLAB looks for a built-in function with the same name. If MATLAB finds a built-in function of that name, it attempts to invoke it. If MATLAB does not find a function with that name, it displays a message stating that it cannot find a method by that name for the class.

For example, MATLAB has a built-in method named `size`, and the Java API `java.awt.Frame` class also has a `size` method. If you call `size` on a `Frame` object, the `size` method defined by `java.awt.Frame` is executed. However, if you call `size` on an object of `java.lang.String`, MATLAB does not find a `size` method for this class. It executes the MATLAB `size` built-in instead.

```
string = java.lang.String('hello');

size(string)
ans =
     1     1
```

Note When you define a Java class for use in MATLAB, avoid giving any of its methods the same name as a MATLAB built-in function.

How MATLAB Handles Java Exceptions

If invoking a Java method or constructor throws an exception, MATLAB catches the exception and transforms it into a MATLAB error. MATLAB puts the text of the Java error message into its own error message. Receiving an error from a Java method or constructor has the same appearance as receiving an error from an M-file.

Working with Java Arrays

You can pass singular Java objects to and from methods or you may pass them in an array, providing the method expects them in that form. This array must either be a Java array (returned from another method call or created within MATLAB) or, under certain circumstances, a MATLAB cell array. This section describes how to create and manipulate Java arrays in MATLAB. Later sections will describe how to use MATLAB cell arrays in calls to Java methods.

Note The term *dimension* here refers more to the number of subscripts required to address the elements of an array than to its length, width, and height characteristics. For example, a 5-by-1 array is referred to as being one-dimensional, as its individual elements can be indexed into using only one array subscript.

This section addresses the following topics:

- "How MATLAB Represents the Java Array"
- "Creating an Array of Objects Within MATLAB"
- "Accessing Elements of a Java Array"
- "Assigning to a Java Array"
- "Concatenating Java Arrays"
- "Creating a New Array Reference"
- "Creating a Copy of a Java Array"

How MATLAB Represents the Java Array

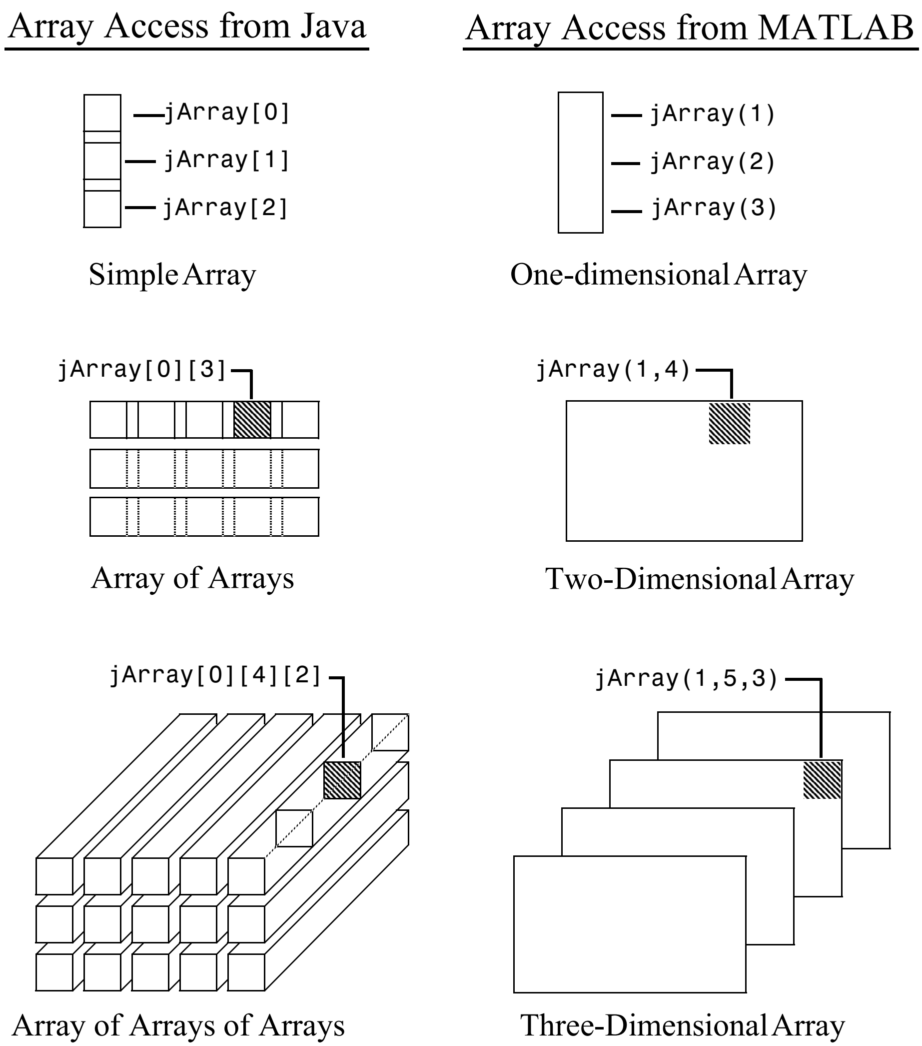
The term *java array* refers to any array of Java objects returned from a call to a Java class constructor or method. You may also construct a Java array within MATLAB using the `javaArray` function. The structure of a Java array is significantly different from that of a MATLAB matrix or array. MATLAB *hides* these differences whenever possible, allowing you to operate on the arrays using the usual MATLAB command syntax. Just the same, it may be helpful to keep the following differences in mind as you work with Java arrays.

Representing More Than One Dimension

An array in the Java language is strictly a one-dimensional structure because it is measured only in length. If you want to work with a two-dimensional array, you can create an equivalent structure using an array of arrays. To add further dimensions, you add more levels to the array, making it an array of arrays of arrays, and so on. You may want to use such multilevel arrays when working in MATLAB as it is a matrix and array-based programming language.

MATLAB makes it easy for you to work with multilevel Java arrays by treating them like the matrices and multidimensional arrays that are a part of the language itself. You access elements of an array of arrays using the same MATLAB syntax that you would use if you were handling a matrix. If you were to add more levels to the array, MATLAB would be able to access and operate on the structure as if it were a multidimensional MATLAB array.

The left side of the following figure shows Java arrays of one, two, and three dimensions. To the right of each is the way the same array is represented to you in MATLAB. Note that single-dimension arrays are represented as a column vector.


Array Access from Java
Array Access from MATLAB
jArray[0]
jArray[1]
jArray[2]
Simple Array
jArray(1)
jArray(2)
jArray(3)
One-dimensional Array
jArray[0][3]
Array of Arrays
jArray(1,4)
Two-Dimensional Array
jArray[0][4][2]
Array of Arrays of Arrays
jArray(1,5,3)
Three-Dimensional Array

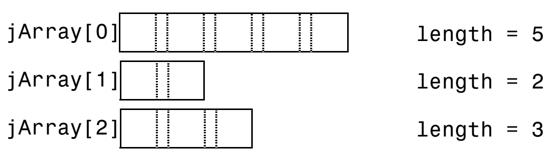
Array Indexing

Java array indexing is different than MATLAB array indexing. Java array indices are zero-based, MATLAB array indices are one-based. In Java programming, you access the elements of array `y` of length `N` using `y[0]` through `y[N-1]`. When working with this array in MATLAB, you access these same elements using the MATLAB indexing style of `y(1)` through `y(N)`. Thus, if you have a Java array of 10 elements, the seventh element is obtained using `y(7)`, and not `y[6]` as you would have used when writing a program in Java.

The Shape of the Java Array

A Java array can be different from a MATLAB array in its overall *shape*. A two-dimensional MATLAB array maintains a rectangular shape, as each row is of equal length and each column of equal height. The Java counterpart of this, an array of arrays, does not necessarily hold to this rectangular form. Each individual lower level array may have a different length.

Such an array structure is pictured below. This is an array of three underlying arrays of different lengths. The term *ragged* is commonly used to describe this arrangement of array elements as the array ends do not match up evenly. When a Java method returns an array with this type of structure, it is stored in a cell array by MATLAB.

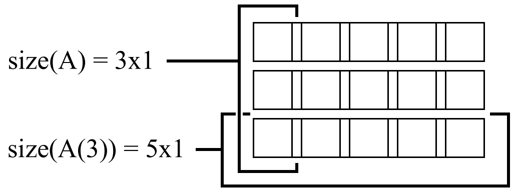


Interpreting the Size of a Java Array

When the MATLAB `size` function is applied to a simple Java array, the number of rows returned is the length of the Java array and the number of columns is always 1.

Determining the size of a Java array of arrays is not so simple. The potentially ragged shape of an array returned from Java makes it impossible to size the array in the same way as for a rectangular matrix. In a ragged Java array, there is no one value that represents the size of the lower level arrays.

When the `size` function is applied to a Java array of arrays, the resulting value describes the top level of the specified array. For the Java array shown here



`size(A)` returns the dimensions of the highest array level of A. The highest level of the array has a size of 3-by-1.

```
size(A)
ans =
     3     1
```

To find the size of a lower level array, say the five-element array in row 3, refer to the row explicitly.

```
size(A(3))
ans =
     5     1
```

You can specify a dimension in the `size` command using the following syntax. However, you will probably find this useful only for sizing the first dimension, `dim=1`, as this will be the only non-unary dimension.

```
m = size(X,dim)

size(A, 1)
ans =
     3
```

Interpreting the Number of Dimensions of a Java Arrays

For Java arrays, whether they are simple one-level arrays or multilevel, the MATLAB `ndims` function always returns a value of 2 to indicate the number of dimensions in the array. This is a measure of the number of dimensions in the top-level array which will always be equal to 2.

Creating an Array of Objects Within MATLAB

To call a Java method that has one or more arguments defined as an array of Java objects, you must, under most circumstances, pass your objects in a Java array. You can construct an array of objects in a call to a Java method or constructor. Or you can create the array within MATLAB.

The MATLAB `javaArray` function lets you create a Java array structure that can be handled in MATLAB as a single multidimensional array. You specify the number and size of the array dimensions along with the class of objects you intend to store in it. Using the one-dimensional Java array as its primary building block, MATLAB then builds an array structure that satisfies the dimensions requested in the `javaArray` command.

Using the javaArray Function

To create a Java object array, use the MATLAB `javaArray` function, which has the following syntax.

```
A = javaArray('element_class', m, n, p, ...)
```

The first argument is the '`element_class`' string, which names the class of the elements in the array. You must specify the fully qualified name (package and class name). The remaining arguments (`m, n, p, ...`) are the number of elements in each dimension of the array.

An array that you create with `javaArray` is equivalent to the array that you would create with the Java code.

```
A = new element_class[m][n][p]...;
```

The following command builds a Java array of four lower level arrays, each capable of holding five objects of the `java.lang.Double` class. (You will probably be more likely to use primitive types of `double` than instances of the `java.lang.Double` class, but in this context, it affords us a simple example.)

```
dblArray = javaArray('java.lang.Double', 4, 5);
```

The `javaArray` function does not deposit any values into the array elements that it creates. You must do this separately. The following MATLAB code stores objects of the `java.lang.Double` type in the Java array `dblArray` that was just created.

```
for m = 1:4
    for n = 1:5
    dblArray(m,n) = java.lang.Double((m*10) + n);
    end
end

dblArray
dblArray =
java.lang.Double[][]:
    [11]    [12]    [13]    [14]    [15]
    [21]    [22]    [23]    [24]    [25]
    [31]    [32]    [33]    [34]    [35]
    [41]    [42]    [43]    [44]    [45]
```

Another Way to Create a Java Array

You can also create an array of Java objects using syntax that is more typical to MATLAB. For example, the following syntax creates a 4-by-5 MATLAB array of type double and assigns zero to each element of the array.

```
matlabArray(4,5) = 0;
```

You use similar syntax to create a Java array in MATLAB, except that you must specify the Java class name. The value being assigned, `0` in this example, is stored in the final element of the array, javaArray`(4,5)`. All other elements of the array receive the empty matrix.

```
javaArray(4,5) = java.lang.Double(0)
javaArray =
java.lang.Double[][]:
     []     []     []     []      []
     []     []     []     []      []
     []     []     []     []      []
     []     []     []     []     [0]
```

Note You cannot change the dimensions of an existing Java array as you can with a MATLAB array. The same restriction exists when working with Java arrays in the Java language. See the example below.

This example first creates a scalar MATLAB array, and then successfully modifies it to be two-dimensional.

```
matlabArray = 0;
matlabArray(4,5) = 0

matlabArray =

     0     0     0     0     0
     0     0     0     0     0
     0     0     0     0     0
     0     0     0     0     0
```

When you try this with a Java array, you get an error. Similarly, you cannot create an array of Java arrays from a Java array, and so forth.

```
javaArray = java.lang.Double(0);
javaArray(4,5) = java.lang.Double(0);
??? Index exceeds Java array dimensions.
```

Accessing Elements of a Java Array

You can access elements of a Java object array by using the MATLAB array indexing syntax, `A(row,col)`. For example, to access the element of array `dblArray` located at row 3, column 4, use

```
row3_col4 = dblArray(3,4)
row3_col4 =
34.0
```

In Java, this would be `dblArray[2][3]`.

You can also use MATLAB array indexing syntax to access an element in an object's data field. Suppose that `myMenuObj` is an instance of a window menu class. This user-supplied class has a data field, `menuItemArray`, which is a Java array of `java.awt.menuItem`. To get element `3` of this array, use the following command.

```
currentItem = myMenuObj.menuItemArray(3)
```

Using Single Subscript Indexing to Access Arrays

Elements of a MATLAB matrix are most commonly referenced using both row and column subscripts. For example, you use `x(3,4)` to reference the array element at the intersection of row 3 and column 4. Sometimes it is more advantageous to use just a single subscript. MATLAB provides this capability (see the section on “Advanced Indexing” in the *Using MATLAB* manual).

Indexing into a MATLAB matrix using a single subscript references one element of the matrix. Using the MATLAB matrix shown here, `matlabArray(3)` returns a single element of the matrix.

```
matlabArray = [11 12 13 14 15; 21 22 23 24 25; ...
               31 32 33 34 35; 41 42 43 44 45]
matlabArray =
    11    12    13    14    15
    21    22    23    24    25
    31    32    33    34    35
    41    42    43    44    45

matlabArray(3)
ans =
    31
```

Indexing this way into a Java array of arrays references an entire subarray of the overall structure. Using the `dblArray` Java array, that looks the same as `matlabArray` shown above, `dblArray(3)` returns the 5-by-1 array that makes up the entire third row.

```
row3 = dblArray(3)
row3 =
java.lang.Double[]:
    [31]
    [32]
    [33]
    [34]
    [35]
```

This is a useful feature of MATLAB as it allows you to specify an entire array from a larger array structure, and then manipulate it as an object.

Using the Colon Operator

Use of the MATLAB `colon` operator (`:`) is supported in subscripting Java array references. This operator works just the same as when referencing the contents of a MATLAB array. Using the Java array of `java.lang.Double` objects shown here, the statement `dblArray(2,2:4)` refers to a portion of the lower level array, `dblArray(2)`. A new array, `row2Array`, is created from the elements in columns 2 through 4.

```
dblArray
dblArray =
java.lang.Double[][]:
    [11]    [12]    [13]    [14]    [15]
    [21]    [22]    [23]    [24]    [25]
    [31]    [32]    [33]    [34]    [35]
    [41]    [42]    [43]    [44]    [45]

row2Array = dblArray(2,2:4)
row2Array =
java.lang.Double[]:
    [22]
    [23]
    [24]
```

You also can use the colon operator in single-subscript indexing, as covered in "Using Single Subscript Indexing to Access Arrays" on page 5-35. By making your subscript a colon rather than a number, you can convert an array of arrays into one linear array. The following example converts the 4-by-5 array `dblArray` into a 20-by-1 linear array.

```
linearArray = dblArray(:)
linearArray =
java.lang.Double[]:
    [11]
    [12]
    [13]
    [14]
    [15]
    [21]
    [22]
     .
     .
     .
```

This works the same way on an N-dimensional Java array structure. Using the colon operator as a single subscripted index into the array produces a linear array composed of all of the elements of the original array.

Note Java and MATLAB arrays are stored differently in memory. This is reflected in the order they are given in a linear array. Java array elements are stored in an order that matches the *rows* of the matrix, (`11, 12, 13, ...` in the array shown above). MATLAB array elements are stored in an order that matches the *columns*, (`11, 21, 31, ...`).

Using END in a Subscript

You can use the `end` keyword in the first subscript of an access statement. The first subscript references the top-level array in a multilevel Java array structure.

Note Using `end` on lower level arrays is not valid due to the potentially ragged nature of these arrays (see "The Shape of the Java Array" on page 5-31). In this case, there is no consistent end value to be derived.

The following example displays data from the third to the last row of Java array `dblArray`.

```
last2rows = dblArray(3:end, :)
last2rows =
java.lang.Double[][]:
    [31]    [32]    [33]    [34]    [35]
    [41]    [42]    [43]    [44]    [45]
```

Assigning to a Java Array

You assign values to objects in a Java array in essentially the same way as you do in a MATLAB array. Although Java and MATLAB arrays are structured quite differently, you use the same command syntax to specify which elements you want to assign to. See "How MATLAB Represents the Java Array" on page 5-29 for more information on Java and MATLAB array differences.

The following example deposits the value 300 in the dblArray element at row 3, column 2. In Java, this would be dblArray[2][1].

```
dblArray(3,2) = java.lang.Double(300)
dblArray =
java.lang.Double[][]:
    [11]    [ 12]    [13]    [14]    [15]
    [21]    [ 22]    [23]    [24]    [25]
    [31]    [300]    [33]    [34]    [35]
    [41]    [ 42]    [43]    [44]    [45]
```

You use the same syntax to assign to an element in an object's data field. Continuing with the myMenuObj example shown in "Accessing Elements of a Java Array" on page 5-35, you assign to the third menu item in menuItemArray as follows.

```
myMenuObj.menuItemArray(3) = java.lang.String('Save As...');
```

Using Single Subscript Indexing for Array Assignment

You can use a single-array subscript to index into a Java array structure that has more than one dimension. Refer to "Using Single Subscript Indexing to Access Arrays" on page 5-35 for a description of this feature as used with Java arrays.

You can use single-subscript indexing to assign values to an array as well. The example below assigns a one-dimensional Java array, onedimArray, to a row of a two-dimensional Java array, dblArray. Start out by creating the one-dimensional array.

```
onedimArray = javaArray('java.lang.Double', 5);
for k = 1:5
    onedimArray(k) = java.lang.Double(100 * k);
    end
```

Since dblArray(3) refers to the 5-by-1 array displayed in the third row of dblArray, you can assign the entire, similarly dimensioned, 5-by-1 onedimArray to it.

```
dblArray(3) = onedimArray
dblArray =
java.lang.Double[][]:
    [ 11]    [ 12]    [ 13]    [ 14]    [ 15]
    [ 21]    [ 22]    [ 23]    [ 24]    [ 25]
    [100]    [200]    [300]    [400]    [500]
    [ 41]    [ 42]    [ 43]    [ 44]    [ 45]
```

Assigning to a Linear Array

You can assign a value to *every* element of a multidimensional Java array by treating the array structure as if it were a single linear array. This entails replacing the single, numerical subscript with the MATLAB colon operator. If you start with the `dblArray` array, you can initialize the contents of every object in the two-dimensional array with the following statement.

```
dblArray(:) = java.lang.Double(0)
dblArray =
java.lang.Double[][]:
    [0]    [0]    [0]    [0]    [0]
    [0]    [0]    [0]    [0]    [0]
    [0]    [0]    [0]    [0]    [0]
    [0]    [0]    [0]    [0]    [0]
```

Using the Colon Operator

You can use the MATLAB colon operator as you would when working with MATLAB arrays. The statements below assign given values to each of the four rows in the Java array, `dblArray`. Remember that each row actually represents a separate Java array in itself.

```
dblArray(1,:) = java.lang.Double(125);
dblArray(2,:) = java.lang.Double(250);
dblArray(3,:) = java.lang.Double(375);
dblArray(4,:) = java.lang.Double(500)
dblArray =
java.lang.Double[][]:
    [125]    [125]    [125]    [125]    [125]
    [250]    [250]    [250]    [250]    [250]
    [375]    [375]    [375]    [375]    [375]
    [500]    [500]    [500]    [500]    [500]
```

Assigning the Empty Matrix

When working with MATLAB arrays, you can assign the empty matrix, (i.e., the 0-by-0 array denoted by []) to an element of the array. For Java arrays, you can also assign [] to array elements. This stores the `NULL` value, rather than a 0-by-0 array, in the Java array element.

Subscripted Deletion

When you assign the empty matrix value to an entire row or column of a MATLAB array, you find that MATLAB actually removes the affected row or column from the array. In the example below, the empty matrix is assigned to all elements of the fourth column in the MATLAB matrix, `matlabArray`. Thus, the fourth column is completely eliminated from the matrix. This changes its dimensions from 4-by-5 to 4-by-4.

```
matlabArray = [11 12 13 14 15; 21 22 23 24 25; ...
               31 32 33 34 35; 41 42 43 44 45]
matlabArray =
    11    12    13    14    15
    21    22    23    24    25
    31    32    33    34    35
    41    42    43    44    45

matlabArray(:,4) = []
matlabArray =
    11    12    13    15
    21    22    23    25
    31    32    33    35
    41    42    43    45
```

You can assign the empty matrix to a Java array, but the effect will be different. The next example shows that, when the same operation is performed on a Java array, the structure is not collapsed; it maintains its 4-by-5 dimensions.

```
dblArray(:,4) = []
dblArray =
java.lang.Double[][]:
    [125]    [125]    [125]     []    [125]
    [250]    [250]    [250]     []    [250]
    [375]    [375]    [375]     []    [375]
    [500]    [500]    [500]     []    [500]
```

The dblArray data structure s actually an array of five-element arrays of java.lang.Double objects. The empty array assignment placed the NULL value in the fourth element of each of the lower level arrays.

Concatenating Java Arrays

You can concatenate arrays of Java objects in the same way as arrays of other data types. (To understand how scalar Java objects are concatenated by MATLAB see "Concatenating Java Objects" on page 5-11.)

Use either the cat function or the square bracket ([]) operators. This example horizontally concatenates two Java arrays: d1, and d2.

```
% Construct a 2-by-3 array of java.lang.Double.
d1 = javaArray('java.lang.Double',2,3);
for m = 1:3     for n = 1:3
d1(m,n) = java.lang.Double(n*2 + m-1);
end;            end;

d1
d1 =
java.lang.Double[][]:
    [2]    [4]    [6]
    [3]    [5]    [7]
    [4]    [6]    [8]

% Construct a 2-by-2 array of java.lang.Double.
d2 = javaArray('java.lang.Double',2,2);
for m = 1:3     for n = 1:2
d2(m,n) = java.lang.Double((n+3)*2 + m-1);
end;            end;
```

```
d2
d2 =
java.lang.Double[][]:
    [ 8]    [10]
    [ 9]    [11]
    [10]    [12]

% Concatenate the two along the second dimension.
d3 = cat(2,d1,d2)
d3 =
java.lang.Double[][]:
    [2]    [4]    [6]    [ 8]    [10]
    [3]    [5]    [7]    [ 9]    [11]
    [4]    [6]    [8]    [10]    [12]
```

Creating a New Array Reference

Because Java arrays in MATLAB are *references*, assigning an array variable to another variable results in a second reference to the array.

Consider the following example where two separate array variables reference a common array. The original array, `origArray`, is created and initialized. The statement `newArrayRef = origArray` creates a copy of this array variable. Changes made to the array referred to by `newArrayRef` also show up in the original array.

```
origArray = javaArray('java.lang.Double', 3, 4);
for m = 1:3
   for n = 1:4
      origArray(m,n) = java.lang.Double((m * 10) + n);
   end
end

origArray
origArray =
java.lang.Double[][]:
    [11]    [12]    [13]    [14]
    [21]    [22]    [23]    [24]
    [31]    [32]    [33]    [34]
```

```
%  ----- Make a copy of the array reference -----
newArrayRef = origArray;
newArrayRef(3,:) = java.lang.Double(0);

origArray
origArray =
java.lang.Double[][]:
    [11]    [12]    [13]    [14]
    [21]    [22]    [23]    [24]
    [ 0]    [ 0]    [ 0]    [ 0]
```

Creating a Copy of a Java Array

You can create an entirely new array from an existing Java array by indexing into the array to describe a block of elements, (or subarray), and assigning this subarray to a variable. The assignment copies the values in the original array to the corresponding cells of the new array.

As with the example in section "Creating a New Array Reference" on page 5-43, an original array is created and initialized. But, this time, a copy is made of the array contents rather than copying the array reference. Changes made using the reference to the new array do not affect the original.

```
origArray = javaArray('java.lang.Double', 3, 4);
for m = 1:3
   for n = 1:4
      origArray(m,n) = java.lang.Double((m * 10) + n);
   end
end

origArray
origArray =
java.lang.Double[][]:
    [11]    [12]    [13]    [14]
    [21]    [22]    [23]    [24]
    [31]    [32]    [33]    [34]
```

```
%  ----- Make a copy of the array contents -----
newArray = origArray(:,:);
newArray(3,:) = java.lang.Double(0);

origArray
origArray =
java.lang.Double[][]:
    [11]    [12]    [13]    [14]
    [21]    [22]    [23]    [24]
    [31]    [32]    [33]    [34]
```

Passing Data to a Java Method

When you make a call from MATLAB to Java code, any MATLAB data types you pass in the call are converted to data types native to the Java language. MATLAB performs this conversion on each argument that is passed, except for those arguments that are already Java objects. This section describes the conversion that is performed on specific MATLAB data types and, at the end, also takes a look at how argument types affect calls made to overloaded methods.

If data is to be returned by the method being called, MATLAB receives this data and converts it to the appropriate MATLAB format wherever necessary. This process is covered in the next section entitled "Handling Data Returned from a Java Method" on page 5-56.

This section addresses the following topics:

- "Conversion of MATLAB Argument Data"
- "Passing Built-In Data Types"
- "Passing String Arguments"
- "Passing Java Objects"
- "Other Data Conversion Topics"
- "Passing Data to Overloaded Methods"

Conversion of MATLAB Argument Data

MATLAB data, passed as arguments to Java methods, are converted by MATLAB into data types that best represent the data to the Java language. The table below shows all of the MATLAB base types for passed arguments and the Java base types defined for input arguments. Each row shows a MATLAB type followed by the possible Java argument matches, from left to right in order of closeness of the match. The MATLAB types (except cell arrays) can all be scalar (1-by-1) arrays or matrices. All of the Java types can be scalar values or arrays.

Table 5-2: Conversion of MATLAB Types to Java Types

MATLAB Argument	Closest Type (7)	Java Input Argument (Scalar or Array)					Least Close Type (1)
double (logical)	boolean	byte	short	int	long	float	double
double	double	float	long	int	short	byte	boolean
single	float	double					
char	String	char					
uint8	byte	short	int	long	float	double	
uint16	short	int	long	float	double		
uint32	int	long	float	double			
int8	byte	short	int	long	float	double	
int16	short	int	long	float	double		
int32	int	long	float	double			
cell array of strings	array of String						
Java object	Object						
cell array of object	array of Object						

Data type conversion of arguments passed to Java code will be discussed in the following three categories. MATLAB handles each category differently.

- "Passing Built-In Data Types"
- "Passing String Arguments"
- "Passing Java Objects"

Passing Built-In Data Types

Java has eight data types that are intrinsic to the language and are not represented as Java objects. These are often referred to as *built-in*, or *elemental*, data types and they include `boolean`, `byte`, `short`, `long`, `int`, `double`, `float`, and `char`. MATLAB converts its own data types to these Java built-in types according to the table, "Conversion of MATLAB Types to Java Types" on page 5-47. Built-in types are in the first 10 rows of the table.

When a Java method you are calling expects one of these data types, you can pass it the type of MATLAB argument shown in the left-most column of the table. If the method takes an array of one of these types, you can pass a MATLAB array of the data type. MATLAB converts the data type of the argument to the type assigned in the method declaration.

The MATLAB code shown below creates a top-level window frame and sets its dimensions. The call to `setBounds` passes four MATLAB scalars of the `double` type to the inherited Java Frame method, `setBounds`, that takes four arguments of the `int` type. MATLAB converts each 64-bit double data type to a 32-bit integer prior to making the call. Shown here is the `setBounds` method declaration followed by the MATLAB code that calls the method.

```
public void setBounds(int x, int y, int width, int height)

frame=java.awt.Frame;
frame.setBounds(200,200,800,400);
frame.setVisible(1);
```

Passing Built-In Types in an Array

To call a Java method with an argument defined as an *array* of a built-in type, you can create and pass a MATLAB matrix with a compatible base type. The following code defines a polygon by sending four `x` and `y` coordinates to the Polygon constructor. Two 1-by-4 MATLAB arrays of `double` are passed to `java.awt.Polygon`, which expects `integer` arrays in the first two arguments. Shown here is the Java method declaration followed by MATLAB code that calls the method, and then verifies the set coordinates.

```
public Polygon(int xpoints[], int ypoints[], int npoints)

poly = java.awt.Polygon([14 42 98 124], [55 12 -2 62], 4);
```

```
[poly.xpoints poly.ypoints]       % Verify the coordinates
ans =
14      55
42      12
98     -2
124     62
```

MATLAB Arrays Are Passed by Value

Since MATLAB arrays are passed by value, any changes that a Java method makes to them will not be visible to your MATLAB code. If you need to access changes that a Java method makes to an array, then, rather than passing a MATLAB array, you should create and pass a Java array, which is a reference. For a description of using Java arrays in MATLAB, see "Working with Java Arrays" on page 5-28.

Note Generally, it is preferable to have methods return data that has been modified using the return argument mechanism as opposed to passing a reference to that data in an argument list.

Passing String Arguments

To call a Java method that has an argument defined as an object of class `java.lang.String`, you can pass either a `String` object that was returned from an earlier Java call or a MATLAB 1-by-n character array. If you pass the character array, MATLAB converts the array to a Java object of `java.lang.String` for you.

For a programming example, see "Example – Reading a URL" on page 5-63. This shows a MATLAB character array that holds a URL being passed to the Java `URL` class constructor. The constructor, shown below, expects a Java String argument.

```
public URL(String spec) throws MalformedURLException
```

In the MATLAB call to this constructor, a character array specifying the URL is passed. MATLAB converts this array to a Java String object prior to calling the constructor.

```
url = java.net.URL(...
     'http://archive.ncsa.uiuc.edu/demoweb/')
```

Passing Strings in an Array

When the method you are calling expects an argument of an array of type `String`, you can create such an array by packaging the strings together in a MATLAB cell array. The strings can be of varying lengths since you are storing them in different cells of the array. As part of the method call, MATLAB converts the cell array to a Java array of `String` objects.

In the following example, the `echoPrompts` method of a user-written class accepts a string array argument that MATLAB converted from its original format as a cell array of strings. The parameter list in the Java method appears as follows.

```
public String[] echoPrompts(String s[])
```

You create the input argument by storing both strings in a MATLAB cell array. MATLAB converts this structure to a Java array of `String`.

```
myaccount.echoPrompts({'Username: ','Password: '})
ans =
'Username: '
'Password: '
```

Passing Java Objects

When calling a method that has an argument belonging to a particular Java class, you must pass an object that is an instance of that class. In the example below, the `add` method belonging to the `java.awt.Menu` class requires, as an argument, an object of the `java.awt.MenuItem` class. The method declaration for this is

```
public MenuItem add(MenuItem mi)
```

The example operates on the frame created in the previous example in "Passing Built-In Data Types" on page 5-48. The second, third, and fourth lines of code shown here add items to a menu to be attached to the existing window frame.

In each of these calls to menu1.add, an object that is an instance of the java.awt.MenuItem Java class is passed.

```
menu1 = java.awt.Menu('File Options');
menu1.add(java.awt.MenuItem('New'));
menu1.add(java.awt.MenuItem('Open'));
menu1.add(java.awt.MenuItem('Save'));

menuBar=java.awt.MenuBar;
menuBar.add(menu1);
frame.setMenuBar(menuBar);
```

Handling Objects of Class java.lang.Object

A special case exists when the method being called takes an argument of the java.lang.Object class. Since this class is the root of the Java class hierarchy, you can pass objects of any class in the argument. The hash table example shown that follows, passes objects belonging to different classes to a common method, put, which expects an argument of java.lang.Object. The method declaration for put is

```
public synchronized Object put(Object key, Object value)
```

The following MATLAB code passes objects of different types (boolean, float, and string) to the put method.

```
hTable = java.util.Hashtable;
hTable.put(0, java.lang.Boolean('TRUE'));
hTable.put(1, java.lang.Float(41.287));
hTable.put(2, java.lang.String('test string'));

hTable                  % Verify hash table contents
hTable =
{1.0=41.287, 2.0=test string, 0.0=true}
```

When passing arguments to a method that takes java.lang.Object, it is not necessary to specify the class name for objects of a built-in data type. Line three, in the example above, specifies that 41.287 is an instance of class java.lang.Float. You can omit this and simply say, 41.287, as shown in the following example. Thus, MATLAB will create each object for you, choosing the closest matching Java object representation for each argument.

