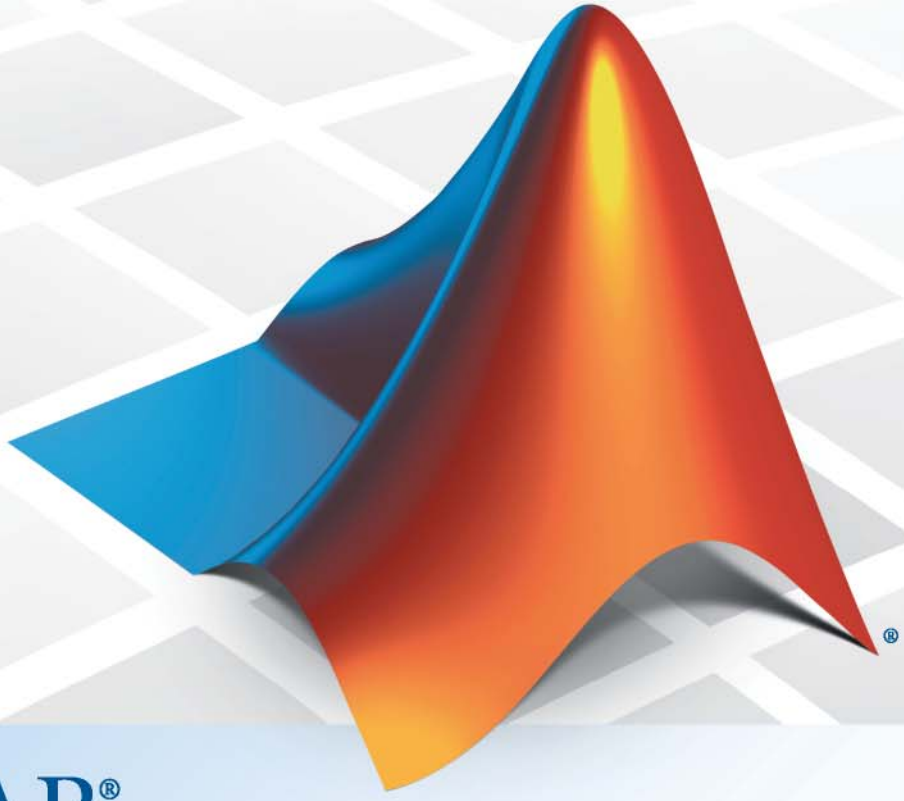
Simulink® 7
User's Guide



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Simulink® User's Guide

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Introduction to Simulink

1

Simulink Basics

The following sections explain how to perform basic tasks when using the Simulink® product.

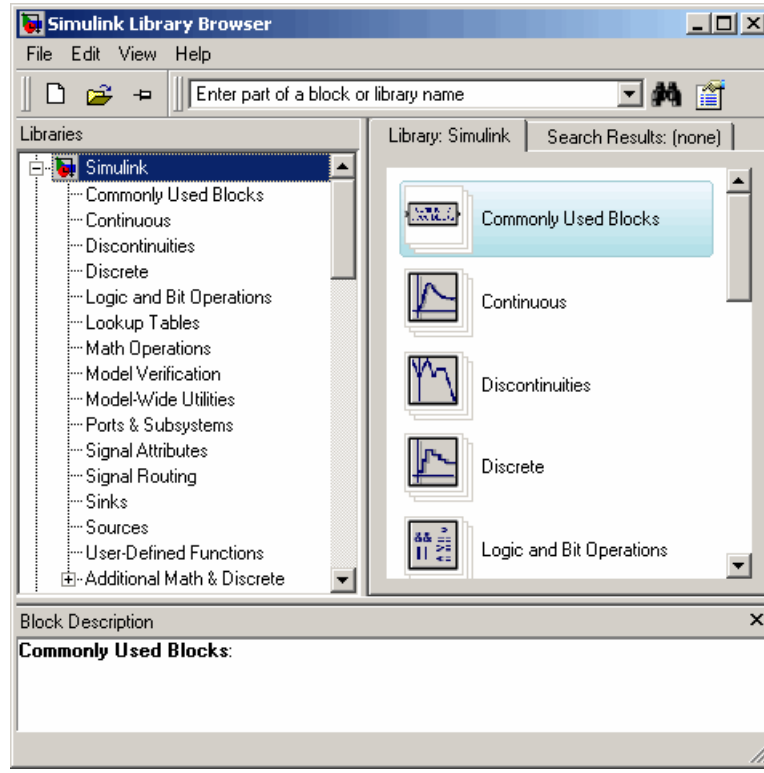
Starting Simulink Software

To start the Simulink software, you must first start the MATLAB® technical computing environment. Consult your MATLAB documentation for more information. You can then start the Simulink software in two ways:

- On the toolbar, click the Simulink icon. 
- Enter the `simulink` command at the MATLAB prompt.

The Library Browser appears. It displays a tree-structured view of the Simulink block libraries installed on your system. You build models by copying blocks from the Library Browser into a model window (see "Editing Blocks").

The Simulink library window displays icons representing the pre-installed block libraries. You can create models by copying blocks from the library into a model window.



Note On computers running the Windows® operating system, you can display the Simulink library window by right-clicking the Simulink node in the Library Browser window.

Opening a Model

In this section...

Introduction

Opening a model both brings the model into memory and displays the model graphically. You can also bring a model into memory without displaying it, as described in "Loading a Model" on page 1-7.

Opening an Existing Model

To open an existing model diagram, either:

- Click the **Open** button on the Library Browser's toolbar (Windows operating systems only) or select **Open** from the Simulink library window's **File** menu and then choose or enter the file name for the model to edit.
- Enter the name of the model (without the `.mdl` extension) in the MATLAB software Command Window. The model must be in the current folder or on the path.

Note If you have an earlier version of the Simulink software, and you want to open a model that was created in a later version, you must first use the later version to save the model in a format compatible with the earlier version. You can then open the model in the earlier version. See "Saving a Model in an Earlier Simulink Version" on page 1-11 for details.

Opening Models with Different Character Encodings

If you open a model created in a MATLAB software session configured to support one character set encoding, for example, `Shift_JIS`, in a session

configured to support another character encoding, for example, `US_ASCII`, the Simulink software displays a warning or an error message, depending on whether it can or cannot encode the model, using the current character encoding, respectively. The warning or error message specifies the encoding of the current session and the encoding used to create the model. To avoid corrupting the model (see "Saving Models with Different Character Encodings" on page 1-10) and ensure correct display of the model's text, you should:

1. Close all models open in the current session.
2. Use the `slCharacterEncoding` command to change the character encoding of the current MATLAB software session to that of the model as specified in the warning message.
3. Reopen the model.

You can now safely edit and save the model.

Avoiding Initial Model Open Delay

You may notice that the first model that you open in a MATLAB technical computing environment session takes longer to open than do subsequent models. This is because to reduce its own startup time and to avoid unnecessary consumption of your system's memory, the MATLAB software does not load the Simulink product into memory until the first time you open a Simulink model. You can cause the MATLAB technical computing environment to load the Simulink software when the MATLAB product starts up, and thus avoid the initial model opening delay. This can be done by using either the `-r` command line option or your MATLAB software `startup.m` file to run either `load_simulink` (loads the Simulink product) or `simulink` (loads the Simulink product and opens the Simulink Library browser). For example, to load the Simulink product when the MATLAB software starts up on a computer running the Microsoft® Windows operating system, create a desktop shortcut with the following target:

```
matlabroot\bin\win32\matlab.exe -r load_simulink
```

Similarly, the following command loads the Simulink software when the MATLAB software starts up on UNIX® systems, systems:

```
matlab -r load_simulink
```

Loading a Model

Loading a model brings it into memory but does not display it graphically. To both bring a model into memory and display it graphically, open the model as described in “Opening a Model” on page 1-4.

After you load a model (as distinct from opening it) you can work with the model programmatically just as you could if it were visible, but you cannot use any GUI techniques on it.

You cannot load a model using the Simulink GUI. To load a model programmatically, enter the Simulink command `load_system` in the MATLAB command window, specifying the model to be opened.

Saving a Model

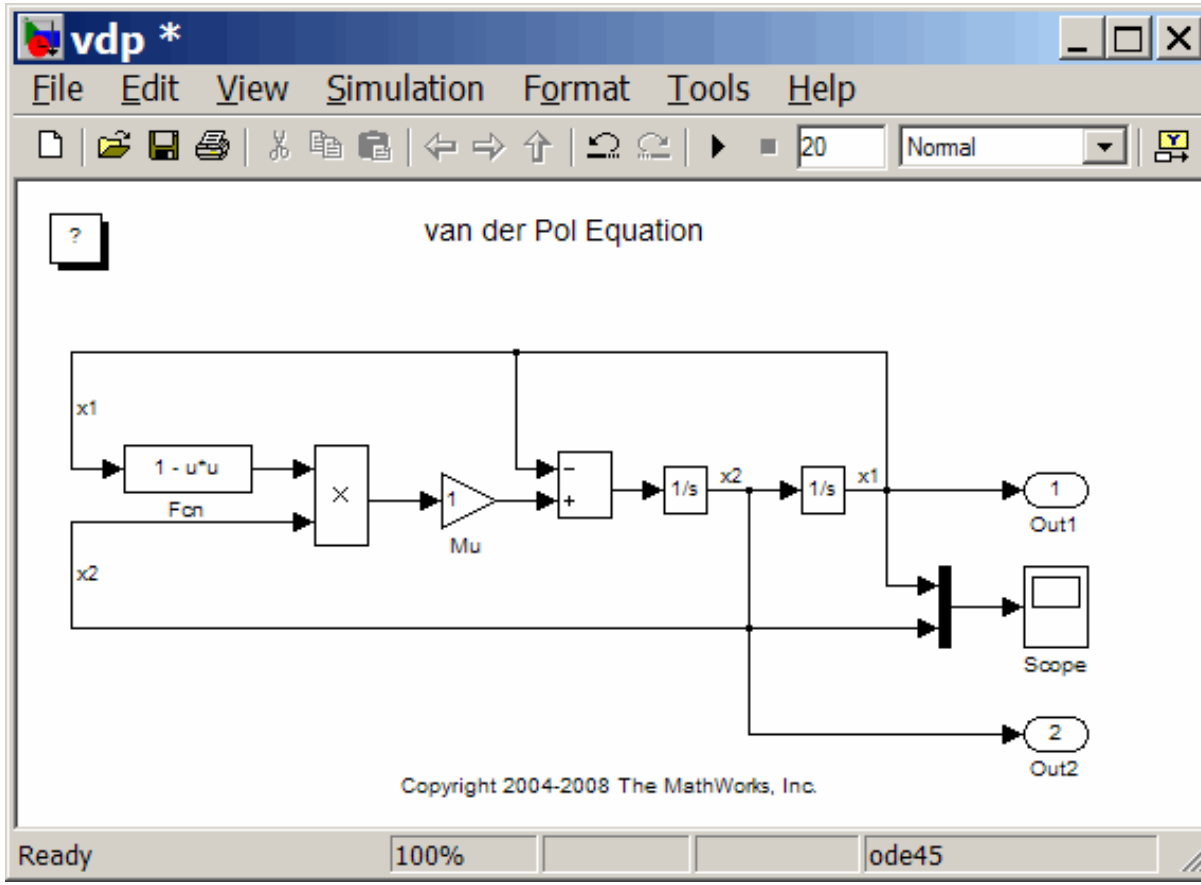
In this section...

Introduction

Changes that you make to a model with the model editor or via MATLAB commands affect only the in-memory copy of your model. To make the changes permanent you must save the model, as described in this section.

How to Tell If a Model Needs Saving

To tell whether a model needs saving, look at the title bar of the model window. An asterisk appears next to the model's name if the model needs saving as in the following example:



At the MATLAB command line and in M programs, you can use the model parameter, Dirty, to determine whether a model needs saving, for example,

```
if strcmp(get_param(gcs, 'Dirty'), 'on')
 save_system;
end
```

Techniques for Saving Models

You can save a model by choosing either the **Save** or **Save As** command from the **File** menu. The model is saved by generating a specially formatted

file called the *model file* (with the `.mdl` extension) that contains the block diagram and block properties.

If you are saving a model for the first time, use the **Save** command to provide a name and location for the model file. Model file names must start with a letter and can contain letters, numbers, and underscores. The total number must not be greater than a certain maximum, usually 63 characters. You can use the MATLAB software `namelengthmax` namelengthmax command to find out if the maximum is greater than 63 characters for your system. The file name must not be the same as that of a MATLAB software command.

If you are saving a model whose model file was previously saved, use the **Save** command to replace the file's contents or the **Save As** command to save the model with a new name or location. You can also use the **Save As** command to save the model in a format compatible with previous releases of the Simulink product (see "Saving a Model in an Earlier Simulink Version" on page 1-11).

The Simulink software follows this procedure while saving a model:

1. If the `mdl` file for the model already exists, it is renamed as a temporary file.
2. All block `PreSaveFcn` callback routines are executed first, then the block diagram's `PreSaveFcn` callback routine are executed.
3. The model file is written to a new file using the same name and an extension of `mdl`.
4. All block `PostSaveFcn` callback routines are executed, then the block diagram's `PostSaveFcn` callback routine is executed.
5. The temporary file is deleted.

If an error occurs during this process, the Simulink software renames the temporary file to the name of the original model file, writes the current version of the model to a file with an `.err` extension, and issues an error message. If an error occurs in step 2, step 3 is omitted and steps 4 and 5 are performed.

Saving Models with Different Character Encodings

When a model is saved, the character encoding in effect when the model was created (the original encoding) is used to encode the text stored in the model's

`.mdl` file, regardless of the character encoding in effect when the model is saved. This can lead to model corruption if you save a model whose original encoding differs from encoding currently in effect.

For example, it is possible that you introduced characters that cannot be represented in the model's original encoding. If this is the case, the model is saved as **`model`**`.err` where **`model`** is the model's name, leaving the original model file unchanged. The Simulink software also displays an error message that specifies the line and column number of the first character which cannot be represented. To recover from this error without losing all of the changes that you have made to the model in the current session, use the following procedure. First, use a text editor to find the character in the `.err` file at the position specified by the save error message. Then, find and delete the corresponding character in the open model and resave the model . Repeat this process until you are able to save the model without error.

It's possible that your model's original encoding can represent all the text changes that you've made in the current session, albeit incorrectly. For example, suppose you open a model whose original encoding is A in a session whose current encoding is B. Further suppose that you edit the model to include a character that has different encodings in A and B and then save the model. If in addition the encoding for x in B is the same as the encoding for y in A, and if you insert x in the model while B is in effect, save the model, and then reopen the model with A in effect the Simulink software will display x as y. To alert you to the possibility of such corruptions, the software displays a warning message whenever you save a model in which the current and original encoding differ but the original encoding can encode, possibly incorrectly, all of the characters to be saved in the model file.