The three calls to put from the preceding example can be rewritten as

```
hTable.put(0, 1);
hTable.put(1, 41.287);
hTable.put(2, 'test string');
```

Passing Objects in an Array

The only types of Java object arrays that you can pass to Java methods are Java arrays and MATLAB cell arrays.

If the objects have already been placed into an array, either an array returned from a Java constructor or constructed in MATLAB by the javaArray function, then you simply pass it as is in the argument to the method being called. No conversion is done by MATLAB, as this is already a Java array.

If you have objects that are not already in a Java array, then MATLAB allows you to simply pass them in a MATLAB cell array. In this case, MATLAB converts the cell array to a Java array prior to passing the argument.

The following example shows the mapPoints method of a user-written class accepting an array of class java.awt.Point. The method declaration for this is

```
public Object mapPoints(java.awt.Point p[])
```

The MATLAB code shown below creates a 2-by-2 cell array containing four Java Point objects. When the cell array is passed to the mapPoints method, MATLAB converts it to a Java array of type java.awt.Point.

```
pointObj1 = java.awt.Point(25,143);
pointObj2 = java.awt.Point(31,147);
pointObj3 = java.awt.Point(49,151);
pointObj4 = java.awt.Point(52,176);

cellArray={pointObj1, pointObj2; pointObj3, pointObj4}
cellArray =
    [1x1 java.awt.Point]    [1x1 java.awt.Point]
    [1x1 java.awt.Point]    [1x1 java.awt.Point]

testData.mapPoints(cellArray);
```

Handling a Cell Array of Java Objects

You create a cell array of Java objects by using the MATLAB syntax {a1,a2,...}. You index into a cell array of Java objects in the usual way, with the syntax a{m,n,...}.

The following example creates a cell array of two Frame objects, frame1 and frame2, and assigns it to variable frames.

```
frame1 = java.awt.Frame('Frame A');
frame2 = java.awt.Frame('Frame B');

frameArray = {frame1, frame2}
frameArray =
[1x1 java.awt.Frame]    [1x1 java.awt.Frame]
```

The next statement assigns element {1,2} of the cell array frameArray to variable f.

```
f = frameArray {1,2}
f =
java.awt.Frame[frame2,0,0,0x0,invalid,hidden,layout =
java.awt.BorderLayout,resizable,title=Frame B]
```

Other Data Conversion Topics

There are several remaining items of interest regarding the way MATLAB converts its data to a compatible Java type. This includes how MATLAB matches array dimensions, and how it handles empty matrices and empty strings.

How Array Dimensions Affect Conversion

The term *dimension*, as used in this section, refers more to the number of subscripts required to address the elements of an array than to its length, width, and height characteristics. For example, a 5-by-1 array is referred to as having one dimension, as its individual elements can be indexed into using only one array subscript.

In converting MATLAB to Java arrays, MATLAB handles dimension in a special manner. For a MATLAB array, dimension can be considered as the number of nonsingleton dimensions in the array. For example, a 10-by-1 array has dimension 1, and a 1-by-1 array has dimension 0. In Java, dimension is determined solely by the number of nested arrays. For example, `double[][]` has dimension 2, and `double` has dimension 0.

If the Java array's number of dimensions exactly matches the MATLAB array's number of dimensions `n`, then the conversion results in a Java array with `n` dimensions. If the Java array has fewer than `n` dimensions, the conversion drops singleton dimensions, starting with the first one, until the number of remaining dimensions matches the number of dimensions in the Java array.

Empty Matrices and Nulls

The empty matrix is compatible with any method argument for which `NULL` is a legal value in Java. The empty string (`''`) in MATLAB translates into an empty (not `NULL`) `String` object in Java.

Passing Data to Overloaded Methods

When you invoke an overloaded method on a Java object, MATLAB determines which method to invoke by comparing the arguments your call passes to the arguments defined for the methods. Note that in this discussion, the term *method* includes constructors. When it determines the method to call, MATLAB converts the calling arguments to Java method types according to Java conversion rules, except for conversions involving objects or cell arrays. See "Passing Objects in an Array" on page 5-52.

How MATLAB Determines the Method to Call

When your MATLAB function calls a Java method, MATLAB:

1. Checks to make sure that the object (or class, for a static method) has a method by that name
2. Determines whether the invocation passes the same number of arguments of at least one method with that name
3. Makes sure that each passed argument can be converted to the Java type defined for the method

If all of the preceding conditions are satisfied, MATLAB calls the method.

In a call to an overloaded method, if there is more than one candidate, MATLAB selects the one with arguments that best fit the calling arguments.

First, MATLAB rejects all methods that have any argument types that are incompatible with the passed arguments (for example, if the method has a `double` argument and the passed argument is a `char`).

Among the remaining methods, MATLAB selects the one with the highest fitness value, which is the sum of the fitness values of all its arguments. The fitness value for each argument is the fitness of the base type minus the difference between the MATLAB array dimension and the Java array dimension. (Array dimensionality is explained in "How Array Dimensions Affect Conversion" on page 5-53.) If two methods have the same fitness, the first one defined in the Java class is chosen.

Example - Calling an Overloaded Method

Suppose a function constructs a `java.io.OutputStreamWriter` object, `osw`, and then invokes a method on the object.

```
osw.write('Test data', 0, 9);
```

MATLAB finds that the class `java.io.OutputStreamWriter` defines three `write` methods.

```
public void write(int c);
public void write(char[] cbuf, int off, int len);
public void write(String str, int off, int len);
```

MATLAB rejects the first `write` method, because it takes only one argument. Then, MATLAB assesses the fitness of the remaining two `write` methods. These differ only in their first argument, as explained below.

In the first of these two `write` methods, the first argument is defined with base type, `char`. The table, Conversion of MATLAB Types to Java Types, shows that for the type of the calling argument (MATLAB `char`), Java type, `char`, has a value of 6. There is no difference between the dimension of the calling argument and the Java argument. So the fitness value for the first argument is 6.

In the other `write` method, the first argument has Java type `String`, which has a fitness value of 7. The dimension of the Java argument is 0, so the difference between it and the calling argument dimension is 1. Therefore, the fitness value for the first argument is 6.

Because the fitness value of those two `write` methods is equal, MATLAB calls the one listed first in the class definition, with `char[]` first argument.

Handling Data Returned from a Java Method

In many cases, data returned from Java is incompatible with the data types operated on within MATLAB. When this is the case, MATLAB converts the returned value to a data type native to the MATLAB language. This section describes the conversion performed on the various data types that can be returned from a call to a Java method.

This section addresses the following topics:

- "Conversion of Java Return Data"
- "Built-In Data Types"
- "Java Objects"
- "Converting Objects to MATLAB Data Types"

Conversion of Java Return Data

The following table lists Java return types and the resulting MATLAB types. For some Java base return types, MATLAB treats scalar and array returns differently, as described following the table.

Table 5-3: Conversion of Java Types to MATLAB Types

Java Return Type	If Scalar Return, Resulting MATLAB Type	If Array Return, Resulting MATLAB Type
`boolean`	`double (logical)`	`double (logical)`
`byte`	`double`	`int8`
`short`	`double`	`int16`
`int`	`double`	`int32`
`long`	`double`	`double`
`float`	`double`	`single`
`double`	`double`	`double`
`char`	`char`	`char`

Built-In Data Types

Java *built-in* data types are described in "Passing Built-In Data Types" on page 5-48. Basically, this data type includes `boolean`, `byte`, `short`, `long`, `int`, `double`, `float`, and `char`. When the value returned from a method call is one of these Java built-in types, MATLAB converts it according to the table, "Conversion of Java Types to MATLAB Types" on page 5-56.

A single numeric or `boolean` value converts to a 1-by-1 matrix of `double`, which is convenient for use in MATLAB. An array of a numeric or `boolean` return values converts to an array of the closest base type, to minimize the required storage space. Array conversions are listed in the right-hand column of the table.

A return value of Java type `char` converts to a 1-by-1 matrix of `char`. And an array of Java `char` converts to a MATLAB array of that type.

Java Objects

When a method call returns Java objects, MATLAB leaves them in their original form. They remain as Java objects so you can continue to use them to interact with other Java methods.

The only exception to this is when the method returns data of type, `java.lang.Object`. This class is the root of the Java class hierarchy and is frequently used as a catchall for objects and arrays of various types. When the method being called returns a value of the `Object` class, MATLAB converts its value according to the table, "Conversion of Java Types to MATLAB Types" on page 5-56. That is, numeric and `boolean` objects such as `java.lang.Integer` or `java.lang.Boolean` convert to a 1-by-1 MATLAB matrix of `double`. Object arrays of these types convert to the MATLAB data types listed in the right-hand column of the table. Other object types are not converted.

Converting Objects to MATLAB Data Types

With the exception of objects of class `String` and class `Object`, MATLAB does not convert Java objects returned from method calls to a native MATLAB data type. If you want to convert Java object data to a form more readily usable in MATLAB, there are a few MATLAB functions that enable you to do this. These are described in the following sections.

Converting to the MATLAB double Data Type

Using the `double` function in MATLAB, you can convert any Java object or array of objects to the MATLAB `double` data type. The action taken by the `double` function depends on the class of the object you specify:

- If the object is an instance of a numeric class (`java.lang.Number` or one of the classes that inherit from that class), then MATLAB uses a preset conversion algorithm to convert the object to a MATLAB `double`.
- If the object is not an instance of a numeric class, MATLAB checks the class definition to see if it implements a method called `toDouble`. Note that MATLAB uses `toDouble` to perform its conversion of Java objects to the MATLAB `double` data type. If such a method is implemented for this class, MATLAB executes it to perform the conversion.
- If you are using a class of your own design, you can write your own `toDouble` method to perform conversions on objects of that class to a MATLAB `double`. This enables you to specify your own means of data type conversion for objects belonging to your own classes.

Note If the class of the specified object is not `java.lang.Number`, does not inherit from that `java.lang.Number`, and it does not implement a `toDouble` method, then an attempt to convert the object using the `double` function results in an error in MATLAB.

The syntax for the `double` command is as follows, where `object` is a Java object or Java array of objects.

```
double(object);
```

Converting to the MATLAB char Data Type

With the MATLAB `char` function, you can convert `java.lang.String` objects and arrays to MATLAB data types. A single `java.lang.String` object converts to a MATLAB character array. An array of `java.lang.String` objects converts to a MATLAB cell array, with each cell holding a character array.

If the object specified in the `char` command is not an instance of the `java.lang.String` class, then MATLAB checks its class to see if it implements a method named `toChar`. If this is the case, then MATLAB executes the `toChar` method of the class to perform the conversion. If you write your own class definitions, then you can make use of this feature by writing a toChar method that performs the conversion according to your own needs.

Note If the class of the specified object is not java.lang.String and it does not implement a toChar method, then an attempt to convert the object using the char function results in an error in MATLAB.

The syntax for the char command is as follows, where object is a Java object or Java array of objects.

```
char(object);
```

Converting to a MATLAB Structure

Java objects are similar to the MATLAB structure in that many of an object's characteristics are accessible via field names defined within the object. You may want to convert a Java object into a MATLAB structure to facilitate the handling of its data in MATLAB. Use the MATLAB struct function on the object to do this.

The syntax for the struct command is as follows, where object is a Java object or Java array of objects.

```
struct(object);
```

The following example converts a java.awt.Polygon object into a MATLAB structure. You can access the fields of the object directly using MATLAB structure operations. The last line indexes into the array, pstruct.xpoints, to deposit a new value into the third array element.

```
polygon = java.awt.Polygon([14 42 98 124], [55 12 -2 62], 4);

pstruct = struct(polygon)
pstruct =
    npoints: 4
    xpoints: [4x1 int32]
    ypoints: [4x1 int32]
```

```
pstruct.xpoints
ans =
    14
    42
    98
   124

pstruct.xpoints(3) = 101;
```

Converting to a MATLAB Cell Array

Use the `cell` function to convert a Java array or Java object into a MATLAB cell array. Elements of the resulting cell array will be of the MATLAB type (if any) closest to the Java array elements or Java object.

The syntax for the `cell` command is as follows, where `object` is a Java object or Java array of objects.

```
cell(object);
```

In the following example, a MATLAB cell array is created in which each cell holds an array of a different data type. The `cell` command used in the first line converts each type of object array into a cell array.

```
import java.lang.* java.awt.*;

% Create a Java array of double
dblArray = javaArray('java.lang.Double', 1, 10);
for m = 1:10
   dblArray(1, m) = Double(m * 7);
end

% Create a Java array of points
ptArray = javaArray('java.awt.Point', 3);
ptArray(1) = Point(7.1, 22);
ptArray(2) = Point(5.2, 35);
ptArray(3) = Point(3.1, 49);

% Create a Java array of strings
strArray = javaArray('java.lang.String', 2, 2);
strArray(1,1) = String('one');    strArray(1,2) = String('two');
strArray(2,1) = String('three');  strArray(2,2) = String('four');
```

```
% Convert each to cell arrays
cellArray = {cell(dblArray), cell(ptArray), cell(strArray)}
cellArray =
    {1x10 cell}    {3x1 cell}    {2x2 cell}

cellArray{1,1}       % Array of type double
ans =

   [7]   [14]   [21]   [28]   [35]   [42]   [49]   [56]   [63]   [70]

cellArray{1,2}       % Array of type Java.awt.Point

ans =

    [1x1 java.awt.Point]
    [1x1 java.awt.Point]
    [1x1 java.awt.Point]

cellArray{1,3}       % Array of type char array

ans =

    'one'      'two'
    'three'    'four'
```

Introduction to Programming Examples

The following programming examples demonstrate the MATLAB interface to Java classes and objects:

- "Example – Reading a URL" on page 5-63
- "Example – Finding an Internet Protocol Address" on page 5-66
- "Example – Communicating Through a Serial Port" on page 5-68
- "Example – Creating and Using a Phone Book" on page 5-73

Each example contains the following sections:

- Overview - Describes what the example does and how it uses the Java interface to accomplish it. Highlighted are the most important Java objects that are constructed and used in the example code.
- Description - provides a detailed description of all code in the example. For longer functions, the description is divided into functional sections that focus on a few statements.
- Running the Example - Shows a sample of the output from execution of the example code.

The example descriptions concentrate on the Java-related functions. For information on other MATLAB programming constructs, operators, and functions used in the examples, see the applicable sections in the MATLAB documentation.

Example – Reading a URL

This program, URLdemo, opens a connection to a web site specified by a URL (Uniform Resource Locator), for the purpose of reading text from a file at that site. It constructs an object of the Java API class, java.net.URL, which enables convenient handling of URLs. Then, it calls a method on the URL object, to open a connection.

To read and display the lines of text at the site, URLdemo uses classes from the Java I/O package java.io. It creates an InputStreamReader object, and then uses that object to construct a BufferedReader object. Finally, it calls a method on the BufferedReader object to read the specified number of lines from the site.

Description of URLdemo

The major tasks performed by URLdemo are:

1. Construct a URL Object

The example first calls a constructor on java.net.URL and assigns the resulting object to variable url. The URL constructor takes a single argument, the name of the URL to be accessed, as a string. The constructor checks whether the input URL has a valid form.

```
url = java.net.URL(...
  'http://www.mathworks.com/support/tech-notes/1100/1109.shtml')
```

2. Open a Connection to the URL

The second statement of the example calls the method, openStream, on the URL object url, to establish a connection with the web site named by the object. The method returns an InputStream object to variable, is, for reading bytes from the site.

```
is = openStream(url)
```

3. Set Up a Buffered Stream Reader

The next two lines create a buffered stream reader for characters. The java.io.InputStreamReader constructor is called with the input stream is, to return to variable isr an object that can read characters. Then, the java.io.BufferedReader constructor is called with isr, to return a

BufferedReader object to variable br. A buffered reader provides for efficient reading of characters, arrays, and lines.

```
isr = java.io.InputStreamReader(is)
br = java.io.BufferedReader(isr)
```

4. Read and Display Lines of Text

The final statements read the initial lines of HTML text from the site, displaying only the first 4 lines that contain meaningful text. Within the MATLAB for statements, the BufferedReader method readLine reads each line of text (terminated by a return and/or line feed character) from the site.

```
for k = 1:108           % Skip initial HTML formatting lines
   s = readLine(br);
end

for k = 1:4             % Read the first 4 lines of text
   s = readLine(br)
end
```

Running the Example

When you run this example, you see output similar to the following.

```
url =
http://www.mathworks.com/support/tech-notes/1100/1109.shtml
is =
ice.net.CachedInputStream@7e700c
isr =
java.io.InputStreamReader@7e6696
br =
java.io.BufferedReader@7e5d1b
s =
      <p class="standard">This technical note provides an
introduction to vectorization techniques.
s =
      In order to understand some of the tricks available, an
introduction to
```

```
s =
      MATLAB indexing is provided. Then several vectorization
techniques are
s =
      discussed, in order of simplest to most complicated.
```

Example – Finding an Internet Protocol Address

The resolveip function returns either the name or address of an IP (internet protocol) host. If you pass resolveip a hostname, it returns the IP address. If you pass resolveip an IP address, it returns the hostname. The function uses the Java API class java.net.InetAddress, which enables you to find an IP address for a hostname, or the hostname for a given IP address, without making DNS calls.

resolveip calls a static method on the InetAddress class to obtain an InetAddress object. Then, it calls accessor methods on the InetAddress object to get the hostname and IP address for the input argument. It displays either the hostname or the IP address, depending on the program input argument.

Description of resolveip

The major tasks performed by resolveip are:

1. Create an InetAddress Object

Instead of constructors, the java.net.InetAddress class has static methods that return an instance of the class. The try statement calls one of those methods, getByName, passing the input argument that the user has passed to resolveip. The input argument can be either a hostname or an IP address. If getByName fails, the catch statement displays an error message.

```
function resolveip(input)
try
   address = java.net.InetAddress.getByName(input);
catch
   error(sprintf('Unknown host %s.', input));
end
```

2. Retrieve the Hostname and IP Address

The example uses calls to the getHostName and getHostAddress accessor functions on the java.net.InetAddress object, to obtain the hostname and IP address, respectively. These two functions return objects of class java.lang.String, so we use the char function to convert them to character arrays.

```
hostname = char(address.getHostName);
ipaddress = char(address.getHostAddress);
```

3. Display the Hostname or IP Address

The example uses the MATLAB `strcmp` function to compare the `input` argument to the resolved IP address. If it matches, MATLAB displays the hostname for the internet address. If the input does not match, MATLAB displays the IP address.

```
if strcmp(input,ipaddress)
   disp(sprintf('Host name of %s is %s', input, hostname));
else
   disp(sprintf('IP address of %s is %s', input, ipaddress));
end;
```

Running the Example

Here is an example of calling the `resolveip` function with a hostname.

```
resolveip ('www.mathworks.com')
IP address of www.mathworks.com is 144.212.100.10
```

Here is a call to the function with an IP address.

```
resolveip ('144.212.100.10')
Host name of 144.212.100.10 is www.mathworks.com
```

Example – Communicating Through a Serial Port

The serialexample program uses classes of the Java API javax.comm package, which support access to communications ports. After defining port configuration variables, serialexample constructs a javax.comm.CommPortIdentifier object, to manage the serial communications port. The program calls the open method on that object to return an object of the javax.comm.SerialPort class, which describes the low-level interface to the COM1 serial port, assumed to be connected to a Tektronix oscilloscope. (The example can be run without an oscilloscope.) The serialexample program then calls several methods on the SerialPort object to configure the serial port.

The serialexample program uses the I/O package java.io, to write to and read from the serial port. It calls a static method to return an OutputStream object for the serial port. It then passes that object to the constructor for java.io.OutputStreamWriter. It calls the write method on the OutputStreamWriter object to write a command to the serial port, which sets the contrast on the oscilloscope. It calls write again to write a command that checks the contrast. It then constructs an object of the java.io.InputStreamWriter class to read from the serial port.

It calls another static method on the SerialPort object to return an OutputStream object for the serial port. It calls a method on that object to get the number of bytes to read from the port. It passes the InputStream object to the constructor for java.io.OutputStreamWriter. Then, if there is data to read, it calls the read method on the OutputStreamWriter object to read the contrast data returned by the oscilloscope.

Note MATLAB also provides built-in serial port support, described in Chapter 8, "Serial Port I/O".

Description of Serial Example

The major tasks performed by `serialexample` are:

1. Define Variables for Serial Port Configuration and Output

The first five statements define variables for configuring the serial port. The first statement defines the baud rate to be 9600, the second defines number of data bits to be 8, and the third defines the number of stop bits to be 1. The fourth statement defines parity to be off, and the fifth statement defines flow control (handshaking) to be off.

```
SerialPort_BAUD_9600 = 9600;
SerialPort_DATABITS_8 = 8;
SerialPort_STOPBITS_1 = 1;
SerialPort_PARITY_NONE = 0;
SerialPort_FLOWCTRL_NONE = 0;
```

The last variable definition sets the terminator character for writing to the serial port, to a carriage return.

```
terminator = char(13);
```

2. Create a CommPortIdentifier Object

Instead of constructors, the `javax.comm.CommPortIdentifier` class has `static` methods that return an instance of the class. The example calls one of these, `getPortIdentifier`, to return a `CommPortIdentifier` object for port `COM1`.

```
commPort = ...
javax.comm.CommPortIdentifier.getPortIdentifier('COM1');
```

3. Open the Serial Port

The example opens the serial port, by calling `open` on the `CommPortIdentifier` object `commPort`. The `open` call returns a `SerialPort` object, assigning it to `serialPort`. The first argument to `open` is the name (owner) for the port, the second argument is the name for the port, and the third argument is the number of milliseconds to wait for the open.

```
serialPort = open(commPort, 'serial', 1000);
```

4. Configure the Serial Port

The next three statements call configuration methods on the SerialPort object serialPort. The first statement calls setSerialPortParams to set the baud rate, data bits, stop bits, and parity. The next two statements call setFlowControlMode to set the flow control, and then enableReceiveTimeout to set the timeout for receiving data.

```
setSerialPortParams(serialPort, SerialPort_BAUD_9600,...
SerialPort_DATABITS_8, SerialPort_STOPBITS_1,...
SerialPort_PARITY_NONE);
setFlowControlMode(serialPort, SerialPort_FLOWCTRL_NONE);
enableReceiveTimeout(serialPort, 1000);
```

5. Set Up an Output Stream Writer

The example then calls a constructor to create and open a java.io.OutputStreamWriter object. The constructor call passes the java.io.OutputStream object, returned by a call to the getOutputStream method serialPort, and assigns the OutputStreamWriter object to out.

```
out = java.io.OutputStreamWriter(getOutputStream(serialPort));
```

6. Write Data to Serial Port and Close Output Stream

The example writes a string to the serial port, by calling write on the object out. The string is formed by concatenating (with MATLAB [] syntax) a command to set the oscilloscope's contrast to 45, with the command terminator that is required by the instrument. The next statement calls flush on out to flush the output stream.

```
write(out, ['Display:Contrast 45' terminator]);
flush(out);
```

Then, the example again calls write on out to send another string to the serial port. This string is a query command, to determine the oscilloscope's contrast setting, concatenated with the command terminator. The example then calls close on the output stream.

```
write(out, ['Display:Contrast?' terminator]);
close(out);
```

7. Open an Input Stream and Determine Number of Bytes to Read

To read the data expected from the oscilloscope in response to the contrast query, the example opens an input stream by calling the `static` method, `InputStream.getInputStream`, to obtain an `InputStream` object for the serial port. Then, the example calls the method `available` on the `InputStream` object, `in`, and assigns the returned number of bytes to `numAvail`.

```
in = getInputStream(serialPort);
numAvail = available(in);
```

8. Create an Input Stream Reader for the Serial Port

The example then calls a `java.io.InputStreamReader` constructor, with the `InputStream` object, `in`, and assigns the new object to `reader`.

```
reader = java.io.InputStreamReader(in);
```

9. Read Data from Serial Port and Close Reader

The example reads from the serial port, by calling the `read` method on the `InputStreamReader` object reader for each available byte. The `read` statement uses MATLAB array concatenation to add each newly read byte to the array of bytes already read. After reading the data, the example calls `close` on `reader` to close the input stream reader.

```
result = [];
for k = 1:numAvail
   result = [result read(reader)];
end
close(reader);
```

10. Close the Serial Port

The example closes the serial port, by calling `close` on the `serialPort` object.

```
close(serialPort);
```

11. Convert Input Argument to a MATLAB Character Array

The last statement of the example uses the MATLAB function, `char`, to convert the array input bytes (integers) to an array of characters:

```
result = char(result);
```

Running the serialexample Program

The value of `result` depends upon whether your system's COM1 port is cabled to an oscilloscope. If you have run the example with an oscilloscope, you see the result of reading the serial port.

```
result =
45
```

If you run the example without an oscilloscope attached, there is no data to read. In that case, you see an empty character array.

```
result =
''
```

Example – Creating and Using a Phone Book

The example's main function, `phonebook`, can be called either with no arguments, or with one argument, which is the key of an entry that exists in the phone book. The function first determines the directory to use for the phone book file.

If no phone book file exists, it creates one by constructing a `java.io.FileOutputStream` object, and then closing the output stream. Next, it creates a data dictionary by constructing an object of the Java API class, `java.util.Properties`, which is a subclass of `java.util.Hashtable` for storing key/value pairs in a hash table. For the `phonebook` program, the key is a name, and the value is one or more telephone numbers.

The `phonebook` function creates and opens an input stream for reading by constructing a `java.io.FileInputStream` object. It calls load on that object to load the hash table contents, if it exists. If the user passed the key to an entry to look up, it looks up the entry by calling `pb_lookup`, which finds and displays it. Then, the `phonebook` function returns.

If `phonebook` was called without the name argument, it then displays a textual menu of the available phone book actions:

- Look up an entry
- Add an entry
- Remove an entry
- Change the phone number(s) in an entry
- List all entries

The menu also has a selection to exit the program. The function uses MATLAB functions to display the menu and to input the user selection.

The `phonebook` function iterates accepting user selections and performing the requested phone book action until the user selects the menu entry to exit. The `phonebook` function then opens an output stream for the file by constructing a `java.io.FileOutputStream` object. It calls `save` on the object to write the current data dictionary to the phone book file. It finally closes the output stream and returns.

Description of Function phonebook

The major tasks performed by phonebook are:

1. Determine the Data Directory and Full Filename

The first statement assigns the phone book filename, 'myphonebook', to the variable pbname. If the phonebook program is running on a PC, it calls the java.lang.System static method getProperty to find the directory to use for the data dictionary. This will be set to the user's current working directory. Otherwise, it uses MATLAB function getenv to determine the directory, using the system variable HOME which you can define beforehand to anything you like. It then assigns to pbname the full pathname, consisting of the data directory and filename 'myphonebook'.

```
function phonebook(varargin)
pbname = 'myphonebook'; % name of data dictionary
if ispc
   datadir = char(java.lang.System.getProperty('user.dir'));
else
   datadir = getenv('HOME');
end;
pbname = fullfile(datadir, pbname);
```

2. If Needed, Create a File Output Stream

If the phonebook file does not already exist, phonebook asks the user whether to create a new one. If the user answers y, phonebook creates a new phone book by constructing a FileOutputStream object. In the try clause of a try-catch block, the argument pbname passed to the FileOutputStream constructor is the full name of the file that the constructor creates and opens. The next statement closes the file by calling close on the FileOutputStream object FOS. If the output stream constructor fails, the catch statement prints a message and terminates the program.

```
if ~exist(pbname)
   disp(sprintf('Data file %s does not exist.', pbname));
   r = input('Create a new phone book (y/n)?','s');
   if r == 'y',
      try
         FOS = java.io.FileOutputStream(pbname);
         FOS.close
      catch
```

```
         error(sprintf('Failed to create %s', pbname));
      end;
   else
      return;
   end;
end;
```

3. Create a Hash Table

The example constructs a `java.util.Properties` object to serve as the hash table for the data dictionary.

```
pb_htable = java.util.Properties;
```

4. Create a File Input Stream

In a `try` block, the example invokes a `FileInputStream` constructor with the name of the phone book file, assigning the object to `FIS`. If the call fails, the `catch` statement displays an `error` message and terminates the program.

```
try
   FIS = java.io.FileInputStream(pbname);
catch
   error(sprintf('Failed to open %s for reading.', pbname));
end;
```

5. Load the Phone Book Keys and Close the File Input Stream

The example calls `load` on the `FileInputStream` object `FIS`, to load the phone book keys and their values (if any) into the hash table. It then closes the file input stream.

```
pb_htable.load(FIS);
FIS.close;
```

6. Display the Action Menu and Get the User's Selection

Within a `while` loop, several `disp` statements display a menu of actions that the user can perform on the phone book. Then, an `input` statement requests the user's typed selection.

```
while 1
   disp ' '
   disp ' Phonebook Menu:'
```

```
disp ' '
disp ' 1. Look up a phone number'
disp ' 2. Add an entry to the phone book'
disp ' 3. Remove an entry from the phone book'
disp ' 4. Change the contents of an entry in the phone book'
disp ' 5. Display entire contents of the phone book'
disp ' 6. Exit this program'
disp ' '
s = input('Please type the number for a menu selection: ','s');
```

7. Invoke the Function to Perform A Phone Book Action

Still within the `while` loop, a `switch` statement provides a case to handle each user selection. Each of the first five cases invokes the function to perform a phone book action.

Case 1 prompts for a name that is a key to an entry. It calls `isempty` to determine whether the user has entered a name. If a name has not been entered, it calls `disp` to display an error message. If a name has been input, it passes it to `pb_lookup`. The `pb_lookup` routine looks up the entry and, if it finds it, displays the entry contents.

```
switch s
   case '1',
      name = input('Enter the name to look up: ','s');
      if isempty(name)
         disp 'No name entered'
      else
         pb_lookup(pb_htable, name);
      end;
```

Case 2 calls pb_add, which prompts the user for a new entry and then adds it to the phone book.

```
case '2',
   pb_add(pb_htable);
```

Case 3 uses input to prompt for the name of an entry to remove. If a name has not been entered, it calls disp to display an error message. If a name has been input, it passes it to pb_remove.

```
case '3',
   name=input('Enter the name of the entry to remove: ', 's');
   if isempty(name)
      disp 'No name entered'
   else
      pb_remove(pb_htable, name);
   end;
```

Case 4 uses input to prompt for the name of an entry to change. If a name has not been entered, it calls disp to display an error message. If a name has been input, it passes it to pb_change.

```
case '4',
   name=input('Enter the name of the entry to change: ', 's');
   if isempty(name)
      disp 'No name entered'
   else
      pb_change(pb_htable, name);
   end;
```

Case 5 calls pb_listall to display all entries.

```
case '5',
   pb_listall(pb_htable);
```

8. Exit by Creating an Output Stream and Saving the Phone Book

If the user has selected case 6 to exit the program, a try statement calls the constructor for a FileOuputStream object, passing it the name of the phone book. If the constructor fails, the catch statement displays an error message.

If the object is created, the next statement saves the phone book data by calling save on the Properties object pb_htable, passing the FileOutputStream object FOS and a descriptive header string. It then calls close on the FileOutputStream object, and returns.

```
    case '6',
       try
          FOS = java.io.FileOutputStream(pbname);
       catch
          error(sprintf('Failed to open %s for writing.',...
                        pbname));
       end;
       pb_htable.save(FOS,'Data file for phonebook program');
       FOS.close;
       return;
    otherwise
       disp 'That selection is not on the menu.'
    end;
 end;
```

Description of Function pb_lookup

Arguments passed to pb_lookup are the Properties object pb_htable and the name key for the requested entry. The pb_lookup function first calls get on pb_htable with the name key, on which support function pb_keyfilter is called to change spaces to underscores. The get method returns the entry (or null, if the entry is not found) to variable entry. Note that get takes an argument of type java.lang.Object and also returns an argument of that type. In this invocation, the key passed to get and the entry returned from it are actually character arrays.

pb_lookup then calls isempty to determine whether entry is null. If it is, it uses disp to display an message stating that the name was not found. If entry is not null, it calls pb_display to display the entry.

```
function pb_lookup(pb_htable,name)
entry = pb_htable.get(pb_keyfilter(name));
if isempty(entry),
   disp(sprintf('The name %s is not in the phone book',name));
else
   pb_display(entry);
end
```

Description of Function pb_add

1. Input the Entry to Add

The pb_add function takes one argument, the Properties object pb_htable. pb_add uses disp to prompt for an entry. Using the up-arrow (^) character as a line delimiter, input inputs a name to the variable entry. Then, within a while loop, it uses input to get another line of the entry into variable line. If the line is empty, indicating that the user has finished the entry, the code breaks out of the while loop. If the line is not empty, the else statement appends line to entry and then appends the line delimiter. At the end, the strcmp checks the possibility that no input was entered and, if that is the case, returns.

```
function pb_add(pb_htable)
disp 'Type the name for the new entry, followed by Enter.'
disp 'Then, type the phone number(s), one per line.'
disp 'To complete the entry, type an extra Enter.'
name = input(':: ','s');
entry=[name '^'];
while 1
   line = input(':: ','s');
   if isempty(line)
      break;
   else
      entry=[entry line '^'];
   end;
end;

if strcmp(entry, '^')
   disp 'No name entered'
   return;
end;
```

2. Add the Entry to the Phone Book

After the input has completed, pb_add calls put on pb_htable with the hash key name (on which pb_keyfilter is called to change spaces to underscores) and entry. It then displays a message that the entry has been added.

```
pb_htable.put(pb_keyfilter(name),entry);
disp ' '
disp(sprintf('%s has been added to the phone book.', name));
```

Description of Function pb_remove

1. Look For the Key in the Phone Book

Arguments passed to pb_remove are the Properties object pb_htable and the name key for the entry to remove. The pb_remove function calls containsKey on pb_htable with the name key, on which support function pb_keyfilter is called to change spaces to underscores. If name is not in the phone book, disp displays a message and the function returns.

```
function pb_remove(pb_htable,name)
if ~pb_htable.containsKey(pb_keyfilter(name))
   disp(sprintf('The name %s is not in the phone book',name))
   return
end;
```

2. Ask for Confirmation and If Given, Remove the Key

If the key is in the hash table, pb_remove asks for user confirmation. If the user confirms the removal by entering y, pb_remove calls remove on pb_htable with the (filtered) name key, and displays a message that the entry has been removed. If the user enters n, the removal is not performed and disp displays a message that the removal has not been performed.

```
r = input(sprintf('Remove entry %s (y/n)? ',name), 's');
if r == 'y'
   pb_htable.remove(pb_keyfilter(name));
   disp(sprintf('%s has been removed from the phone book',name))
else
   disp(sprintf('%s has not been removed',name))
end;
```

Description of Function pb_change

1. Find the Entry to Change, and Confirm

Arguments passed to pb_change are the Properties object pb_htable and the name key for the requested entry. The pb_change function calls get on pb_htable with the name key, on which pb_keyfilter is called to change spaces to underscores. The get method returns the entry (or null, if the entry is not found) to variable entry. pb_change calls isempty to determine whether the entry is empty. If the entry is empty, pb_change displays a message that the name will be added to the phone book, and allows the user to enter the phone number(s) for the entry.

If the entry is found, in the else clause, pb_change calls pb_display to display the entry. It then uses input to ask the user to confirm the replacement. If the user enters anything other than y, the function returns.

```
function pb_change(pb_htable,name)
entry = pb_htable.get(pb_keyfilter(name));
if isempty(entry)
   disp(sprintf('The name %s is not in the phone book', name));
   return;
else
   pb_display(entry);
   r = input('Replace phone numbers in this entry (y/n)? ','s');
   if r ~= 'y'
      return;
   end;
end;
```

2. Input New Phone Number(s) and Change the Phone Book Entry

pb_change uses disp to display a prompt for new phone number(s). Then, pb_change inputs data into variable entry, with the same statements described in "1. Input the Entry to Add" on page 5-79.

Then, to replace the existing entry with the new one, pb_change calls put on pb_htable with the (filtered) key name and the new entry. It then displays a message that the entry has been changed.

```
disp 'Type in the new phone number(s), one per line.'
disp 'To complete the entry, type an extra Enter.'
disp(sprintf(':: %s', name));
entry=[name '^'];
while 1
   line = input(':: ','s');
   if isempty(line)
      break;
   else
      entry=[entry line '^'];
   end;
end;
```

```
pb_htable.put(pb_keyfilter(name),entry);
disp ' '
disp(sprintf('The entry for %s has been changed', name));
```

Description of Function pb_listall

The `pb_listall` function takes one argument, the `Properties` object `pb_htable`. The function calls `propertyNames` on the `pb_htable` object to return to `enum` a `java.util.Enumeration` object, which supports convenient enumeration of all the keys. In a `while` loop, `pb_listall` calls `hasMoreElements` on `enum`, and if it returns true, `pb_listall` calls `nextElement` on `enum` to return the next key. It then calls `pb_display` to display the key and entry, which it retrieves by calling `get` on `pb_htable` with the key.

```
function pb_listall(pb_htable)
enum = pb_htable.propertyNames;
while enum.hasMoreElements
   key = enum.nextElement;
   pb_display(pb_htable.get(key));
end;
```

Description of Function pb_display

The `pb_display` function takes an argument `entry`, which is a phone book entry. After displaying a horizontal line, `pb_display` calls MATLAB function `strtok` to extract the first line the entry, up to the line delimiter (`^`), into `t` and and the remainder into `r`. Then, within a `while` loop that terminates when `t` is empty, it displays the current line in `t`. Then it calls strtok to extract the next line from `r`, into `t`. When all lines have been displayed, `pb_display` indicates the end of the entry by displaying another horizontal line.

```
function pb_display(entry)
disp ' '
disp '-------------------------'
[t,r] = strtok(entry,'^');
while ~isempty(t)
   disp(sprintf(' %s',t));
   [t,r] = strtok(r,'^');
end;
disp '-------------------------'
```

Description of Function pb_keyfilter

The pb_keyfilter function takes an argument key, which is a name used as a key in the hash table, and either filters it for storage or unfilters it for display. The filter, which replaces each space in the key with an underscore (_), makes the key usable with the methods of java.util.Properties.

```
function out = pb_keyfilter(key)
if ~isempty(findstr(key,' '))
   out = strrep(key,' ','_');
else
   out = strrep(key,'_',' ');
end;
```

Running the phonebook Program

In this sample run, a user invokes phonebook with no arguments. The user selects menu action 5, which displays the two entries currently in the phone book (all entries are fictitious). Then, the user selects 2, to add an entry. After adding the entry, the user again selects 5, which displays the new entry along with the other two entries.

```
Phonebook Menu:

     1. Look up a phone number
     2. Add an entry to the phone book
     3. Remove an entry from the phone book
     4. Change the contents of an entry in the phone book
     5. Display entire contents of the phone book
     6. Exit this program

Please type the number for a menu selection: 5

-------------------------
 Sylvia Woodland
 (508) 111-3456
-------------------------

-------------------------
 Russell Reddy
 (617) 999-8765
-------------------------
```

```
Phonebook Menu:

     1. Look up a phone number
     2. Add an entry to the phone book
     3. Remove an entry from the phone book
     4. Change the contents of an entry in the phone book
     5. Display entire contents of the phone book
     6. Exit this program

Please type the number for a menu selection: 2

Type the name for the new entry, followed by Enter.
Then, type the phone number(s), one per line.
To complete the entry, type an extra Enter.
:: BriteLites Books
:: (781) 777-6868
::

BriteLites Books has been added to the phone book.

Phonebook Menu:

     1. Look up a phone number
     2. Add an entry to the phone book
     3. Remove an entry from the phone book
     4. Change the contents of an entry in the phone book
     5. Display entire contents of the phone book
     6. Exit this program

Please type the number for a menu selection: 5

-------------------------
 BriteLites Books
 (781) 777-6868
-------------------------


-------------------------
 Sylvia Woodland
```

```
 (508) 111-3456
-------------------------

-------------------------
 Russell Reddy
 (617) 999-8765
-------------------------
```

6

Importing and Exporting Data

You can use MAT-files, the data file format MATLAB uses for saving data to disk, to import data to and export data from the MATLAB environment. MAT-files provide a convenient mechanism for moving your MATLAB data between different platforms in a highly portable manner. In addition, they provide a means to import and export your data to other stand-alone MATLAB applications.

Using MAT-Files

This section describes the various techniques for importing data to and exporting data from the MATLAB environment. The main topics that are discussed are:

- "Importing Data to MATLAB"
- "Exporting Data from MATLAB"
- "Exchanging Data Files Between Platforms"
- "Reading and Writing MAT-Files"
- "Finding Associated Files"

The most important approach to importing and exporting data involves the use of MAT-files, the data file format that MATLAB uses for saving data to your disk. MAT-files provide a convenient mechanism for moving your MATLAB data between different platforms and for importing and exporting your data to other stand-alone MATLAB applications.

To simplify your use of MAT-files in applications outside of MATLAB, we have developed a library of access routines with a `mat` prefix that you can use in your own C or Fortran programs to read and write MAT-files. Programs that access MAT-files also use the `mx` prefixed API routines discussed in Chapter 2, "Creating C Language MEX-Files" and Chapter 3, "Creating Fortran MEX-Files."

Importing Data to MATLAB

You can introduce data from other programs into MATLAB by several methods. The best method for importing data depends on how much data there is, whether the data is already in machine-readable form, and what format the data is in. Here are some choices. Select the one that best meets your needs.

- **Enter the data as an explicit list of elements.**

  If you have a small amount of data, less than 10-15 elements, it is easy to type the data explicitly using brackets `[ ]`. This method is awkward for larger amounts of data because you can't edit your input if you make a mistake.
- **Create data in an M-file.**

  Use your text editor to create an M-file that enters your data as an explicit list of elements. This method is useful when the data isn't already in computer-readable form and you have to type it in. Essentially the same as the first method, this method has the advantage of allowing you to use your editor to change the data and correct mistakes. You can then just rerun your M-file to re-enter the data.

- **Load data from an ASCII flat file.**

  A *flat file* stores the data in ASCII form, with fixed-length rows terminated with new lines (carriage returns) and with spaces separating the numbers. You can edit ASCII flat files using a normal text editor. Flat files can be read directly into MATLAB using the `load` command. The result is to create a variable with the same name as the filename.

  See the `load` function reference page for more information.

- **Read data using MATLAB I/O functions.**

  You can read data using `fopen`, `fread`, and MATLAB other low-level I/O functions. This method is useful for loading data files from other applications that have their own established file formats.

- **Write a MEX-file to read the data.**

  This is the method of choice if subroutines are already available for reading data files from other applications. See the section, "Introducing MEX-Files" on page 1-2, for more information.

- **Write a program to translate your data.**

  You can write a program in C or Fortran to translate your data into MAT-file format. You can then read the MAT-file into MATLAB using the `load` command. Refer to the section, "Reading and Writing MAT-Files" on page 6-5, for more information.

Exporting Data from MATLAB

There are several methods for getting MATLAB data back to the outside world:

- **Create a diary file.**

  For small matrices, use the `diary` command to create a diary file and display the variables, echoing them into this file. You can use your text editor to manipulate the diary file at a later time. The output of `diary` includes the MATLAB commands used during the session, which is useful for inclusion into documents and reports.

- **Use the Save command.**

  Save the data in ASCII form using the `save` command with the `-ascii` option. For example,

  ```
  A = rand(4,3);
  save temp.dat A -ascii
  ```

  creates an ASCII file called `temp.dat` containing

  ```
  1.3889088e-001  2.7218792e-001  4.4509643e-001
  2.0276522e-001  1.9881427e-001  9.3181458e-001
  1.9872174e-001  1.5273927e-002  4.6599434e-001
  6.0379248e-001  7.4678568e-001  4.1864947e-001
  ```

  The `-ascii` option supports two-dimensional double and character arrays only. Multidimensional arrays, cell arrays, and structures are not supported.

  See the `save` function reference page for more information.

- **Use MATLAB I/O functions.**

  Write the data in a special format using `fopen`, `fwrite`, and the other low-level I/O functions. This method is useful for writing data files in the file formats required by other applications.

- **Develop a MEX-file to write the data.**

  You can develop a MEX-file to write the data. This is the method of choice if subroutines are already available for writing data files in the form needed by other applications. See the section, "Introducing MEX-Files" on page 1-2, for more information.

- **Translate data from a MAT-file.**

  You can write out the data as a MAT-file using the `save` command. You can then write a program in C or Fortran to translate the MAT-file into your own special format. See the section, "Reading and Writing MAT-Files" on page 6-5, for more information.

Exchanging Data Files Between Platforms

You may want to work with MATLAB implementations on several different computer systems, or need to transmit MATLAB applications to users on other systems. MATLAB applications consist of M-files containing functions and scripts, and MAT-files containing binary data.

Both types of files can be transported directly between machines: M-files because they are platform independent and MAT-files because they contain a machine signature in the file header. MATLAB checks the signature when it loads a file and, if a signature indicates that a file is foreign, performs the necessary conversion.

Using MATLAB across several different machine architectures requires a facility for exchanging both binary and ASCII data between the various machines. Examples of this type of facility include FTP, NFS, Kermit, and other communication programs. When using these programs, be careful to transmit binary MAT-files in *binary file mode* and ASCII M-files in *ASCII file mode*. Failure to set these modes correctly corrupts the data.

Reading and Writing MAT-Files

The `save` command in MATLAB saves the MATLAB arrays currently in memory to a binary disk file called a MAT-file. The term MAT-file is used because these files have the extension `.mat`. The `load` command performs the reverse operation. It reads the MATLAB arrays from a MAT-file on disk back into MATLAB workspace.

A MAT-file may contain one or more of any of the data types supported in MATLAB 5 or later, including strings, matrices, multidimensional arrays, structures, and cell arrays. MATLAB writes the data sequentially onto disk as a continuous byte stream.

MAT-File Interface Library

The MAT-file interface library contains a set of routines for reading and writing MAT-files. You can call these routines from within your own C and Fortran programs. We recommend that you use these routines, rather than attempt to write your own code, to perform these operations. By using the routines in this library, you will be insulated from future changes to the MAT-file structure.

The MAT-file library contains routines for reading and writing MAT-files. They all begin with the three-letter prefix `mat`. These tables list all the available MAT-functions and their purposes.

Table 6-1: C MAT-File Routines

MAT-Function	Purpose
`matOpen`	Open a MAT-file
`matClose`	Close a MAT-file
`matGetDir`	Get a list of MATLAB arrays from a MAT-file
`matGetFp`	Get an ANSI C file pointer to a MAT-file
`matGetVariable`	Read a MATLAB array from a MAT-file
`matPutVariable`	Write a MATLAB array to a MAT-file
`matGetNextVariable`	Read the next MATLAB array from a MAT-file
`matDeleteVariable`	Remove a MATLAB array from a MAT-file
`matPutVariableAsGlobal`	Put a MATLAB array into a MAT-file such that the `load` command will place it into the global workspace
`matGetVariableInfo`	Load a MATLAB array header from a MAT-file (no data)
`matGetNextVariableInfo`	Load the next MATLAB array header from a MAT-file (no data)

Table 6-2: Fortran MAT-File Routines

MAT-Function	Purpose
`matOpen`	Open a MAT-file
`matClose`	Close a MAT-file
`matGetDir`	Get a list of MATLAB arrays from a MAT-file
`matGetVariable`	Get a named MATLAB array from a MAT-file
`matGetVariableInfo`	Get header for named MATLAB array from a MAT-file
`matPutVariable`	Put a MATLAB array into a MAT-file
`matPutVariableAsGlobal`	Put a MATLAB array into a MAT-file
`matGetNextVariable`	Get the next sequential MATLAB array from a MAT-file
`matGetNextVariableInfo`	Get header foro next sequential MATLAB array from a MAT-file
`matDeleteVariable`	Remove a MATLAB array from a MAT-file

Finding Associated Files

A collection of files associated with reading and writing MAT-files is located on your disk. The following table, MAT-Function Subdirectories, lists the path to the required subdirectories for importing and exporting data using MAT-functions.

Table 6-3: MAT-Function Subdirectories

Platform	Contents	Directories
Windows	Include Files	`<matlab>\extern\include`
	Libraries	`<matlab>\bin\win32`
	Examples	`<matlab>\extern\examples/eng_mat`
UNIX	Include Files	`<matlab>/extern/include`
	Libraries	`<matlab>/extern/lib/$arch`
	Examples	`<matlab>/extern/examples/eng_mat`

Include Files

The `include` directory holds header files containing function declarations with prototypes for the routines that you can access in the API Library. These files are the same for both Windows and UNIX. Included in the subdirectory are:

- `matrix.h`, the header file that defines MATLAB array access and creation methods
- `mat.h`, the header file that defines MAT-file access and creation methods

Libraries

The subdirectory that contains shared (dynamically linkable) libraries for linking your programs is platform dependent.

Shared Libraries on Windows. The `bin` subdirectory contains the shared libraries for linking your programs:

- `libmat.dll`, the library of MAT-file routines (C and Fortran)
- `libmx.dll`, the library of array access and creation routines

Shared Libraries on UNIX. The `extern/lib/$arch` subdirectory, where `$arch` is your machine's architecture, contains the shared libraries for linking your programs. For example, on `sol2`, the subdirectory is `extern/lib/sol2`:

- `libmat.so`, the library of MAT-file routines (C and Fortran)
- `libmx.so`, the library of array access and creation routines

Example Files

The `examples/eng_mat` subdirectory contains C and Fortran source code for a number of example files that demonstrate how to use the MAT-file routines. The source code files are the same for both Windows and UNIX.

Table 6-4: C and Fortran Examples

Library	Description
`matcreat.c`	Example C program that demonstrates how to use the library routines to create a MAT-file that can be loaded into MATLAB
`matdgns.c`	Example C program that demonstrates how to use the library routines to read and diagnose a MAT-file
`matdemo1.f`	Example Fortran program that demonstrates how to call the MATLAB MAT-file functions from a Fortran program
`matdemo2.f`	Example Fortran program that demonstrates how to use the library routines to read in the MAT-file created by `matdemo1.f` and describe its contents

For additional information about the MATLAB API files and directories, see "Additional Information" on page 1-41.

Examples of MAT-Files

This section includes C and Fortran examples of writing, reading, and diagnosing MAT-files. The examples cover the following topics:

- "Creating a MAT-File in C"
- "Reading a MAT-File in C" on page 6-15
- "Creating a MAT-File in Fortran" on page 6-19
- "Reading a MAT-File in Fortran" on page 6-24

Creating a MAT-File in C

This sample program illustrates how to use the library routines to create a MAT-file that can be loaded into MATLAB. The program also demonstrates how to check the return values of MAT-function calls for read or write failures.

```
/*
 * MAT-file creation program
 *
 * See the MATLAB API Guide for compiling information.
 *
 * Calling syntax:
 *
 *   matcreat
 *
 * Create a MAT-file which can be loaded into MATLAB.
 *
 * This program demonstrates the use of the following functions:
 *
 *  matClose
 *  matGetVariable
 *  matOpen
 *  matPutVariable
 *  matPutVariableAsGlobal
 *
 * Copyright 1984-2000 The MathWorks, Inc.
 * $Revision: 1.13 $
 */
#include <stdio.h>
#include <string.h> /* For strcmp() */
```

```
#include <stdlib.h> /* For EXIT_FAILURE, EXIT_SUCCESS */
#include "mat.h"

#define BUFSIZE 256

int main() {
  MATFile *pmat;
  mxArray *pa1, *pa2, *pa3;
  double data[9] = { 1.0, 4.0, 7.0, 2.0, 5.0, 8.0, 3.0, 6.0, 9.0 };
  const char *file = "mattest.mat";
  char str[BUFSIZE];
  int status;

  printf("Creating file %s...\n\n", file);
  pmat = matOpen(file, "w");
  if (pmat == NULL) {
    printf("Error creating file %s\n", file);
    printf("(Do you have write permission in this directory?)\n");
    return(EXIT_FAILURE);
  }

  pa1 = mxCreateDoubleMatrix(3,3,mxREAL);
  if (pa1 == NULL) {
      printf("%s : Out of memory on line %d\n", __FILE__,
              __LINE__);
      printf("Unable to create mxArray.\n");
      return(EXIT_FAILURE);
  }

  pa2 = mxCreateDoubleMatrix(3,3,mxREAL);
  if (pa2 == NULL) {
      printf("%s : Out of memory on line %d\n", __FILE__,
             __LINE__);
      printf("Unable to create mxArray.\n");
      return(EXIT_FAILURE);
  }
  memcpy((void *)(mxGetPr(pa2)), (void *)data, sizeof(data));

  pa3 = mxCreateString("MATLAB: the language of technical
                         computing");
```

```
if (pa3 == NULL) {
    printf("%s :  Out of memory on line %d\n", __FILE__,
            __LINE__);
    printf("Unable to create string mxArray.\n");
    return(EXIT_FAILURE);
}

status = matPutVariable(pmat, "LocalDouble", pa1);
if (status != 0) {
    printf("%s :  Error using matPutVariable on line %d\n",
            __FILE__, __LINE__);
    return(EXIT_FAILURE);
}

status = matPutVariableAsGlobal(pmat, "GlobalDouble", pa2);
if (status != 0) {
    printf("Error using matPutVariableAsGlobal\n");
    return(EXIT_FAILURE);
}

status = matPutVariable(pmat, "LocalString", pa3);
if (status != 0) {
    printf("%s :  Error using matPutVariable on line %d\n",
            __FILE__, __LINE__);
    return(EXIT_FAILURE);
}

/*
 * Ooops! we need to copy data before writing the array.  (Well,
  * ok, this was really intentional.) This demonstrates that
 * matPutVariable will overwrite an existing array in a MAT-file.
  */
memcpy((void *)(mxGetPr(pa1)), (void *)data, sizeof(data));
status = matPutVariable(pmat, "LocalDouble", pa1);
if (status != 0) {
    printf("%s :  Error using matPutVariable on line %d\n",
            __FILE__, __LINE__);
    return(EXIT_FAILURE);
}
```

```
/* Clean up. */
mxDestroyArray(pa1);
mxDestroyArray(pa2);
mxDestroyArray(pa3);

if (matClose(pmat) != 0) {
  printf("Error closing file %s\n",file);
  return(EXIT_FAILURE);
}

/* Re-open file and verify its contents with matGetVariable. */
pmat = matOpen(file, "r");
if (pmat == NULL) {
  printf("Error reopening file %s\n", file);
  return(EXIT_FAILURE);
}

/* Read in each array we just wrote. */
pa1 = matGetVariable(pmat, "LocalDouble");
if (pa1 == NULL) {
  printf("Error reading existing matrix LocalDouble\n");
  return(EXIT_FAILURE);
}
if (mxGetNumberOfDimensions(pa1) != 2) {
  printf("Error saving matrix: result does not have two
          dimensions\n");
  return(EXIT_FAILURE);
}

pa2 = matGetVariable(pmat, "GlobalDouble");
if (pa2 == NULL) {
  printf("Error reading existing matrix GlobalDouble\n");
  return(EXIT_FAILURE);
}
if (!(mxIsFromGlobalWS(pa2))) {
 printf("Error saving global matrix: result is not global\n");
  return(EXIT_FAILURE);
}

pa3 = matGetVariable(pmat, "LocalString");
```

```
    if (pa3 == NULL) {
      printf("Error reading existing matrix LocalString\n");
      return(EXIT_FAILURE);
    }

    status = mxGetString(pa3, str, sizeof(str));
    if(status != 0) {
        printf("Not enough space. String is truncated.");
        return(EXIT_FAILURE);
    }
    if (strcmp(str, "MATLAB: the language of technical
               computing")) {
      printf("Error saving string: result has incorrect
              contents\n");
      return(EXIT_FAILURE);
    }

    /* Clean up before exit. */
    mxDestroyArray(pa1);
    mxDestroyArray(pa2);
    mxDestroyArray(pa3);

    if (matClose(pmat) != 0) {
      printf("Error closing file %s\n",file);
      return(EXIT_FAILURE);
    }
    printf("Done\n");
    return(EXIT_SUCCESS);
  }
```

To produce an executable version of this example program, compile the file and link it with the appropriate library. Details on how to compile and link MAT-file programs on the various platforms are discussed in the section, “Compiling and Linking MAT-File Programs” on page 6-28.

Once you have compiled and linked your MAT-file program, you can run the stand-alone application you have just produced. This program creates a MAT-file, `mattest.mat`, that can be loaded into MATLAB. To run the application, depending on your platform, either double-click on its icon or enter `matcreat` at the system prompt.

```
matcreat
Creating file mattest.mat...
```

To verify that the MAT-file has been created, at the MATLAB prompt enter

```
whos -file mattest.mat
  Name                   Size           Bytes  Class

  GlobalDouble         3x3               72  double array (global)
  LocalDouble          3x3               72  double array
  LocalString          1x43              86  char array

Grand total is 61 elements using 230 bytes
```

Reading a MAT-File in C

This sample program illustrates how to use the library routines to read and diagnose a MAT-file.

```
/*
 * MAT-file diagnose program
 *
 * Calling syntax:
 *
 *   matdgns <matfile.mat>
 *
 * It diagnoses the MAT-file named <matfile.mat>.
 *
 * This program demonstrates the use of the following functions:
 *
 *  matClose
 *  matGetDir
 *  matGetNextVariable
 *  matGetNextVariableInfo
 *  matOpen
 *
 *  Copyright (c) 1984-2000 The MathWorks, Inc.
 *  $Revision: 1.8 $
 */

#include <stdio.h>
```

```
#include <stdlib.h>
#include "mat.h"

int diagnose(const char *file) {
  MATFile *pmat;
  char **dir;
  const char *name;
  int ndir;
  int i;
  mxArray *pa;

  printf("Reading file %s...\n\n", file);

  /* Open file to get directory. */
  pmat = matOpen(file, "r");
  if (pmat == NULL) {
    printf("Error opening file %s\n", file);
    return(1);
  }

  /* Get directory of MAT-file. */
  dir = matGetDir(pmat, &ndir);
  if (dir == NULL) {
    printf("Error reading directory of file %s\n", file);
    return(1);
  } else {
    printf("Directory of %s:\n", file);
    for (i=0; i < ndir; i++)
      printf("%s\n", dir[i]);
  }
  mxFree(dir);

  /* In order to use matGetNextXXX correctly, reopen file to
     read in headers. */
  if (matClose(pmat) != 0) {
    printf("Error closing file %s\n",file);
    return(1);
  }
  pmat = matOpen(file, "r");
  if (pmat == NULL) {
```

```
  printf("Error reopening file %s\n", file);
  return(1);
}

/* Get headers of all variables. */
printf("\nExamining the header for each variable:\n");
for (i=0; i < ndir; i++) {
  pa = matGetNextVariableInfo(pmat, &name);
  if (pa == NULL) {
    printf("Error reading in file %s\n", file);
    return(1);
  }
  /* Diagnose header pa. */
 printf("According to its header, array %s has %d dimensions\n",
        name, mxGetNumberOfDimensions(pa));
  if (mxIsFromGlobalWS(pa))
    printf("  and was a global variable when saved\n");
  else
    printf("  and was a local variable when saved\n");
  mxDestroyArray(pa);
}

/* Reopen file to read in actual arrays. */
if (matClose(pmat) != 0) {
  printf("Error closing file %s\n",file);
  return(1);
}
pmat = matOpen(file, "r");
if (pmat == NULL) {
  printf("Error reopening file %s\n", file);
  return(1);
}

/* Read in each array. */
printf("\nReading in the actual array contents:\n");
for (i=0; i<ndir; i++) {
  pa = matGetNextVariable(pmat, &name);
  if (pa == NULL) {
    printf("Error reading in file %s\n", file);
    return(1);
```

```
    }
    /*
     * Diagnose array pa
     */
    printf("According to its contents, array %s has %d
            dimensions\n", name, mxGetNumberOfDimensions(pa));
    if (mxIsFromGlobalWS(pa))
      printf("  and was a global variable when saved\n");
    else
      printf("  and was a local variable when saved\n");
    mxDestroyArray(pa);
  }

  if (matClose(pmat) != 0) {
    printf("Error closing file %s\n",file);
    return(1);
  }
  printf("Done\n");
  return(0);
}


int main(int argc, char **argv)
{
  int result;

  if (argc > 1)
    result = diagnose(argv[1]);
  else{
    result = 0;
    printf("Usage: matdgns <matfile>");
    printf(" where <matfile> is the name of the MAT-file");
    printf(" to be diagnosed\n");
  }
  return (result==0) ? EXIT_SUCCESS : EXIT_FAILURE;
}
```

After compiling and linking this program, you can view its results.

```
matdgns mattest.mat
Reading file mattest.mat...

Directory of mattest.mat:
GlobalDouble
LocalString
LocalDouble

Examining the header for each variable:
According to its header, array GlobalDouble has 2 dimensions
  and was a global variable when saved
According to its header, array LocalString has 2 dimensions
  and was a local variable when saved
According to its header, array LocalDouble has 2 dimensions
  and was a local variable when saved

Reading in the actual array contents:
According to its contents, array GlobalDouble has 2 dimensions
  and was a global variable when saved
According to its contents, array LocalString has 2 dimensions
  and was a local variable when saved
According to its contents, array LocalDouble has 2 dimensions
  and was a local variable when saved
Done
```

Creating a MAT-File in Fortran

This example creates a MAT-file, `matdemo.mat`.

```
C     matdemo1.f
C     This is a simple program that illustrates how to call the
C     MATLAB MAT-file functions from a Fortran program.  This
C     demonstration focuses on writing MAT-files.
C
C     matdemo1 - Create a new MAT-file from scratch.
C
C     Copyright (c) 1984-2000 The MathWorks, Inc.
C     $Revision: 1.9 $
```

```
      program matdemo1
C-----------------------------------------------------------------
C     (pointer) Replace integer by integer*8 on the DEC alpha
C     64-bit platform
C
      integer matOpen, mxCreateDoubleMatrix, mxCreateString
      integer matGetVariable, mxGetPr
      integer mp, pa1, pa2, pa3, pa0
C-----------------------------------------------------------------

C     Other variable declarations here.
      integer status, matClose, mxIsFromGlobalWS
      integer matPutVariable, matPutVariableAsGlobal
      integer matDeleteVariable
      double precision dat(9)
      data dat / 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0 /

C     Open MAT-file for writing.
      write(6,*) 'Creating MAT-file matdemo.mat ...'
      mp = matOpen('matdemo.mat', 'w')
      if (mp .eq. 0) then
         write(6,*) 'Can''t open ''matdemo.mat'' for writing.'
         write(6,*) '(Do you have write permission in this
                       directory?)'
         stop
      end if

C     Create variables.
      pa0 = mxCreateDoubleMatrix(3,3,0)
      call mxCopyReal8ToPtr(dat, mxGetPr(pa0), 9)

      pa1 = mxCreateDoubleMatrix(3,3,0)

      pa2 = mxCreateString('MATLAB: The language of computing')

      pa3 = mxCreateString('MATLAB: The language of computing')

      status = matPutVariableAsGlobal(mp, 'NumericGlobal', pa0)
      if (status .ne. 0) then
```

```
             write(6,*) 'matPutVariableAsGlobal ''Numeric Global''
                          failed'
             stop
          end if
          status = matPutVariable(mp, 'Numeric', pa1)
          if (status .ne. 0) then
             write(6,*) 'matPutVariable ''Numeric'' failed'
             stop
          end if
          status = matPutVariable(mp, 'String', pa2)
          if (status .ne. 0) then
             write(6,*) 'matPutVariable ''String'' failed'
             stop
          end if
          status = matPutVariable(mp, 'String2', pa3)
          if (status .ne. 0) then
             write(6,*) 'matPutVariable ''String2'' failed'
             stop
          end if

    C     Whoops! Forgot to copy the data into the first matrix --
    C     it is now blank.  Well, ok, this was deliberate.  This
    C     demonstrates that matPutVariable will overwrite existing
    C     matrices.

          call mxCopyReal8ToPtr(dat, mxGetPr(pa1), 9)
          status = matPutVariable(mp, 'Numeric', pa1)
          if (status .ne. 0) then
             write(6,*) 'matPutVariable ''Numeric'' failed 2nd time'
             stop
          end if

    C     We will delete String2 from the MAT-file.

          status = matDeleteVariable(mp, 'String2')
          if (status .ne. 0) then
             write(6,*) 'matDeleteVariable ''String2'' failed'
             stop
          end if
```

```
C     Finally, read back in MAT-file to make sure we know what
C     we put in it.

      status = matClose(mp)
      if (status .ne. 0) then
         write(6,*) 'Error closing MAT-file'
         stop
      end if

      mp = matOpen('matdemo.mat', 'r')
      if (mp .eq. 0) then
         write(6,*) 'Can''t open ''matdemo.mat'' for reading.'
         stop
      end if

      pa0 = matGetVariable(mp, 'NumericGlobal')
      if (mxIsFromGlobalWS(pa0) .eq. 0) then
        write(6,*) 'Invalid non-global matrix written to MAT-file'
         stop
      end if

      pa1 = matGetVariable(mp, 'Numeric')
      if (mxIsNumeric(pa1) .eq. 0) then
         write(6,*) 'Invalid non-numeric matrix written to
                     MAT-file'
         stop
      end if


      pa2 = matGetVariable(mp, 'String')
      if (mxIsString(pa2) .eq. 0) then
        write(6,*) 'Invalid non-string matrix written to MAT-file'
         stop
      end if

      pa3 = matGetVariable(mp, 'String2')
      if (pa3 .ne. 0) then
         write(6,*) 'String2 not deleted from MAT-file'
         stop
      end if
```

```
C     Clean up memory.
      call mxDestroyArray(pa0)
      call mxDestroyArray(pa1)
      call mxDestroyArray(pa2)
      call mxDestroyArray(pa3)

      status = matClose(mp)
      if (status .ne. 0) then
         write(6,*) 'Error closing MAT-file'
         stop
      end if

      write(6,*) 'Done creating MAT-file'
      stop
      end
```

Once you have compiled and linked your MAT-file program, you can run the stand-alone application you have just produced. This program creates a MAT-file, `matdemo.mat`, that can be loaded into MATLAB. To run the application, depending on your platform, either double-click on its icon or enter `matdemo1` at the system prompt.

```
matdemo1
Creating MAT-file matdemo.mat ...
Done creating MAT-file
```

To verify that the MAT-file has been created, at the MATLAB prompt enter

```
 whos -file matdemo.mat
 Name           Size         Bytes  Class

 Numeric        3x3             72  double array
 String         1x33            66  char array

Grand total is 42 elements using 138 bytes
```

Note For an example of a Windows stand-alone program (not MAT-file specific), see `engwindemo.c` in the `<matlab>\extern\examples\eng_mat` directory.