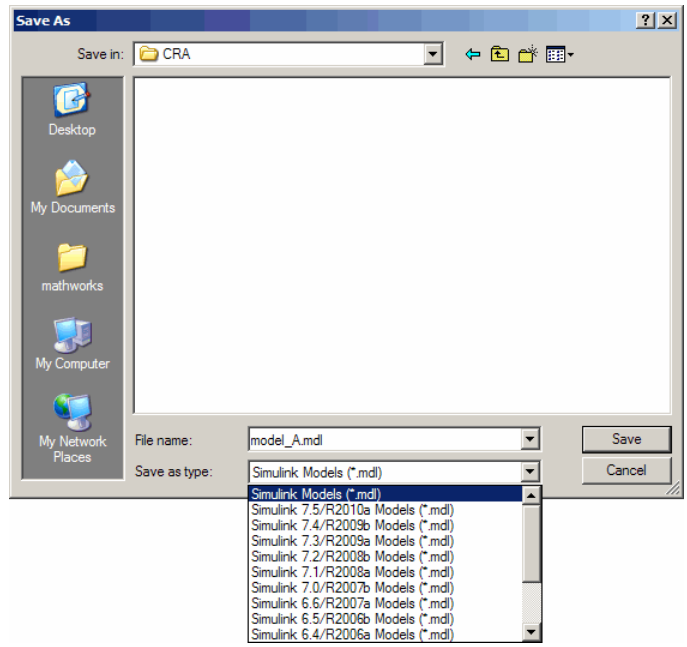
Saving a Model in an Earlier Simulink Version

The **Save As** command allows you to save a model created with the latest version of the Simulink software in formats used by earlier versions, including: Simulink 6 (Release 14, Release 14SP1, Release 14SP2, Release 14SP3, Release 2006a, Release 2006b, and Release 2007a), and Simulink® 7 (Release 2007b, Release 2008a, Release 2008b, Release 2009a, Release 2009b, and Release 2010a). You might want to perform such a **Save As** if, for example, you need to make a model available to colleagues who only have access to one of these earlier versions of the Simulink product.

To save a model in an earlier format:

1. Select **Save** from the **File** menu. This saves a copy in the latest version of Simulink. This step is necessary to avoid compatibility problems.
2. Select **Save As** from the **File** menu.

   The **Save As** dialog box is displayed.



3. Select a format from the **Save as type** list in the dialog box.
4. Click the **Save** button.

When saving a model in an earlier version's format, the model is saved in the earlier format regardless of whether the model contains blocks and features that were introduced after that version. If the model does contain blocks or use features that postdate the earlier version, the model might not give correct results when run by the earlier version. In addition, Simulink converts blocks that postdate an earlier version into empty masked Subsystem blocks

colored yellow. For example, if you save a model that contains Polynomial blocks to Release R2007b, Simulink will convert the Polynomial blocks into empty masked Subsystem blocks and will color them yellow. Simulink also removes any unsupported functionality of the model.

Saving from One Earlier Simulink Version to Another

You can open a model created in an earlier version of Simulink and use **Save as** to save the model in a different earlier version. To prevent compatibility problems, use the following procedure if you need to save a model from one earlier version to another:

1. Use the current version of Simulink to open the model created with the earlier version.
2. Before making any changes, use **Save** to save the model in the current version.

   After saving the model in the current version, you change and resave it as needed.
3. Use **Save as** to save the model in the earlier version of Simulink.
4. Start the earlier Simulink version and use it to open the saved model.
5. Use **Save** to save the model in the earlier version.

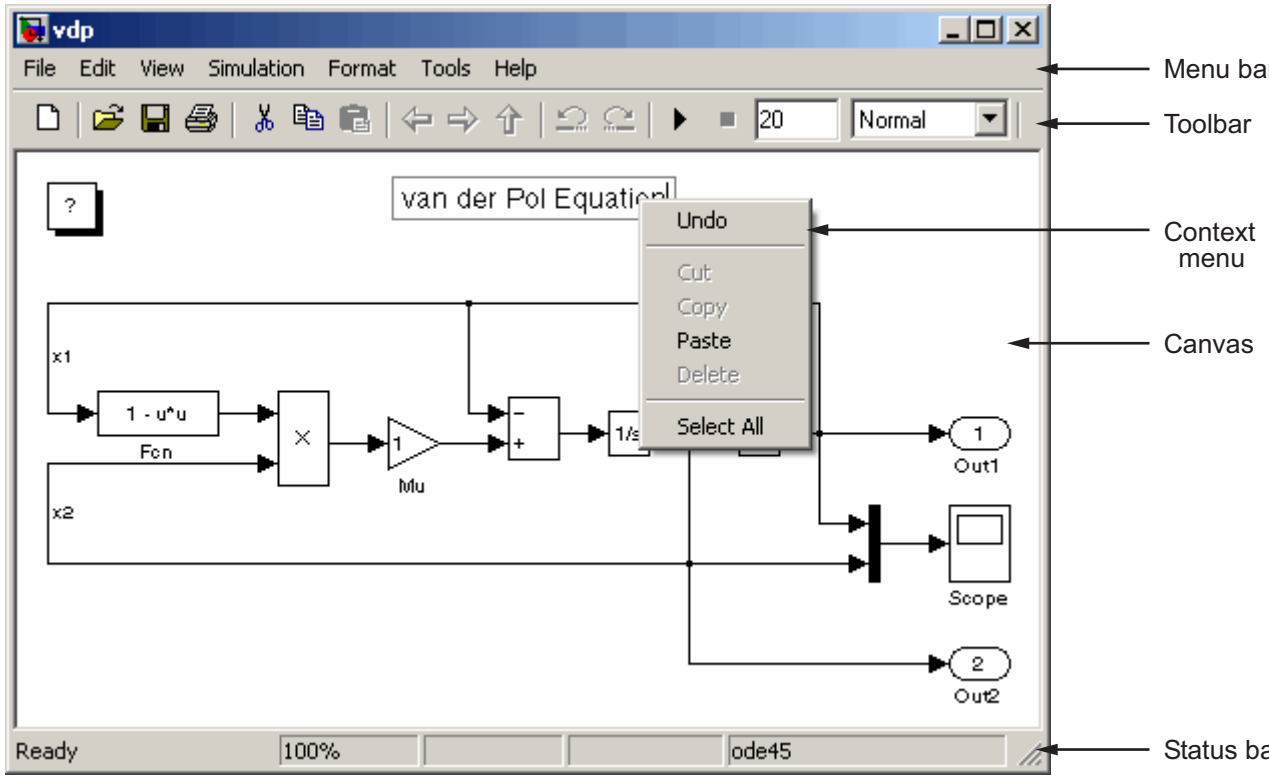
You can now use the model in the earlier version of Simulink exactly as you could if it had been created in that version.

Using the Model Editor

In this section...

Editor Overview

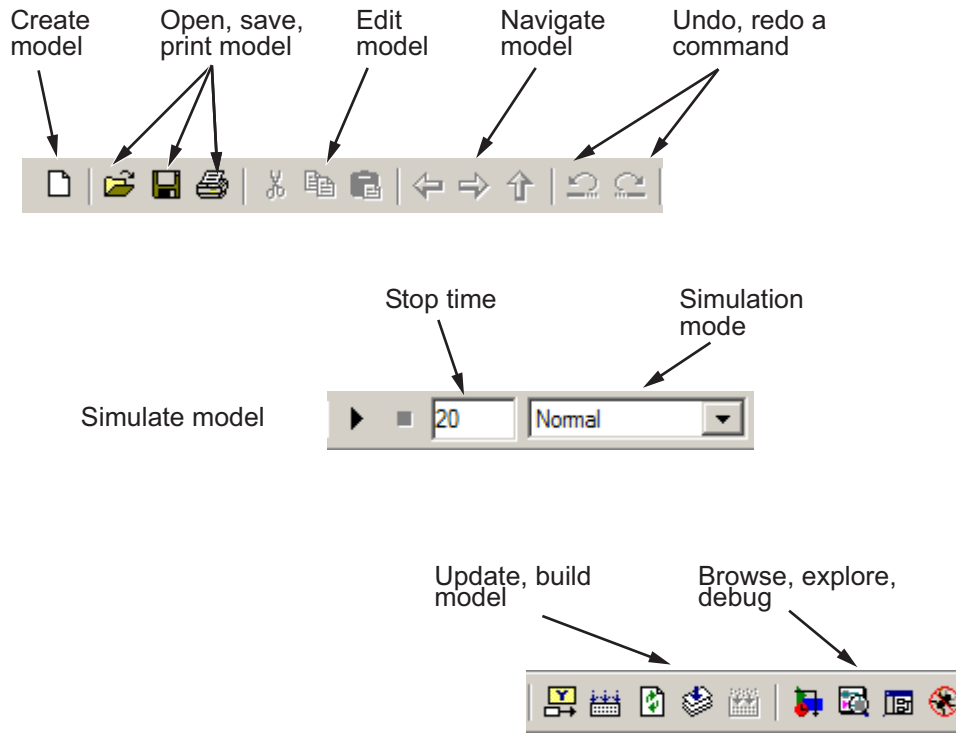
Opening a Simulink model or library displays the model or library in an instance of the Model Editor.



The Model Editor includes the following components.

Toolbar

The editor toolbar allow you to use your mouse to execute the Simulink software's most frequently used model editing, building, and simulation commands.



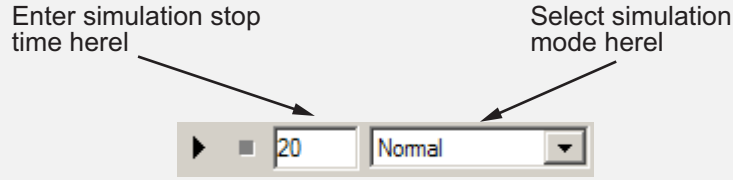
Using the Toolbar

Clicking a button executes the corresponding command. For example, to open a Simulink model, click the open folder icon on the toolbar. Letting the mouse cursor hover over a toolbar button or control causes a tooltip to appear. The tooltip describes the purpose of the button or control. You can hide the toolbar by clearing the **Toolbar** option on the editor **View** menu.

Button Reference

The following table summarizes the usage of each button on the editor toolbar. The buttons appear in the table in the same order as they appear left to right on the toolbar.

Button	Usage
	Create a new model (see “Creating an Empty Model” on page 3-2).
	Open a model (see “Opening a Model” on page 1-4).
	Save the current model (see “Saving a Model” on page 1-8).
	Print the current model (see “Printing a Block Diagram” on page 1-29).
	Cut the diagram object selected in the editor window to the system clipboard .
	Copy the selected diagram object to the system clipboard.
	Paste a diagram object from the system clipboard into the current diagram.
	Go back to the subsystem previously displayed in this editor window. This button works only in window reuse mode (see “Viewing Command History” on page 1-25).
	Go forward to the subsystem displayed after the subsystem currently displayed in this editor window. This button works only in window reuse mode.
	Go to the parent of the subsystem currently displayed in the editor window (see “Model Navigation Commands” on page 3-40).
	Undo the last editor command (see “Undoing a Command” on page 1-22).
	Redo the last undone command.

Button	Usage
	Start simulating the model displayed in this editor window (see "Starting a Simulation" on page 11-3). **Note** The controls to the right of this button enable you to set the end time of the simulation and the simulation mode, respectively. 
	Pause the current simulation (see "Pausing or Stopping a Simulation" on page 11-5). **Note** This button replaces the **Start** button while a simulation is in progress.
	Stop the current simulation.
	Display block outputs as tool tips during simulation (see "Displaying Block Outputs" on page 18-29).
	Build the RTW target for this model. **Note** This button is enabled only if the Real-Time Workshop is installed on your system (see "Initiating the Build Process" for more information)..
	Refresh Model blocks residing in this model (see "Refreshing Model Blocks" on page 5-69).

Button	Usage
	Update this model's diagram (see "Updating a Block Diagram" on page 1-27).
	Build the selected subsystem. **Note** This button is enabled only if you have selected a subsystem and the Real-Time Workshop is installed on your system (see "Generating Code and Executables from Subsystems"for more information).
	Open the Library Browser (see "Library Browser").
	Open the Model Explorer (see "The Model Explorer: Overview" on page 8-2).
	Open the Model Browser (see "The Model Browser" on page 8-73).
	Open the Simulink Debugger (see Chapter 16, "Simulink Debugger").

Menu Bar

The Simulink menu bar contains commands for creating, editing, viewing, printing, and simulating models. The menu commands apply to the model displayed in the editor. See "Creating a Model" and "Running Simulations" for more information.

Canvas

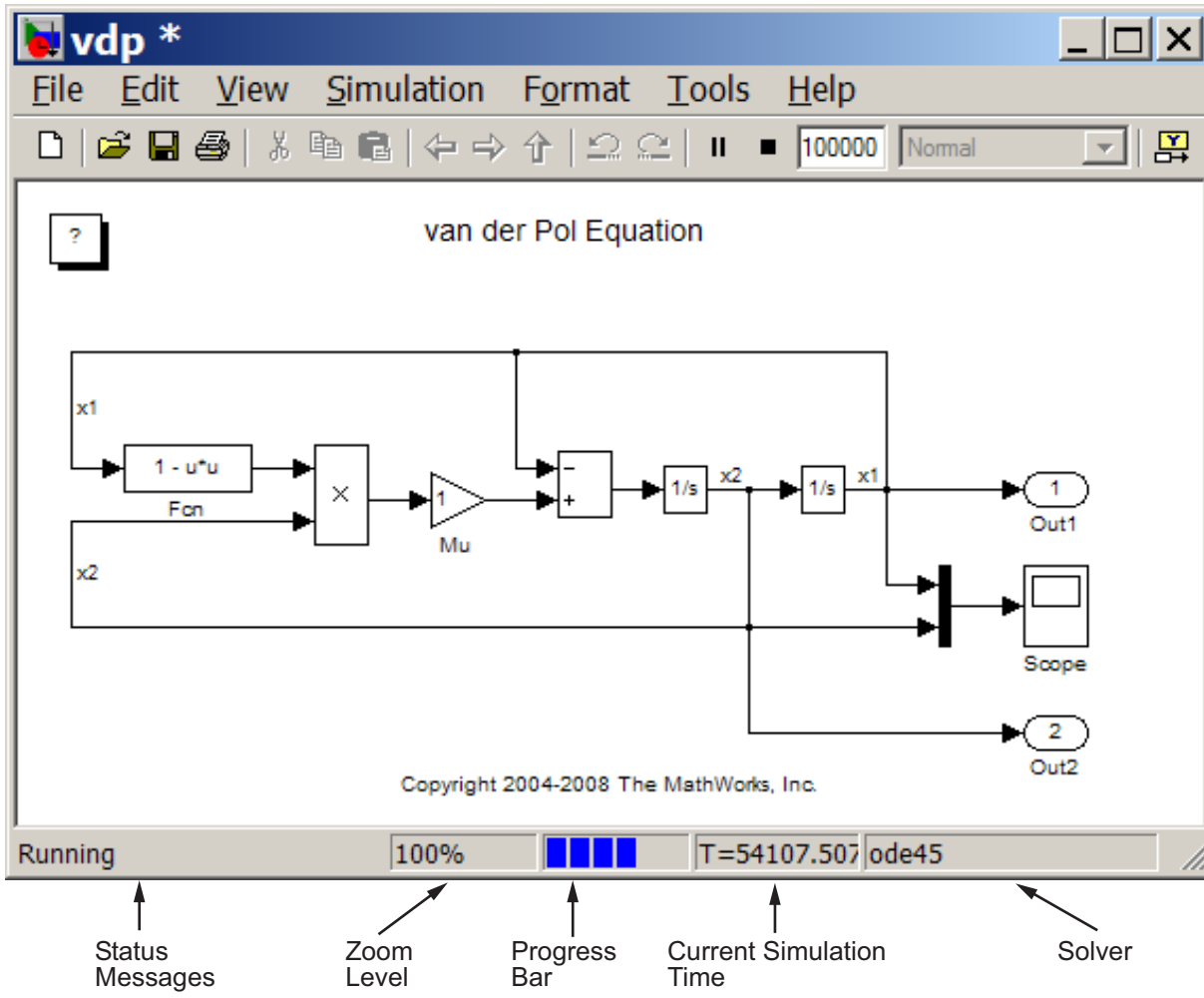
The canvas displays the model's block diagram. The canvas allows you to edit the block diagram. You can use your system's mouse and keyboard to create and connect blocks, select and move blocks, edit block labels, display block dialog boxes, and so on. See "Working with Blocks" for more information.

Context Menus

A context-sensitive menu is displayed when you click the right mouse button over the canvas. The contents of the menu depend on whether a block, line, annotation, or other object is selected. If an object is selected, the menu displays commands that apply only to the selected object. If no object is selected, the menu displays commands that apply to a model or library as a whole.

Status Bar

The status bar appears only in the Windows operating system version of the Model Editor. It displays the update and simulation status of the model.



The status bar includes the following areas:

- status message

  Displays the status of a simulation (e.g., ready to run or running) or of a model update.

- zoom level

Displays the zoom level of the model window as a percentage of normal.

- progress bar

  Indicates how far a model update or simulation has progressed. The color of the status bar indicates whether Simulink is updating the model (green) or simulating the model (blue).

- current simulation time
- current solver

You can display or hide the status bar by selecting or clearing the **Status Bar** option on the **View** menu.

Undoing a Command

You can cancel the effects of up to 101 consecutive operations by choosing **Undo** from the **Edit** menu. You can undo these operations:

- Adding, deleting, or moving a block
- Adding, deleting, or moving a line
- Adding, deleting, or moving a model annotation
- Editing a block name
- Creating a subsystem (see "Undoing Subsystem Creation" for more information)

You can reverse the effects of an **Undo** command by choosing **Redo** from the **Edit** menu.

Zooming Block Diagrams

You can enlarge or shrink the view of the block diagram in the current Simulink software window. To zoom a view:

- Select **Zoom In** from the **View** menu (or type **r**) to enlarge the view.
- Select **Zoom Out** from the **View** menu (or type **v**) to shrink the view.
- Select **Fit System To View** from the **View** menu (or press the space bar) to fit the diagram to the view.
- Select **Normal** from the **View** menu (or type **1**) to view the diagram at actual size.

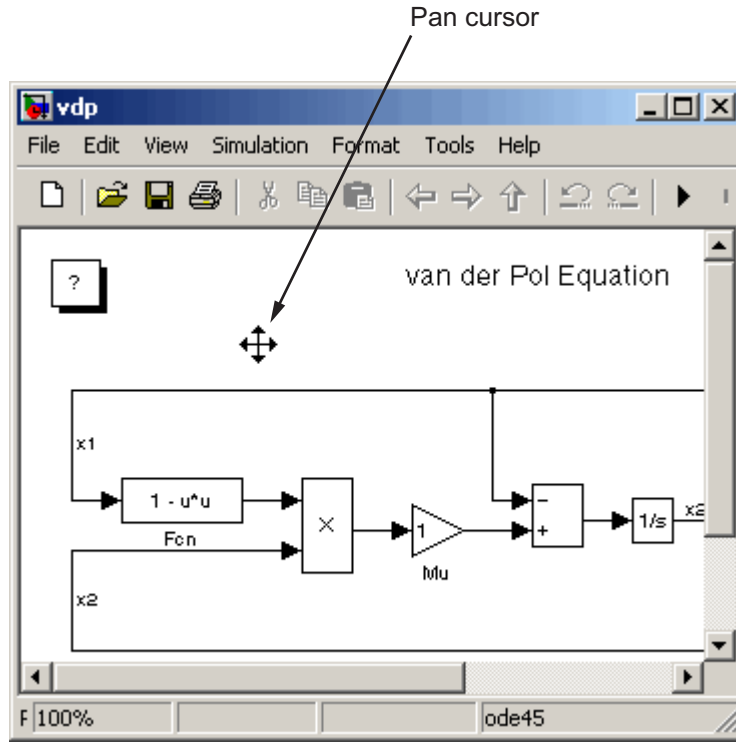
By default, the Simulink software fits a block diagram to view when you open the diagram either in the model browser's content pane or in a separate window. If you change a diagram's zoom setting and save the model containing the diagram, the model editor restores the setting the next time you open the diagram. If you want to restore the default behavior, choose **Fit System To View** from the **View** menu the next time you open the diagram.

Panning Block Diagrams

You can use your keyboard alone (see "Model Viewing Shortcuts" on page 1-43) or in combination with your mouse to pan model diagrams that are too large to fit in the Model Editor's window. To use the keyboard and the mouse, position the mouse over the diagram, hold down the **p** or **q** key on the keyboard, then hold down the left mouse button.

Note You must press and hold down the key first and then the mouse button. The reverse does not work.

A pan cursor appears.



Moving the mouse now pans the model diagram in the editor window.

Viewing Command History

A history of the modeling viewing commands is maintained (such as pan and zoom) that you execute for each model window. The history allows you to quickly return to a previous view in a window, using the following commands, accessible from the Model Editor's **View** menu and tool bar:

- **Back** () — Displays the previous view in the view history.
- **Forward** () — Displays the next view in the view history.
- **Go To Parent** () — Opens, if necessary, the parent of the current subsystem and brings its window to the top of the desktop.

Note A separate view history is maintained for each model window opened in the current session. As a result, the **View > Back** and **View > Forward** commands cannot cross window boundaries. For example, if window reuse is not on and you open a subsystem in another window, you cannot use the **View > Back** command to go to the window displaying the parent system. You must use the **View > Go To Parent** command in this case. On the other hand, if you enable window reuse and open a subsystem in the current window, you can use **View > Back** to restore the parent view.

Bringing the MATLAB Software Desktop Forward

The Simulink product opens model windows on top of the MATLAB desktop. To bring the MATLAB desktop back to the top of your screen, select **View > MATLAB Desktop** from the Model Editor's menu bar.

Copying Models to Third-Party Applications

On a computer running the Microsoft Windows operating system, you can copy a Simulink product model to the Windows operating system clipboard, then paste it to a third-party application such as word processing software. The Simulink product allows you to copy a model in either bitmap or metafile format. You can then paste the clipboard model to an application that accepts figures in bitmap or metafile format. See "Exporting to the Windows or Macintosh® Clipboard" for a description of how to set up the figure settings and save a figure to the clipboard.

The following steps give an example of how use the MATLAB software to copy a model to a third-party application:

1. Set the figure copying options.
   a. Select **File > Preferences**. The Preferences dialog box appears.
   b. Under the **Figure Copy Template** node, select **Copy Options**.
   c. In the Clipboard format pane on the right, select **Preserve information (metafile if possible)**.

      With this setting, the MATLAB software selects the figure format for you, and uses the metafile format whenever possible.
   d. Click **OK**.
2. Click **OK**.
3. Open the `vdp` model.
4. In the Model Editor, select **Edit > Copy Model to Clipboard**.
5. Open a document in Microsoft Word and paste the contents of the clipboard.

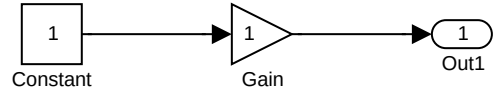
Updating a Block Diagram

You can leave many attributes of a block diagram, such as signal data types and sample times, unspecified. The Simulink product then infers the values of block diagram attributes based on block connectivity and attributes that you do specify, a process known as *updating the diagram*. The Simulink software tries to infer the most appropriate value for an attribute that you do not specify. If an attribute cannot be inferred, it halts the update and displays an error dialog box.

A model's block diagram is updated at the start of every simulation of a model. This assures that the simulation reflects the latest changes that you have made to a model. In addition, you can command the Simulink software to update a diagram at any time by selecting **Edit > Update Diagram** from the Model Editor's menu bar or context menu, or by pressing **Ctrl+D**. This allows you to determine the values of block diagram attributes inferred by the Simulink software immediately after opening or editing a model.

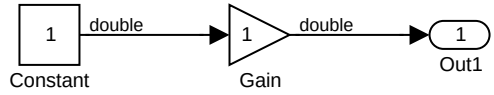
For example:

1 Create the following model.



2 Select **Format > Port/Signal Displays > Port Data Types** from the Model Editor's menu bar.

The data types of the output ports of the Constant and Gain blocks appear. The data type of both ports is `double`, the default value.

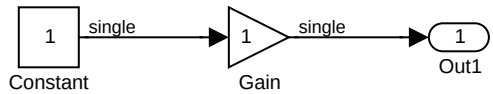


3 Set the **Output data type** parameter of the Constant block (see Constant) to `single`.

The output port data type displays on the block diagram do not reflect this change.

4 Select **Edit > Update Diagram** from the Model Editor's menu bar or press **Ctrl-D**.

The block diagram is updated to reflect the change that you made previously.



Note that the Simulink software has inferred a data type for the output of the Gain block. This is because you did not specify a data type for the block. The data type inferred is `single` because single precision is all that is necessary to simulate the model accurately, given that the precision of the block's input is single.

Printing a Block Diagram

In this section...

About Printing

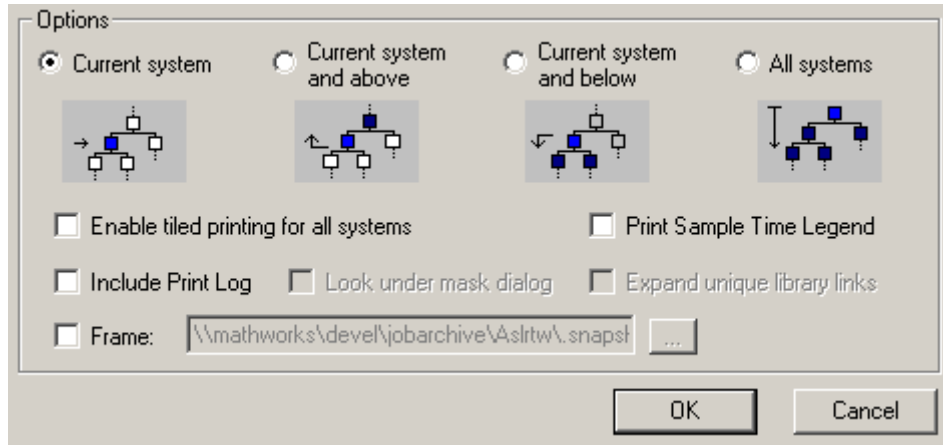
You can print a block diagram by selecting **Print** from the **File** menu or by using the `print` command in the MATLAB software Command Window.

Print Dialog Box

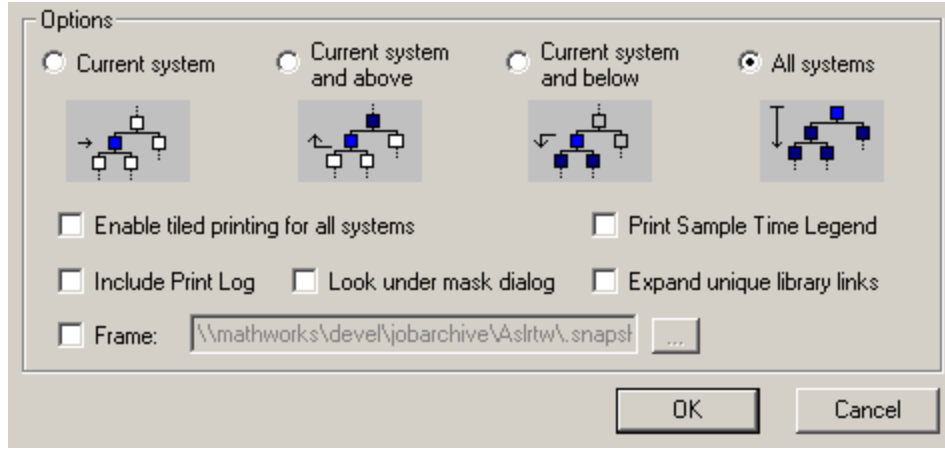
When you select the **Print** menu item, the **Print** dialog box appears. The **Print** dialog box enables you to selectively print systems within your model. Using the dialog box, you can print

- The current system only
- The current system and all systems above it in the model hierarchy
- The current system and all systems below it in the model hierarchy, with the option of looking into the contents of masked and library blocks
- All systems in the model, with the option of looking into the contents of masked and library blocks
- The entire diagram over multiple pages
- An overlay frame on each diagram

The portion of the **Print** dialog box that supports selective printing is similar on supported platforms. This figure shows how it looks on a computer running the Microsoft Windows operating system. In this figure, only the current system is to be printed.



When you select either the **Current system and below** or **All systems** option, two check boxes become enabled. In this figure, **All systems** is selected.



Selecting the **Look under mask dialog** check box prints the contents of masked subsystems when encountered at or below the level of the current block. When you are printing all systems, the top-level system is considered the current block, so the Simulink software looks under any masked blocks encountered.

Selecting the **Expand unique library links** check box prints the contents of library blocks when those blocks are systems. Only one copy is printed regardless of how many copies of the block are contained in the model. For more information about libraries, see Chapter 23, "Working with Block Libraries".

The print log lists the blocks and systems printed. To print the print log, select the **Include Print Log** check box.

Selecting the **Enable tiled printing for all systems** check box overrides the tiled-print settings for individual subsystems in a model. See "Tiled Printing" on page 1-32 for more information.

Selecting the **Frame** check box prints a title block frame on each diagram. Enter the path to the title block frame in the adjacent edit box. You can create a customized title block frame, using the MATLAB product frame editor. See `frameedit` for information on using the frame editor to create title block frames.

Specifying Paper Size and Orientation

You can specify the type and orientation of the paper used to print a model diagram. You can do this on all platforms by setting the model's `PaperType` and `PaperOrientation` properties, respectively (see "Model and Block Parameters" in the online reference), using the `set_param` command. You can set the paper orientation alone, using the MATLAB software `orient` command. On computers running the Windows, operating system, the **Print** and **Printer Setup** dialog boxes let you set the page type and orientation properties as well.