Reading a MAT-File in Fortran

This sample program illustrates how to use the library routines to read in the MAT-file created by `matdemo1.f` and describe its contents.

```
C     matdemo2.f
C
C     This is a simple program that illustrates how to call the
C     MATLAB MAT-file functions from a Fortran program.  This
C     demonstration focuses on reading MAT-files. It reads in
C     the MAT-file created by matdemo1.f and describes its
C     contents.
C
C     Copyright (c) 1984-2000 The MathWorks, Inc.
C     $Revision: 1.11 $

      program matdemo2
C-------------------------------------------------------------
C     (pointer) Replace integer by integer*8 on the DEC Alpha
C     64-bit platform

      integer matOpen, matGetDir, matGetNextVariable
      integer matGetNextVariableInfo
      integer mp, dir, adir(100), pa
C-------------------------------------------------------------

C     Other variable declarations here.
      integer   mxGetM, mxGetN, matClose
      integer   ndir, i, stat
      character*32 names(100), name

C     Open file and read directory.
      mp = matOpen('matdemo.mat', 'r')
      if (mp .eq. 0) then
```

```
            write(6,*) 'Can''t open ''matdemo.mat''.'
            stop
         end if

         dir = matgetdir(mp, ndir)
         if (dir .eq. 0) then
            write(6,*) 'Can''t read directory.'
            stop
         endif

C        Copy pointer into an array of pointers.
         call mxCopyPtrToPtrArray(dir, adir, ndir)

C        Copy pointer to character string.
         do 20 i=1,ndir
            call mxCopyPtrToCharacter(adir(i), names(i), 32)
   20    continue

         write(6,*) 'Directory of Mat-file:'
         do 30 i=1,ndir
            write(6,*) names(i)
   30    continue

         stat = matClose(mp)
         if (stat .ne. 0) then
            write(6,*) 'Error closing ''matdemo.mat''.'
            stop
         end if

C        Reopen file and read full arrays.
         mp = matOpen('matdemo.mat', 'r')
         if (mp .eq. 0) then
            write(6,*) 'Can''t open ''matdemo.mat''.'
            stop
         end if

C        Get Information on first array in mat file.
         write(6,*) 'Getting Header info from first array.'
         pa = matGetVariableInfo(mp, names(1))
         write(6,*) 'Retrieved ', names(1)
```

```
      write(6,*) '  With size ', mxGetM(pa), '-by-', mxGetN(pa)
      call mxDestroyArray(pa)

      write(6,*) 'Getting Header info from next array.'
      pa = matGetNextVariableInfo(mp, name)
      write(6,*) 'Retrieved ', name
      write(6,*) '  With size ', mxGetM(pa), '-by-', mxGetN(pa)
      call mxDestroyArray(pa)

C     Read directory.
      write(6,*) 'Getting rest of array contents:'
      pa = matGetNextVariable(mp, name)

C     Copy name to character string.
      do while (pa .ne. 0)
         i=mxGetM(pa)
         write(*, *) i
         write(6,*) 'Retrieved ', name
        write(6,*) '  With size ', mxGetM(pa), '-by-', mxGetN(pa)
         call mxDestroyArray(pa)
         pa = matGetNextVariable(mp, name)
      end do

      stat = matClose(mp)
      if (stat .ne. 0) then
         write(6,*) 'Error closing ''matdemo.mat''.'
         stop
      end if
      stop
      end
```

After compiling and linking this program, you can view its results.

```
matdemo2
Directory of Mat-file:
String
Numeric
Getting full array contents:
  1
Retrieved String
  With size   1-by-  33
  3
Retrieved Numeric
  With size   3-by-  3
```

Compiling and Linking MAT-File Programs

This section describes the steps required to compile and link MAT-file programs on UNIX and Windows systems. It begins by looking at a special consideration for compilers that do not mask floating-point exceptions. Topics covered are:

- "Masking Floating Point Exceptions"
- "Compiling and Linking on UNIX" on page 6-29
- "Compiling and Linking on Windows" on page 6-30

Masking Floating Point Exceptions

Certain mathematical operations can result in nonfinite values. For example, division by zero results in the nonfinite IEEE value, `inf`. A floating-point exception occurs when such an operation is performed. Because MATLAB uses an IEEE model that supports nonfinite values such as `inf` and `NaN`, MATLAB disables, or *masks*, floating-point exceptions.

Some compilers do not mask floating-point exceptions by default. This causes MAT-file applications built with such compilers to terminate when a floating-point exception occurs. Consequently, you need to take special precautions when using these compilers to mask floating-point exceptions so that your MAT-file application will perform properly.

Note MATLAB-based applications should never get floating-point exceptions. If you do get a floating-point exception, verify that any third party libraries that you link against do not enable floating-point exception handling.

The only compiler and platform on which you need to mask floating-point exceptions is the Borland C++ compiler on Windows.

Borland C++ Compiler on Windows

To mask floating-point exceptions when using the Borland C++ compiler on the Windows platform, you must add some code to your program. Include the following at the beginning of your `main()` or `WinMain()` function, before any calls to MATLAB API functions.

```
#include <float.h>
    .
    .
    .
_control87(MCW_EM,MCW_EM);
    .
    .
    .
```

Compiling and Linking on UNIX

Under UNIX at runtime, you must tell the system where the API shared libraries reside. These sections provide the necessary UNIX commands depending on your shell and system architecture.

Setting Runtime Library Path

In C shell, the command to set the library path is

```
setenv LD_LIBRARY_PATH <matlab>/extern/lib/$Arch:$LD_LIBRARY_PATH
```

In Bourne shell, the commands to set the library path are

```
LD_LIBRARY_PATH=<matlab>/extern/lib/$Arch:$LD_LIBRARY_PATH
export LD_LIBRARY_PATH
```

where `<matlab>` is the MATLAB root directory and `$Arch` is your system architecture (`alpha`, `glnx86`, `sgi`, `sol2`, `hp700`, or `ibm_rs`).

Note that the environment variable (LD_LIBRARY_PATH in this example) varies on several platforms. The following table lists the different environment variable names you should use on these systems.

Table 6-5: Environment Variable Names

Architecture	Environment Variable
HP700	SHLIB_PATH
IBM RS/6000	LIBPATH

It is convenient to place these commands in a startup script such as `~/.cshrc` for C shell or `~/.profile` for Bourne shell.

Using the Options File

MATLAB provides an options file, matopts.sh, that lets you use the mex script to easily compile and link MAT-file applications. For example, to compile and link the matcreat.c example, you can use

```
mex -f <matlab>/bin/matopts.sh <pathname>/matcreat.c
```

where <pathname> specifies the complete path to the specified file.

If you need to modify the options file for your particular compiler or platform, use the -v switch to view the current compiler and linker settings and then make the appropriate changes in a local copy of the matopts.sh file.

Compiling and Linking on Windows

To compile and link Fortran or C MAT-file programs, use the mex script with a MAT options file. Table 1-2, Options Files, on page 1-16 lists the MAT options files included in this release. All of these options files are located in <matlab>\bin\win32\mexopts.

As an example, to compile and link the stand-alone MAT application matcreat.c on Windows using MSVC (Version 5.0), use

```
mex -f <matlab>\bin\win32\mexopts\msvc50engmatopts.bat <pathname>\matcreat.c
```

where <pathname> specifies the complete path to the specified file. If you need to modify the options file for your particular compiler, use the -v switch to view the current compiler and linker settings and then make the appropriate changes in a local copy of the options file.

7

COM and DDE Support

Component Object Model, or COM, is a set of object-oriented technologies and tools that allow software developers to integrate application-specific components from different vendors into their own application solution. COM support in MATLAB enables you to interact with contained controls or server processes, or to configure MATLAB as a computational server controlled by your client application programs.

Dynamic Data Exchange, or DDE, is a feature of Microsoft Windows that allows two programs to share data or send commands directly to each other. MATLAB provides functions that use this data exchange to enable access between MATLAB and other Windows applications in a wide range of contexts.

Introducing MATLAB COM Integration

The *Component Object Model*, or COM, provides a framework for integrating reusable, binary software components into an application. Because components are implemented with compiled code, the source code may be written in any of the many programming languages that support COM. Upgrades to applications are simplified, as components can be simply swapped without the need to recompile the entire application. In addition, a component's location is transparent to the application, so components may be relocated to a separate process or even a remote system without having to modify the application.

Using COM, developers and end users can select application-specific components produced by different vendors and integrate them into a complete application solution. For example, a single application may require database access, mathematical analysis, and presentation-quality business graphs. Using COM, a developer may choose a database-access component by one vendor, a business graph component by another, and integrate these into a mathematical analysis package produced by yet a third.

This section covers:

Concepts and Terminology

Here are some terms that you should be familiar with when reading this chapter.

COM Objects

A COM object is an instance of a component object class, or component. COM enforces complete encapsulation of the object, preventing its data and implementation from being accessed directly. The methods of an object must be accessed through *interfaces*. (See "COM Interfaces", below).

COM objects operate either as *in-process* or *out-of-process* servers. When in-process, the objects are implemented in DLL files, and are loaded into the client application's address space. No interprocess communication is required. For out-of-process, the objects are in EXE files, and run in a separate server process and the application must communicate with them across process boundaries.

Objects may also reside on a remote system connected by a network. In this case, the *Distributed Component Object Model*, or DCOM, is used.

COM Interfaces

An interface provides access to the methods of a COM object. In fact, the only way to access a COM object is through an interface. Through certain methods (`get` and `set`), you also gain access to the object's properties. An interface does not contain any method implementation; it just serves as a pointer to the methods within the object.

Interfaces usually group a set of logically related methods together. An object may, and frequently does, *expose* (or make available) more than one interface. In order to use any COM object, you must learn about which interfaces it supports, and the methods, properties, and events implemented by the object. The COM object's vendor provides this information.

Automation

Automation is a simpler method of communication between COM clients and servers. It uses a single standard COM interface called *IDispatch*. This interface enables the client to find out about and invoke or access methods and properties supported by a COM object. A client and server that communicate using IDispatch are known as an Automation client and Automation server.

IDispatch is the only interface supported by MATLAB. Custom and dual interfaces are not supported.

Controls

A control is an Automation component that has a user interface, enabling it to respond to actions taken by the user. A window that has **OK** and **Cancel** buttons is an example of a control. A control runs in the process address space of its client application. The client, in this case, is said to be a control *container* since it contains the control.

Because a control communicates through Automation, the client application is able to directly invoke its methods and access its properties. The control must also be able to communicate back to the client. This enables it to notify the client application of an event occurence, such as a mouse click.

Overview of MATLAB COM Support

You can configure MATLAB to either control or be controlled by other COM components. When MATLAB controls another component, MATLAB is the *client*, and the other component is the *server*. When MATLAB is controlled by another component, it is acting as the server.

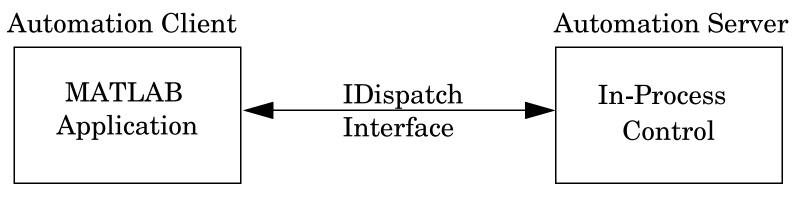
MATLAB supports four different COM client-server configurations:

- "MATLAB Client and In-Process (Control) Server" on page 7-4
- "MATLAB Client and Out-of-Process Server" on page 7-5
- "Client Application and MATLAB Automation Server" on page 7-6
- "Client Application and MATLAB Engine Server" on page 7-6

The first three configurations communicate using an Automation interface that the client program, in turn, accesses via a COM interface called IDispatch. The last MATLAB configuration uses a faster, custom COM interface called IEngine.

MATLAB Client and In-Process (Control) Server

You would set up the configuration shown here when you want to interact with a COM control. Controls are application components that can be both visually and programmatically integrated into a control container, such as a MATLAB figure window. Some examples of useful controls are the Microsoft Internet Explorer Web Browser control, the Microsoft Windows Communications control for serial port access, and the graphical user interface controls delivered with the Visual Basic development environment.



Your MATLAB application is the Automation client. It "contains" the control, because the control runs in the MATLAB process address space rather than as a separate process. The COM control runs as the Automation server.

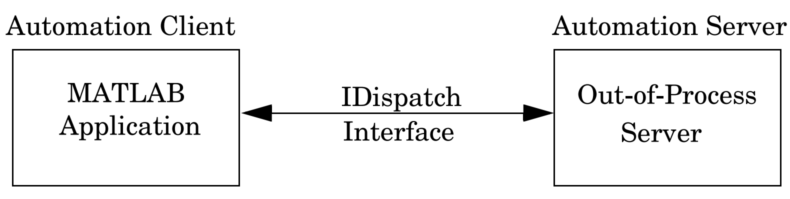
You create the control using the MATLAB `actxcontrol` function. This function creates a MATLAB figure window and positions the graphical user interface of the control within that window. Users commonly interact with this interface using GUI menus, buttons, etc. Doing so often triggers an *event* that gets communicated from the control to its client MATLAB application. The client then decides what to do about the event and responds appropriately.

MATLAB ships with a very simple sample ActiveX control that draws a circle on the screen and displays some text. This allows MATLAB users to try out MATLAB COM control support with a known control. For more information, see "MATLAB Sample Control" on page 7-30.

To learn more about working with MATLAB as a client, see "MATLAB COM Client Support" on page 7-8 and "Additional COM Client Information" on page 7-32

MATLAB Client and Out-of-Process Server

This configuration runs the server in a separate process from that of the client application. The server is no longer contained by the client process, and it does not run as part of MATLAB in a figure window. Any user interface displayed is in a separate window. Examples of local servers are Microsoft Excel and Microsoft Word.



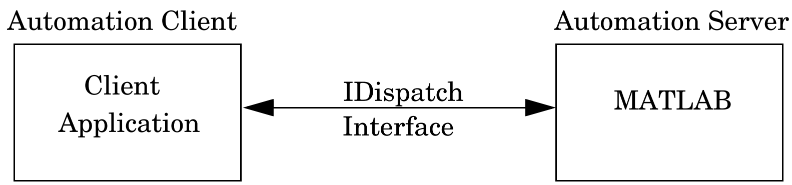
The client and server use Automation to communicate through a COM IDispatch interface. Since the server runs in a separate process, it may be run on either a local or remote system. There is currently no support for events generated from Automation servers.

The MATLAB `actxserver` function creates a COM Automation server and returns a COM object for the server's default interface.

To learn more about working with MATLAB as a client, see "MATLAB COM Client Support" on page 7-8 and "Additional COM Client Information" on page 7-32

Client Application and MATLAB Automation Server

MATLAB operates as the Automation server in this configuration. It can be launched and controlled by any Windows program that can be an *Automation Controller*. Some examples of applications that can be Automation Controllers are Microsoft Excel, Microsoft Access, Microsoft Project, and many Visual Basic and Visual C++ programs.



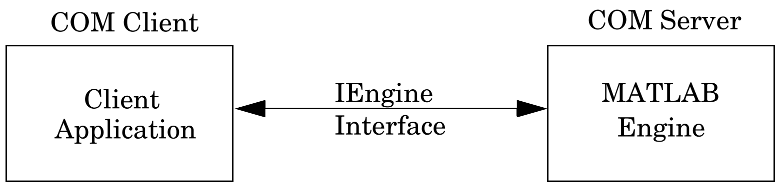
MATLAB Automation server capabilities include the ability to execute commands in the MATLAB workspace, and to get and put matrices directly from and into the workspace. You can launch a MATLAB server to run in either a dedicated or shared mode. You also have the option of running it on a local or remote system.

Note Because VBScript client programs require an Automation interface to communicate with servers, this is the only configuration that will support a VBScript client.

To learn more about working with MATLAB Automation servers, see "MATLAB Automation Server Support" on page 7-36 and "Additional Automation Server Information" on page 7-41.

Client Application and MATLAB Engine Server

MATLAB provides a faster, custom interface called *IEngine* for client applications written in C, C++, or Fortran. MATLAB uses this COM interface to communicate between the client application and the *MATLAB Engine* running as a COM server. A library of functions is provided with MATLAB that enables you to start and end the server process, and to send commands to be processed by MATLAB.



To learn more about the MATLAB Engine and the functions provided in its C and Fortran libraries, see Chapter 4, "Calling MATLAB from C and Fortran Programs".

MATLAB COM Client Support

This section introduces the MATLAB functions you need to create, manipulate, and destroy COM control and server objects. These objects are instances of the MATLAB `COM` class. The topics covered here are

- "Creating COM Objects" on page 7-8
- "Object Properties" on page 7-10
- "Invoking Methods" on page 7-17
- "COM Control Events" on page 7-20
- "Identifying Objects" on page 7-23
- "Saving Your Work" on page 7-24
- "Releasing COM Interfaces and Objects" on page 7-25
- "Writing Event Handlers" on page 7-26
- "Examples of MATLAB as an Automation Client" on page 7-30

MATLAB includes three demos showing how to use the COM client interface. To run any of the demos, click on the **Demos** tab in the MATLAB Help Browser. Then click to expand the folder called Automation Client Interface (COM).

Creating COM Objects

To create a COM Automation control or server in MATLAB, use one of the two functions shown here.

Function	Description
`actxcontrol`	Create a COM Automation control
`actxserver`	Create a COM Automation server

Both of these functions require an argument called the `ProgID`. This is a string that is defined by the vendor and can be obtained from the vendor's documentation. For example, the `ProgID` for MATLAB is `matlab.application`.

`actxcontrol` and `actxserver` create an object that is an instance of the MATLAB `com` class. These functions return a handle to the object that you use to reference the object in other COM function calls.

This example creates a COM server application running Excel. The returned handle is assigned to h:

```
h = actxserver('excel.application')
h =
    COM.excel.application
```

Getting Interfaces from an Object

Once an object has been created, you can obtain interfaces from it, either by assigning an Interface property from the object or by invoking certain methods on it.

This example creates a Workbooks interface to the Excel application using the get function. The get function returns an interface handle that is assigned here to w. Use this handle in other COM function calls as a reference to this interface:

```
w = get(h, 'Workbooks')
w =
   Interface.excel.application.Workbooks
```

Repositioning a Control

When MATLAB creates a COM control, it places the control figure inside of a MATLAB figure window. You can create the figure window yourself and specify the control's initial position in the window with the actxcontrol function:

```
f = figure ('pos', [0 0 300 300]);
sample = actxcontrol ('mwsamp.mwsampctrl.2', [0 0 200 200], f);
```

Once a control has been created, you can change its shape and position in the window with the move function.

Function	Description
move	Resize or reposition a control in its parent window

Observe what happens to the object in your figure window when you specify new origin coordinates (70, 120) and a new height dimension (100):

```
move(sample, [70 120 200 100]);
```

Object Properties

Use these MATLAB functions to get, set, and modify the properties of a COM object or interface, or to add your own custom properties.

Function	Description
addproperty	Add a custom property to a COM object
deleteproperty	Remove a custom property from a COM object
get	List one or more properties and their values
inspect	Display graphical interface to list and modify property values
propedit	Display the control's built-in property page
set	Set a property on an interface

Getting the Value of a Property

The get function returns information on one or more properties belonging to a COM object or interface. Use get with only the handle argument, and MATLAB returns a list of all properties for the object, and their values:

```
h = actxserver('excel.application');

get(h)
ans =
   Application: [1x1 Interface.excel.application.Application]
       Creator: 'xlCreatorCode'
        Parent: [1x1 Interface.excel.application.Parent]
    ActiveCell: []
   ActiveChart: [1x50 char]
 ActivePrinter: '\\PRINTERS\Kunkel on Ne01:'
   ActiveSheet: []
  ActiveWindow: []
        AddIns: [1x1 Interface.excel.application.AddIns]
          :
          :
```

To return the value of just one property, specify the property name in the argument list:

```
get(h, 'OrganizationName')
ans =
   The MathWorks, Inc.
```

Property names are not case sensitive and may also be abbreviated, as long as you include enough letters in the name to make it unambiguous. You can use `'org'` in place of the full `'OrganizationName'` property name used above:

```
get(h, 'org')
ans =
   The MathWorks, Inc.
```

Setting the Value of a Property

Use `set` to change the value of a property, specifying both the property name and new value:

```
set(h, 'DefaultFilePath', 'C:\ExcelWork');
```

You can change more than one property at a time using this syntax:

```
set(h, 'prop1', 'value1', 'prop2', 'value2', ...);
```

For example, to set the `Label` and `Radius` fields of COM object h, use

```
set(h, 'Label', 'Click to fire event', 'Radius', 40);
```

Get and Set on Multiple Objects

You can use the `get` and `set` functions on more than one object at a time by putting the object handles into a vector and then operating on the vector.

This example creates a vector of handles to four Microsoft Calendar objects. It then modifies the Day property of all the objects in one operation by invoking `set` on the vector.

```
h1 = actxcontrol('mscal.calendar', [0 200 250 200]);
h2 = actxcontrol('mscal.calendar', [250 200 250 200]);
h3 = actxcontrol('mscal.calendar', [0 0 250 200]);
h4 = actxcontrol('mscal.calendar', [250 0 250 200]);
H = [h1 h2 h3 h4];
```

```
set(H, 'Day', 23)
get(H, 'Day')
ans =
    [23]
    [23]
    [23]
    [23]
```

Using Enumerated Values for Properties

Enumeration makes examining and changing properties easier because each possible value for the property is given a string to represent it. For example, one of the values for the `DefaultSaveFormat` property in an Excel application is `xlUnicodeText`. This is much easier to remember than a numeric value like `57`.

Finding All Enumerated Properties. The MATLAB COM `get` and `set` functions support enumerated values for properties for those applications that provide them. To see which properties use enumerated types, use the `set` function with just the object handle argument:

```
h = actxserver('excel.application');

set(h)
ans =
                     Creator: {'xlCreatorCode'}
           ConstrainNumeric: {}
       CopyObjectsWithCells: {}
                      Cursor: {4x1 cell}
                 CutCopyMode: {2x1 cell}
                           .
                           .
```

MATLAB displays the properties that accept enumerated types as nonempty cell arrays. Properties for which there is a choice of settings are displayed as a multirow cell array, with one row per setting (see `Cursor` in the example above). Properties for which there is only one possible setting are displayed as a one row cell array (see `Creator`, above).

To display the current values of these properties, use `get` with just the object handle argument:

```
get(h)
                    Creator: 'xlCreatorCode'
            ConstrainNumeric: 0
        CopyObjectsWithCells: 1
                     Cursor: 'xlDefault'
                CutCopyMode: ''
                          .
                          .
```

Setting an Enumerated Value. To list all possible enumerated values for a specific property, use `set` with the property name argument. The output is a cell array of strings, one string for each possible setting of the specified property:

```
set(h, 'Cursor')
ans =
    'xlIBeam'
    'xlDefault'
    'xlNorthwestArrow'
    'xlWait'
```

To set the value of a property to an enumerated type, use `set` with the property name and enumerated value. (You can also set these properties to an integer value.) Note that you can abbreviate the enumeration string, as in the second line shown below. You must use enough letters in the string to make it unambiguous. The enumeration string is also case-insensitive.

Either of the following commands sets the `Cursor` to a `NorthwestArrow` type:

```
set(h, 'Cursor', 'xlNorthwestArrow')
set(h, 'Cursor', 'xln')
```

Use `get` with the property name argument to read the value of the property you have just set:

```
get(h, 'Cursor')
ans =
   xlNorthwestArrow
```

Using the Property Inspector

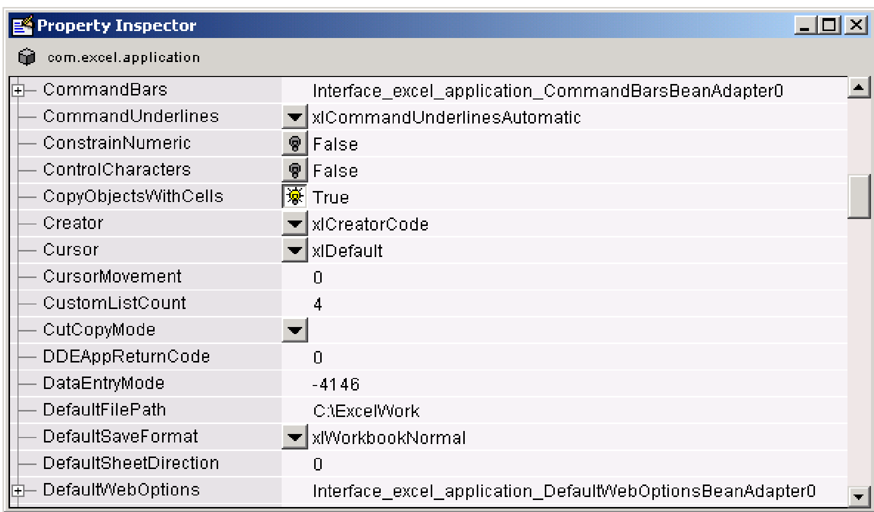
MATLAB also provides a graphical user interface to display and modify properties. You can open the Property Inspector by either of these two methods:

- Invoke the `inspect` function from the MATLAB command line
- Double-click on the object in the Workspace Browser

Using the same Excel server, invoke the `inspect` function to display a new window showing the server object's properties:

```
inspect(h)
```

Scroll down until you see the `DefaultFilePath` property that you just changed. It should read `C:\ExcelWork`.



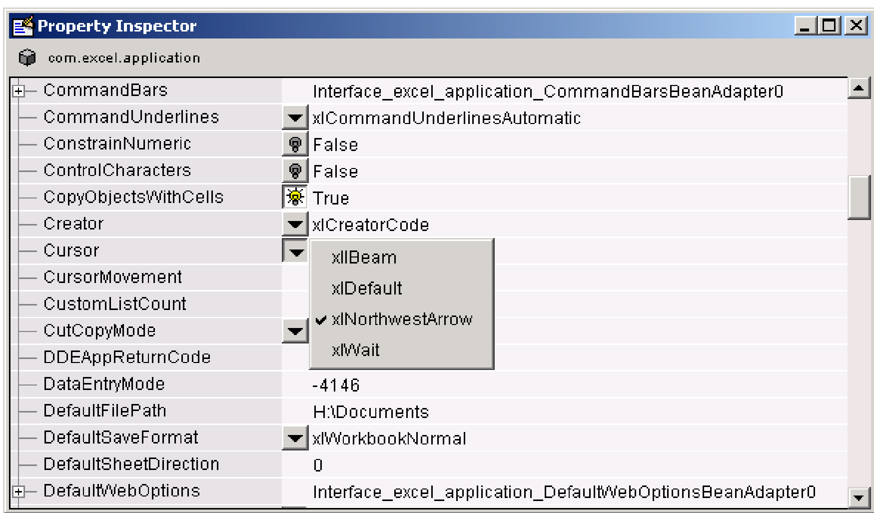
Using the Property Inspector, change `DefaultFilePath` once more, this time to `C:\MyWorkDirectory`. To do this, click on the property name at the left and then enter the new value at the right.

Now check this field in the MATLAB command window and confirm that it has changed:

```
get(h, 'DefaultFilePath')
ans =
   C:\MyWorkDirectory
```

Note If you modify properties at the MATLAB command line, you must refresh the Property Inspector window to see the change reflected there. Refresh the Property Inspector by reinvoking `inspect` on the object.

Using the Property Inspector on Enumerated Values. Properties that accept enumerated values are marked by a ▼ button in the Property Inspector window. The window shown below displays four enumerated values for the `Cursor` property. The current value, `xlNorthwestArrow`, is indicated by a checkmark.



To change a property's value using the Property Inspector, simply click on the ▼ button to display the options for that property, and then click on the desired value.

Custom Properties

You can attach your own properties to a control using the `addproperty` function. The syntax shown here creates a custom property for control, `h`:

```
addproperty(h, 'propertyName')
```

This example creates the `mwsamp` control, adds a new property called `Position` to it, and assigns the value `[200 120]` to that property:

```
h = actxcontrol('mwsamp.mwsampctrl.2', [200 120 200 200]);
addproperty(h, 'Position');
set(h, 'Position', [200 120]);
```

Use `get` to list all properties of control, `h`. You see that the new `Position` property has been added:

```
get(h)
ans =
     Label: 'Label'
    Radius: 20
  Position: [200 120]

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

To remove custom properties from a control, use `deleteproperty` with the following syntax:

```
deleteproperty(h, 'propertyName')
```

For example, delete the `Position` property that you just created, and use `get` to show that it no longer exists:

```
deleteproperty(h, 'Position');

get(h)
     Label: 'Label'
    Radius: 20
```

Invoking Methods

Use these MATLAB functions to find out what methods a COM object has and to invoke any COM or MATLAB method on that object.

Function	Description
invoke	Invoke a method or display a list of methods and types
methods	List all method names for the control or server
methodsview	GUI interface to list information on all methods and types

The invoke function either invokes a method or returns information on the methods implemented for a COM object or available through an interface. Create a Microsoft Calendar control and use invoke without arguments to return a list of all methods for the control:

```
cal = actxcontrol('mscal.calendar', [0 0 500 500])
cal =
   COM.mscal.calendar

invoke(cal)
   NextDay = HRESULT NextDay(handle)
   NextMonth = HRESULT NextMonth(handle)
   NextWeek = HRESULT NextWeek(handle)
   NextYear = HRESULT NextYear(handle)
   PreviousDay = HRESULT PreviousDay(handle)
   PreviousMonth = HRESULT PreviousMonth(handle)
   PreviousWeek = HRESULT PreviousWeek(handle)
   PreviousYear = HRESULT PreviousYear(handle)
   Refresh = HRESULT Refresh(handle)
   Today = HRESULT Today(handle)
   AboutBox = HRESULT AboutBox(handle)
```

You can invoke any of these methods on the object using the arguments shown in the returned method list. The following example reads today's date and then advances it by 50 years using the NextYear method in a loop.

To get today's date, type

```
sprintf('%d/%d/%d', cal.Month, cal.Day, cal.Year)
ans =
   11/5/2001
```

Now, use `NextYear` to advance the date, and then verify the results:

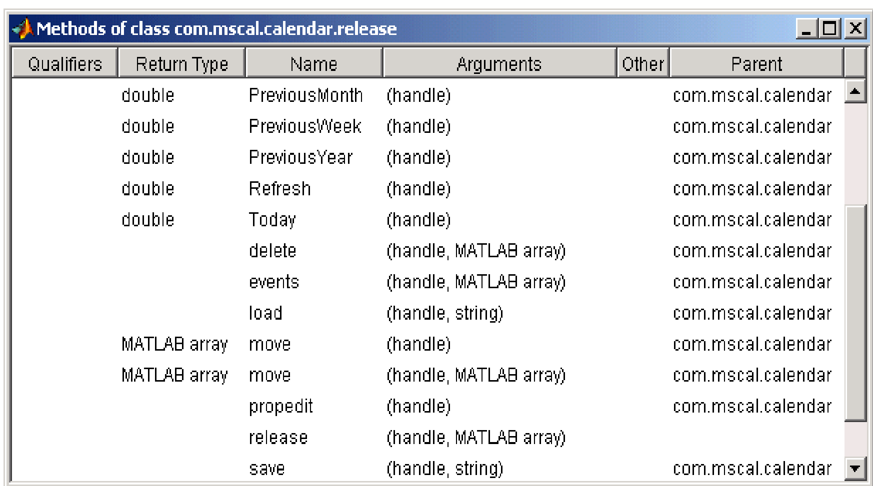
```
for k=1:50
   NextYear(cal);
end

sprintf('%d/%d/%d', cal.Month, cal.Day, cal.Year)
ans =
   11/5/2051
```

Graphical Methods Display

MATLAB also has a graphical user interface to view the methods of an object along with related fields of information. Type

```
methodsview(h)
```

to bring up a window such as the one shown here.


Methods of class com.mscal.calendar.release

Qualifiers	Return Type	Name	Arguments	Other	Parent
	double	PreviousMonth	(handle)		com.mscal.calendar
	double	PreviousWeek	(handle)		com.mscal.calendar
	double	PreviousYear	(handle)		com.mscal.calendar
	double	Refresh	(handle)		com.mscal.calendar
	double	Today	(handle)		com.mscal.calendar
		delete	(handle, MATLAB array)		com.mscal.calendar
		events	(handle, MATLAB array)		com.mscal.calendar
		load	(handle, string)		com.mscal.calendar
	MATLAB array	move	(handle)		com.mscal.calendar
	MATLAB array	move	(handle, MATLAB array)		com.mscal.calendar
		propedit	(handle)		com.mscal.calendar
		release	(handle, MATLAB array)		
		save	(handle, string)		com.mscal.calendar

Methods that return void show no Return Type in the display.

Returning Multiple Output Arguments

If you know that a server function supports multiple outputs, you can return any or all of those outputs to a MATLAB client. Specify the output arguments within brackets on the left-hand side of the equation. This gives the MATLAB client code access to any values returned by the server function.

The syntax shown here shows a server function being called by the MATLAB client. The function's return value is shown as `retval`. The function's output arguments (`out1`, `out2`, `...`) follow this.