Positioning and Sizing a Diagram

You can use a model's `PaperPositionMode` and `PaperPosition` parameters to position and size the model's diagram on the printed page. The value of the

`PaperPosition` parameter is a vector of form `[left bottom width height]`. The first two elements specify the bottom-left corner of a rectangular area on the page, measured from the page's bottom-left corner. The last two elements specify the width and height of the rectangle. When the model's `PaperPositionMode` is manual, the Simulink software positions (and scales, if necessary) the model's diagram to fit inside the specified print rectangle. For example, the following commands

```
vdp
set_param('vdp', 'PaperType', 'usletter')
set_param('vdp', 'PaperOrientation', 'landscape')
set_param('vdp', 'PaperPositionMode', 'manual')
set_param('vdp', 'PaperPosition', [0.5 0.5 4 4])
print -svdp
```

print the block diagram of the `vdp` sample model in the lower-left corner of a U.S. letter-size page in landscape orientation.

If `PaperPositionMode` is `auto`, the Simulink software centers the model diagram on the printed page, scaling the diagram, if necessary, to fit the page.

Tiled Printing

By default, each block diagram is scaled during the printing process such that it fits on a single page. That is, the size of a small diagram is increased or the size of a large diagram is decreased to confine its printed image to one page. In the case of a large diagram, scaling can make the printed image difficult to read.

By contrast, tiled printing enables you to print even the largest block diagrams without sacrificing clarity and detail. Tiled printing allows you to distribute a block diagram over multiple pages. You can control the number of pages over which the Simulink software prints the block diagram, and hence, the total size of the printed diagram.

Moreover, different tiled-print settings are accommodated for each of the systems in your model. Consequently, you can customize the appearance of all printed images to best suit your needs. The following sections describe how to utilize tiled printing.

Enabling Tiled Printing

To enable tiled printing for a particular system in your model, select the **Enable Tiled Printing** item from the **File** menu associated with that system's Model Editor.

Or you can enable tiled printing programmatically using the `set_param` command. Simply set the system's `PaperPositionMode` parameter to `tiled` (see "Model Parameters" in the online Simulink reference). For example, the following commands

```
sldemo_f14
set_param('sldemo_f14/Controller', 'PaperPositionMode', 'tiled')
```

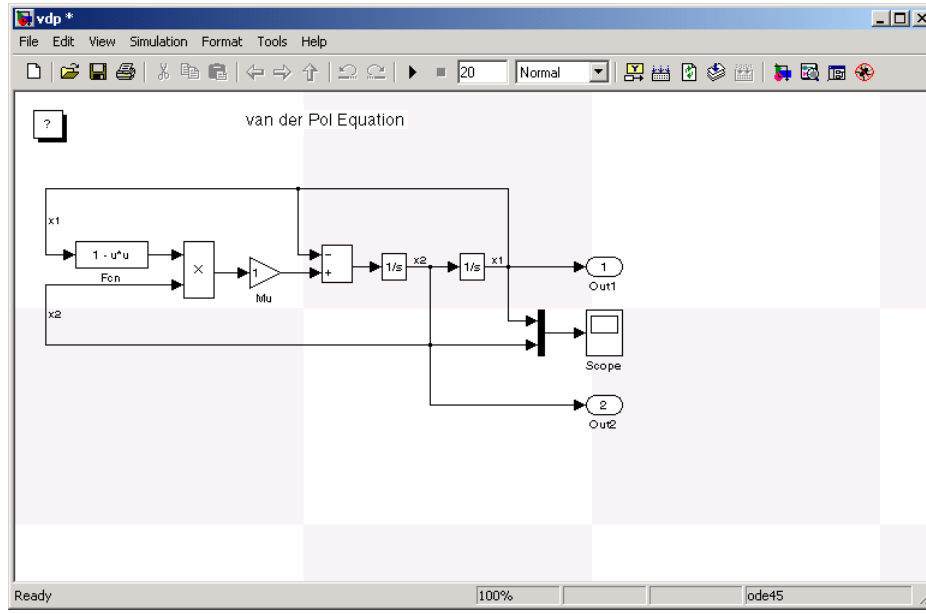
open the `f14` demo model and enable tiled printing for the `Controller` subsystem.

To enable tiled printing for all systems in your model, select the **Enable tiled printing for all systems** check box on the **Print** dialog box (see "Print Dialog Box" on page 1-29). If you select this option, the Simulink software overrides the individual tiled-print settings for all systems in your model.

Displaying Page Boundaries

You can display the page boundaries in the Model Editor to visualize the model's size and layout with respect to the page. To make the page boundaries visible for a particular system in your model, select the **Show Page Boundaries** item from the **View** menu associated with that system's Model Editor. Or you can display the page boundaries programmatically using the `set_param` command. Simply set the system's `ShowPageBoundaries` parameter to `on` (see "Model Parameters" in the online Simulink reference).

The Simulink software renders the page boundaries on the Model Editor's canvas. If tiled printing is enabled, page boundaries are represented by a checkerboard pattern. As illustrated in the following figure, each checkerboard square indicates the extent of a separate page.



If tiled printing is disabled, only a single page is displayed on the Model Editor's canvas.

Specifying Tiled Print Settings

You can use a system's `TiledPageScale` and `TiledPaperMargins` parameters to customize certain aspects of tiled printing. You specify values for these parameters using the `set_param` command.

The `TiledPageScale` parameter scales the block diagram so that more or less of it appears on a single tiled page. By default, its value is `1`. Values greater than `1` proportionally scale the diagram such that it occupies a smaller percentage of the tiled page, while values between `0` and `1` proportionally scale the diagram such that it occupies a larger percentage of the tiled page. For example, a `TiledPageScale` of `0.5` makes the printed diagram appear twice its size on a tiled page, while a `TiledPageScale` of `2` makes the printed diagram appear half its size on a tiled page.

You can specify the margin sizes associated with tiled pages using the `TiledPaperMargins` parameter. The value of `TiledPaperMargins` is a

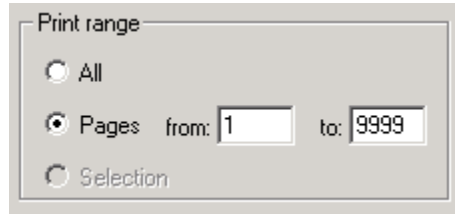
vector of form `[left top right bottom]`. Each element specifies the size of the margin at a particular edge of the page. The value of the `PaperUnits` parameter is used to determine its units of measurement. Each margin to 0.5 inches by default. By decreasing the margin sizes, you can increase the printable area of the tiled pages.

Printing Tiled Pages

By default, all of a system's tiled pages are printed when you select **Print** from the **File** menu or use the `print` command at the MATLAB software prompt.

Alternatively, you can specify the range of tiled page numbers that are printed, as follows:

- On a computer running the Microsoft Windows operating system, you can specify a range of tiled page numbers to be printed using the **Print range** portion of the **Print** dialog box. This field is accessible if you select both the **Current system** and **Enable tiled printing for all systems** options (see "Print Dialog Box" on page 1-29).



- On all platforms, you can specify a range of tiled page numbers to be printed using the `print` command at the MATLAB software prompt. The print command's `tileall` option enables tiled printing for the system, and its `pages` option indicates the range of tiled page numbers to be printed (see "Print Command" on page 1-36). For example, the following commands

```
vdp
set_param('vdp', 'PaperPositionMode', 'tiled')
set_param('vdp', 'ShowPageBoundaries', 'on')
set_param('vdp', 'TiledPageScale', '0.1')
```

  open the `vdp` demo model, enable tiled printing, display the page boundaries, and scale the tiled pages such that the block diagram spans

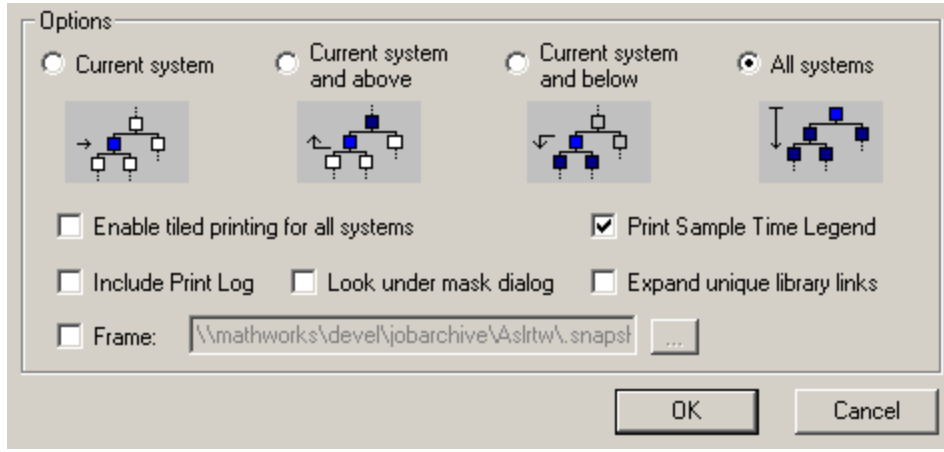
multiple pages. You can print the second, third, and fourth pages by issuing the following command at the MATLAB software prompt:

```
print('-svdp', '-tileall', '-pages[2 4]')
```

Note The Simulink software uses a row-major scheme to number tiled pages. For example, the first page of the first row is 1, the second page of the first row is 2, etc.

Print Sample Time Legend

If you select the **Print Sample Time Legend** option, the Sample Time Legend will print on a separate page from your model. The legend contains sample time information for your entire system, including any subsystems.



For more information about the contents and the settings of the legend, see "How to View Sample Time Information" on page 4-9.

Print Command

The format of the `print` command is

```
print -ssys -device -tileall -pagesp filename
```

sys is the name of the system to be printed. The system name must be preceded by the `s` switch identifier and is the only required argument. *sys* must be open or must have been open during the current session. If the system name contains spaces or takes more than one line, you need to specify the name as a string. See the examples below.

device specifies a device type. For a list and description of device types, see the documentation for the MATLAB software `print` function.

`tileall` specifies the tiled printing option (see "Tiled Printing" on page 1-32).

p is a two-element vector specifying the range of tiled page numbers to be printed. The vector must be preceded by the `pages` switch identifier. This option is valid only when you enable tiled printing using the `tileall` switch. For an example of its usage, see "Printing Tiled Pages" on page 1-35.

`filename` is the PostScript® file to which the output is saved. If `filename` exists, it is replaced. If `filename` does not include an extension, an appropriate one is appended.

For example, this command prints a system named `untitled`.

```
print -suntitled
```

This command prints the contents of a subsystem named `Sub1` in the current system.

```
print -sSub1
```

This command prints the contents of a subsystem named `Requisite Friction`.

```
print (['-sRequisite Friction'])
```

The next example prints a system named `Friction Model`, a subsystem whose name appears on two lines. The first command assigns the newline character to a variable; the second prints the system.

```
cr = sprintf('\n');
print (['-sFriction' cr 'Model'])
```

To print the currently selected subsystem, enter

```
print(['-s', gcb])
```

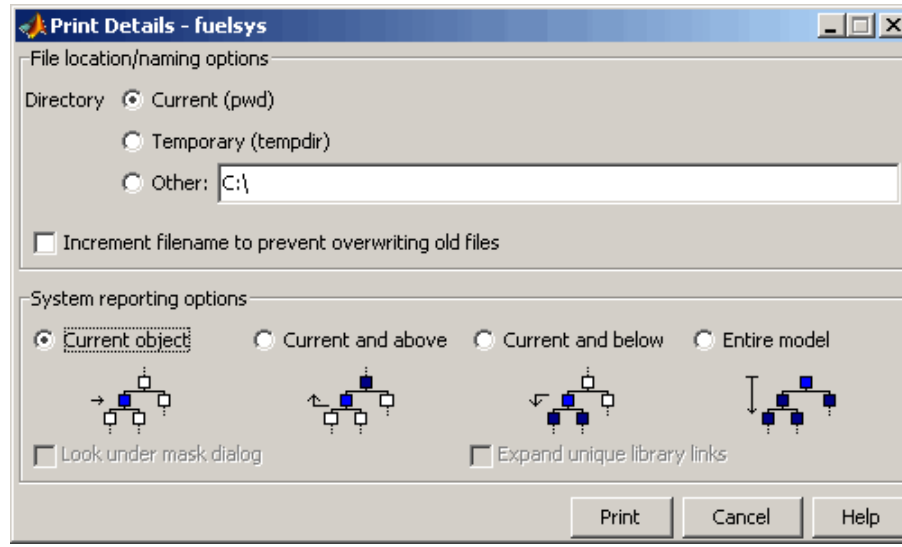
Generating a Model Report

A model report is an HTML document that describes a model's structure and content. The report includes block diagrams of the model and its subsystems and the settings of its block parameters.

To generate a report for the current model:

1. Select **Print Details** from the model's **File** menu.

   The **Print Details** dialog box appears.



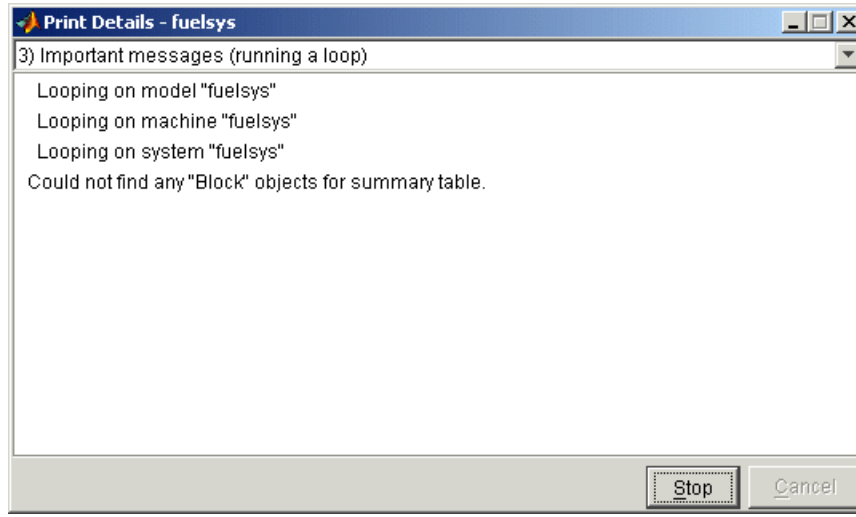
   The dialog box allows you to select various report options (see "Model Report Options" on page 1-40).

2. Select the desired report options on the dialog box.

3. Select **Print**.

The Simulink software generates the HTML report and displays the report in your system's default HTML browser.

While generating the report, the Simulink software displays status messages on a messages pane that replaces the options pane on the **Print Details** dialog box.



You can select the detail level of the messages from the list at the top of the messages pane. When the report generation process begins, the **Print** button on the **Print Details** dialog box changes to a **Stop** button. Clicking this button terminates the report generation. When the report generation process finishes, the **Stop** button changes to an **Options** button. Clicking this button redisplays the report generation options, allowing you to generate another report without having to reopen the **Print Details** dialog box.

Model Report Options

The **Print Details** dialog box allows you to select the following report options.

Directory

The folder where the HTML report is stored. The options include your system's temporary folder (the default), your system's current folder, or another folder whose path you specify in the adjacent edit field.