```
[retval out1 out2 ...] = functionname(handle, in1, in2, ...);
```

MATLAB makes use of the pass by reference capabilities in COM to implement this feature. Note that pass by reference is a COM feature. It is not available in MATLAB at this time.

Argument Callouts in Error Messages

When a MATLAB client sends a command with an invalid argument to a COM server application, the server sends back an error message similar to that shown here, identifying the invalid argument. Be careful when interpreting the argument callout in this type of message.

```
PutFullMatrix(handle, 'a', 'base', 7, [5 8]);
??? Error: Type mismatch, argument 3.
```

In the `PutFullMatrix` command shown above, it is the fourth argument, `7`, that is invalid. (It is scalar and not the expected array data type.) However, the error message identifies the failing argument as `argument 3`.

This is because the COM server receives only the last four of the arguments shown in the MATLAB code. (The `handle` argument merely identifies the server. It does not get passed to the server). So the server sees `'a'` as the first argument, and the invalid argument, `7`, as the third.

As another example, submitting the same command with the `invoke` function makes the invalid argument fifth in the MATLAB client code. Yet the server still identifies it as `argument 3` because neither of the first two arguments are seen by the server.

```
invoke(handle, 'PutFullMatrix', 'a', 'base', 7, [5 8]);
??? Error: Type mismatch, argument 3.
```

COM Control Events

Use these MATLAB functions on a control to find out what events the control generates, and to enable or disable handler routines to respond to those events.

Function	Description
`eventlisteners`	Return a list of events attached to listeners
`events`	List all events registered for a control
`registerevent`	Register an event handler with a control's event
`unregisterallevents`	Unregister all events for a control
`unregisterevent`	Unregister an event handler with a control's event

COM controls listen to events initiated by users of the control. An example of an event is clicking a mouse button in a window. If a handler routine for the event has been written and registered with the control, then the control responds to the event by executing the event handler routine.

Registering Events with the Control

You can register event handler routines with their associated events either when you create the control, using `actxcontrol`, or any time afterwards, using the `registerevent` function.

This example registers two events (`Click` and `MouseDown`) and two respective handler routines (`myclick` and `mymoused`) with the `mwsamp` control at the time the control is created. Event handlers for the `mwsamp` control are defined in the section, "Sample Event Handlers" on page 7-28:

```
f = figure('pos', [100 200 200 200]);
h = actxcontrol('mwsamp.mwsampctrl.2', [0 0 200 200], f, ...
    {'Click' 'myclick'; 'MouseDown' 'mymoused'});
```

You could have also used the following `registerevent` call at any time after creating the control:

```
registerevent(h, {'Click' 'myclick'; 'MouseDown' 'mymoused'});
```

Listing a Control's Events

Use the `events` function to list all events the control is capable of responding to. Note that `events` lists both registered and unregistered events. In this example, the `DblClick` event is not registered at this time:

```
events(h)
   Click = void Click()
   DblClick = void DblClick()
   MouseDown = void MouseDown(int16 Button, int16 Shift,
      Variant x, Variant y)
```

To list only those events that are currently registered with the control, use the `eventlisteners` function. This function lists both the event names and their handler routines:

```
eventlisteners(h)
ans =
    'click'          'myclick'
    'mousedown'      'mymoused'
```

Firing an Event

When MATLAB creates the `mwsamp` control, it also displays a figure window showing a label and circle at the center. If you click on different positions in this window, you will see a report of the `X` and `Y` position of the mouse in the MATLAB command window. MATLAB is responding to the `MouseDown` event:

```
The X position is:
ans =
    [122]
The Y position is:
ans =
    [63]
```

You also see the following line reported in response to the `Click` event:

```
Single click function
```

Double-clicking the mouse does nothing different, since the `DblClick` event has yet to be registered.

Unregistering Events

Use the unregisterevent function to unregister an event handler with an event. For example, if you unregister the MouseDown event, you will notice that MATLAB no longer reports the X and Y position when you click in the window:

```
unregisterevent(h, {'MouseDown' 'mymoused'});
```

Now, register the DblClick event, connecting it with handler routine my2click:

```
registerevent(h, {'DblClick', 'my2click'});
```

If you call eventlisteners again, you will see that the registered events are now Click and DblClick:

```
eventlisteners(h)
ans =
    'click'        'myclick'
    'dblclick'     'my2click'
```

When you double-click the mouse button, MATLAB responds to both the Click and DblClick events by displaying the following in the command window:

```
Single click function
Double click function
```

An easy way to unregister all events for a control is to use the unregisterallevents function. When there are no events registered, eventlisteners returns an empty cell array:

```
unregisterallevents(h)

eventlisteners(h)
ans =
     {}
```

Clicking the mouse in the control window now does nothing since there are no active events.

Identifying Objects

Use these MATLAB functions to get information about a COM object.

Function	Description
class	Return the class of a COM object
isa	Detect a COM object of a given class
isevent	Determine if an item is an event of a COM object
ismethod	Determine if an item is a method of a COM object
isprop	Determine if an item is a property of a COM object

Create a COM object, h, in an Automation server running Excel, and also a Workbooks interface, w, to the object:

```
h = actxserver('excel.application');
w = get(h, 'Workbooks');
```

To find out the class of variable w, use the class function:

```
class(w)
ans =
   Interface.excel.application.Workbooks
```

To test a variable against a known class name, use isa:

```
isa(h, 'COM.excel.application')
ans =
     1
```

To see if UsableWidth is a property of object h, use isprop:

```
isprop(h, 'UsableWidth')
ans =
     1
```

To see if SaveWorkspace is a method of object h, use ismethod. Method names are case sensitive and cannot be abbreviated:

```
ismethod(h, 'SaveWorkspace')
ans =
     1
```

Create the sample mwsamp control that comes with MATLAB, and use isevent to see if DblClick is one of the events that this control recognizes:

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

isevent(h, 'DblClick')
ans =
     1
```

Saving Your Work

Use these MATLAB functions to save and restore the state of a COM control object.

Function	Description
load	Initialize a COM control object from a file
save	Serialize a COM control object to a file

Save the current state of a COM control to a file using the save function. The following example creates an mwsamp control and saves its original state to the file mwsample:

```
f = figure('pos', [100 200 200 200]);
h = actxcontrol('mwsamp.mwsampctrl.2', [0 0 200 200], f);
save(h, 'mwsample')
```

Now, alter the figure by changing its label and the radius of the circle:

```
set(h, 'Label', 'Circle');
set(h, 'Radius', 50);
Redraw(h);
```

Using the `load` function, you can restore the control to its original state:

```
load(h, 'mwsample');
get(h)
ans =
     Label: 'Label'
    Radius: 20
```

Note The COM `save` and `load` functions are only supported for controls at this time.

Releasing COM Interfaces and Objects

Use these MATLAB functions to release or delete a COM object or interface.

Function	Description
`delete`	Delete a COM object or interface
`release`	Release a COM object or interface

When each interface is no longer needed, use the `release` function to release the interface and reclaim the memory used by it. When the entire control or server is no longer needed, use the `delete` function to delete it. Alternatively, you can use the `delete` function on any valid interface. All interfaces for that object are automatically released and the server or control itself is deleted.

Note In versions of MATLAB earlier than 6.5, failure to explicitly release interface handles or delete the control or server often results in a memory leak. This is true even if the variable representing the interface or COM object has been reassigned. In MATLAB 6.5 and later, the control or server, along with all interfaces to it, is destroyed on reassignment of the variable or when the variable representing a COM object or interface goes out of scope.

MATLAB automatically releases all interfaces for a control when the figure window that contains that control is deleted or closed. MATLAB also automatically releases all handles for an Automation server when MATLAB is shut down.

Writing Event Handlers

An event is fired when a control wants to notify its container that something of interest has occurred. For example, many controls trigger an event when the user single-clicks on the control. In MATLAB, you can create and register your own M-file functions so that they respond to events when they occur. These functions serve as event handlers. You can create one handler function to handle all events or a separate handler for each type of event.

Register your handler functions either at the time you create the control (using `actxcontrol`), or at any time afterwards (using `registerevent`). Specify the event handler in the argument list, as shown below for `actxcontrol`. The event handler argument can be either the name of a single callback routine or a cell array that associates specific events with their respective event handlers:

```
h = actxcontrol (progid, position, handle, ...
callback | {event1 eventhandler1; event2 eventhandler2; ...})
```

When you specify the single `callback` routine, MATLAB registers all events with that one routine. When any event is fired, MATLAB executes the common `callback` routine.

You can list all the events that a COM object recognizes using the `events` function. For example, to list all events for the `mwsamp` control, use

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

events(h)
   Click = void Click()
   DblClick = void DblClick()
   MouseDown = void MouseDown(int16 Button, int16 Shift,
      Variant x, Variant y)
```

Arguments Passed to Event Handlers

When a registered event is triggered, MATLAB passes information from the event to its handler function as shown in this table.

Arguments Passed by MATLAB

Arg. No.	Contents	Format
1	Object Name	MATLAB `com` class
2	Event ID	`double`
3	Start of Event Arg. List	As passed by the control
`end-2`	End of Event Arg. List (Arg. N)	As passed by the control
`end-1`	Event Structure	`structure`
`end`	Event Name	`char array`

When writing an event handler function, use the Event Name argument to identify the source of the event. Get the arguments passed by the control from the Event Argument List (arguments `3` through `end-2`). All event handlers must accept a variable number of arguments:

```
function event (varargin)
if (varargin{end}) == 'MouseDown')      % Check the event name
    x_pos = varargin{5};               % Read 5th Event Argument
    y_pos = varargin{6};               % Read 6th Event Argument
end
```

Note The values passed vary with the particular event and control being used.

Event Structure

The second to last argument passed by MATLAB is the Event Structure, which has the following fields.

Fields of the Event Structure

Field Name	Description	Format
`Type`	Event Name	`char array`
`Source`	Control Name	MATLAB `com` class
`EventID`	Event Identifier	`double`
`Event Arg Name 1`	Event Arg Value 1	As passed by the control
`Event Arg Name 2`	Event Arg Value 2	As passed by the control
etc.		

For example, when the `MouseDown` event of the `mwsamp` control is triggered, MATLAB passes this Event Structure to the registered event handler:

```
     Type: 'MouseDown'
   Source: [1x1 COM.mwsamp.mwsampctrl.2]
  EventID: -605
   Button: 1
    Shift: 0
        x: 27
        y: 24
```

Sample Event Handlers

Specify a single callback, `sampev`:

```
f = figure('pos', [100 200 200 200]);
h = actxcontrol('mwsamp.mwsampctrl.2', [0 0 200 200], ...
    gcf, 'sampev')
h =
    COM.mwsamp.mwsampctrl.2
```

Or specify several events using the cell array format:

```
h = actxcontrol('mwsamp.mwsampctrl.2', [0 0 200 200], f, ...
    {'Click' 'myclick'; 'DblClick' 'my2click'; ...
    'MouseDown' 'mymoused'});
```

The event handlers, `myclick.m`, `my2click.m`, and `mymoused.m`, are

```
function myclick(varargin)
disp('Single click function')

function my2click(varargin)
disp('Double click function')

function mymoused(varargin)
disp('You have reached the mouse down function')
disp('The X position is: ')
double(varargin{6})
disp('The Y position is: ')
double(varargin{7})
```

Alternatively, you can use the same event handler for all the events you want to monitor using the cell array pairs. Response time will be better than using the callback style.

For example:

```
f = figure('pos', [100 200 200 200]);
h = actxcontrol('mwsamp.mwsampctrl.2', ...
[0 0 200 200], f, {'Click' 'allevents'; ...
'DblClick' 'allevents'; 'MouseDown' 'allevents'})
```

where `allevents.m` is

```
function allevents(varargin)
if (varargin{3} = 'Click')
   disp ('Single Click Event Fired')
elseif (varargin{3} = 'DblClick')
   disp ('Double Click Event Fired')
elseif (varargin{3} = 'MouseDown')
   disp ('Mousedown Event Fired')
end
```

Examples of MATLAB as an Automation Client

This section provides examples of using MATLAB as an Automation client with controls and servers.

MATLAB Sample Control

MATLAB ships with a very simple example COM control that draws a circle on the screen, displays some text, and fires events when the user single- or double-clicks on the control. Create the control by running the `mwsamp.m` file in the directory, `winfun\comcli`, or type

```
h = actxcontrol('mwsamp.mwsampctrl.2', [0 0 300 300]);
```

This control is stored in the MATLAB `bin`, or executable, directory along with the control's *type library*. The type library is a binary file used by COM tools to decipher the control's capabilities. See the section "Writing Event Handlers" on page 7-26 for other examples that use the `mwsamp` controls.

Using MATLAB as an Automation Client

This example uses MATLAB as an Automation client and Microsoft Excel as the server. It provides a good overview of typical functions. In addition, it is a good example of using the Automation interface of another application:

```
% MATLAB Automation client example
%
% Open Excel, add workbook, change active worksheet,
% get/put array, save.

% First, open an Excel Server.
e = actxserver('excel.application');

% Insert a new workbook.
eWorkbooks = get(e, 'Workbooks');
eWorkbook = Add(eWorkbooks);
set(e, 'Visible', 1);

% Make the second sheet active.
eActiveWorkbook = get(e, 'ActiveWorkBook');
eSheets = get(eActiveWorkbook, 'Sheets');
eSheet2 = Item(eSheets, 2);
Activate(eSheet2);
```

```
% Get a handle to the active sheet.
eActiveSheet = get(e, 'ActiveSheet');

% Put a MATLAB array into Excel.
A = [1 2; 3 4];
eActiveSheetRange = Range(eActiveSheet, 'A1', 'B2');
set(eActiveSheetRange, 'Value', A);

% Get back a range.  It will be a cell array, since the cell range
% can contain different types of data.
eRange = Range(eActiveSheet, 'A1', 'B2');
B = get(eRange, 'Value');

% Convert to a double matrix.  The cell array must contain only
% scalars.
B = reshape([B{:}], size(B));

% Now, save the workbook.
SaveAs(eWorkbook, 'myfile.xls');

% To avoid saving the workbook and being prompted to do so,
% uncomment the following code.
% set(eWorkbook, 'Saved', 1);
% Close(eWorkbook);

% Quit Excel and delete the server.
% Quit(e);
% delete(e);
```

Note Make sure that you always close any workbooks that you add in Excel. This can prevent potential memory leaks.

Additional COM Client Information

Using COM Collections

COM *collections* are a way to support groups of related COM objects that can be iterated over. A collection is itself a special interface with a Count property (read only), which contains the number of items in the collection, and an Item method, which allows you to retrieve a single item from the collection.

The Item method is indexed, which means that it requires an argument that specifies which item in the collection is being requested. The data type of the index can be any data type that is appropriate for the particular collection and is specific to the control or server that supports the collection. Although integer indices are common, the index could just as easily be a string value. Often, the return value from the Item method is itself an interface. Like all interfaces, this interface should be released when you are finished with it.

This example iterates through the members of a collection. Each member of the collection is itself an interface (called Plot and represented by a MATLAB COM object called hPlot.) In particular, this example iterates through a collection of Plot interfaces, invokes the Redraw method for each interface, and then releases each interface:

```
hCollection = get(hControl, 'Plots');
for i = 1:get(hCollection, 'Count')
    hPlot = invoke(hCollection, 'Item', i);
    invoke(hPlot, 'Redraw');
    release(hPlot);
end;
release(hCollection);
```

Converting Data

Since COM defines a number of different data formats and types, you will need to know how MATLAB converts data from COM objects into variables in the MATLAB workspace. Data from COM objects must be converted:

- When a property value is retrieved
- When a value is returned from a method invocation

This chart shows how COM data types are converted into variables in the MATLAB workspace.

COM Data Type	**MATLAB Variable**
String File Time Error Decimal Date	MATLAB String
Currency Hresult Int/Unsigned (2, 4, 8) Bool Real (Single/Double Precision)	Scalar Double
Null	NaN

COM Data Type	MATLAB Variable
Array of Currency Hresult Int/Unsigned (2, 4, 8) Bool Real (Single/Double Precision)	Matrix of Double
Variant Array of Variant	Cell Array
IDispatch *	COM Object
Empty Unknown Void Ptr Carray Userdefined Blob Stream Storage Streamed Object Stored Object Blob Object CF	Not Converted (error)

Using MATLAB as a DCOM Server Client

Distributed Component Object Model (DCOM) is an object distribution mechanism that allows clients to use remote COM objects over a network. Additionally, MATLAB can be used as a DCOM client with remote Automation servers if the operating system on which MATLAB is running is DCOM enabled.

Note If you use MATLAB as a remote DCOM server, all MATLAB windows will appear on the remote machine.

MATLAB COM Support Limitations

The following is a list of limitations of MATLAB COM support:

- MATLAB only supports indexed collections.
- COM controls are not printed with figure windows.
- MATLAB supports events from controls only, not from servers.
- MATLAB supports only the IDispatch interface. It does not support custom interfaces.

MATLAB Automation Server Support

MATLAB on Microsoft Windows supports COM Automation server capabilities. Automation is a COM protocol that allows one application or component (the *controller*) to control another application or component (the *server*). Thus, MATLAB can be launched and controlled by any Windows program that can be an Automation Controller. Some examples of applications that can be Automation Controllers are Microsoft Excel, Microsoft Access, Microsoft Project, and many Visual Basic and Visual C++ programs. Using Automation, you can execute MATLAB commands, and get and put `mxArrays` from and to the MATLAB workspace.

To use MATLAB as an Automation server, follow steps 1 and 2:

1 **Invoke a COM Automation server.**

   Consult the documentation of your controller to find out how to invoke a COM Automation server. The name of the MATLAB COM object that is placed in the registry is `Matlab.Application`. Exactly how you invoke the MATLAB server depends on which controller you choose, but all controllers require this name to identify the server.

2 **Use the Execute method on command strings.**

   The Automation interface to MATLAB supports several methods. Here is a Visual Basic code fragment that invokes the MATLAB Automation `Execute` method, and that works in Microsoft Excel or any other Visual Basic or Visual Basic for Applications (VBA)-enabled application. The `Execute` method takes a command string as an argument and returns the results as a string. The command string can be any command that would normally be typed in the command window; the result contains any output that would have been printed to the command window as a result of executing the string, including errors:

```
Dim MatLab As Object

Dim Result As String
Set MatLab = CreateObject("Matlab.Application")
Result = MatLab.Execute("surf(peaks)")
```

Note The first statement above should be declared in the general declarations section in order to keep the scope throughout the application.

MATLAB COM Automation Methods

This section lists the methods that are supported by the MATLAB Automation Server. The data types for the arguments and return values are expressed as Automation data types, which are language-independent types defined by the Automation protocol. For example, `BSTR` is a wide-character string type defined as an Automation type, and is the same data format used by Visual Basic to store strings. Any COM-compliant controller should support these data types, although the details of how you declare and manipulate these are controller specific.

BSTR Execute([in] BSTR Command);

This command accepts a single string (`Command`), which contains any command that can be typed at the MATLAB command window prompt. MATLAB will execute the command and return the results as a string. Any figure windows generated by the command are displayed on the screen as if the command were executed directly from the command window or an M-file. A Visual Basic example is

```
Dim MatLab As Object

Dim Result As String
Set MatLab = CreateObject("Matlab.Application")
Result = MatLab.Execute("surf(peaks)")
```

```
void GetFullMatrix(
          [in] BSTR Name,
          [in] BSTR Workspace,
          [in, out] SAFEARRAY(double)* pr,
          [in, out] SAFEARRAY(double)* pi);
```

Note The first statement above should be declared in the general declarations section in order to keep the scope throughout the application.

This method retrieves a full, one- or two-dimensional real or imaginary mxArray from the named workspace. The real and (optional) imaginary parts are retrieved into separate arrays of doubles.

Name. Identifies the name of the mxArray to be retrieved.

Workspace. Identifies the workspace that contains the mxArray. Use the workspace name “base” to retrieve an mxArray from the default MATLAB workspace. Use the workspace name “global” to put the mxArray into the global MATLAB workspace. The “caller” workspace does not have any context in the API when used outside of MEX-files.

pr. Array of reals that is dimensioned to be the same size as the mxArray being retrieved. On return, this array will contain the real values of the mxArray.

pi. Array of reals that is dimensioned to be the same size as the mxArray being retrieved. On return, this array will contain the imaginary values of the mxArray. If the requested mxArray is not complex, an empty array must be passed. In Visual Basic, an empty array is declared as `Dim Mempty() as Double`. A Visual Basic example of this method is

```
Dim MatLab As Object

Dim Result As String
Dim MReal(1, 3) As Double
Dim MImag() As Double
Dim RealValue As Double
Dim i, j As Integer

rem We assume that the connection to MATLAB exists.
Result = MatLab.Execute("a = [1 2 3 4; 5 6 7 8;]")
Call MatLab.GetFullMatrix("a", "base", MReal, MImag)

For i = 0 To 1
   For j = 0 To 3
   RealValue = MReal(i, j)
   Next j
Next i
```

```
void PutFullMatrix(
          [in] BSTR Name,
          [in] BSTR Workspace,
          [in] SAFEARRAY(double) pr,
          [in] SAFEARRAY(double) pi);
```

Note The first statement above should be declared in the general declarations section in order to keep the scope throughout the application.

This method puts a full, one- or two-dimensional real or imaginary `mxArray` into the named workspace. The real and (optional) imaginary parts are passed in through separate arrays of doubles.

Name. Identifies the name of the `mxArray` to be placed.

Workspace. Identifies the workspace into which the `mxArray` should be placed. Use the workspace name "base" to put the `mxArray` into the default MATLAB workspace. Use the workspace name "global" to put the `mxArray` into the global MATLAB workspace. The "caller" workspace does not have any context in the API when used outside of MEX-files.

pr. Array of reals that contains the real values for the `mxArray`.

pi. Array of reals that contains the imaginary values for the `mxArray`. If the `mxArray` that is being sent is not complex, an empty array must be passed for this parameter. In Visual Basic, an empty array is declared as `Dim Mempty() as Double`. A Visual Basic example of this method is

```
Dim MatLab As Object

Dim MReal(1, 3) As Double
Dim MImag() As Double
Dim i, j As Integer
For i = 0 To 1
   For j = 0 To 3
   MReal(i, j)  = I * j;
   Next j
Next I
rem We assume that the connection to MATLAB exists.
Call MatLab.PutFullMatrix("a", "base", MReal, MImag)
```

Note The first statement above should be declared in the general declarations section in order to keep the scope throughout the application.

MATLAB Automation Properties

You have the option of making your server application visible or not by setting the `Visible` property. When visible, the server window appears on the desktop, enabling the user to interact with the server application. This may be useful for such purposes as debugging. When not visible, the server window does not appear, thus perhaps making for a cleaner interface and also preventing any interaction with the server application.

By default, the `Visible` property is enabled, or set to `1`:

```
h = actxserver('Matlab.Application');
get(h, 'visible')
ans =
     1
```

You can change the setting of `Visible` by setting it to `0` (invisible) or `1` (visible). The following command removes the server application window from the desktop:

```
set(h, 'visible', 0);

get(h, 'visible')
ans =
     0
```

Additional Automation Server Information

Launching the MATLAB Server

For MATLAB to act as an Automation server, it must be started with the /Automation command line argument. Microsoft Windows does this automatically when a COM connection is established by a controller. However, if MATLAB is already running and was launched *without* this parameter, any request by an Automation controller to connect to MATLAB as a server will cause Windows to launch another instance of MATLAB with the /Automation parameter. This protects controllers from interfering with any interactive MATLAB sessions that may be running.

Specifying a Shared or Dedicated Server

You can launch the MATLAB Automation server in one of two modes — shared or dedicated. A dedicated server is dedicated to a single client; a shared server is shared by multiple clients.

The mode is determined by the Program ID (ProgID) used by the client to launch MATLAB. The ProgID, `Matlab.Application`, specifies the default mode, which is shared. You can also use the version-specific ProgID, `Matlab.Application.N`, where `N` is equal to the major version of MATLAB you are running, (for example, `N = 6` for MATLAB 6.5).

To specify a dedicated server, use the ProgID, `Matlab.Application.Single`, (or the version-specific ProgID, `Matlab.Application.Single.N`). The term `Single` refers to the number of clients that may connect to this server.

Once MATLAB is launched as a shared server, all clients that request a connection to MATLAB by using the shared server ProgID will connect to the already running instance of MATLAB. In other words, there is never more than one instance of a shared server running, since it is shared by all clients that use the ProgID that specifies a shared server.

Note Clients will not connect to an interactive instance of MATLAB, that is, an instance of MATLAB that was launched manually and without the `/Automation` command line flag.

Each client that requests a connection to MATLAB using a dedicated ProgID will cause a separate instance of MATLAB to be launched, and that server will not be shared with any other client. Therefore, there can be several instances of a dedicated server running simultaneously, since the dedicated server is not shared by multiple clients.

Using MATLAB as a DCOM Server

DCOM is a protocol that allows COM connections to be established over a network. If you are using a version of Windows that supports DCOM (Windows NT 4.0 at the time of this writing) and a controller that supports DCOM, you can use the controller to launch MATLAB on a remote machine. To do this, DCOM must be configured properly, and MATLAB must be installed on each machine that is used as a client or server. (Even though the client machine will not be running MATLAB in such a configuration, the client machine must have a MATLAB installation because certain MATLAB components are required to establish the remote connection.) Consult the DCOM documentation for how to configure DCOM for your environment.

Dynamic Data Exchange (DDE)

MATLAB provides functions that enable MATLAB to access other Windows applications and for other Windows applications to access MATLAB in a wide range of contexts. These functions use dynamic data exchange (DDE), software that allows Microsoft Windows applications to communicate with each other by exchanging data.

This section describes using DDE in MATLAB:

DDE Concepts and Terminology

Applications communicate with each other by establishing a DDE *conversation*. The application that initiates the conversation is called the *client*. The application that responds to the client application is called the *server*.

When a client application initiates a DDE conversation, it must identify two DDE parameters that are defined by the server:

- The name of the application it intends to have the conversation with, called the *service name*
- The subject of the conversation, called the *topic*

When a server application receives a request for a conversation involving a supported topic, it acknowledges the request, establishing a DDE conversation. The combination of a service and a topic identifies a conversation uniquely. The service or topic cannot be changed for the duration of the conversation, although the service can maintain more than one conversation.

During a DDE conversation, the client and server applications exchange data concerning items. An *item* is a reference to data that is meaningful to both applications in a conversation. Either application can change the item during a conversation. These concepts are discussed in more detail below.

The Service Name

Every application that can be a DDE server has a unique *service name*. The service name is usually the application's executable filename without any extension. Service names are not case sensitive. Here are some commonly used service names:

- The service name for MATLAB is *Matlab*.
- The service name for Microsoft Word for Windows is *WinWord*.
- The service name for Microsoft Excel is *Excel*.

For the service names of other Windows applications, refer to the application documentation.

The Topic

The *topic* defines the subject of a DDE conversation and is usually meaningful to both the client and server applications. Topic names are not case sensitive. MATLAB topics are *System* and *Engine* and are discussed in "Accessing MATLAB as a Server" on page 7-45. Most applications support the *System* topic and at least one other topic. Consult your application documentation for information about supported topics.

The Item

Each topic supports one or more items. An *item* identifies the data being passed during the DDE conversation. Case sensitivity of items depends on the application. MATLAB *Engine* items are case sensitive if they refer to matrices because matrix names are case sensitive.

Clipboard Formats

DDE uses the Windows clipboard formats for formatting data sent between applications. As a client, MATLAB supports only Text format. As a server, MATLAB supports Text, Metafilepict, and XLTable formats, described below:

- **Text** – Data in Text format is a buffer of characters terminated by the `null` character. Lines of text in the buffer are delimited by a carriage return line-feed combination. If the buffer contains columns of data, those columns are delimited by the tab character. MATLAB supports Text format for obtaining the results of a remote EvalString command and requests for matrix data. Also, matrix data can be sent to MATLAB in Text format.

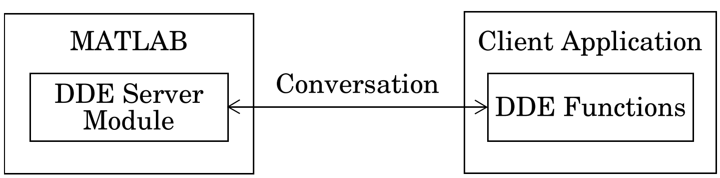
- **Metafilepict –** Metafilepict format is a description of graphical data containing the drawing commands for graphics. As a result, data stored in this format is scalable and device independent. MATLAB supports Metafilepict format for obtaining the result of a remote command that causes some graphic action to occur.
- **XLTable –** XLTable format is the clipboard format used by Microsoft Excel and is supported for ease and efficiency in exchanging data with Excel. XLTable format is a binary buffer with a header that describes the data held in the buffer. For a full description of XLTable format, consult the Microsoft Excel SDK documentation.

Accessing MATLAB as a Server

A client application can access MATLAB as a DDE server in the following ways, depending on the client application:

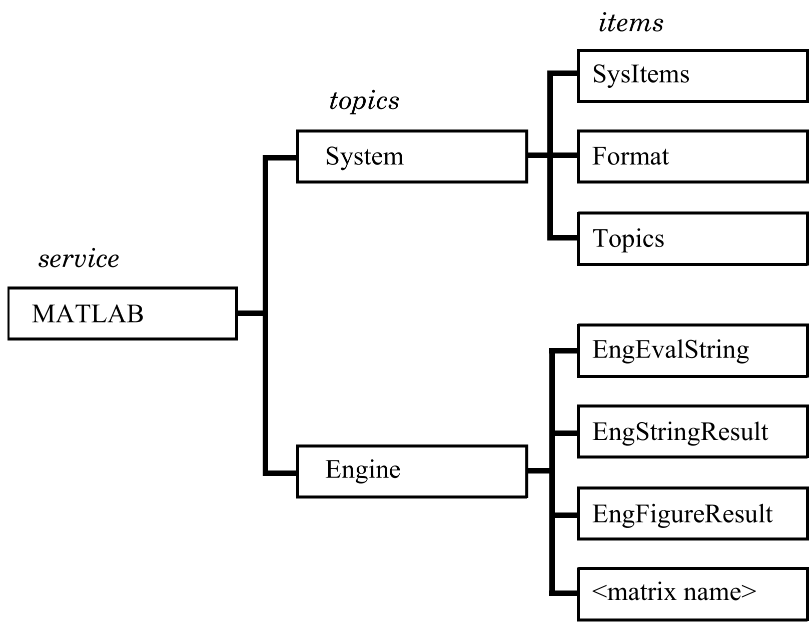
- If you are using an application that provides functions or macros to conduct DDE conversations, you can use these functions or macros. For example, Microsoft Excel, Word for Windows, and Visual Basic provide DDE functions or macros. For more information about using these functions or macros, see the appropriate Microsoft documentation.
- If you are creating your own application, you can use the MATLAB Engine Library or DDE directly. For more information about using the Engine Library, see "Using the MATLAB Engine" on page 4-2. For more information about using DDE routines, see the *Microsoft Windows Programmer's Guide*.

The figure below illustrates how MATLAB communicates as a server. DDE functions in the client application communicate with the MATLAB DDE server module. The client's DDE functions can be provided by either the application or the MATLAB Engine Library.



The DDE Name Hierarchy

When you access MATLAB as a server, you must specify its service name, topic, and item. The figure below illustrates the MATLAB DDE name hierarchy. Topics and items are described in more detail below.



The two MATLAB topics are *System* and *Engine*.

MATLAB System Topic

The System topic allows users to browse the list of topics provided by the server, the list of System topic items provided by the server, and the formats supported by the server.

The MATLAB System topic supports these items:

- **SysItems**
  Provides a tab-delimited list of items supported under the System topic (this list).

- **Format**

  Provides a tab-delimited list of string names of all the formats supported by the server. MATLAB supports Text, Metafilepict, and XLTable. These formats are described in "Clipboard Formats" on page 7-44.

- **Topics**

  Provides a tab-delimited list of the names of the topics supported by MATLAB.

MATLAB Engine Topic

The Engine topic allows users to use MATLAB as a server by passing it a command to execute, requesting data, or sending data.

The MATLAB Engine topic supports these items:

- **EngEvalString**

  Specifies an item name, if required, when you send a command to MATLAB for evaluation.

- **EngStringResult**

  Provides the string result of a DDE execute command when you request data from MATLAB.

- **EngFigureResult**

  Provides the graphical result of a DDE execute command when you request data from MATLAB.

- **<matrix name>**

  When requesting data from MATLAB, this is the name of the matrix for which data is being requested. When sending data to MATLAB, this is the name of the matrix to be created or updated.

The MATLAB Engine topic supports three operations that may be used by applications with a DDE client interface. These operations include sending commands to MATLAB for evaluation, requesting data from MATLAB, and sending data to MATLAB.

Sending Commands to MATLAB for Evaluation

Clients send commands to MATLAB using the DDE `execute` operation. The Engine topic supports DDE `execute` in two forms because some clients require that you specify the item name and the command to execute, while others require only the command. Where an item name is required, use `EngEvalString`. In both forms, the format of the command must be Text. Most clients default to Text for DDE `execute`. If the format cannot be specified, it is probably Text. The table summarizes the DDE `execute` parameters.

Item	Format	Command
`EngEvalString`	Text	String
`null`	Text	String

Requesting Data from MATLAB

Clients request data from MATLAB using the DDE `request` operation. The Engine topic supports DDE requests for three functions:

Text that is the result of the previous DDE execute command. You request the string result of a DDE execute command using the `EngStringResult` item with Text format.

Graphical results of the previous DDE execute command. You request the graphical result of a DDE execute command using the `EngFigureResult` item. The `EngFigureResult` item can be used with Text or Metafilepict formats:

- Specifying the Text format results in a string having a value of “yes” or “no.” If the result is “yes,” the metafile for the current figure is placed on the clipboard. This functionality is provided for DDE clients that can retrieve only text from DDE requests, such as Word for Windows. If the result is “no,” no metafile is placed on the clipboard.
- Specifying the Metafilepict format when there is a graphical result causes a metafile to be returned directly from the DDE request.

The data for a specified matrix. You request the data for a matrix by specifying the name of the matrix as the item. You can specify either the Text or XLTable format.

The table summarizes the DDE `request` parameters.

Item	Format	Result
`EngStringResult`	Text	String
`EngFigureResult`	Text	Yes/No
`EngFigureResult`	Metafilepict	Metafile of the current figure
`<matrix name>`	Text	Character buffer, tab-delimited columns, CR/LF-delimited rows
`<matrix name>`	XLTable	Binary data in a format compatible with Microsoft Excel

Sending Data to MATLAB

Clients send data to MATLAB using the DDE `poke` operation. The Engine topic supports DDE poke for updating or creating new matrices in the MATLAB workspace. The item specified is the name of the matrix to be updated or created. If a matrix with the specified name already exists in the workspace it will be updated; otherwise it will be created. The matrix data can be in Text or XLTable format.

The table summarizes the DDE `poke` parameters.

Item	Format	Poke Data
`<matrix name>`	Text	Character buffer, tab-delimited columns, CR/LF-delimited rows
`<matrix name>`	XLTable	Binary data in a format compatible with Microsoft Excel

Example: Using Visual Basic and the MATLAB DDE Server

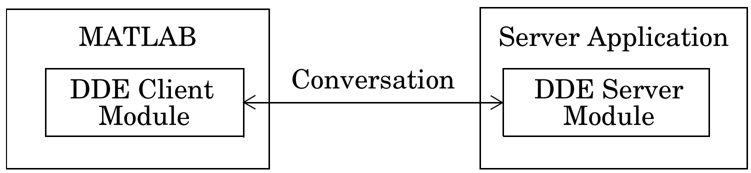
This example shows a Visual Basic form that contains two text edit controls, **TextInput** and **TextOutput**. This code is the `TextInput_KeyPress` method.