Increment filename to prevent overwriting old files

Creates a unique report file name each time you generate a report for the same model in the current session. This preserves each report.

Current object

Include only the currently selected object in the report.

Current and above

Include the current object and all levels of the model above the current object in the report.

Current and below

Include the current object and all levels below the current object in the report.

Entire model

Include the entire model in the report.

Look under mask dialog

Include the contents of masked subsystems in the report.

Expand unique library links

Include the contents of library blocks that are subsystems. The report includes a library subsystem only once even if it occurs in more than one place in the model.

Ending a Simulink Session

Terminate a Simulink software session by closing all Simulink windows.

Terminate a MATLAB software session by choosing one of these commands from the **File** menu:

- On a computer running the Microsoft Windows operating system: **Exit MATLAB**
- On a UNIX system, system: **Quit MATLAB**

Summary of Mouse and Keyboard Actions

In this section...

Model Viewing Shortcuts

The following table lists keyboard shortcuts for viewing models.

Task	Microsoft Windows Operating System	UNIX System
Zoom in	**r**	**r**
Zoom out	**v**	**v**
Zoom to normal (100%)	**1**	**1**
Pan left	**d** or **Ctrl+Left Arrow**	**d** or **Ctrl+Left Arrow**
Pan right	**g** or **Ctrl+Right Arrow**	**g** or **Ctrl+Right Arrow**
Pan up	**e** or **Ctrl+Up Arrow**	**e** or **Ctrl+Up Arrow**
Pan down	**c** or **Ctrl+Down Arrow**	**c** or **Ctrl+Down Arrow**
Fit selection to screen	**f**	**f**
Fit diagram to screen	**Space**	**Space**
Pan with mouse	Hold down **p** or **q** and drag mouse	Hold down **p** or **q** and drag mouse
Go back in pan/zoom history	**b** or **Shift+Left Arrow**	**b** or **Shift+Left Arrow**

Task	Microsoft Windows Operating System	UNIX System
Go forward in pan/zoom history	**t** or **Shift+Right Arrow**	**t** or **Shift+Right Arrow**
Delete selection	**Delete** or **Back Space**	**Delete** or **Back Space**
Move selection	Use arrow keys	Use arrow keys

Block Editing Shortcuts

The following table lists mouse and keyboard actions that apply to blocks.

Task	Microsoft Windows Operating System	UNIX System
Select one block	LMB	LMB
Select multiple blocks	**Shift** + LMB	**Shift** + LMB; or CMB alone
Copy block from another window	Drag block	Drag block
Move block	Drag block	Drag block
Duplicate block	**Ctrl** + LMB and drag; or RMB and drag	**Ctrl** + LMB and drag; or RMB and drag
Connect blocks	LMB	LMB
Disconnect block	**Shift** + drag block	**Shift** + drag block; or CMB and drag
Open selected subsystem	**Enter**	**Return**
Go to parent of selected subsystem	**Esc**	**Esc**

Line Editing Shortcuts

The following table lists mouse and keyboard actions that apply to lines.

Task	Microsoft Windows Operating System	UNIX System
Select one line	LMB	LMB
Select multiple lines	**Shift** + LMB	**Shift** + LMB; or CMB alone
Draw branch line	**Ctrl** + drag line; or RMB and drag line	**Ctrl** + drag line; or RMB + drag line
Route lines around blocks	**Shift** + draw line segments	**Shift** + draw line segments; or CMB and draw segments
Move line segment	Drag segment	Drag segment
Move vertex	Drag vertex	Drag vertex
Create line segments	**Shift** + drag line	**Shift** + drag line; or CMB + drag line

Signal Label Editing Shortcuts

The next table lists mouse and keyboard actions that apply to signal labels.

Action	Microsoft Windows Operating System	UNIX System
Create signal label	Double-click line, then enter label	Double-click line, then enter label
Copy signal label	**Ctrl** + drag label	**Ctrl** + drag label
Move signal label	Drag label	Drag label
Edit signal label	Click in label, then edit	Click in label, then edit
Delete signal label	**Shift** + click label, then press **Delete**	**Shift** + click label, then press **Delete**

Annotation Editing Shortcuts

The next table lists mouse and keyboard actions that apply to annotations.

Action	Microsoft Windows Operating System	UNIX System
Create annotation	Double-click in diagram, then enter text	Double-click in diagram, then enter text
Copy annotation	**Ctrl** + drag label	**Ctrl** + drag label
Move annotation	Drag label	Drag label
Edit annotation	Click in text, then edit	Click in text, then edit
Delete annotation	**Shift** + select annotation, then press **Delete**	**Shift** + select annotation, then press **Delete**

2

How Simulink Works

Introduction

Simulink is a software package that enables you to model, simulate, and analyze systems whose outputs change over time. Such systems are often referred to as dynamic systems. The Simulink software can be used to explore the behavior of a wide range of real-world dynamic systems, including electrical circuits, shock absorbers, braking systems, and many other electrical, mechanical, and thermodynamic systems. This section explains how Simulink works.

Simulating a dynamic system is a two-step process. First, a user creates a block diagram, using the Simulink model editor, that graphically depicts time-dependent mathematical relationships among the system's inputs, states, and outputs. The user then commands the Simulink software to simulate the system represented by the model from a specified start time to a specified stop time.

Modeling Dynamic Systems

In this section...

Block Diagram Semantics

A classic block diagram model of a dynamic system graphically consists of blocks and lines (signals). The history of these block diagram models is derived from engineering areas such as Feedback Control Theory and Signal Processing. A block within a block diagram defines a dynamic system in itself. The relationships between each elementary dynamic system in a block diagram are illustrated by the use of signals connecting the blocks. Collectively the blocks and lines in a block diagram describe an overall dynamic system.

The Simulink product extends these classic block diagram models by introducing the notion of two classes of blocks, nonvirtual blocks and virtual blocks. Nonvirtual blocks represent elementary systems. Virtual blocks exist for graphical and organizational convenience only: they have no effect on the system of equations described by the block diagram model. You can use virtual blocks to improve the readability of your models.

In general, blocks and lines can be used to describe many "models of computations." One example would be a flow chart. A flow chart consists of blocks and lines, but one cannot describe general dynamic systems using flow chart semantics.

The term "time-based block diagram" is used to distinguish block diagrams that describe dynamic systems from that of other forms of block diagrams, and the term block diagram (or model) is used to refer to a time-based block diagram unless the context requires explicit distinction.

To summarize the meaning of time-based block diagrams:

- Simulink block diagrams define time-based relationships between signals and state variables. The solution of a block diagram is obtained by evaluating these relationships over time, where time starts at a user specified "start time" and ends at a user specified "stop time." Each evaluation of these relationships is referred to as a time step.
- Signals represent quantities that change over time and are defined for all points in time between the block diagram's start and stop time.
- The relationships between signals and state variables are defined by a set of equations represented by blocks. Each block consists of a set of equations (block methods). These equations define a relationship between the input signals, output signals and the state variables. Inherent in the definition of a equation is the notion of parameters, which are the coefficients found within the equation.

Creating Models

The Simulink product provides a graphical editor that allows you to create and connect instances of block types (see Chapter 3, "Creating a Model") selected from libraries of block types (see Blocks — Alphabetical List) via a library browser. Libraries of blocks are provided representing elementary systems that can be used as building blocks. The blocks supplied with Simulink are called built-in blocks. Users can also create their own block types and use the Simulink editor to create instances of them in a diagram. User-defined blocks are called custom blocks.

Time

Time is an inherent component of block diagrams in that the results of a block diagram simulation change with time. Put another way, a block diagram represents the instantaneous behavior of a dynamic system. Determining a system's behavior over time thus entails repeatedly solving the model at intervals, called time steps, from the start of the time span to the end of the time span. The process of solving a model at successive time steps is referred to as *simulating* the system that the model represents.

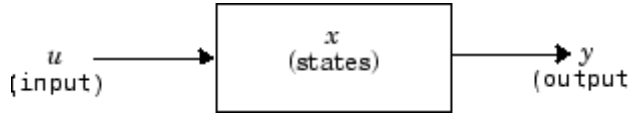
States

Typically the current values of some system, and hence model, outputs are functions of the previous values of temporal variables. Such variables are called states. Computing a model's outputs from a block diagram hence entails saving the value of states at the current time step for use in computing the outputs at a subsequent time step. This task is performed during simulation for models that define states.

Two types of states can occur in a Simulink model: discrete and continuous states. A continuous state changes continuously. Examples of continuous states are the position and speed of a car. A discrete state is an approximation of a continuous state where the state is updated (recomputed) using finite (periodic or aperiodic) intervals. An example of a discrete state would be the position of a car shown on a digital odometer where it is updated every second as opposed to continuously. In the limit, as the discrete state time interval approaches zero, a discrete state becomes equivalent to a continuous state.

Blocks implicitly define a model's states. In particular, a block that needs some or all of its previous outputs to compute its current outputs implicitly defines a set of states that need to be saved between time steps. Such a block is said to have states.

The following is a graphical representation of a block that has states:



Blocks that define continuous states include the following standard Simulink blocks:

- Integrator
- State-Space
- Transfer Fcn
- Variable Transport Delay
- Zero-Pole

The total number of a model's states is the sum of all the states defined by all its blocks. Determining the number of states in a diagram requires parsing the diagram to determine the types of blocks that it contains and then aggregating the number of states defined by each instance of a block type that defines states. This task is performed during the Compilation phase of a simulation.

Working with States

The following facilities are provided for determining, initializing, and logging a model's states during simulation:

- The `model` command displays information about the states defined by a model, including the total number of states defined by the model, the block that defines each state, and the initial value of each state.
- The Simulink debugger displays the value of a state at each time step during a simulation, and the Simulink debugger's `states` command displays information about the model's current states (see Chapter 16, "Simulink Debugger").
- The **Data Import/Export** pane of a model's Configuration Parameters dialog box (see Chapter 27, "Importing and Exporting Data") allows you to specify initial values for a model's states, and to record the values of the states at each time step during simulation as an array or structure variable in the MATLAB workspace.
- The Block Parameters dialog box (and the `ContinuousStateAttributes` parameter) allows you to give names to states for those blocks (such as the Integrator) that employ continuous states. This can simplify analyzing data logged for states, especially when a block has multiple states.

The Two Cylinder Model with Load Constraints demo illustrates the logging of continuous states.

Continuous States

Computing a continuous state entails knowing its rate of change, or derivative. Since the rate of change of a continuous state typically itself changes continuously (i.e., is itself a state), computing the value of a continuous state at the current time step entails integration of its derivative from the start of a simulation. Thus modeling a continuous state entails representing the operation of integration and the process of computing the state's derivative at each point in time. Simulink block diagrams use Integrator blocks to indicate integration and a chain of blocks connected to an integrator block's input to represent the method for computing the state's derivative. The chain of blocks connected to the integrator block's input is the graphical counterpart to an ordinary differential equation (ODE).

In general, excluding simple dynamic systems, analytical methods do not exist for integrating the states of real-world dynamic systems represented by ordinary differential equations. Integrating the states requires the use of numerical methods called ODE solvers. These various methods trade computational accuracy for computational workload. The Simulink product comes with computerized implementations of the most common ODE integration methods and allows a user to determine which it uses to integrate states represented by Integrator blocks when simulating a system.

Computing the value of a continuous state at the current time step entails integrating its values from the start of the simulation. The accuracy of numerical integration in turn depends on the size of the intervals between time steps. In general, the smaller the time step, the more accurate the simulation. Some ODE solvers, called variable time step solvers, can automatically vary the size of the time step, based on the rate of change of the state, to achieve a specified level of accuracy over the course of a simulation. The user can specify the size of the time step in the case of fixed-step solvers, or the solver can automatically determine the step size in the case of variable-step solvers. To minimize the computation workload, the variable-step solver chooses the largest step size consistent with achieving an overall level of precision specified by the user for the most rapidly changing model state. This ensures that all model states are computed to the accuracy specified by the user.

Discrete States

Computing a discrete state requires knowing the relationship between its value at the current time step and its value at the previous time step. This is referred to this relationship as the state's update function. A discrete state depends not only on its value at the previous time step but also on the values of a model's inputs. Modeling a discrete state thus entails modeling the state's dependency on the systems' inputs at the previous time step. Simulink block diagrams use specific types of blocks, called discrete blocks, to specify update functions and chains of blocks connected to the inputs of discrete blocks to model the dependency of a system's discrete states on its inputs.

As with continuous states, discrete states set a constraint on the simulation time step size. Specifically, the step size must ensure that all the sample times of the model's states are hit. This task is assigned to a component of the Simulink system called a discrete solver. Two discrete solvers are provided: a fixed-step discrete solver and a variable-step discrete solver. The fixed-step discrete solver determines a fixed step size that hits all the sample times of all the model's discrete states, regardless of whether the states actually change value at the sample time hits. By contrast, the variable-step discrete solver varies the step size to ensure that sample time hits occur only at times when the states change value.

Modeling Hybrid Systems

A hybrid system is a system that has both discrete and continuous states. Strictly speaking, any model that has both continuous and discrete sample times is treated as a hybrid model, presuming that the model has both continuous and discrete states. Solving such a model entails choosing a step size that satisfies both the precision constraint on the continuous state integration and the sample time hit constraint on the discrete states. The Simulink software meets this requirement by passing the next sample time hit, as determined by the discrete solver, as an additional constraint on the continuous solver. The continuous solver must choose a step size that advances the simulation up to but not beyond the time of the next sample time hit. The continuous solver can take a time step short of the next sample time hit to meet its accuracy constraint but it cannot take a step beyond the next sample time hit even if its accuracy constraint allows it to.

You can simulate hybrid systems using any one of the integration methods, but certain methods are more effective than others. For most hybrid systems,

the Runge-Kutta variable-step methods, `ode23` and `ode45`, are superior to the other solvers in terms of efficiency. Because of discontinuities associated with the sample and hold of the discrete blocks, MathWorks does not recommend the `ode15s` and `ode113` solvers for hybrid systems.

Block Parameters

Key properties of many standard blocks are parameterized. For example, the Constant value of the Simulink Constant block is a parameter. Each parameterized block has a block dialog that lets you set the values of the parameters. You can use MATLAB expressions to specify parameter values. Simulink evaluates the expressions before running a simulation. You can change the values of parameters during a simulation. This allows you to determine interactively the most suitable value for a parameter.

A parameterized block effectively represents a family of similar blocks. For example, when creating a model, you can set the Constant value parameter of each instance of the Constant block separately so that each instance behaves differently. Because it allows each standard block to represent a family of blocks, block parameterization greatly increases the modeling power of the standard Simulink libraries. See Chapter 19, “Working with Block Parameters” and Chapter 23, “Working with Block Libraries” for more information.

Tunable Parameters

Many block parameters are tunable. A *tunable parameter* is a parameter whose value can be changed without recompiling the model (see “Model Compilation” on page 2-18 for more information on compiling a model). For example, the gain parameter of the Gain block is tunable. You can alter the block’s gain while a simulation is running. If a parameter is not tunable and the simulation is running, the dialog box control that sets the parameter is disabled.

You can not change the values of source block parameters through either a dialog box or the Model Explorer while a simulation is running. Opening the dialog box of a source block with tunable parameters causes a running simulation to pause. While the simulation is paused, you can edit the parameter values displayed on the dialog box. However, you must close the dialog box to have the changes take effect and allow the simulation

to continue. The changes take effect at the start of the next time step. See Chapter 19, "Working with Block Parameters" and "Using Tunable Parameters" on page 19-13 for more information.

Block Sample Times

Every Simulink block has a sample time which defines when the block will execute . Most blocks allow you to specify the sample time via a `SampleTime` parameter. Common choices include discrete, continuous, and inherited sample times.

Common Sample Time Types	Sample Time	Examples
Discrete	[T_s, T_o]	Unit Delay, Digital Filter
Continuous	[0, 0]	Integrator, Derivative
Inherited	[–1, 0]	Gain, Sum

For discrete blocks, the sample time is a vector [Ts, To] where Ts is the time interval or period between consecutive sample times and To is an initial offset to the sample time. In contrast, the sample times for nondiscrete blocks are represented by ordered pairs that use zero, a negative integer, or infinity to represent a specific type of sample time (see "How to View Sample Time Information" on page 4-9). For example, continuous blocks have a nominal sample time of [0, 0] and are used to model systems in which the states change continuously (e.g., a car accelerating). Whereas you indicate the sample time type of an inherited block symbolically as [–1, 0] and Simulink then determines the actual value based upon the context of the inherited block within the model.

Note that not all blocks accept all types of sample times. For example, a discrete block cannot accept a continuous sample time.

For a visual aid, Simulink allows the optional color-coding and annotation of any block diagram to indicate the type and speed of the block sample times. You can capture all of the colors and the annotations within a legend (see "How to View Sample Time Information" on page 4-9).

For a more detailed discussion of sample times, see Chapter 4, "Working with Sample Times"

Custom Blocks

You can create libraries of custom blocks that you can then use in your models. You can create a custom block either graphically or programmatically. To create a custom block graphically, you draw a block diagram representing the block's behavior, wrap this diagram in an instance of the Simulink Subsystem block, and provide the block with a parameter dialog, using the Simulink block mask facility. To create a block programmatically, you create a MATLAB file or a MEX-file that contains the block's system functions (see *Developing S-Functions*). The resulting file is called an S-function. You then associate the S-function with instances of the Simulink S-Function block in your model. You can add a parameter dialog to your S-Function block by wrapping it in a Subsystem block and adding the parameter dialog to the Subsystem block. See Chapter 22, "Creating Custom Blocks" for more information.

Systems and Subsystems

A Simulink block diagram can consist of layers. Each layer is defined by a subsystem. A subsystem is part of the overall block diagram and ideally has no impact on the meaning of the block diagram. Subsystems are provided primarily to help with the organizational aspects of a block diagram. Subsystems do not define a separate block diagram.

The Simulink software differentiates between two different types of subsystems: virtual and nonvirtual. The primary difference is that nonvirtual subsystems provide the ability to control when the contents of the subsystem are evaluated.

Virtual Subsystems

Virtual subsystems provide graphical hierarchy in models. Virtual subsystems do not impact execution. During model execution, the Simulink engine flattens all virtual subsystems, i.e., Simulink expands the subsystem in place before execution. This expansion is very similar to the way macros work in a programming language such as C or C++. Roughly speaking, there will be one system for the top-level block diagram which is referred to as the root system, and several lower-level systems derived from nonvirtual

subsystems and other elements in the block diagram. You will see these systems in the Simulink Debugger. The act of creating these internal systems is often referred to as *flattening the model hierarchy*.

Nonvirtual Subsystems

Nonvirtual subsystems provide execution and graphical hierarchy in models. Nonvirtual subsystems are executed as a single unit (atomic execution) by the Simulink engine. You can create conditionally executed subsystems that are executed only when a transition occurs on a triggering, function-call, action, or enabling input (see Chapter 6, "Creating Conditional Subsystems"). The blocks within a nonvirtual subsystem execute only when all subsystem inputs are valid. All nonvirtual subsystems are drawn with a bold border. Simulink defines the following nonvirtual subsystems:

Atomic subsystems. The primary characteristic of an atomic subsystem is that blocks in an atomic subsystem execute as a single unit. This provides the advantage of grouping functional aspects of models at the execution level. Any Simulink block can be placed in an atomic subsystem, including blocks with different execution rates. You can create an atomic subsystem by selecting the `Treat as atomic unit` option on a virtual subsystem (see the Atomic Subsystem block for more information).

Enabled subsystems. An enabled subsystem behaves similarly to an atomic subsystem, except that it executes only when the signal driving the subsystem's enable port is greater than zero. You can also configure an enabled subsystem to hold or reset the states of blocks within the enabled subsystem via the `States when enabling` parameter in the enable port block. Each output port of an enabled subsystem can be configured to hold or reset its output via the `Output when disabled` parameter in the outport block. You can create an enabled subsystem by placing an enable port block within a subsystem.

Triggered subsystems. A triggered subsystem executes when a rising or falling edge with respect to zero is seen on the signal driving the subsystem trigger port. The direction of the triggering edge is defined by the `Trigger type` parameter on the trigger port block. Simulink limits the type of blocks placed in a triggered subsystem to blocks that do not have explicit sample times (i.e., blocks within the subsystem must have a sample time of -1) because the contents of a triggered subsystem execute in an aperiodic fashion. You create a triggered subsystem by placing a trigger port block within a subsystem. A Stateflow chart can also have a trigger port which is defined by using the Stateflow editor. From Simulink's perspective there is no difference between a triggered subsystem and a triggered chart.

Function-call subsytems. A function-call subsystem is a subsystem that another block can invoke directly during a simulation. It is analogous to a function in a procedural programming language. Invoking a function-call subsystem is equivalent to invoking the output methods of the blocks that the subsystem contains in sorted order. The block that invokes a function-call subsystem is called the function-call initiator. Stateflow, Function-Call Generator, and S-function blocks can all serve as function-call initiators. To create a function-call subsystem, drag a Function-Call Subsystem block from Simulink's Ports & Subsystems library into your model and connect a function-call initiator to the function-call port displayed on top the subsystem. You can also create a function-call subsystem from scratch by first creating a Subsystem block in your model and then creating a Trigger block in the subsystem and setting the Trigger block's `Trigger type` to `function-call`.

You can configure a function-call subsystem to be triggered (the default) or periodic by setting its `Sample time type` to be `triggered` or `periodic`, respectively. A function-call initiator can invoke a triggered function-call subsystem zero, once, or multiple times per time step. The sample times of all the blocks in a triggered function-call subsystem must be set to inherited (-1).

A function-call initiator can invoke a periodic function-call subsystem only once per time step and must invoke the subsystem periodically. If the initiator invokes a periodic function-call subsystem aperiodically, Simulink halts the simulation and displays an error message. The blocks in a periodic function-call subsystem can specify a non-inherited sample time or inherited (-1) sample time. All blocks that specify a non-inherited sample time must specify the same sample time, i.e., if one block specifies .1 as its sample time, all other blocks must specify a sample time of .1 or -1. If a function-call

initiator invokes a periodic function-call subsystem at a rate that differs from the sample time specified by the blocks in the subsystem, Simulink halts the simulation and displays an error message.

Enabled with trigger subsystems. An enabled with trigger subsystem is essentially a triggered subsystem that executes when the subsystem is enabled and a rising or falling edge with respect to zero is seen on the signal driving the subsystem trigger port. The direction of the triggering edge is defined by the `Trigger type` parameter on the trigger port block. Simulink limits the types of blocks placed in an enabled with triggered subsystem to blocks that do not have explicit sample times (i.e., blocks within the subsystem must have a sample time of -1) because the contents of a triggered subsystem execute in an aperiodic fashion. You can create an enabled with triggered subsystem by placing a trigger port block and a enable port block within a subsystem.

Action subsystems. Action subsystems can be thought of as an intersection of the properties of enabled subsystems and function-call subsystems. Action subsystems are restricted to have one sample time (e.g., a continuous, discrete, or inherited sample time). Action subsystems must be executed by an action subsystem initiator. This is either an If block or a SwitchCase block. All action subsystems connected to a given action subsystem initiator must have the same sample time. An action subsystem is created by placing an action port block within a subsystem. The subsystem icon will automatically adapt to the type of block (i.e., If or SwitchCase block) that is executing the action subsystem.

Action subsystems can be executed at most once by the action subsystem initiator. Action subsystems give you control over when the states reset via the `States when execution is resumed` parameter on the action port block. Action subsystems also give you control over whether or not to hold the outport values via the `Output when disabled` parameter on the outport block. This is analogous to enabled subsystems.

Action subsystems behave very similarly to function-call subsystems because they must be executed by an initiator block. *Function-call subsystems can be executed more than once on any given time step whereas action subsystems can be executed at most once.* This restriction means that a larger set of blocks (e.g., periodic blocks) can be placed in action subsystems when compared

with function-call subsystems. This restriction also means that you can have control over how the states and outputs behave.

While-subsystems. A while-subsystem will run multiple iterations on each model time step. The number of iterations is controlled by the while-iterator block condition. A while-subsystem is created by placing a while-iterator block within a subsystem block.

A while-subsystem is very similar to a function-call subsystem in that it can run for any number of iterations on a given time step. The while-subsystem differs from a function-call subsystem in that there is no separate initiator (e.g., a Stateflow Chart). In addition, a while-subsystem has access to the current iteration number optionally produced by the while-iterator block. A while-subsystem also gives you control over whether or not to reset states when starting via the `States when starting` parameter on the while-iterator block.

For-subsystems. A for-subsystem will run a fixed number of iterations on each model time step. The number of iterations can be an external input to the for-subsystem or specified internally on the for-iterator block. A for-subsystem is created by placing a for-iterator block within a subsystem block.

A for-subsystem has access to the current iteration number that is optionally produced by the for-iterator block. A for-subsystem also gives you control over whether or not to reset states when starting via the `States when starting` parameter on the for-iterator block. A for-subsystem is very similar to a while-subsystem with the restriction that the number of iterations on any given time step is fixed.

Signals

The term *signal* refers to a time varying quantity that has values at all points in time. You can specify a wide range of signal attributes, including signal name, data type (e.g., 8-bit, 16-bit, or 32-bit integer), numeric type (real or complex), and dimensionality (one-dimensional, two-dimensional, or multidimensional array). Many blocks can accept or output signals of any data or numeric type and dimensionality. Others impose restrictions on the attributes of the signals they can handle.

On the block diagram, signals are represented with lines that have an arrowhead. The source of the signal corresponds to the block that writes to the signal during evaluation of its block methods (equations). The destinations of the signal are blocks that read the signal during the evaluation of the block's methods (equations).

A good way to understand the definition of a signal is to consider a classroom. The teacher is the one responsible for writing on the white board and the students read what is written on the white board when they choose to. This is also true of Simulink signals: a reader of the signal (a block method) can choose to read the signal as frequently or infrequently as so desired.

For more information about signals, see Chapter 29, "Working with Signals".

Block Methods

Blocks represent multiple equations. These equations are represented as block methods. These block methods are evaluated (executed) during the execution of a block diagram. The evaluation of these block methods is performed within a simulation loop, where each cycle through the simulation loop represents the evaluation of the block diagram at a given point in time.

Method Types

Names are assigned to the types of functions performed by block methods. Common method types include:

- Outputs

  Computes the outputs of a block given its inputs at the current time step and its states at the previous time step.

- Update

  Computes the value of the block's discrete states at the current time step, given its inputs at the current time step and its discrete states at the previous time step.

- Derivatives

  Computes the derivatives of the block's continuous states at the current time step, given the block's inputs and the values of the states at the previous time step.

Method Naming Convention

Block methods perform the same types of operations in different ways for different types of blocks. The Simulink user interface and documentation uses dot notation to indicate the specific function performed by a block method:

```
BlockType.MethodType
```

For example, the method that computes the outputs of a Gain block is referred to as

```
Gain.Outputs
```

The Simulink debugger takes the naming convention one step further and uses the instance name of a block to specify both the method type and the block instance on which the method is being invoked during simulation, e.g.,

```
g1.Outputs
```

Model Methods

In addition to block methods, a set of methods is provided that compute the model's properties and its outputs. The Simulink software similarly invokes these methods during simulation to determine a model's properties and its outputs. The model methods generally perform their tasks by invoking block methods of the same type. For example, the model Outputs method invokes the Outputs methods of the blocks that it contains in the order specified by the model to compute its outputs. The model Derivatives method similarly invokes the Derivatives methods of the blocks that it contains to determine the derivatives of its states.

Simulating Dynamic Systems

In this section...

Model Compilation

The first phase of simulation occurs when you choose **Start** from the Model Editor's **Simulation** menu, with the system's model open. This causes the Simulink engine to invoke the model compiler. The model compiler converts the model to an executable form, a process called compilation. In particular, the compiler

- Evaluates the model's block parameter expressions to determine their values.
- Determines signal attributes, e.g., name, data type, numeric type, and dimensionality, not explicitly specified by the model and checks that each block can accept the signals connected to its inputs.
- A process called attribute propagation is used to determine unspecified attributes. This process entails propagating the attributes of a source signal to the inputs of the blocks that it drives.
- Performs block reduction optimizations.
- Flattens the model hierarchy by replacing virtual subsystems with the blocks that they contain (see "Solvers" on page 2-21).
- Determines the block sorted order (see "Controlling and Displaying the Sorted Order" on page 18-34 for more information).

- Determines the sample times of all blocks in the model whose sample times you did not explicitly specify (see "How Propagation Affects Inherited Sample Times" on page 4-31).

Link Phase

In this phase, the Simulink Engine allocates memory needed for working areas (signals, states, and run-time parameters) for execution of the block diagram. It also allocates and initializes memory for data structures that store run-time information for each block. For built-in blocks, the principal run-time data structure for a block is called the SimBlock. It stores pointers to a block's input and output buffers and state and work vectors.

Method Execution Lists

In the Link phase, the Simulink engine also creates method execution lists. These lists list the most efficient order in which to invoke a model's block methods to compute its outputs. The block sorted order lists generated during the model compilation phase is used to construct the method execution lists.

Block Priorities

You can assign update priorities to blocks (see "Assigning Block Priorities" on page 18-47). The output methods of higher priority blocks are executed before those of lower priority blocks. The priorities are honored only if they are consistent with its block sorting rules.

Simulation Loop Phase

Once the Link Phase completes, the simulation enters the simulation loop phase. In this phase, the Simulink engine successively computes the states and outputs of the system at intervals from the simulation start time to the finish time, using information provided by the model. The successive time points at which the states and outputs are computed are called time steps. The length of time between steps is called the step size. The step size depends on the type of solver (see "Solvers" on page 2-21) used to compute the system's continuous states, the system's fundamental sample time (see "Managing Sample Times in Systems" on page 4-22), and whether the system's continuous states have discontinuities (see "Zero-Crossing Detection" on page 2-23).