```
Sub TextInput_KeyPress(KeyAscii As Integer)
rem If the user presses the return key
rem in the TextInput control.
If KeyAscii = vbKeyReturn then

rem Initiate the conversation between the TextInput
rem control and MATLAB under the Engine topic.
rem Set the item to EngEvalString.
                   TextInput.LinkMode = vbLinkNone
                   TextInput.LinkTopic = "MATLAB|Engine"
                   TextInput.LinkItem = "EngEvalString"
                   TextInput.LinkMode = vbLinkManual

rem Get the current string in the TextInput control.
rem This text is the command string to send to MATLAB.
                   szCommand = TextInput.Text

rem Perform DDE Execute with the command string.
                   TextInput.LinkExecute szCommand
                   TextInput.LinkMode = vbLinkNone

rem Initiate the conversation between the TextOutput
rem control and MATLAB under the Engine topic.
rem Set the item to EngStringResult.
                   TextOutput.LinkMode = vbLinkNone
                   TextOutput.LinkTopic = "MATLAB|Engine"
                   TextOutput.LinkItem = "EngStringResult"
                   TextOutput.LinkMode = vbLinkManual

rem Request the string result of the previous EngEvalString
rem command. The string ends up in the text field of the
rem control TextOutput.text.
                   TextOutput.LinkRequest
                   TextOutput.LinkMode = vbLinkNone

End If
End Sub
```

Using MATLAB as a Client

For MATLAB to act as a client application, you can use the MATLAB DDE client functions to establish and maintain conversations.

This figure illustrates how MATLAB communicates as a client to a server application.



The MATLAB DDE client module includes a set of functions. This table describes the functions that enable you to use MATLAB as a client.

Function	Description
`ddeadv`	Sets up advisory link between MATLAB and DDE server application.
`ddeexec`	Sends execution string to DDE server application.
`ddeinit`	Initiates DDE conversation between MATLAB and another application.
`ddepoke`	Sends data from MATLAB to DDE server application.
`ddereq`	Requests data from DDE server application.
`ddeterm`	Terminates DDE conversation between MATLAB and server application.
`ddeunadv`	Releases advisory link between MATLAB and DDE server application.

If the server application is Microsoft Excel, you can specify the *System* topic or a topic that is a filename. If you specify the latter, the filename ends in `.XLS` or

.XLC and includes the full path if necessary. A Microsoft Excel item is a cell reference, which can be an individual cell or a range of cells.

Microsoft Word for Windows topics are *System* and document names that are stored in files whose names end in .DOC or .DOT. A Word for Windows item is any bookmark in the document specified by the topic.

The following example is an M-file that establishes a DDE conversation with Microsoft Excel, and then passes a 20-by-20 matrix of data to Excel:

```
% Initialize conversation with Excel.
chan = ddeinit('excel', 'Sheet1');

% Create a surface of peaks plot.
h = surf(peaks(20));
% Get the z data of the surface
z = get(h, 'zdata');

% Set range of cells in Excel for poking.
range = 'r1c1:r20c20';

% Poke the z data to the Excel spread sheet.
rc = ddepoke(chan, range, z);
```

DDE Advisory Links

You can use DDE to notify a client application when data at a server has changed. For example, if you use MATLAB to analyze data entered in an Excel spreadsheet, you can establish a link that causes Excel to notify MATLAB when this data changes. You can also establish a link that automatically updates a matrix with the new or modified spreadsheet data.

MATLAB supports two kinds of advisory links, distinguished by the way in which the server application advises MATLAB when the data that is the subject of the item changes at the server:

- A *hot link* causes the server to supply the data to MATLAB when the data defined by the item changes.
- A *warm link* causes the server to notify MATLAB when the data changes but supplies the data only when MATLAB requests it.

You set up and release advisory links with the `ddeadv` and `ddeunadv` functions. MATLAB only supports links when MATLAB is a client.

This example establishes a DDE conversation between MATLAB, acting as a client, and Microsoft Excel. The example extends the example in the previous section by creating a hot link with Excel. The link updates matrix `z` and evaluates a callback when the range of cells changes. A push-button, user interface control terminates the advisory link and the DDE conversation when pressed. (For more information about creating a graphical user interface, see the online MATLAB manual, *Creating Graphical User Interfaces*.)

```
% Initialize conversation with Excel.
chan = ddeinit('excel', 'Sheet1');

% Set range of cells in Excel for poking.
range = 'r1c1:r20c20';

% Create a surface of peaks plot.
h = surf(peaks(20));

% Get the z data of the surface.
z = get(h, 'zdata');

% Poke the z data to the Excel spread sheet.
rc = ddepoke(chan, range, z);

% Set up a hot link ADVISE loop with Excel
% and the MATLAB matrix 'z'.
% The callback sets the zdata and cdata for
% the surface h to be the new data sent from Excel.
rc = ddeadv(chan, range,...
     'set(h,''zdata'',z);set(h,''cdata'',z);','z');

% Create a push button that will end the ADVISE link,
% terminate the DDE conversation,
% and close the figure window.
c = uicontrol('String','&Close','Position',[5 5 80 30],...
     'Callback',...
     'rc = ddeunadv(chan,range);ddeterm(chan);close;');
```

8

Serial Port I/O

The serial port I/O chapter includes these sections.

Introduction

What Is the MATLAB Serial Port Interface?

The MATLAB serial port interface provides direct access to peripheral devices such as modems, printers, and scientific instruments that you connect to your computer's serial port. This interface is established through a serial port object. The serial port object supports functions and properties that allow you to

- Configure serial port communications
- Use serial port control pins
- Write and read data
- Use events and callbacks
- Record information to disk

If you want to communicate with PC-compatible data acquisition hardware such as multifunction I/O boards, you need the Data Acquisition Toolbox. If you want to communicate with GPIB- or VISA-compatible instruments, you need the Instrument Control Toolbox. Note that this toolbox also includes additional serial I/O utility functions that facilitate object creation and configuration, instrument communication, and so on.

For more information about these products, visit the MathWorks Web site at `http://www.mathworks.com/products`.

Supported Serial Port Interface Standards

Over the years, several serial port interface standards have been developed. These standards include RS-232, RS-422, and RS-485 – all of which are supported by the MATLAB serial port object. Of these, the most widely used interface standard for connecting computers to peripheral devices is RS-232.

In this guide, it is assumed you are using the RS-232 standard, which is discussed in "Overview of the Serial Port" on page 8-4. Refer to your computer and device documentation to see which interface standard you can use.

Supported Platforms

The MATLAB serial port interface is supported on Microsoft Windows, Linux, and Sun Solaris platforms.

Using the Examples with Your Device

Many of the examples in this section reflect specific peripheral devices connected to a PC serial port – in particular a Tektronix TDS 210 two-channel oscilloscope connected to the COM1 port. Therefore, many of the string commands are specific to this instrument.

If your peripheral device is connected to a different serial port, or if it accepts different commands, you should modify the examples accordingly.

Overview of the Serial Port

This section provides an overview of the serial port. Topics include

- What is Serial Communication?
- The Serial Port Interface Standard
- Connecting Two Devices with a Serial Cable
- Serial Port Signals and Pin Assignments
- Serial Data Format
- Finding Serial Port Information for Your Platform

For many serial port applications, you can communicate with your device without detailed knowledge of how the serial port works. If your application is straightforward, or if you are already familiar with the topics mentioned above, you might want to begin with "The Serial Port Session" on page 8-19 to see how to use your serial port device with MATLAB.

What Is Serial Communication?

Serial communication is the most common low-level protocol for communicating between two or more devices. Normally, one device is a computer, while the other device can be a modem, a printer, another computer, or a scientific instrument such as an oscilloscope or a function generator.

As the name suggests, the serial port sends and receives bytes of information in a serial fashion – one bit at a time. These bytes are transmitted using either a binary (numerical) format or a text format.

The Serial Port Interface Standard

The serial port interface for connecting two devices is specified by the TIA/EIA-232C standard published by the Telecommunications Industry Association.

The original serial port interface standard was given by RS-232, which stands for Recommended Standard number 232. The term "RS-232" is still in popular use, and is used in this guide when referring to a serial communication port that follows the TIA/EIA-232 standard. RS-232 defines these serial port characteristics:

- The maximum bit transfer rate and cable length

- The names, electrical characteristics, and functions of signals
- The mechanical connections and pin assignments

Primary communication is accomplished using three pins: the Transmit Data pin, the Receive Data pin, and the Ground pin. Other pins are available for data flow control, but are not required.

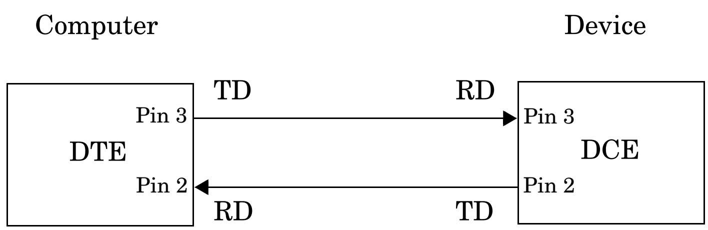
Other standards such as RS-485 define additional functionality such as higher bit transfer rates, longer cable lengths, and connections to as many as 256 devices.

Connecting Two Devices with a Serial Cable

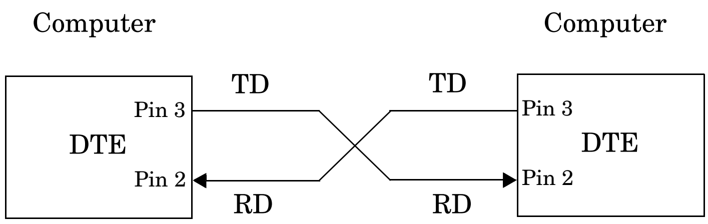
The RS-232 standard defines the two devices connected with a serial cable as the Data Terminal Equipment (DTE) and Data Circuit-Terminating Equipment (DCE). This terminology reflects the RS-232 origin as a standard for communication between a computer terminal and a modem.

Throughout this guide, your computer is considered a DTE, while peripheral devices such as modems and printers are considered DCE's. Note that many scientific instruments function as DTE's.

Because RS-232 mainly involves connecting a DTE to a DCE, the pin assignments are defined such that straight-through cabling is used, where pin 1 is connected to pin 1, pin 2 is connected to pin 2, and so on. A DTE to DCE serial connection using the transmit data (TD) pin and the receive data (RD) pin is shown below. Refer to "Serial Port Signals and Pin Assignments" on page 8-6 for more information about serial port pins.



If you connect two DTE's or two DCE's using a straight serial cable, then the TD pin on each device are connected to each other, and the RD pin on each device are connected to each other. Therefore, to connect two like devices, you must use a *null modem* cable. As shown below, null modem cables cross the transmit and receive lines in the cable.

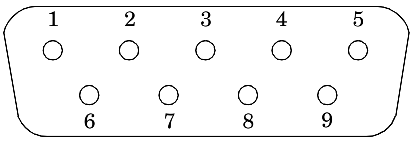


Note You can connect multiple RS-422 or RS-485 devices to a serial port. If you have an RS-232/RS-485 adaptor, then you can use the MATLAB serial port object with these devices.

Serial Port Signals and Pin Assignments

Serial ports consist of two signal types: data signals and control signals. To support these signal types, as well as the signal ground, the RS-232 standard defines a 25-pin connection. However, most PC's and UNIX platforms use a 9-pin connection. In fact, only three pins are required for serial port communications: one for receiving data, one for transmitting data, and one for the signal ground.

The pin assignment scheme for a 9-pin male connector on a DTE is given below.



The pins and signals associated with the 9-pin connector are described below. Refer to the RS-232 standard for a description of the signals and pin assignments used for a 25-pin connector.

Table 8-1: Serial Port Pin and Signal Assignments

Pin	Label	Signal Name	Signal Type
1	CD	Carrier Detect	Control
2	RD	Received Data	Data
3	TD	Transmitted Data	Data
4	DTR	Data Terminal Ready	Control
5	GND	Signal Ground	Ground
6	DSR	Data Set Ready	Control
7	RTS	Request to Send	Control
8	CTS	Clear to Send	Control
9	RI	Ring Indicator	Control

The term “data set” is synonymous with “modem” or “device,” while the term “data terminal” is synonymous with “computer.”

Note The serial port pin and signal assignments are with respect to the DTE. For example, data is transmitted from the TD pin of the DTE to the RD pin of the DCE.

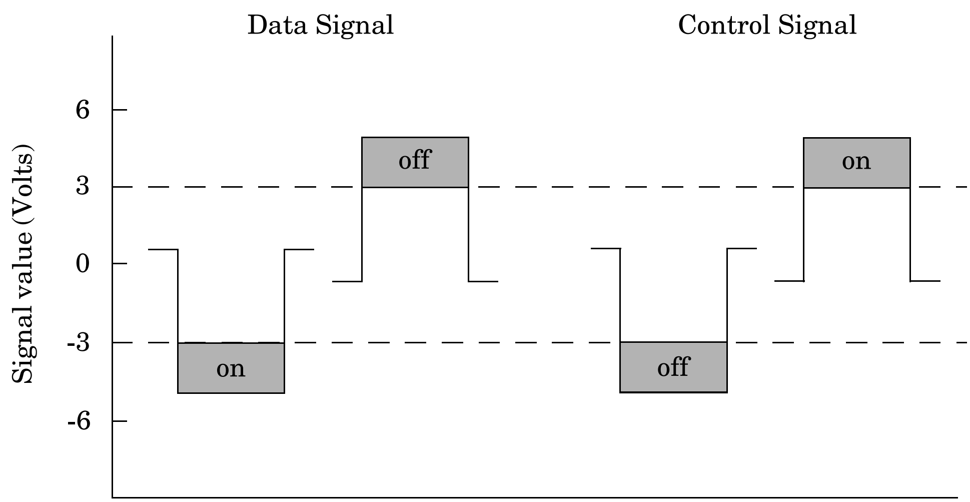
Signal States

Signals can be in either an *active* state or an *inactive* state. An active state corresponds to the binary value 1, while an inactive state corresponds to the binary value 0. An active signal state is often described as *logic 1*, *on*, *true*, or a *mark*. An inactive signal state is often described as *logic 0*, *off*, *false*, or a *space*.

For data signals, the "on" state occurs when the received signal voltage is more negative than -3 volts, while the "off" state occurs for voltages more positive than 3 volts. For control signals, the "on" state occurs when the received signal voltage is more positive than 3 volts, while the "off" state occurs for voltages more negative than -3 volts. The voltage between -3 volts and +3 volts is considered a transition region, and the signal state is undefined.

To bring the signal to the "on" state, the controlling device *unasserts* (or *lowers*) the value for data pins and *asserts* (or *raises*) the value for control pins. Conversely, to bring the signal to the "off" state, the controlling device asserts the value for data pins and unasserts the value for control pins.

The “on” and “off” states for a data signal and for a control signal are shown below.



The Data Pins

Most serial port devices support *full-duplex* communication meaning that they can send and receive data at the same time. Therefore, separate pins are used for transmitting and receiving data. For these devices, the TD, RD, and GND pins are used. However, some types of serial port devices support only one-way or *half-duplex* communications. For these devices, only the TD and GND pins are used. In this guide, it is assumed that a full-duplex serial port is connected to your device.

The TD pin carries data transmitted by a DTE to a DCE. The RD pin carries data that is received by a DTE from a DCE.

The Control Pins

9-pin serial ports provide several control pins that:

- Signal the presence of connected devices
- Control the flow of data

The control pins include RTS and CTS, DTR and DSR, CD, and RI.

The RTS and CTS Pins. The RTS and CTS pins are used to signal whether the devices are ready to send or receive data. This type of data flow control – called hardware handshaking – is used to prevent data loss during transmission. When enabled for both the DTE and DCE, hardware handshaking using RTS and CTS follows these steps:

1 The DTE asserts the RTS pin to instruct the DCE that it is ready to receive data.

2 The DCE asserts the CTS pin indicating that it is clear to send data over the TD pin. If data can no longer be sent, the CTS pin is unasserted.

3 The data is transmitted to the DTE over the TD pin. If data can no longer be accepted, the RTS pin is unasserted by the DTE and the data transmission is stopped.

To enable hardware handshaking in MATLAB, refer to “Controlling the Flow of Data: Handshaking” on page 8-59.

The DTR and DSR Pins. Many devices use the DSR and DTR pins to signal if they are connected and powered. Signaling the presence of connected devices using DTR and DSR follows these steps:

1 The DTE asserts the DTR pin to request that the DCE connect to the communication line.

2 The DCE asserts the DSR pin to indicate it’s connected.

3 DCE unasserts the DSR pin when it’s disconnected from the communication line.

The DTR and DSR pins were originally designed to provide an alternative method of hardware handshaking. However, the RTS and CTS pins are usually used in this way, and not the DSR and DTR pins. However, you should refer to your device documentation to determine its specific pin behavior.

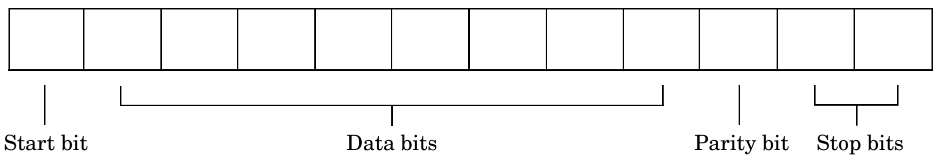
The CD and RI Pins. The CD and RI pins are typically used to indicate the presence of certain signals during modem-modem connections.

CD is used by a modem to signal that it has made a connection with another modem, or has detected a carrier tone. CD is asserted when the DCE is receiving a signal of a suitable frequency. CD is unasserted if the DCE is not receiving a suitable signal.

RI is used to indicate the presence of an audible ringing signal. RI is asserted when the DCE is receiving a ringing signal. RI is unasserted when the DCE is not receiving a ringing signal (for example, it's between rings).

Serial Data Format

The serial data format includes one start bit, between five and eight data bits, and one stop bit. A parity bit and an additional stop bit might be included in the format as well. The diagram below illustrates the serial data format.



The format for serial port data is often expressed using the following notation

number of data bits - parity type - number of stop bits

For example, 8-N-1 is interpreted as eight data bits, no parity bit, and one stop bit, while 7-E-2 is interpreted as seven data bits, even parity, and two stop bits.

The data bits are often referred to as a *character* because these bits usually represent an ASCII character. The remaining bits are called *framing bits* because they frame the data bits.

Bytes Versus Values

The collection of bits that comprise the serial data format is called a *byte*. At first, this term might seem inaccurate because a byte is 8 bits and the serial data format can range between 7 bits and 12 bits. However, when serial data is stored on your computer, the framing bits are stripped away, and only the data bits are retained. Moreover, eight data bits are always used regardless of the number of data bits specified for transmission, with the unused bits assigned a value of 0.

When reading or writing data, you might need to specify a *value*, which can consist of one or more bytes. For example, if you read one value from a device using the `int32` format, then that value consists of four bytes. For more information about reading and writing values, refer to "Writing and Reading Data" on page 8-29.

Synchronous and Asynchronous Communication

The RS-232 standard supports two types of communication protocols: synchronous and asynchronous.

Using the synchronous protocol, all transmitted bits are synchronized to a common clock signal. The two devices initially synchronize themselves to each other, and then continually send characters to stay synchronized. Even when actual data is not really being sent, a constant flow of bits allows each device to know where the other is at any given time. That is, each bit that is sent is either actual data or an idle character. Synchronous communications allows faster data transfer rates than asynchronous methods, because additional bits to mark the beginning and end of each data byte are not required.

Using the asynchronous protocol, each device uses its own internal clock resulting in bytes that are transferred at arbitrary times. So, instead of using time as a way to synchronize the bits, the data format is used.

In particular, the data transmission is synchronized using the start bit of the word, while one or more stop bits indicate the end of the word. The requirement to send these additional bits causes asynchronous communications to be slightly slower than synchronous. However, it has the advantage that the processor does not have to deal with the additional idle characters. Most serial ports operate asynchronously.

Note When used in this guide, the terms "synchronous" and "asynchronous" refer to whether read or write operations block access to the MATLAB command line. Refer to "Controlling Access to the MATLAB Command Line" on page 8-29 for more information.

How Are the Bits Transmitted?

By definition, serial data is transmitted one bit at a time. The order in which the bits are transmitted is given below:

1 The start bit is transmitted with a value of 0.

2 The data bits are transmitted. The first data bit corresponds to the least significant bit (LSB), while the last data bit corresponds to the most significant bit (MSB).

3 The parity bit (if defined) is transmitted.

4 One or two stop bits are transmitted, each with a value of 1.

The number of bits transferred per second is given by the *baud rate*. The transferred bits include the start bit, the data bits, the parity bit (if defined), and the stop bits.

Start and Stop Bits

As described in “Synchronous and Asynchronous Communication” on page 8-12, most serial ports operate asynchronously. This means that the transmitted byte must be identified by start and stop bits. The start bit indicates when the data byte is about to begin and the stop bit(s) indicates when the data byte has been transferred. The process of identifying bytes with the serial data format follows these steps:

1 When a serial port pin is idle (not transmitting data), then it is in an “on” state.

2 When data is about to be transmitted, the serial port pin switches to an “off” state due to the start bit.

3 The serial port pin switches back to an “on” state due to the stop bit(s). This indicates the end of the byte.

Data Bits

The data bits transferred through a serial port might represent device commands, sensor readings, error messages, and so on. The data can be transferred as either binary data or ASCII data.

Most serial ports use between five and eight data bits. Binary data is typically transmitted as eight bits. Text-based data is transmitted as either seven bits or eight bits. If the data is based on the ASCII character set, then a minimum of seven bits is required because there are 2^7 or 128 distinct characters. If an eighth bit is used, it must have a value of 0. If the data is based on the extended ASCII character set, then eight bits must be used because there are 2^8 or 256 distinct characters.

The Parity Bit

The parity bit provides simple error (parity) checking for the transmitted data. The types of parity checking are given below.

Table 8-2: Parity Types

Parity Type	Description
Even	The data bits plus the parity bit result in an even number of 1's.
Mark	The parity bit is always 1.
Odd	The data bits plus the parity bit result in an odd number of 1's.
Space	The parity bit is always 0.

Mark and space parity checking are seldom used because they offer minimal error detection. You might choose to not use parity checking at all.

The parity checking process follows these steps:

1 The transmitting device sets the parity bit to 0 or to 1 depending on the data bit values and the type of parity checking selected.

2 The receiving device checks if the parity bit is consistent with the transmitted data. If it is, then the data bits are accepted. If it is not, then an error is returned.

Note Parity checking can detect only 1-bit errors. Multiple-bit errors can appear as valid data.

For example, suppose the data bits 01110001 are transmitted to your computer. If even parity is selected, then the parity bit is set to 0 by the transmitting device to produce an even number of 1's. If odd parity is selected, then the parity bit is set to 1 by the transmitting device to produce an odd number of 1's.

Finding Serial Port Information for Your Platform

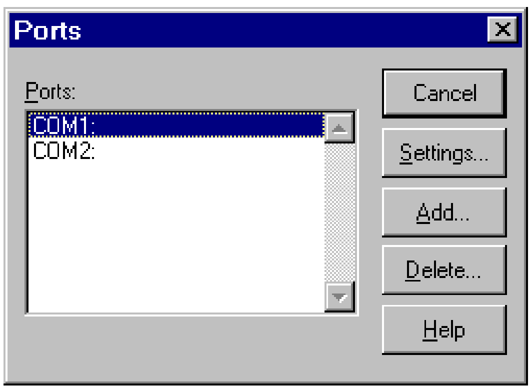
The ways to find serial port information for Windows and UNIX platforms are described below.

Note Your operating system provides default values for all serial port settings. However, these settings are overridden by your MATLAB code, and will have no effect on your serial port application.

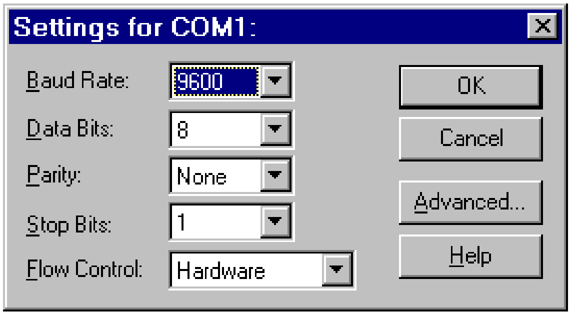
Windows Platform

You can easily access serial port information through the Windows Control Panel. You can invoke the Control Panel with the **Start** button (**Start -> Settings -> Control Panel**).

For Windows NT, you access the serial ports by selecting the Ports icon within the Control Panel. The resulting **Ports** dialog box is shown below.



To obtain information on the possible settings for COM1, select this port under the **Ports** list box and then select **Settings**.



You can access serial port information for the Windows 98 and Windows 2000 operating systems with the **System Properties** dialog box, which is available through the Control Panel.

UNIX Platform

To find serial port information for UNIX platforms, you need to know the serial port names. These names might vary between different operating systems.

On Linux, serial port devices are typically named `ttyS0`, `ttyS1`, and so on. You can use the `setserial` command to display or configure serial port information. For example, to display which ports are available

```
setserial -bg /dev/ttyS*
/dev/ttyS0 at 0x03f8 (irq = 4) is a 16550A
/dev/ttyS1 at 0x02f8 (irq = 3) is a 16550A
```

To display detailed information about `ttyS0`

```
setserial -ag /dev/ttyS0
/dev/ttyS0, Line 0, UART: 16550A, Port: 0x03f8, IRQ: 4
        Baud_base: 115200, close_delay: 50, divisor: 0
        closing_wait: 3000, closing_wait2: infinte
        Flags: spd_normal skip_test session_lockout
```

Note If the `setserial -ag` command does not work, make sure that you have read and write permission for the port.

For all supported UNIX platforms, you can use the `stty` command to display or configure serial port information. For example, to display serial port properties for `ttyS0`

```
stty -a < /dev/ttyS0
```

To configure the baud rate to 4800 bits per second

```
stty speed 4800 < /dev/ttyS0 > /dev/ttyS0
```

Selected Bibliography

1. TIA/EIA-232-F, *Interface Between Data Terminal Equipment and Data Circuit-Terminating Equipment Employing Serial Binary Data Interchange*.
2. Jan Axelson, *Serial Port Complete*, Lakeview Research, Madison, WI, 1998.
3. *Instrument Communication Handbook*, IOTech, Inc., Cleveland, OH, 1991.
4. *TDS 200-Series Two Channel Digital Oscilloscope Programmer Manual,* Tektronix, Inc., Wilsonville, OR.
5. *Courier High Speed Modems User's Manua*l, U.S. Robotics, Inc., Skokie, IL, 1994.
6. *Getting Started with Your AT Serial Hardware and Software for Windows 98/95*, National Instruments, Inc., Austin, TX, 1998.

Getting Started with Serial I/O

To get you started with the MATLAB serial port interface, this section provides the following information:

- "Example: Getting Started" illustrates some basic serial port commands.
- "The Serial Port Session" describes the steps you use to perform any serial port task from beginning to end.
- "Configuring and Returning Properties" describes how you display serial port property names and property values, and how you assign values to properties.

Example: Getting Started

If you have a device connected to the serial port COM1 and configured for a baud rate of 4800, you can execute the following complete example.

```
s = serial('COM1');
set(s,'BaudRate',4800);
fopen(s);
fprintf(s,'*IDN?')
out = fscanf(s);
fclose(s)
delete(s)
clear s
```

The `*IDN?` command queries the device for identification information, which is returned to `out`. If your device does not support this command, or if it is connected to a different serial port, you should modify the above example accordingly.

Note `*IDN?` is one of the commands supported by the Standard Commands for Programmable Instruments (SCPI) language, which is used by many modern devices. Refer to your device documentation to see if it supports the SCPI language.

The Serial Port Session

The serial port *session* comprises all the steps you are likely to take when communicating with a device connected to a serial port. These steps are:

1. **Create a serial port object** – You create a serial port object for a specific serial port using the `serial` creation function.

   You can also configure properties during object creation. In particular, you might want to configure properties associated with serial port communications such as the baud rate, the number of data bits, and so on.

2. **Connect to the device** – You connect the serial port object to the device using the `fopen` function.

   After the object is connected, you can alter device settings by configuring property values, read data, and write data.

3. **Configure properties** – To establish the desired serial port object behavior, you assign values to properties using the `set` function or dot notation.

   In practice, you can configure many of the properties at any time including during, or just after, object creation. Conversely, depending on your device settings and the requirements of your serial port application, you might be able to accept the default property values and skip this step.

4. **Write and read data** – You can now write data to the device using the `fprintf` or `fwrite` function, and read data from the device using the `fgetl`, `fgets`, `fread`, `fscanf`, or `readasync` function.

   The serial port object behaves according to the previously configured or default property values.

5. **Disconnect and clean up** – When you no longer need the serial port object, you should disconnect it from the device using the `fclose` function, remove it from memory using the `delete` function, and remove it from the MATLAB workspace using the `clear` command.

The serial port session is reinforced in many of the serial port documentation examples. Refer to “Example: Getting Started” on page 8-18 to see a basic example that uses the steps shown above.

Configuring and Returning Properties

You establish the desired serial port object behavior by configuring property values. You can display or configure property values using the set function, the get function, or dot notation.

Displaying Property Names and Property Values

Once the serial port object is created, you can use the set function to display all the configurable properties to the command line. Additionally, if a property has a finite set of string values, then set also displays these values.

```
s = serial('COM1');
set(s)
    ByteOrder: [ {littleEndian} | bigEndian ]
    BytesAvailableFcn
    BytesAvailableFcnCount
    BytesAvailableFcnMode: [ {terminator} | byte ]
    ErrorFcn
    InputBufferSize
    Name
    OutputBufferSize
    OutputEmptyFcn
    RecordDetail: [ {compact} | verbose ]
    RecordMode: [ {overwrite} | append | index ]
    RecordName
    Tag
    Timeout
    TimerFcn
    TimerPeriod
    UserData

    SERIAL specific properties:
    BaudRate
    BreakInterruptFcn
    DataBits
    DataTerminalReady: [ {on} | off ]
    FlowControl: [ {none} | hardware | software ]
    Parity: [ {none} | odd | even | mark | space ]
    PinStatusFcn
    Port
    ReadAsyncMode: [ {continuous} | manual ]
```

```
        RequestToSend: [ {on} | off ]
        StopBits
        Terminator
```

You can use the get function to display one or more properties and their current values to the command line. To display all properties and their current values

```
    get(s)
        ByteOrder = littleEndian
        BytesAvailable = 0
        BytesAvailableFcn =
        BytesAvailableFcnCount = 48
        BytesAvailableFcnMode = terminator
        BytesToOutput = 0
        ErrorFcn =
        InputBufferSize = 512
        Name = Serial-COM1
        OutputBufferSize = 512
        OutputEmptyFcn =
        RecordDetail = compact
        RecordMode = overwrite
        RecordName = record.txt
        RecordStatus = off
        Status = closed
        Tag =
        Timeout = 10
        TimerFcn =
        TimerPeriod = 1
        TransferStatus = idle
        Type = serial
        UserData = []
        ValuesReceived = 0
        ValuesSent = 0

        SERIAL specific properties:
        BaudRate = 9600
        BreakInterruptFcn =
        DataBits = 8
        DataTerminalReady = on
        FlowControl = none
```

```
Parity = none
PinStatus = [1x1 struct]
PinStatusFcn =
Port = COM1
ReadAsyncMode = continuous
RequestToSend = on
StopBits = 1
Terminator = LF
```

To display the current value for one property, you supply the property name to `get`.

```
get(s,'OutputBufferSize')
ans =
   512
```

To display the current values for multiple properties, you must include the property names as elements of a cell array.

```
get(s,{'Parity','TransferStatus'})
ans =
    'none'    'idle'
```

You can also use the dot notation to display a single property value.

```
s.Parity
ans =
none
```

Configuring Property Values

You can configure property values using the `set` function

```
set(s,'BaudRate',4800);
```

or the dot notation.

```
s.BaudRate = 4800;
```

To configure values for multiple properties, you can supply multiple property name/property value pairs to `set`.

```
set(s,'DataBits',7,'Name','Test1-serial')
```

Note that you can configure only one property value at a time using the dot notation.

In practice, you can configure many of the properties at any time while the serial port object exists – including during object creation. However, some properties are not configurable while the object is connected to the device or when recording information to disk. Refer to “Property Reference” on page 8-70 for information about when a property is configurable.

Specifying Property Names

Serial port property names are presented using mixed case. While this makes property names easier to read, you can use any case you want when specifying property names. Additionally, you need use only enough letters to identify the property name uniquely, so you can abbreviate most property names. For example, you can configure the `BaudRate` property any of these ways.

```
set(s,'BaudRate',4800)
set(s,'baudrate',4800)
set(s,'BAUD',4800)
```

When you include property names in an M-file, you should use the full property name. This practice can prevent problems with future releases of MATLAB if a shortened name is no longer unique because of the addition of new properties.

Default Property Values

Whenever you do not explicitly define a value for a property, then the default value is used. All configurable properties have default values.

Note Your operating system provides default values for all serial port settings such as the baud rate. However, these settings are overridden by your MATLAB code, and will have no effect on your serial port application.

If a property has a finite set of string values, then the default value is enclosed by `{}`. For example, the default value for the `Parity` property is `none`.

```
set(s,'Parity')
[ {none} | odd | even | mark | space ]
```

You can find the default value for any property in the property reference pages.

Creating a Serial Port Object

You create a serial port object with the `serial` function. `serial` requires the name of the serial port connected to your device as an input argument. Additionally, you can configure property values during object creation. For example, to create a serial port object associated with the serial port COM1

```
s = serial('COM1');
```

The serial port object `s` now exists in the MATLAB workspace. You can display the class of `s` with the `whos` command.

```
whos s
  Name      Size         Bytes  Class

  s         1x1            512  serial object

Grand total is 11 elements using 512 bytes
```

Once the serial port object is created, the properties listed below are automatically assigned values. These general purpose properties provide descriptive information about the serial port object based on the object type and the serial port.

Table 8-3: Descriptive General Purpose Properties

Property Name	Description
`Name`	Specify a descriptive name for the serial port object
`Port`	Indicate the platform-specific serial port name
`Type`	Indicate the object type

You can display the values of these properties for `s` with the `get` function.

```
get(s,{'Name','Port','Type'})
ans =
    'Serial-COM1'    'COM1'    'serial'
```

Configuring Properties During Object Creation

You can configure serial port properties during object creation. `serial` accepts property names and property values in the same format as the `set` function. For example, you can specify property name/property value pairs.

```
s = serial('COM1','BaudRate',4800,'Parity','even');
```

If you specify an invalid property name, the object is not created. However, if you specify an invalid value for some properties (for example, `BaudRate` is set to 50), the object might be created but you will not be informed of the invalid value until you connect the object to the device with the `fopen` function.

The Serial Port Object Display

The serial port object provides you with a convenient display that summarizes important configuration and state information. You can invoke the display summary these three ways:

- Type the serial port object variable name at the command line.
- Exclude the semicolon when creating a serial port object.
- Exclude the semicolon when configuring properties using the dot notation.

The display summary for the serial port object `s` is given below.

```
Serial Port Object : Serial-COM1

Communication Settings
   Port:              COM1
   BaudRate:          9600
   Terminator:        'LF'

Communication State
   Status:            closed
   RecordStatus:      off

Read/Write State
   TransferStatus:    idle
   BytesAvailable:    0
   ValuesReceived:    0
   ValuesSent:        0
```

Creating an Array of Serial Port Objects

In MATLAB, you can create an array from existing variables by concatenating those variables together. The same is true for serial port objects. For example, suppose you create the serial port objects `s1` and `s2`

```
s1 = serial('COM1');
s2 = serial('COM2');
```

You can now create a serial port object array consisting of `s1` and `s2` using the usual MATLAB syntax. To create the row array `x`

```
x = [s1 s2]

Instrument Object Array

   Index:   Type:        Status:      Name:
   1        serial       closed       Serial-COM1
   2        serial       closed       Serial-COM2
```

To create the column array `y`

```
y = [s1;s2];
```

Note that you cannot create a matrix of serial port objects. For example, you cannot create the matrix

```
z = [s1 s2;s1 s2];
??? Error using ==> serial/vertcat
Only a row or column vector of instrument objects can be created.
```

Depending on your application, you might want to pass an array of serial port objects to a function. For example, to configure the baud rate and parity for `s1` and `s2` using one call to `set`

```
set(x,'BaudRate',19200,'Parity','even')
```

Refer to the serial port function reference to see which functions accept a serial port object array as an input.

Connecting to the Device

Before you can use the serial port object to write or read data, you must connect it to your device via the serial port specified in the `serial` function. You connect a serial port object to the device with the `fopen` function.

```
fopen(s)
```

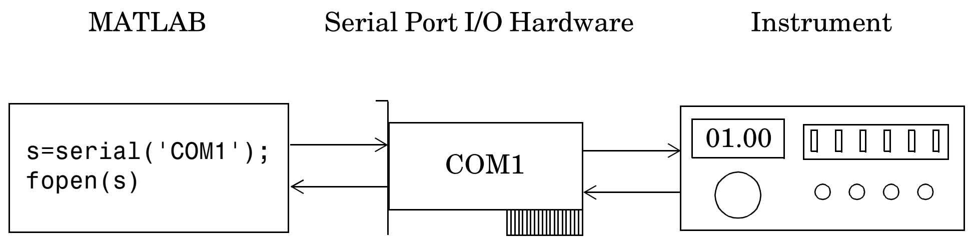
Some properties are read-only while the serial port object is connected and must be configured before using `fopen`. Examples include the `InputBufferSize` and the `OutputBufferSize` properties. Refer to “Property Reference” on page 8-70 to determine when you can configure a property.

Note You can create any number of serial port objects. However, you can connect only one serial port object to a given serial port at a time.

You can examine the `Status` property to verify that the serial port object is connected to the device.

```
s.Status
ans =
open
```

As illustrated below, the connection between the serial port object and the device is complete, and you can write and read data.



Configuring Communication Settings

Before you can write or read data, both the serial port object and the device must have identical communication settings. Configuring serial port communications involves specifying values for properties that control the baud rate and the serial data format. These properties are given below.

Table 8-4: Communication Properties

Property Name	Description
`BaudRate`	Specify the rate at which bits are transmitted
`DataBits`	Specify the number of data bits to transmit
`Parity`	Specify the type of parity checking
`StopBits`	Specify the number of bits used to indicate the end of a byte
`Terminator`	Specify the terminator character

Note If the serial port object and the device communication settings are not identical, then you cannot successfully read or write data.

Refer to your device documentation for an explanation of its supported communication settings.

Writing and Reading Data

For many serial port applications, there are three important questions that you should consider when writing or reading data:

- Will the read or write function block access to the MATLAB command line?
- Is the data to be transferred binary (numerical) or text?
- Under what conditions will the read or write operation complete?

For write operations, these questions are answered in "Writing Data" on page 8-31. For read operations, these questions are answered in "Reading Data" on page 8-36.

Example: Introduction to Writing and Reading Data

Suppose you want to return identification information for a Tektronix TDS 210 two-channel oscilloscope connected to the serial port COM1. This requires writing the `*IDN?` command to the instrument using the `fprintf` function, and then reading back the result of that command using the `fscanf` function.

```
s = serial('COM1');
fopen(s)
fprintf(s,'*IDN?')
out = fscanf(s)
```

The resulting identification information is shown below.

```
out =
TEKTRONIX,TDS 210,0,CF:91.1CT FV:v1.16 TDS2CM:CMV:v1.04
```

End the serial port session.

```
fclose(s)
delete(s)
clear s
```

Controlling Access to the MATLAB Command Line

You control access to the MATLAB command line by specifying whether a read or write operation is *synchronous* or *asynchronous*.

A synchronous operation blocks access to the command line until the read or write function completes execution. An asynchronous operation does not block access to the command line, and you can issue additional commands while the read or write function executes in the background.

The terms “synchronous” and “asynchronous” are often used to describe how the serial port operates at the hardware level. The RS-232 standard supports an asynchronous communication protocol. Using this protocol, each device uses its own internal clock. The data transmission is synchronized using the start bit of the bytes, while one or more stop bits indicate the end of the byte. Refer to “Serial Data Format” on page 8-11 for more information on start bits and stop bits. The RS-232 standard also supports a synchronous mode where all transmitted bits are synchronized to a common clock signal.

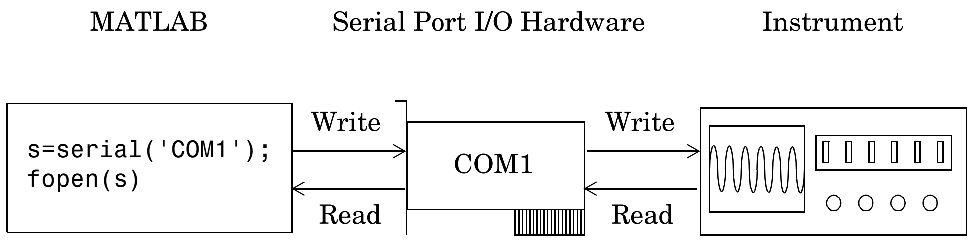
At the hardware level, most serial ports operate asynchronously. However, using the default behavior for many of the read and write functions, you can mimic the operation of a synchronous serial port.

Note When used in this guide, the terms “synchronous” and “asynchronous” refer to whether read or write operations block access to the MATLAB command line. In other words, these terms describe how the software behaves, and not how the hardware behaves.

The two main advantages of writing or reading data asynchronously are:

- You can issue another command while the write or read function is executing.
- You can use all supported callback properties (see “Events and Callbacks” on page 8-48).

For example, because serial ports have separate read and write pins, you can simultaneously read and write data. This is illustrated below.



Writing Data

This section describes writing data to your serial port device in three parts:

- "The Output Buffer and Data Flow" describes the flow of data from MATLAB to the device.
- "Writing Text Data" describes how to write text data (string commands) to the device.
- "Writing Binary Data" describes how to write binary (numerical) data to the device.

The functions associated with writing data are given below.

Table 8-5: Functions Associated with Writing Data

Function Name	Description
`fprintf`	Write text to the device
`fwrite`	Write binary data to the device
`stopasync`	Stop asynchronous read and write operations

The properties associated with writing data are given below.

Table 8-6: Properties Associated with Writing Data

Property Name	Description
BytesToOutput	Indicate the number of bytes currently in the output buffer
OutputBufferSize	Specify the size of the output buffer in bytes
Timeout	Specify the waiting time to complete a read or write operation
TransferStatus	Indicate if an asynchronous read or write operation is in progress
ValuesSent	Indicate the total number of values written to the device

The Output Buffer and Data Flow

The output buffer is computer memory allocated by the serial port object to store data that is to be written to the device. When writing data to your device, the data flow follows these two steps:

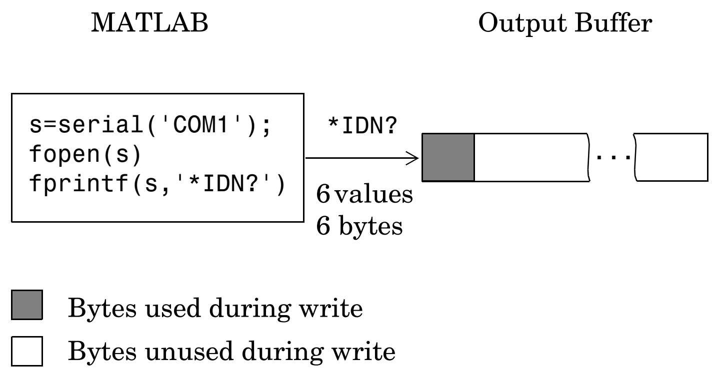
1. The data specified by the write function is sent to the output buffer.
2. The data in the output buffer is sent to the device.

The `OutputBufferSize` property specifies the maximum number of bytes that you can store in the output buffer. The `BytesToOutput` property indicates the number of bytes currently in the output buffer. The default values for these properties are given below.

```
s = serial('COM1');
get(s,{'OutputBufferSize','BytesToOutput'})
ans =
    [512]    [0]
```

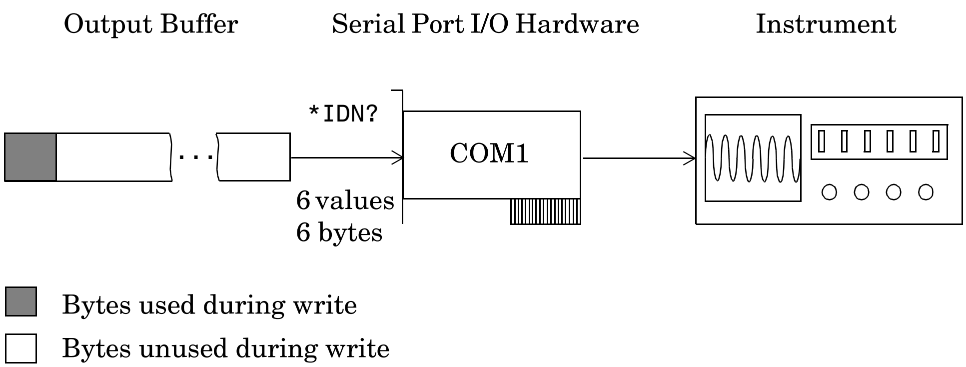
If you attempt to write more data than can fit in the output buffer, an error is returned and no data is written.

For example, suppose you write the string command `*IDN?` to the TDS 210 oscilloscope using the `fprintf` function. As shown below, the string is first written to the output buffer as six values.



The `*IDN?` command consists of six values because the terminator is automatically written. Moreover, the default data format for the `fprintf` function specifies that one value corresponds to one byte. For more information about bytes and values, refer to "Bytes Versus Values" on page 8-11. `fprintf` and the terminator are discussed in "Writing Text Data" on page 8-34.

As shown below, after the string is written to the output buffer, it is then written to the device via the serial port.



Writing Text Data

You use the `fprintf` function to write text data to the device. For many devices, writing text data means writing string commands that change device settings, prepare the device to return data or status information, and so on.

For example, the `Display:Contrast` command changes the display contrast of the oscilloscope.

```
s = serial('COM1');
fopen(s)
fprintf(s,'Display:Contrast 45')
```

By default, `fprintf` writes data using the `%s\n` format because many serial port devices accept only text-based commands. However, you can specify many other formats as described in the `fprintf` reference pages.

You can verify the number of values sent to the device with the `ValuesSent` property.

```
s.ValuesSent
ans =
    20
```

Note that the `ValuesSent` property value includes the terminator because each occurrence of `\n` in the command sent to the device is replaced with the `Terminator` property value.

```
s.Terminator
ans =
LF
```

The default value of `Terminator` is the line feed character. The terminator required by your device will be described in its documentation.

Synchronous Versus Asynchronous Write Operations. By default, `fprintf` operates synchronously and will block the MATLAB command line until execution completes. To write text data asynchronously to the device, you must specify `async` as the last input argument to `fprintf`.

```
fprintf(s,'Display:Contrast 45','async')
```

Asynchronous operations do not block access to the MATLAB command line. Additionally, while an asynchronous write operation is in progress, you can:

- Execute an asynchronous read operation because serial ports have separate pins for reading and writing
- Make use of all supported callback properties

You can determine which asynchronous operations are in progress with the `TransferStatus` property. If no asynchronous operations are in progress, then `TransferStatus` is `idle`.

```
s.TransferStatus
ans =
idle
```

Rules for Completing a Write Operation with fprintf. A synchronous or asynchronous write operation using `fprintf` completes when:

- The specified data is written.
- The time specified by the `Timeout` property passes.

Additionally, you can stop an asynchronous write operation with the `stopasync` function.

Writing Binary Data

You use the `fwrite` function to write binary data to the device. Writing binary data means writing numerical values. A typical application for writing binary data involves writing calibration data to an instrument such as an arbitrary waveform generator.

Note Some serial port devices accept only text-based commands. These commands might use the SCPI language or some other vendor-specific language. Therefore, you might need to use the `fprintf` function for all write operations.

By default, `fwrite` translates values using the `uchar` precision. However, you can specify many other precisions as described in the reference pages for this function.

By default, `fwrite` operates synchronously. To write binary data asynchronously to the device, you must specify `async` as the last input argument to `fwrite`. For more information about synchronous and asynchronous write operations, refer to the “Writing Text Data” on page 8-34. For a description of the rules used by `fwrite` to complete a write operation, refer to its reference pages.

Reading Data

This section describes reading data from your serial port device in three parts:

- “The Input Buffer and Data Flow” describes the flow of data from the device to MATLAB.
- “Reading Text Data” describes how to read from the device, and format the data as text.
- “Reading Binary Data” describes how to read binary (numerical) data from the device.

The functions associated with reading data are given below.

Table 8-7: Functions Associated with Reading Data

Function Name	Description
`fgetl`	Read one line of text from the device and discard the terminator
`fgets`	Read one line of text from the device and include the terminator
`fread`	Read binary data from the device
`fscanf`	Read data from the device, and format as text
`readasync`	Read data asynchronously from the device
`stopasync`	Stop asynchronous read and write operations

The properties associated with reading data are given below.

Table 8-8: Properties Associated with Reading Data

Property Name	Description
`BytesAvailable`	Indicate the number of bytes available in the input buffer
`InputBufferSize`	Specify the size of the input buffer in bytes
`ReadAsyncMode`	Specify whether an asynchronous read operation is continuous or manual
`Timeout`	Specify the waiting time to complete a read or write operation
`TransferStatus`	Indicate if an asynchronous read or write operation is in progress
`ValuesReceived`	Indicate the total number of values read from the device

The Input Buffer and Data Flow

The input buffer is computer memory allocated by the serial port object to store data that is to be read from the device. When reading data from your device, the data flow follows these two steps:

1 The data read from the device is stored in the input buffer.

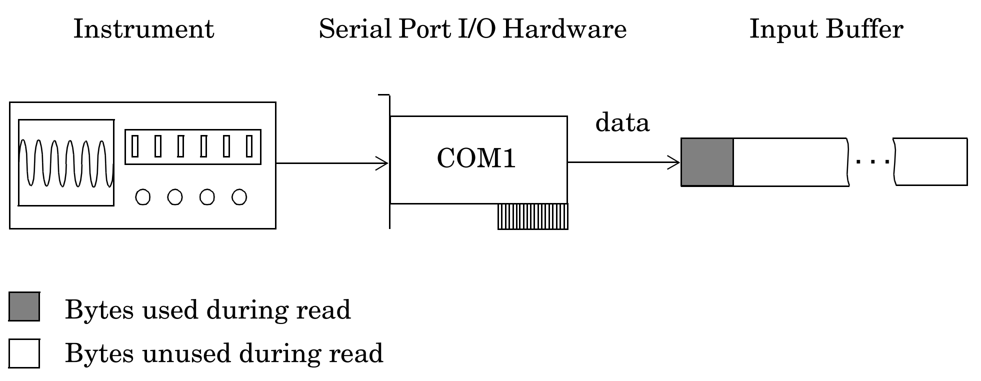
2 The data in the input buffer is returned to the MATLAB variable specified by the read function.

The `InputBufferSize` property specifies the maximum number of bytes that you can store in the input buffer. The `BytesAvailable` property indicates the number of bytes currently available to be read from the input buffer. The default values for these properties are given below.

```
s = serial('COM1');
get(s,{'InputBufferSize','BytesAvailable'})
ans =
    [512]    [0]
```

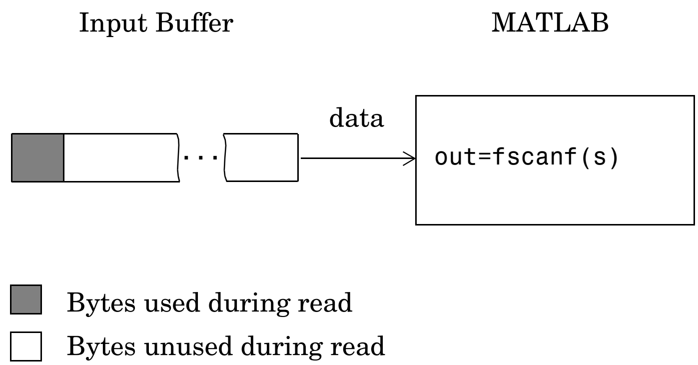
If you attempt to read more data than can fit in the input buffer, an error is returned and no data is read.

For example, suppose you use the `fscanf` function to read the text-based response of the `*IDN?` command previously written to the TDS 210 oscilloscope. As shown below, the text data is first read into to the input buffer via the serial port.



Note that for a given read operation, you might not know the number of bytes returned by the device. Therefore, you might need to preset the `InputBufferSize` property to a sufficiently large value before connecting the serial port object.

As shown below, after the data is stored in the input buffer, it is then transferred to the output variable specified by `fscanf`.



Reading Text Data

You use the `fgetl`, `fgets`, and `fscanf` functions to read data from the device, and format the data as text.

For example, suppose you want to return identification information for the oscilloscope. This requires writing the `*IDN?` command to the instrument, and then reading back the result of that command.

```
s = serial('COM1');
fopen(s)
fprintf(s,'*IDN?')
out = fscanf(s)
out =
TEKTRONIX,TDS 210,0,CF:91.1CT FV:v1.16 TDS2CM:CMV:v1.04
```

By default, `fscanf` reads data using the `%c` format because the data returned by many serial port devices is text based. However, you can specify many other formats as described in the `fscanf` reference pages.

You can verify the number of values read from the device – including the terminator – with the `ValuesReceived` property.

```
s.ValuesReceived
ans =
    56
```

Synchronous Versus Asynchronous Read Operations. You specify whether read operations are synchronous or asynchronous with the `ReadAsyncMode` property. You can configure `ReadAsyncMode` to `continuous` or `manual`.

If `ReadAsyncMode` is `continuous` (the default value), the serial port object continuously queries the device to determine if data is available to be read. If data is available, it is asynchronously stored in the input buffer. To transfer the data from the input buffer to MATLAB, you use one of the synchronous (blocking) read functions such as `fgetl` or `fscanf`. If data is available in the input buffer, these functions will return quickly.

```
s.ReadAsyncMode = 'continuous';
fprintf(s,'*IDN?')
s.BytesAvailable
ans =
    56
out = fscanf(s);
```

If `ReadAsyncMode` is `manual`, the serial port object does not continuously query the device to determine if data is available to be read. To read data asynchronously, you use the `readasync` function.You then use one of the synchronous read functions to transfer data from the input buffer to MATLAB.

```
s.ReadAsyncMode = 'manual';
fprintf(s,'*IDN?')
s.BytesAvailable
ans =
    0
readasync(s)
s.BytesAvailable
ans =
    56
out = fscanf(s);
```

Asynchronous operations do not block access to the MATLAB command line. Additionally, while an asynchronous read operation is in progress, you can:

- Execute an asynchronous write operation because serial ports have separate pins for reading and writing
- Make use of all supported callback properties

You can determine which asynchronous operations are in progress with the `TransferStatus` property. If no asynchronous operations are in progress, then `TransferStatus` is `idle`.

```
s.TransferStatus
ans =
idle
```

Rules for Completing a Read Operation with fscanf. A read operation with `fscanf` blocks access to the MATLAB command line until:

- The terminator specified by the `Terminator` property is read.
- The time specified by the `Timeout` property passes.
- The specified number of values specified is read.
- The input buffer is filled.

Reading Binary Data

You use the `fread` function to read binary data from the device. Reading binary data means that you return numerical values to MATLAB.

For example, suppose you want to return the cursor and display settings for the oscilloscope. This requires writing the `CURSOR?` and `DISPLAY?` commands to the instrument, and then reading back the results of those commands.

```
s = serial('COM1');
fopen(s)
fprintf(s,'CURSOR?')
fprintf(s,'DISPLAY?')
```

Because the default value for the `ReadAsyncMode` property is `continuous`, data is asynchronously returned to the input buffer as soon as it is available from the device. You can verify the number of values read with the BytesAvailable property.

```
s.BytesAvailable
ans =
    69
```

You can return the data to MATLAB using any of the synchronous read functions. However, if you use `fgetl`, `fgets`, or `fscanf`, then you must issue the function twice because there are two terminators stored in the input buffer. If you use `fread`, then you can return all the data to MATLAB in one function call.

```
out = fread(s,69);
```

By default, `fread` returns numerical values in double precision arrays. However, you can specify many other precisions as described in the `fread` reference pages. You can convert the numerical data to text using the MATLAB `char` function.

```
val = char(out)'
val =
HBARS;CH1;SECONDS;-1.0E-3;1.0E-3;VOLTS;-6.56E-1;6.24E-1
YT;DOTS;0;45
```

For more information about synchronous and asynchronous read operations, refer to "Reading Text Data" on page 8-39. For a description of the rules used by `fread` to complete a read operation, refer to its reference pages.

Example: Writing and Reading Text Data

This example illustrates how to communicate with a serial port instrument by writing and reading text data.

The instrument is a Tektronix TDS 210 two-channel oscilloscope connected to the COM1 port. Therefore, many of the commands given below are specific to this instrument. A sine wave is input into channel 2 of the oscilloscope, and your job is to measure the peak-to-peak voltage of the input signal.

1 **Create a serial port object –** Create the serial port object `s` associated with serial port COM1.

   ```
   s = serial('COM1');
   ```

2 **Connect to the device –** Connect `s` to the oscilloscope. Because the default value for the `ReadAsyncMode` property is `continuous`, data is asynchronously returned to the input buffer as soon as it is available from the instrument.

```
fopen(s)
```

3 **Write and read data –** Write the `*IDN?` command to the instrument using `fprintf`, and then read back the result of the command using `fscanf`.

```
fprintf(s,'*IDN?')
idn = fscanf(s)
idn =
TEKTRONIX,TDS 210,0,CF:91.1CT FV:v1.16 TDS2CM:CMV:v1.04
```

You need to determine the measurement source. Possible measurement sources include channel 1 and channel 2 of the oscilloscope.

```
fprintf(s,'MEASUREMENT:IMMED:SOURCE?')
source = fscanf(s)
source =
CH1
```

The scope is configured to return a measurement from channel 1. Because the input signal is connected to channel 2, you must configure the instrument to return a measurement from this channel.

```
fprintf(s,'MEASUREMENT:IMMED:SOURCE CH2')
fprintf(s,'MEASUREMENT:IMMED:SOURCE?')
source = fscanf(s)
source =
CH2
```

You can now configure the scope to return the peak-to-peak voltage, and then request the value of this measurement.

```
fprintf(s,'MEASUREMENT:MEAS1:TYPE PK2PK')
fprintf(s,'MEASUREMENT:MEAS1:VALUE?')
```

Transfer data from the input buffer to MATLAB using `fscanf`.

```
ptop = fscanf(s,'%g')
ptop =
2.0199999809E0
```

4 **Disconnect and clean up –** When you no longer need s, you should disconnect it from the instrument, and remove it from memory and from the MATLAB workspace.

```
fclose(s)
delete(s)
clear s
```

Example: Parsing Input Data Using strread

This example illustrates how to use the strread function to parse and format data that you read from a device. strread is particularly useful when you want to parse a string into one or more variables, where each variable has its own specified format.

The instrument is a Tektronix TDS 210 two-channel oscilloscope connected to the serial port COM1.

1 **Create a serial port object –** Create the serial port object s associated with serial port COM1.

```
s = serial('COM1');
```

2 **Connect to the device –** Connect s to the oscilloscope. Because the default value for the ReadAsyncMode property is continuous, data is asynchronously returned to the input buffer as soon as it is available from the instrument.

```
fopen(s)
```

3 **Write and read data –** Write the RS232? command to the instrument using fprintf, and then read back the result of the command using fscanf. RS232? queries the RS-232 settings and returns the baud rate, the software flow control setting, the hardware flow control setting, the parity type, and the terminator.

```
fprintf(s,'RS232?')
data = fscanf(s)
data =
9600;0;0;NONE;LF
```

Use the strread function to parse and format the data variable into five new variables.