The Simulation Loop phase has two subphases: the Loop Initialization phase and the Loop Iteration phase. The initialization phase occurs once, at the start of the loop. The iteration phase is repeated once per time step from the simulation start time to the simulation stop time.

At the start of the simulation, the model specifies the initial states and outputs of the system to be simulated. At each step, new values for the system's inputs, states, and outputs are computed, and the model is updated to reflect the computed values. At the end of the simulation, the model reflects the final values of the system's inputs, states, and outputs. The Simulink software provides data display and logging blocks. You can display and/or log intermediate results by including these blocks in your model.

Loop Iteration

At each time step, the Simulink Engine:

1. Computes the model's outputs.

   The Simulink Engine initiates this step by invoking the Simulink model Outputs method. The model Outputs method in turn invokes the model system Outputs method, which invokes the Outputs methods of the blocks that the model contains in the order specified by the Outputs method execution lists generated in the Link phase of the simulation (see "Solvers" on page 2-21).

   The system Outputs method passes the following arguments to each block Outputs method: a pointer to the block's data structure and to its SimBlock structure. The SimBlock data structures point to information that the Outputs method needs to compute the block's outputs, including the location of its input buffers and its output buffers.

2. Computes the model's states.

   The Simulink Engine computes a model's states by invoking a solver. Which solver it invokes depends on whether the model has no states, only discrete states, only continuous states, or both continuous and discrete states.

   If the model has only discrete states, the Simulink Engine invokes the discrete solver selected by the user. The solver computes the size of the time step needed to hit the model's sample times. It then invokes the

Update method of the model. The model Update method invokes the Update method of its system, which invokes the Update methods of each of the blocks that the system contains in the order specified by the Update method lists generated in the Link phase.

If the model has only continuous states, the Simulink Engine invokes the continuous solver specified by the model. Depending on the solver, the solver either in turn calls the Derivatives method of the model once or enters a subcycle of minor time steps where the solver repeatedly calls the model's Outputs methods and Derivatives methods to compute the model's outputs and derivatives at successive intervals within the major time step. This is done to increase the accuracy of the state computation. The model Outputs method and Derivatives methods in turn invoke their corresponding system methods, which invoke the block Outputs and Derivatives in the order specified by the Outputs and Derivatives methods execution lists generated in the Link phase.

3 Optionally checks for discontinuities in the continuous states of blocks.

A technique called zero-crossing detection is used to detect discontinuities in continuous states. See "Zero-Crossing Detection" on page 2-23 for more information.

4 Computes the time for the next time step.

Steps 1 through 4 are repeated until the simulation stop time is reached.

Solvers

A dynamic system is simulated by computing its states at successive time steps over a specified time span, using information provided by the model. The process of computing the successive states of a system from its model is known as solving the model. No single method of solving a model suffices for all systems. Accordingly, a set of programs, known as *solvers*, are provided that each embody a particular approach to solving a model. The Configuration Parameters dialog box allows you to choose the solver most suitable for your model (see "Choosing a Solver Type" on page 11-10).

Fixed-Step Solvers Versus Variable-Step Solvers

The solvers provided in the Simulink software fall into two basic categories: fixed-step and variable-step.

Fixed-step solvers solve the model at regular time intervals from the beginning to the end of the simulation. The size of the interval is known as the step size. You can specify the step size or let the solver choose the step size. Generally, decreasing the step size increases the accuracy of the results while increasing the time required to simulate the system.

Variable-step solvers vary the step size during the simulation, reducing the step size to increase accuracy when a model's states are changing rapidly and increasing the step size to avoid taking unnecessary steps when the model's states are changing slowly. Computing the step size adds to the computational overhead at each step but can reduce the total number of steps, and hence simulation time, required to maintain a specified level of accuracy for models with rapidly changing or piecewise continuous states.

Continuous Versus Discrete Solvers

The Simulink product provides both continuous and discrete solvers.

Continuous solvers use numerical integration to compute a model's continuous states at the current time step based on the states at previous time steps and the state derivatives. Continuous solvers rely on the individual blocks to compute the values of the model's discrete states at each time step.

Mathematicians have developed a wide variety of numerical integration techniques for solving the ordinary differential equations (ODEs) that represent the continuous states of dynamic systems. An extensive set of fixed-step and variable-step continuous solvers are provided, each of which implements a specific ODE solution method (see "Choosing a Solver Type" on page 11-10).

Discrete solvers exist primarily to solve purely discrete models. They compute the next simulation time step for a model and nothing else. In performing these computations, they rely on each block in the model to update its individual discrete states. They do not compute continuous states.

Note You must use a continuous solver to solve a model that contains both continuous and discrete states. You cannot use a discrete solver because discrete solvers cannot handle continuous states. If, on the other hand, you select a continuous solver for a model with no states or discrete states only, Simulink software uses a discrete solver.

Two discrete solvers are provided: A fixed-step discrete solver and a variable-step discrete solver. The fixed-step solver by default chooses a step size and hence simulation rate fast enough to track state changes in the fastest block in your model. The variable-step solver adjusts the simulation step size to keep pace with the actual rate of discrete state changes in your model. This can avoid unnecessary steps and hence shorten simulation time for multirate models (see "Managing Sample Times in Systems" on page 4-22 for more information).

Minor Time Steps

Some continuous solvers subdivide the simulation time span into major and minor time steps, where a minor time step represents a subdivision of the major time step. The solver produces a result at each major time step. It uses results at the minor time steps to improve the accuracy of the result at the major time step.

Shape Preservation

Usually the integration step size is only related to the current step size and the current integration error. However, for signals whose derivative changes rapidly more accurate integration results can be obtained by including the derivative input information at each time step. This is done by activating the **Shapes Preservation** option in the Solver pane of the Configuration Parameter dialog.

Zero-Crossing Detection

A variable-step solver dynamically adjusts the time step size, causing it to increase when a variable is changing slowly and to decrease when the variable changes rapidly. This behavior causes the solver to take many small steps in

the vicinity of a discontinuity because the variable is rapidly changing in this region. This improves accuracy but can lead to excessive simulation times.

The Simulink software uses a technique known as *zero-crossing detection* to accurately locate a discontinuity without resorting to excessively small time steps. Usually this technique improves simulation run time, but it can cause some simulations to halt before the intended completion time.

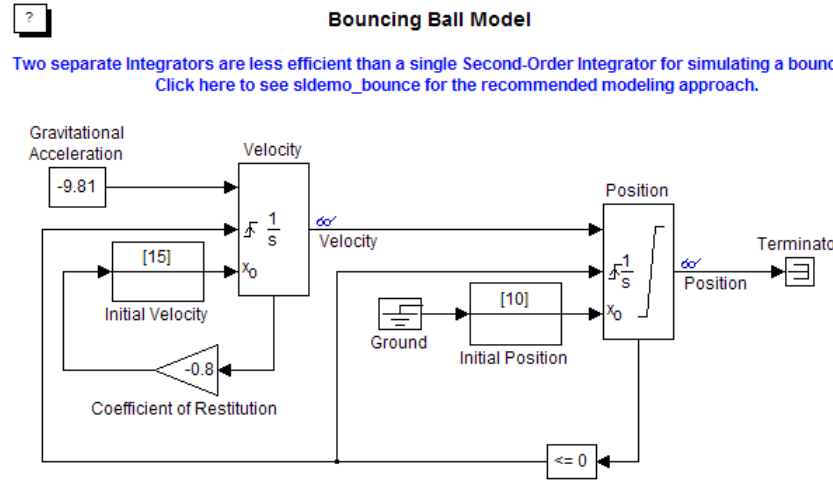
Two algorithms are provided in the Simulink software: Nonadaptive and Adaptive. For information about these techniques, see "Zero-Crossing Algorithms" on page 2-33.

Demonstrating Effects of Excessive Zero-Crossing Detection

The Simulink software comes with three demos that illustrate zero-crossing behavior: `sldemo_bounce_two_integrators`, `sldemo_doublebounce`, and `sldemo_bounce`.

- The `sldemo_bounce_two_integrators` demo demonstrates how excessive zero crossings can cause a simulation to halt before the intended completion time unless you use the adaptive algorithm.
- The `sldemo_bounce` demo uses a better model design than `sldemo_bounce_two_integrators`.
- The `sldemo_doublebounce` demo demonstrates how the adaptive algorithm successfully solves a complex system with two distinct zero-crossing requirements.

The Bounce Demo with Two Integrators.



1 At the MATLAB command prompt, type `sldemo_bounce_two_integrators` to load the demo.

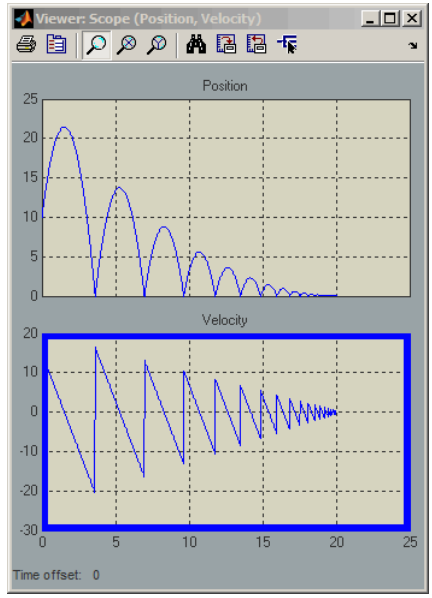
2 Once the block diagram appears, navigate to the Configuration Parameters dialog box. Confirm that the **Algorithm** parameter is set to `Nonadaptive`.

3 Set the **Stop time** to 20 s.

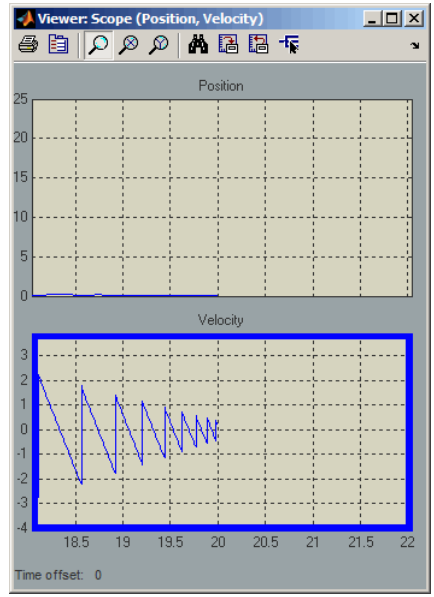
4 Run the model by clicking the **Start simulation** button.

5 After the simulation completes, click the scope window to see the results.

You may need to click on **Autoscale** to view the results in their entirety.



6 Use the scope zoom controls to closely examine the last portion of the simulation. You can see that the velocity is hovering just above zero at the last time point.



7 Change the simulation **Stop time** to 25 seconds, and run the simulation again.

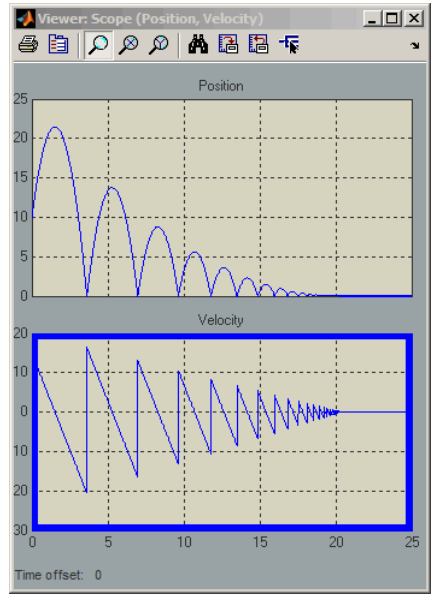
8 This time the simulation halts with an error shortly after it passes the simulated 20 second time point.

Excessive chattering as the ball repeatedly approaches zero velocity has caused the simulation to exceed the default limit of 1000 for the number of consecutive zero crossings allowed. Although this limit can be increased by adjusting the **Number of consecutive zero crossings parameter** in the Configuration Parameters dialog box, doing so in this case does not allow the simulation to simulate for 25 seconds.

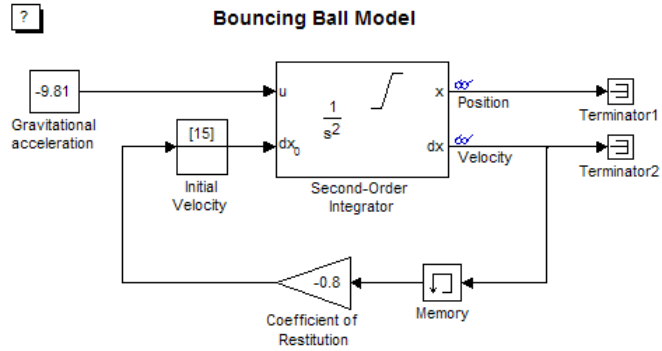
9 Navigate to the Configuration Parameters dialog box. From the **Algorithm** pull down menu, select the **Adaptive** algorithm.

10 Run the simulation again.

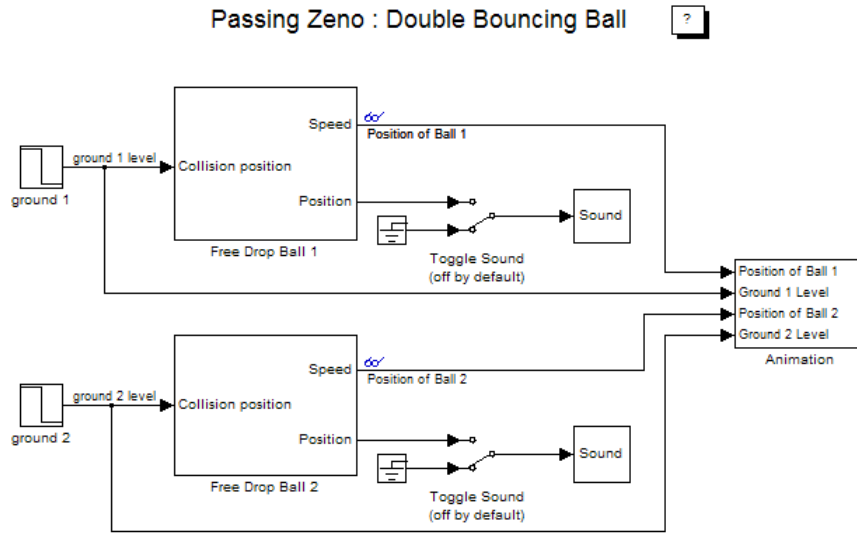
11 This time the simulation runs to completion because the adaptive algorithm prevented an excessive number of zero crossings from occurring.



Bounce Demo with a Second-Order Integrator.



The Double-Bounce Demo.



1 At the MATLAB command prompt, type `sldemo_doublebounce` to load the demo. The model and an animation window open. In the animation window, two balls are resting on two platforms.

2 In the animation window, click the **Nonadaptive** button to run the demo using the nonadaptive algorithm. This is the default setting used by the Simulink software for all models.

3 The ball on the right is given a larger initial velocity and has Consequently, the two balls hit the ground and recoil at different times.