```
[br,sfc,hfc,par,tm] = strread(data,'%d%d%d%s%s','delimiter',';')

br =
        9600
sfc =
     0
hfc =
     0
par =
    'NONE'
tm =
    'LF'
```

4 **Disconnect and clean up –** When you no longer need s, you should disconnect it from the instrument, and remove it from memory and from the MATLAB workspace.

```
fclose(s)
delete(s)
clear s
```

Example: Reading Binary Data

This example illustrates how you can download the TDS 210 oscilloscope screen display to MATLAB. The screen display data is transferred and saved to disk using the Windows bitmap format. This data provides a permanent record of your work, and is an easy way to document important signal and scope parameters.

Because the amount of data transferred is expected to be fairly large, it is asynchronously returned to the input buffer as soon as it is available from the instrument. This allows you to perform other tasks as the transfer progresses. Additionally, the scope is configured to its highest baud rate of 19,200.

1 **Create a serial port object –** Create the serial port object s associated with serial port COM1.

```
s = serial('COM1');
```

2 **Configure property values –** Configure the input buffer to accept a reasonably large number of bytes, and configure the baud rate to the highest value supported by the scope.

```
s.InputBufferSize = 50000;
s.BaudRate = 19200;
```

3 **Connect to the device –** Connect `s` to the oscilloscope. Because the default value for the `ReadAsyncMode` property is `continuous`, data is asynchronously returned to the input buffer as soon as it is available from the instrument.

```
fopen(s)
```

4 **Write and read data –** Configure the scope to transfer the screen display as a bitmap.

```
fprintf(s,'HARDCOPY:PORT RS232')
fprintf(s,'HARDCOPY:FORMAT BMP')
fprintf(s,'HARDCOPY START')
```

Wait until all the data is sent to the input buffer, and then transfer the data to the MATLAB workspace as unsigned 8-bit integers.

```
out = fread(s,s.BytesAvailable,'uint8');
```

5 **Disconnect and clean up –** When you no longer need `s`, you should disconnect it from the instrument, and remove it from memory and from the MATLAB workspace.

```
fclose(s)
delete(s)
clear s
```

Viewing the Bitmap Data

To view the bitmap data, you should follow these steps:

1 Open a disk file.

2 Write the data to the disk file.

3 Close the disk file.

4 Read the data into MATLAB using the `imread` function.

5 Scale and display the data using the `imagesc` function.

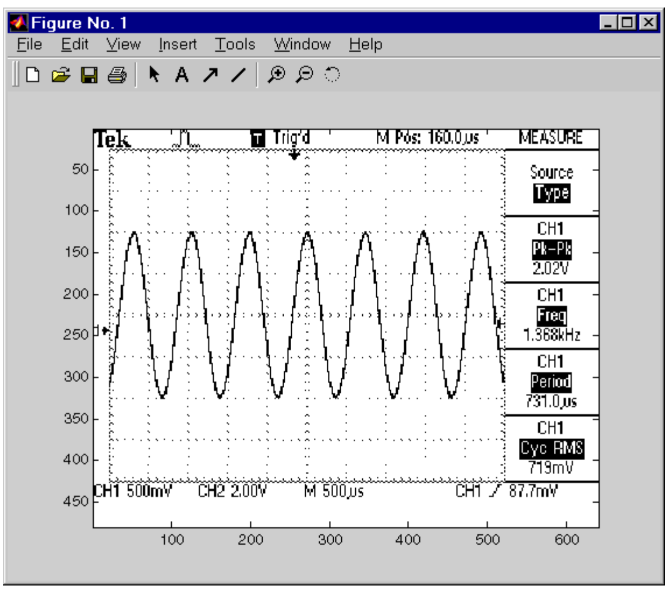
Note that the file I/O versions of the `fopen`, `fwrite`, and `fclose` functions are used.

```
fid = fopen('test1.bmp','w');
fwrite(fid,out,'uint8');
fclose(fid)
a = imread('test1.bmp','bmp');
imagesc(a)
```

Because the scope returns the screen display data using only two colors, an appropriate colormap is selected.

```
mymap = [0 0 0; 1 1 1];
colormap(mymap)
```

The resulting bitmap image is shown below.



Events and Callbacks

You can enhance the power and flexibility of your serial port application by using *events*. An event occurs after a condition is met and might result in one or more callbacks.

While the serial port object is connected to the device, you can use events to display a message, display data, analyze data, and so on. Callbacks are controlled through *callback properties* and *callback functions*. All event types have an associated callback property. Callback functions are M-file functions that you construct to suit your specific application needs.

You execute a callback when a particular event occurs by specifying the name of the M-file callback function as the value for the associated callback property.

Example: Introduction to Events and Callbacks

This example uses the M-file callback function `instrcallback` to display a message to the command line when a bytes-available event occurs. The event is generated when the terminator is read.

```
s = serial('COM1');
fopen(s)
s.BytesAvailableFcnMode = 'terminator';
s.BytesAvailableFcn = @instrcallback;
fprintf(s,'*IDN?')
out = fscanf(s);
```

The resulting display from `instrcallback` is shown below.

```
BytesAvailable event occurred at 17:01:29 for the object:
Serial-COM1.
```

End the serial port session.

```
fclose(s)
delete(s)
clear s
```

You can use the `type` command to display `instrcallback` at the command line.

Event Types and Callback Properties

The serial port event types and callback properties are described below.

Table 8-9: Event Types and Callback Properties

Event Type	Associated Properties
Break interrupt	`BreakInterruptFcn`
Bytes available	`BytesAvailableFcn`
	`BytesAvailableFcnCount`
	`BytesAvailableFcnMode`
Error	`ErrorFcn`
Output empty	`OutputEmptyFcn`
Pin status	`PinStatusFcn`
Timer	`TimerFcn`
	`TimerPeriod`

Break-Interrupt Event. A break-interrupt event is generated immediately after a break interrupt is generated by the serial port. The serial port generates a break interrupt when the received data has been in an inactive state longer than the transmission time for one character.

This event executes the callback function specified for the `BreakInterruptFcn` property. It can be generated for both synchronous and asynchronous read and write operations.

Bytes-Available Event. A bytes-available event is generated immediately after a predetermined number of bytes are available in the input buffer or a terminator is read, as determined by the `BytesAvailableFcnMode` property.

If `BytesAvailableFcnMode` is `byte`, the bytes-available event executes the callback function specified for the `BytesAvailableFcn` property every time the number of bytes specified by `BytesAvailableFcnCount` is stored in the input buffer. If `BytesAvailableFcnMode` is `terminator`, then the callback function executes every time the character specified by the `Terminator` property is read.

This event can be generated only during an asynchronous read operation.

Error Event. An error event is generated immediately after an error occurs.

This event executes the callback function specified for the `ErrorFcn` property. It can be generated only during an asynchronous read or write operation.

An error event is generated when a timeout occurs. A timeout occurs if a read or write operation does not successfully complete within the time specified by the `Timeout` property. An error event is not generated for configuration errors such as setting an invalid property value.

Output-Empty Event. An output-empty event is generated immediately after the output buffer is empty.

This event executes the callback function specified for the `OutputEmptyFcn` property. It can be generated only during an asynchronous write operation.

Pin Status Event. A pin status event is generated immediately after the state (pin value) changes for the CD, CTS, DSR, or RI pins. Refer to "Serial Port Signals and Pin Assignments" on page 8-6 for a description of these pins.

This event executes the callback function specified for the `PinStatusFcn` property. It can be generated for both synchronous and asynchronous read and write operations.

Timer Event. A timer event is generated when the time specified by the `TimerPeriod` property passes. Time is measured relative to when the serial port object is connected to the device.

This event executes the callback function specified for the `TimerFcn` property. Note that some timer events might not be processed if your system is significantly slowed or if the `TimerPeriod` value is too small.

Storing Event Information

You can store event information in a callback function or in a record file. Event information is stored in a callback function using two fields: `Type` and `Data`. The `Type` field contains the event type, while the `Data` field contains event-specific information. As described in "Creating and Executing Callback Functions" on page 8-52, these two fields are associated with a structure that you define in the callback function header. Refer to “Debugging: Recording Information to Disk” on page 8-62 to learn about recording data and event information to a record file.

The event types and the values for the Type and Data fields are given below.

Table 8-10: Event Information

Event Type	Field	Field Value
Break interrupt	Type	BreakInterrupt
	Data.AbsTime	day-month-year hour:minute:second
Bytes available	Type	BytesAvailable
	Data.AbsTime	day-month-year hour:minute:second
Error	Type	Error
	Data.AbsTime	day-month-year hour:minute:second
	Data.Message	An error string
Output empty	Type	OutputEmpty
	Data.AbsTime	day-month-year hour:minute:second
Pin status	Type	PinStatus
	Data.AbsTime	day-month-year hour:minute:second
	Data.Pin	CarrierDetect, ClearToSend, DataSetReady, or RingIndicator
	Data.PinValue	on or off
Timer	Type	Timer
	Data.AbsTime	day-month-year hour:minute:second

The Data field values are described below.

The AbsTime Field. `AbsTime` is defined for all events, and indicates the absolute time the event occurred. The absolute time is returned using the `clock` format.

day-month-year hour:minute:second

The Pin Field. `Pin` is used by the pin status event to indicate if the CD, CTS, DSR, or RI pins changed state. Refer to "Serial Port Signals and Pin Assignments" on page 8-6 for a description of these pins.

The PinValue Field. `PinValue` is used by the pin status event to indicate the state of the CD, CTS, DSR, or RI pins. Possible values are `on` or `off`.

The Message Field. `Message` is used by the error event to store the descriptive message that is generated when an error occurs.

Creating and Executing Callback Functions

You can specify the callback function to be executed when a specific event type occurs by including the name of the M-file as the value for the associated callback property. You can specify the callback function as a function handle or as a string cell array element. Function handles are described in the `function_handle` reference pages.

For example, to execute the callback function `mycallback` every time the terminator is read from your device

```
s.BytesAvailableFcnMode = 'terminator';
s.BytesAvailableFcn = @mycallback;
```

Alternatively, you can specify the callback function as a cell array.

```
s.BytesAvailableFcn = {'mycallback'};
```

M-file callback functions require at least two input arguments. The first argument is the serial port object. The second argument is a variable that captures the event information given in Table 8-10, Event Information, on page 8-51. This event information pertains only to the event that caused the callback function to execute. The function header for `mycallback` is shown below.

```
function mycallback(obj,event)
```

You pass additional parameters to the callback function by including both the callback function and the parameters as elements of a cell array. For example, to pass the MATLAB variable `time` to `mycallback`

```
time = datestr(now,0);
s.BytesAvailableFcnMode = 'terminator';
s.BytesAvailableFcn = {@mycallback,time};
```

Alternatively, you can specify the callback function as a string in the cell array.

```
s.BytesAvailableFcn = {'mycallback',time};
```

The corresponding function header is

```
function mycallback(obj,event,time)
```

If you pass additional parameters to the callback function, then they must be included in the function header after the two required arguments.

Note You can also specify the callback function as a string. In this case, the callback is evaluated in the MATLAB workspace and no requirements are made on the input arguments of the callback function.

Enabling Callback Functions After They Error

If an error occurs while a callback function is executing, then:

- The callback function is automatically disabled.
- A warning is displayed at the command line, indicating that the callback function is disabled.

If you want to enable the same callback function, you can set the callback property to the same value or you can disconnect the object with the `fclose` function. If you want to use a different callback function, the callback will be enabled when you configure the callback property to the new value.

Example: Using Events and Callbacks

This example uses the M-file callback function `instrcallback` to display event-related information to the command line when a bytes-available event or an output-empty event occurs.

1 **Create a serial port object –** Create the serial port object `s` associated with serial port COM1.

```
s = serial('COM1');
```

2 **Connect to the device –** Connect `s` to the Tektronix TDS 210 oscilloscope. Because the default value for the `ReadAsyncMode` property is `continuous`, data is asynchronously returned to the input buffer as soon as it is available from the instrument.

```
fopen(s)
```

3 **Configure properties –** Configure `s` to execute the callback function `instrcallback` when a bytes-available event or an output-empty event occurs. Because `instrcallback` requires the serial port object and event information to be passed as input arguments, the callback function is specified as a function handle.

```
s.BytesAvailableFcnMode = 'terminator';
s.BytesAvailableFcn = @instrcallback;
s.OutputEmptyFcn = @instrcallback;
```

4 **Write and read data –** Write the `RS232?` command asynchronously to the oscilloscope. This command queries the RS-232 settings and returns the baud rate, the software flow control setting, the hardware flow control setting, the parity type, and the terminator.

```
fprintf(s,'RS232?','async')
```

`instrcallback` is called after the `RS232?` command is sent, and when the terminator is read. The resulting displays are shown below.

```
OutputEmpty event occurred at 17:37:21 for the object:
Serial-COM1.

BytesAvailable event occurred at 17:37:21 for the object:
Serial-COM1.
```

Read the data from the input buffer.

```
out = fscanf(s)
out =
9600;0;0;NONE;LF
```

5 Disconnect and clean up – When you no longer need s, you should disconnect it from the instrument, and remove it from memory and from the MATLAB workspace.

```
fclose(s)
delete(s)
clear s
```

Using Control Pins

As described in "Serial Port Signals and Pin Assignments" on page 8-6, 9-pin serial ports include six control pins. These control pins allow you to:

- Signal the presence of connected devices
- Control the flow of data

The properties associated with the serial port control pins are given below.

Table 8-11: Control Pin Properties

Property Name	Description
`DataTerminalReady`	Specify the state of the DTR pin
`FlowControl`	Specify the data flow control method to use
`PinStatus`	Indicate the state of the CD, CTS, DSR, and RI pins
`RequestToSend`	Specify the state of the RTS pin

Signaling the Presence of Connected Devices

DTE's and DCE's often use the CD, DSR, RI, and DTR pins to indicate whether a connection is established between serial port devices. Once the connection is established, you can begin to write or read data.

You can monitor the state of the CD, DSR, and RI pins with the `PinStatus` property. You can specify or monitor the state of the DTR pin with the `DataTerminalReady` property.

The following example illustrates how these pins are used when two modems are connected to each other.

Example: Connecting Two Modems

This example connects two modems to each other via the same computer, and illustrates how you can monitor the communication status for the computer-modem connections, and for the modem-modem connection. The first modem is connected to COM1, while the second modem is connected to COM2.

1 **Create the serial port objects –** After the modems are powered on, the serial port object `s1` is created for the first modem, and the serial port object `s2` is created for the second modem.

```
s1 = serial('COM1');
s2 = serial('COM2');
```

2 **Connect to the devices –** `s1` and `s2` are connected to the modems. Because the default value for the `ReadAsyncMode` property is `continuous`, data is asynchronously returned to the input buffers as soon as it is available from the modems.

```
fopen(s1)
fopen(s2)
```

Because the default `DataTerminalReady` property value is `on`, the computer (data terminal) is now ready to exchange data with the modems. You can verify that the modems (data sets) can communicate with the computer by examining the value of the Data Set Ready pin with the `PinStatus` property.

```
s1.Pinstatus
ans =
    CarrierDetect: 'off'
      ClearToSend: 'on'
     DataSetReady: 'on'
    RingIndicator: 'off'
```

The value of the `DataSetReady` field is `on` because both modems were powered on before they were connected to the objects.

3 **Configure properties –** Both modems are configured for a baud rate of 2400 bits per second and a carriage return (CR) terminator.

```
s1.BaudRate = 2400;
s1.Terminator = 'CR';
s2.BaudRate = 2400;
s2.Terminator = 'CR';
```

4 **Write and read data –** Write the `atd` command to the first modem. This command puts the modem "off the hook," which is equivalent to manually lifting a phone receiver.

```
fprintf(s1,'atd')
```

Write the ata command to the second modem. This command puts the modem in “answer mode,” which forces it to connect to the first modem.

```
fprintf(s2,'ata')
```

After the two modems negotiate their connection, you can verify the connection status by examining the value of the Carrier Detect pin using the PinStatus property.

```
s1.PinStatus
ans =
    CarrierDetect: 'on'
      ClearToSend: 'on'
     DataSetReady: 'on'
    RingIndicator: 'off'
```

You can also verify the modem-modem connection by reading the descriptive message returned by the second modem.

```
s2.BytesAvailable
ans =
    25
out = fread(s2,25);
char(out)'
ans =
ata
CONNECT 2400/NONE
```

Now break the connection between the two modems by configuring the DataTerminalReady property to off. You can verify that the modems are disconnected by examining the Carrier Detect pin value.

```
s1.DataTerminalReady = 'off';
s1.PinStatus
ans =
    CarrierDetect: 'off'
      ClearToSend: 'on'
     DataSetReady: 'on'
    RingIndicator: 'off'
```

5 Disconnect and clean up – Disconnect the objects from the modems, and remove the objects from memory and from the MATLAB workspace.

```
fclose([s1 s2])
delete([s1 s2])
clear s1 s2
```

Controlling the Flow of Data: Handshaking

Data flow control or *handshaking* is a method used for communicating between a DCE and a DTE to prevent data loss during transmission. For example, suppose your computer can receive only a limited amount of data before it must be processed. As this limit is reached, a handshaking signal is transmitted to the DCE to stop sending data. When the computer can accept more data, another handshaking signal is transmitted to the DCE to resume sending data.

If supported by your device, you can control data flow using one of these methods:

- Hardware handshaking
- Software handshaking

Note Although you might be able to configure your device for both hardware handshaking and software handshaking at the same time, MATLAB does not support this behavior.

You can specify the data flow control method with the `FlowControl` property. If `FlowControl` is `hardware`, then hardware handshaking is used to control data flow. If `FlowControl` is `software`, then software handshaking is used to control data flow. If `FlowControl` is `none`, then no handshaking is used.

Hardware Handshaking

Hardware handshaking uses specific serial port pins to control data flow. In most cases, these are the RTS and CTS pins. Hardware handshaking using these pins is described in "The RTS and CTS Pins" on page 8-10.

If `FlowControl` is `hardware`, then the RTS and CTS pins are automatically managed by the DTE and DCE. You can return the CTS pin value with the

PinStatus property. You can configure or return the RTS pin value with the RequestToSend property.

Note Some devices also use the DTR and DSR pins for handshaking. However, these pins are typically used to indicate that the system is ready for communication, and are not used to control data transmission. In MATLAB, hardware handshaking always uses the RTS and CTS pins.

If your device does not use hardware handshaking in the standard way, then you might need to manually configure the RequestToSend property. In this case, you should configure FlowControl to none. If FlowControl is hardware, then the RequestToSend value that you specify might not be honored. Refer to the device documentation to determine its specific pin behavior.

Software Handshaking

Software handshaking uses specific ASCII characters to control data flow. These characters, known as Xon and Xoff (or XON and XOFF), are described below.

Table 8-12: Software Handshaking Characters

Character	Integer Value	Description
Xon	17	Resume data transmission
Xoff	19	Pause data transmission

When using software handshaking, the control characters are sent over the transmission line the same way as regular data. Therefore you need only the TD, RD, and GND pins.

The main disadvantage of software handshaking is that you cannot write the Xon or Xoff characters while numerical data is being written to the device. This is because numerical data might contain a 17 or 19, which makes it impossible to distinguish between the control characters and the data. However, you can write Xon or Xoff while data is being asynchronously read from the device because you are using both the TD and RD pins.

Example: Using Software Handshaking

Suppose you want to use software flow control with the example described in "Example: Reading Binary Data" on page 8-45. To do this, you must configure the oscilloscope and serial port object for software flow control.

```
fprintf(s,'RS232:SOFTF ON')
s.FlowControl = 'software';
```

To pause data transfer, you write the numerical value 19 to the device.

```
fwrite(s,19)
```

To resume data transfer, you write the numerical value 17 to the device.

```
fwrite(s,17)
```

Debugging: Recording Information to Disk

While the serial port object is connected to the device, you can record this information to a disk file:

- The number of values written to the device, the number of values read from the device, and the data type of the values
- Data written to the device, and data read from the device
- Event information

Recording information to disk provides a permanent record of your serial port session, and is an easy way to debug your application.

You record information to a disk file with the `record` function. The properties associated with recording information to disk are given below.

Table 8-13: Recording Properties

Property Name	Description
`RecordDetail`	Specify the amount of information saved to a record file
`RecordMode`	Specify whether data and event information is saved to one record file or to multiple record files
`RecordName`	Specify the name of the record file
`RecordStatus`	Indicate if data and event information are saved to a record file

Example: Introduction to Recording Information

This example records the number of values written to and read from the device, and stores the information to the file `myfile.txt`

```
s = serial('COM1');
fopen(s)
s.RecordName = 'myfile.txt';
record(s)
fprintf(s,'*IDN?')
idn = fscanf(s);
```

```
fprintf(s,'RS232?')
rs232 = fscanf(s);
```

End the serial port session.

```
fclose(s)
delete(s)
clear s
```

You can use the `type` command to display `myfile.txt` at the command line.

Creating Multiple Record Files

When you initiate recording with the `record` function, the `RecordMode` property determines if a new record file is created or if new information is appended to an existing record file.

You can configure `RecordMode` to `overwrite`, `append`, or `index`. If `RecordMode` is `overwrite`, then the record file is overwritten each time recording is initiated. If `RecordMode` is `append`, then the new information is appended to the file specified by `RecordName`. If `RecordMode` is `index`, a different disk file is created each time recording is initiated. The rules for specifying a record filename are discussed in the next section.

Specifying a Filename

You specify the name of the record file with the `RecordName` property. You can specify any value for `RecordName` – including a directory path – provided the filename is supported by your operating system. Additionally, if `RecordMode` is `index`, then the filename follows these rules:

- Indexed filenames are identified by a number. This number precedes the filename extension and is increased by 1 for successive record files.
- If no number is specified as part of the initial filename, then the first record file does not have a number associated with it. For example, if `RecordName` is `myfile.txt`, then `myfile.txt` is the name of the first record file, `myfile01.txt` is the name of the second record file, and so on.
- `RecordName` is updated after the record file is closed.
- If the specified filename already exists, then the existing file is overwritten.

The Record File Format

The record file is an ASCII file that contains a record of one or more serial port sessions. You specify the amount of information saved to a record file with the `RecordDetail` property.

`RecordDetail` can be `compact` or `verbose`. A compact record file contains the number of values written to the device, the number of values read from the device, the data type of the values, and event information. A verbose record file contains the preceding information as well as the data transferred to and from the device.

Binary data with precision given by `uchar`, `schar`, `(u)int8`, `(u)int16` or `(u)int32` is recorded using hexadecimal format. For example, if the integer value 255 is read from the instrument as a 16-bit integer, the hexadecimal value 00FF is saved in the record file. Single- and double-precision floating-point numbers are recorded as decimal values using the `%g` format, and as hexadecimal values using the format specified by the IEEE Standard 754-1985 for Binary Floating-Point Arithmetic.

The IEEE floating-point format includes three components: the sign bit, the exponent field, and the significand field. Single-precision floating-point values consist of 32 bits. The value is given by

$$\text{value} = (-1)^{\text{sign}}(2^{\text{exp-127}})(1.\text{significand})$$

Double-precision floating-point values consist of 64 bits. The value is given by

$$\text{value} = (-1)^{\text{sign}}(2^{\text{exp-1023}})(1.\text{significand})$$

The floating-point format component, and the associated single-precision and double-precision bits are given below.

Component	Single-Precision Bits	Double-Precision Bits
`sign`	1	1
`exp`	2-9	2-12
`significand`	10-32	13-64

Bit 1 is the left-most bit as stored in the record file.

Example: Recording Information to Disk

This example illustrates how to record information transferred between a serial port object and a Tektronix TDS 210 oscilloscope. Additionally, the structure of the resulting record file is presented.

1 **Create the serial port object –** Create the serial port object `s` associated with the serial port COM1.

```
s = serial('COM1');
```

2 **Connect to the device –** Connect `s` to the oscilloscope. Because the default value for the `ReadAsyncMode` property is `continuous`, data is asynchronously returned the input buffer as soon as it is available from the instrument.

```
fopen(s)
```

3 **Configure property values –** Configure `s` to record information to multiple disk files using the verbose format. Recording is then initiated with the first disk file defined as `WaveForm1.txt`.

```
s.RecordMode = 'index';
s.RecordDetail = 'verbose';
s.RecordName = 'WaveForm1.txt';
record(s)
```

4 **Write and read data –** The commands written to the instrument, and the data read from the instrument are recorded in the record file. Refer to "Example: Writing and Reading Text Data" on page 8-42 for an explanation of the oscilloscope commands.

```
fprintf(s,'*IDN?')
idn = fscanf(s);
fprintf(s,'MEASUREMENT:IMMED:SOURCE CH2')
fprintf(s,'MEASUREMENT:IMMED:SOURCE?')
source = fscanf(s);
```

Read the peak-to-peak voltage with the `fread` function. Note that the data returned by `fread` is recorded using hex format.

```
fprintf(s,'MEASUREMENT:MEAS1:TYPE PK2PK')
fprintf(s,'MEASUREMENT:MEAS1:VALUE?')
ptop = fread(s,s.BytesAvailable);
```

Convert the peak-to-peak voltage to a character array.

```
char(ptop)'
ans =
2.0199999809E0
```

The recording state is toggled from `on` to `off`. Because the `RecordMode` value is `index`, the record filename is automatically updated.

```
record(s)
s.RecordStatus
ans =
off
s.RecordName
ans =
WaveForm2.txt
```

5. **Disconnect and clean up –** When you no longer need `s`, you should disconnect it from the instrument, and remove it from memory and from the MATLAB workspace.

```
fclose(s)
delete(s)
clear s
```

The Record File Contents

The contents of the WaveForm1.txt record file are shown below. Because the `RecordDetail` property was `verbose`, the number of values, commands, and data were recorded. Note that data returned by the `fread` function is in hex format.

```
type WaveForm1.txt

Legend:
  * - An event occurred.
  > - A write operation occurred.
  < - A read operation occurred.

1      Recording on 22-Jan-2000 at 11:21:21.575. Binary data in...
2     > 6 ascii values.
        *IDN?
3     < 56 ascii values.
        TEKTRONIX,TDS 210,0,CF:91.1CT FV:v1.16 TDS2CM:CMV:v1.04
4     > 29 ascii values.
        MEASUREMENT:IMMED:SOURCE CH2
5     > 26 ascii values.
        MEASUREMENT:IMMED:SOURCE?
6     < 4 ascii values.
        CH2
7     > 27 ascii values.
        MEASUREMENT:MEAS1:TYPE PK2PK
8     > 25 ascii values.
        MEASUREMENT:MEAS1:VALUE?
9     < 15 uchar values.
        32 2e 30 31 39 39 39 39 39 38 30 39 45 30 0a
10      Recording off.
```

Saving and Loading

You can save serial port objects to a MAT-file just as you would any workspace variable – using the save command. For example, suppose you create the serial port object s associated with the serial port COM1, configure several property values, and perform a write and read operation.

```
s = serial('COM1');
s.BaudRate = 19200;
s.Tag = 'My serial object';
fopen(s)
fprintf(s, '*IDN?')
out = fscanf(s);
```

To save the serial port object and the data read from the device to the MAT-file myserial.mat

```
save myserial s out
```

Note You can save data and event information as text to a disk file with the record function.

You can recreate s and out in the workspace using the load command.

```
load myserial
```

Values for read-only properties are restored to their default values upon loading. For example, the Status property is restored to closed. Therefore, to use s, you must connect it to the device with the fopen function. To determine if a property is read-only, examine its reference pages.

Using Serial Port Objects on Different Platforms

If you save a serial port object from one platform, and then load that object on a different platform having different serial port names, then you will need to modify the Port property value. For example, suppose you create the serial port object s associated with the serial port COM1 on a Windows platform. If you want to save s for eventual use on a Linux platform, you should configure Port to an appropriate value such as ttyS0 after the object is loaded.

Disconnecting and Cleaning Up

When you no longer need your serial port object, you should disconnect it from the device, and clean up your MATLAB environment by removing the object from memory and from the workspace. These are the steps you take to end a serial port session.

Disconnecting a Serial Port Object

When you no longer need to communicate with the device, you should disconnect it from the serial port object with the `fclose` function.

```
fclose(s)
```

You can examine the `Status` property to verify that the serial port object and the device are disconnected.

```
s.Status
ans =
closed
```

After `fclose` is issued, the serial port associated with `s` is available. You can now connect another serial port object to it using `fopen`.

Cleaning Up the MATLAB Environment

When you no longer need the serial port object, you should remove it from memory with the `delete` function.

```
delete(s)
```

Before using `delete`, you must disconnect the serial port object from the device with the `fclose` function.

A deleted serial port object is *invalid*, which means that you cannot connect it to the device. In this case, you should remove the object from the MATLAB workspace. To remove serial port objects and other variables from the MATLAB workspace, use the `clear` command.

```
clear s
```

If you use `clear` on a serial port object that is still connected to a device, the object is removed from the workspace but remains connected to the device. You can restore cleared objects to MATLAB with the `instrfind` function.

Property Reference

This section includes information to help you learn about serial port properties. The information is organized using these topics:

- "The Property Reference Page Format" describes the organization of the property reference pages.
- "Serial Port Object Properties" summarizes the properties using several categories based on how they are used. Following this section, the properties are listed alphabetically and described in detail.

The Property Reference Page Format

Each serial port property description contains some or all of this information:

- The property name
- A description of the property
- The property characteristics, including:
  - Read only – the condition under which the property is read only

    A property can be read only always, never, while the serial port object is open, or while the serial port object is recording. You can configure a property value using the `set` function or dot notation. You can return the current property value using the `get` function or dot notation.
  - Data type – the property data type

    This is the data type you use when specifying a property value.
- Valid property values including the default value

  When property values are given by a predefined list, the default value is usually indicated by `{}`.
- An example using the property
- Related properties and functions

Serial Port Object Properties

The serial port object properties are briefly described below, and organized into categories based on how they are used. Following this section, the properties are listed alphabetically and described in detail.

Communications Properties	
BaudRate	Specify the rate at which bits are transmitted
DataBits	Specify the number of data bits to transmit
Parity	Specify the type of parity checking
StopBits	Specify the number of bits used to indicate the end of a byte
Terminator	Specify the terminator character

Write Properties	
BytesToOutput	Indicate the number of bytes currently in the output buffer
OutputBufferSize	Specify the size of the output buffer in bytes
Timeout	Specify the waiting time to complete a read or write operation
TransferStatus	Indicate if an asynchronous read or write operation is in progress
ValuesSent	Indicate the total number of values written to the device

Read Properties	
`BytesAvailable`	Indicate the number of bytes available in the input buffer
`InputBufferSize`	Specify the size of the input buffer in bytes
`ReadAsyncMode`	Specify whether an asynchronous read operation is continuous or manual
`Timeout`	Specify the waiting time to complete a read or write operation
`TransferStatus`	Indicate if an asynchronous read or write operation is in progress
`ValuesReceived`	Indicate the total number of values read from the device

Callback Properties	
`BreakInterrupt Fcn`	Specify the M-file callback function to execute when a break-interrupt event occurs
`BytesAvailable Fcn`	Specify the M-file callback function to execute when a specified number of bytes is available in the input buffer, or a terminator is read
`BytesAvailable FcnCount`	Specify the number of bytes that must be available in the input buffer to generate a bytes-available event
`BytesAvailable FcnMode`	Specify if the bytes-available event is generated after a specified number of bytes is available in the input buffer, or after a terminator is read
`ErrorFcn`	Specify the M-file callback function to execute when an error event occurs

Callback Properties (Continued)	
OutputEmptyFcn	Specify the M-file callback function to execute when the output buffer is empty
PinStatusFcn	Specify the M-file callback function to execute when the CD, CTS, DSR, or RI pins change state
TimerFcn	Specify the M-file callback function to execute when a predefined period of time passes
TimerPeriod	Specify the period of time between timer events

Control Pin Properties	
DataTerminal Ready	Specify the state of the DTR pin
FlowControl	Specify the data flow control method to use
PinStatus	Indicate the state of the CD, CTS, DSR, and RI pins
RequestToSend	Specify the state of the RTS pin

Recording Properties	
RecordDetail	Specify the amount of information saved to a record file
RecordMode	Specify whether data and event information are saved to one record file or to multiple record files
RecordName	Specify the name of the record file
RecordStatus	Indicate if data and event information are saved to a record file

General Purpose Properties	
`ByteOrder`	Specify the order in which the device stores bytes
`Name`	Specify a descriptive name for the serial port object
`Port`	Indicate the platform-specific serial port name
`Status`	Indicate if the serial port object is connected to the device
`Tag`	Specify a label to associate with a serial port object
`Type`	Indicate the object type
`UserData`	Specify data that you want to associate with a serial port object

Index

Symbols

A

B

C

D

M

X

Y