4 The simulation halts after 14 seconds because the ball on the left exceeded the number of zero crossings limit. The ball on the right is left hanging in mid air.

5 An error message dialog opens. Click **OK** to close it.

6 Click on the **Adaptive** button to run the simulation with the adaptive algorithm.

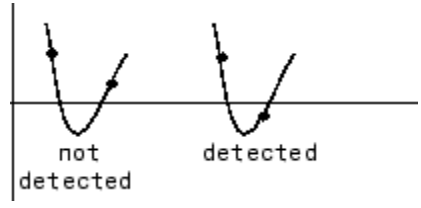
7 Notice that this time the simulation runs to completion, even after the ground shifts out from underneath the ball on the left at 20 seconds.

How the Simulator Can Miss Zero-Crossing Events

The bounce and double-bounce demos show that high-frequency fluctuations about a discontinuity ('chattering') can cause a simulation to prematurely halt.

It is also possible for the solver to entirely miss zero crossings if the solver error tolerances are too large. This is possible because the zero-crossing detection technique checks to see if the value of a signal has changed sign after a major time step. A sign change indicates that a zero crossing has occurred, and the zero-crossing algorithm will then hunt for the precise crossing time. However, if a zero crossing occurs within a time step, but the values at the beginning and end of the step do not indicate a sign change, the solver steps over the crossing without detecting it.

The following figure shows a signal that crosses zero. In the first instance, the integrator steps over the event because the sign has not changed between time steps. In the second, the solver detects change in sign and so detects the zero-crossing event.



Preventing Excessive Zero Crossings

Use the following table to prevent excessive zero-crossing errors in your model.

Make this change...	How to make this change...	Rational for making this change...
Increase the number of allowed zero crossings	Increase the value of the **Number of consecutive zero crossings**. option on the **Solver** pane in the Configuration Parameters dialog box.	This may give your model enough time to resolve the zero crossing.
Relax the **Signal threshold**	Select **Adaptive** from the **Algorithm** pull down and increase the value of the **Signal threshold** option on the **Solver** pane in the Configuration Parameters dialog box.	The solver requires less time to precisely locate the zero crossing. This can reduce simulation time and eliminate an excessive number of consecutive zero-crossing errors. However, relaxing the **Signal threshold** may reduce accuracy.
Use the **Adaptive** Algorithm	Select **Adaptive** from the **Algorithm** pull down on the **Solver** pane in the Configuration Parameters dialog box.	This algorithm dynamically adjusts the zero-crossing threshold, which improves accuracy and reduces the number of consecutive zero crossings detected. With this algorithm you have the option of specifying both the **Time tolerance** and the **Signal threshold**.

Make this change...	How to make this change...	Rational for making this change...
Disable zero-crossing detection for a specific block	1 Clear the **Enable zero-crossing detection** check box on the block's parameter dialog box. 2 Select `Use local settings` from the **Zero-crossing control** pull down on the **Solver** pane of the Configuration Parameters dialog box.	Locally disabling zero-crossing detection prevents a specific block from stopping the simulation because of excessive consecutive zero crossings. All other blocks continue to benefit from the increased accuracy that zero-crossing detection provides.
Disable zero-crossing detection for the entire model	Select `Disable all` from the **Zero-crossing control** pull down on the **Solver** pane of the Configuration Parameters dialog box.	This prevents zero crossings from being detected anywhere in your model. A consequence is that your model no longer benefits from the increased accuracy that zero-crossing detection provides.
If using the `ode15s` solver, consider adjusting the order of the numerical differentiation formulas	Select a value from the `Maximum order` pull down on the **Solver** pane of the Configuration Parameters dialog box.	For more information, see "Maximum order".
Reduce the maximum step size	Enter a value for the `Max step size` option on the **Solver** pane of the Configuration Parameters dialog box.	This can insure the solver takes steps small enough to resolve the zero crossing. However, reducing the step size can increase simulation time, and

Make this change...	How to make this change...	Rational for making this change...
		is seldom necessary when using the Adaptive algorithm.

Zero-Crossing Algorithms

The Simulink software includes two zero-crossing detection algorithms: Nonadaptive and Adaptive.

To choose the algorithm, either use the **Algorithm** option in the Solver pane of the Configuration Parameter dialog box, or use the `ZeroCrossAlgorithm` command. The command can either be set to `'Nonadaptive'` or `'Adaptive'`.

The Nonadaptive algorithm is provided for backwards compatibility with older versions of Simulink and is the default. It brackets the zero-crossing event and uses increasingly smaller time steps to pinpoint when the zero crossing has occurred. Although adequate for many types of simulations, the Nonadaptive algorithm can result in very long simulation times when a high degree of 'chattering' (high frequency oscillation around the zero-crossing point) is present.

The Adaptive algorithm dynamically turns the bracketing on and off, and is a good choice when:

- The system contains a large amount of chattering.
- You wish to specify a guard band (tolerance) around which the zero crossing is detected.

The Adaptive algorithm turns off zero-crossing bracketing (stops iterating) if either of the following are satisfied:

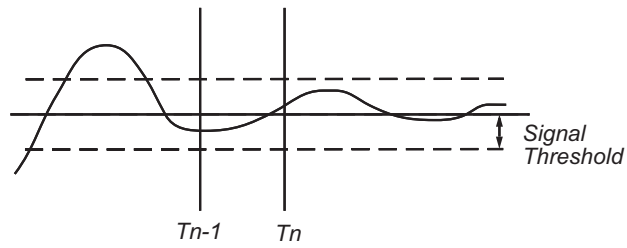
- The zero crossing error is exceeded. This is determined by the value specified in the **Signal threshold** option in the Solver pane of the Configuration Parameters dialog box. This can also be set with the `ZCThreshold` command. The default is `Auto`, but you can enter any real number greater than zero for the tolerance.

- The system has exceeded the number of consecutive zero crossings specified in the **Number of consecutive zero crossings** option in the Solver pane of the Configuration Parameters dialog box. Alternatively, this can be set with the `MaxConsecutiveZCs` command.

Understanding Signal Threshold

The Adaptive algorithm automatically sets a tolerance for zero-crossing detection. Alternatively, you can set the tolerance by entering a real number greater than or equal to zero in the Configuration Parameters Solver pane, `Signal threshold` pull down. This option only becomes active when the zero-crossing algorithm is set to `Adaptive`.

This graphic shows how the Signal threshold sets a window region around the zero-crossing point. Signals falling within this window are considered as being at zero.



The zero-crossing event is bracketed by time steps T_{n-1} and T_n. The solver iteratively reduces the time steps until the state variable lies within the band defined by the signal threshold, or until the number of consecutive zero crossings equals or exceeds the value in the Configuration Parameters Solver pane, `Number of consecutive zero crossings` pull down.

It is evident from the figure that increasing the signal threshold increases the distance between the time steps which will be executed. This often results in faster simulation times, but might reduce accuracy.

How Blocks Work with Zero-Crossing Detection

A block can register a set of zero-crossing variables, each of which is a function of a state variable that can have a discontinuity. The zero-crossing function passes through zero from a positive or negative value when the corresponding discontinuity occurs. The registered zero-crossing variables are updated at the end of each simulation step, and any variable that has changed sign is identified as having had a zero-crossing event.

If any zero crossings are detected, the Simulink software interpolates between the previous and current values of each variable that changed sign to estimate the times of the zero crossings (that is, the discontinuities).

Blocks That Register Zero Crossings. The following table lists blocks that register zero crossings and explains how the blocks use the zero crossings:

Block	Description of Zero Crossing
Abs	One: to detect when the input signal crosses zero in either the rising or falling direction.
Backlash	Two: one to detect when the upper threshold is engaged, and one to detect when the lower threshold is engaged.
Compare To Constant	One: to detect when the signal equals a constant.
Compare To Zero	One: to detect when the signal equals zero.
Dead Zone	Two: one to detect when the dead zone is entered (the input signal minus the lower limit), and one to detect when the dead zone is exited (the input signal minus the upper limit).
Enable	One: If an Enable port is inside of a Subsystem block, it provides the capability to detect zero crossings. See the Enable Subsystem block for details “Enabled Subsystems” on page 6-4.
From Workspace	One: to detect when the input signal has a discontinuity in either the rising or falling direction
If	One: to detect when the If condition is met.

Block	Description of Zero Crossing
Integrator	If the reset port is present, to detect when a reset occurs. If the output is limited, there are three zero crossings: one to detect when the upper saturation limit is reached, one to detect when the lower saturation limit is reached, and one to detect when saturation is left.
MinMax	One: for each element of the output vector, to detect when an input signal is the new minimum or maximum.
Relational Operator	One: to detect when the specified relation is true.
Relay	One: if the relay is off, to detect the switch-on point. If the relay is on, to detect the switch-off point.
Saturation	Two: one to detect when the upper limit is reached or left, and one to detect when the lower limit is reached or left.
Second-Order Integrator	Five: two to detect when the state x upper or lower limit is reached; two to detect when the state dx/dt upper or lower limit is reached; and one to detect when a state leaves saturation.
Sign	One: to detect when the input crosses through zero.
Signal Builder	One: to detect when the input signal has a discontinuity in either the rising or falling direction
Step	One: to detect the step time.
Switch	One: to detect when the switch condition occurs.
Switch Case	One: to detect when the case condition is met.

Block	Description of Zero Crossing
Trigger	One: If a Triggered port is inside of a Subsystem block, it provides the capability to detect zero crossings. See the Triggered Subsystem block for details: "Triggered Subsystems" on page 6-14.
Enabled and Triggered Subsystem	Two: one for the enable port and one for the trigger port. See the Triggered and Enabled Subsystem block for details: "Triggered and Enabled Subsystems" on page 6-18

Note Zero-crossing detection is also available for a Stateflow® chart that uses continuous-time mode. See "Configuring a Stateflow Chart to Update in Continuous-Time" in the Stateflow documentation for more information.

Implementation Example: Saturation Block. An example of a Simulink block that registers zero crossings is the Saturation block. Zero-crossing detection identifies these state events in the Saturation block:

- The input signal reaches the upper limit.
- The input signal leaves the upper limit.
- The input signal reaches the lower limit.
- The input signal leaves the lower limit.

Simulink blocks that define their own state events are considered to have *intrinsic zero crossings*. Use the Hit Crossing block to receive explicit notification of a zero-crossing event. See "Blocks That Register Zero Crossings" on page 2-35 for a list of blocks that incorporate zero crossings.

The detection of a state event depends on the construction of an internal zero-crossing signal. This signal is not accessible by the block diagram. For the Saturation block, the signal that is used to detect zero crossings for the upper limit is `zcSignal = UpperLimit - u`, where `u` is the input signal.

Zero-crossing signals have a direction attribute, which can have these values:

- *rising* — A zero crossing occurs when a signal rises to or through zero, or when a signal leaves zero and becomes positive.
- *falling* — A zero crossing occurs when a signal falls to or through zero, or when a signal leaves zero and becomes negative.
- *either* — A zero crossing occurs if either a rising or falling condition occurs.

For the Saturation block's upper limit, the direction of the zero crossing is *either*. This enables the entering and leaving saturation events to be detected using the same zero-crossing signal.

Algebraic Loops

What Is an Algebraic Loop?

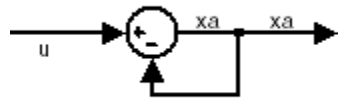
Algebraic Loops in Simulink. An *algebraic loop* in a Simulink model occurs when an input port depends on the output. Typically, algebraic loops occur by direct feedthrough, within the block or through a feedback path through other blocks with direct feedthrough.

Some Simulink blocks have input ports with *direct feedthrough*. These blocks can cause algebraic loops in your model. The software cannot compute the output of these blocks without knowing the values of the signals entering the blocks at these input ports. Some examples of blocks with direct feedthrough inputs are as follows:

- Math Function block
- Gain block
- Integrator block, when the initial condition port depends on the block output
- Product block
- State-Space block, when the D matrix coefficient is nonzero
- Sum block

- Transfer Fcn block, when the numerator and denominator are of the same order
- Zero-Pole block, when the block has as many zeros as poles

An example of an algebraic loop is the following simple scalar loop.



Mathematically, this loop implies that the output of the Sum block is an algebraic state x_a that is constrained to equal the first input u minus x_a (for example, $x_a = u - x_a$). The solution of this simple loop is $x_a = u/2$.

Mathematical Definition of an Algebraic Loop. Simulink contains a suite of numerical solvers for simulating *ordinary differential equations (ODEs)*, which are systems of equations that you can write as:

$$\dot{x} = f(x,t),$$

where x is the state vector and t is the independent time variable.

Some systems of equations contain additional constraints that involve the independent variable and the state vector, but not the derivative. Such systems are *differential algebraic equations (DAEs)*, not ODEs.

The term *algebraic* refers to equations that do not involve any derivatives. You can usually express DAEs that arise in engineering in a semi-explicit form, as follows:

$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}, \mathbf{x_a}, t)$$
$$0 = \mathbf{g}(\mathbf{x}, \mathbf{x_a}, t),$$

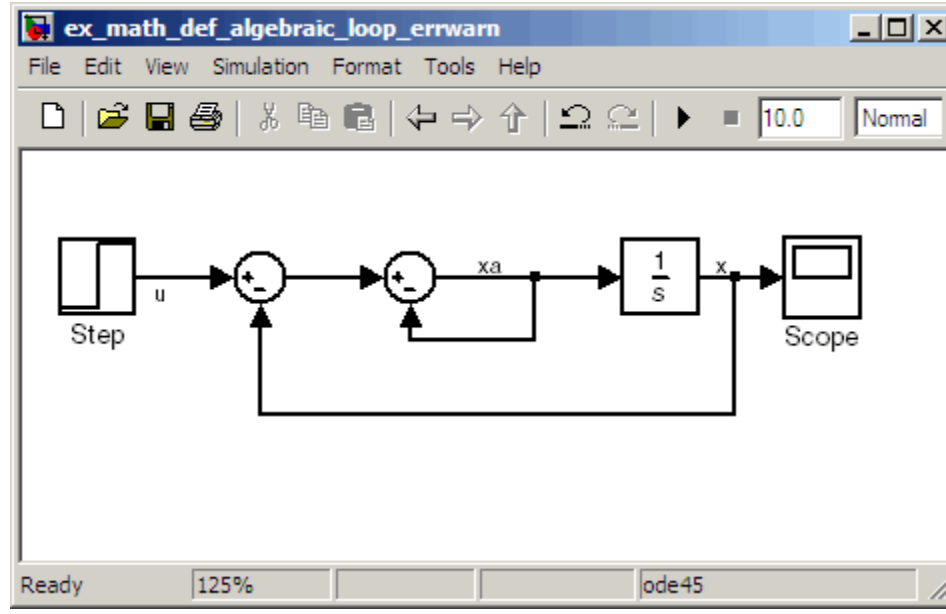
where:

- **f** and **g** can be vector functions.
- The first equation is the differential equation.
- The second equation is the algebraic equation
- The vector of differential variables is **x**.
- The vector of algebraic variables is $\mathbf{x}_a$.

In Simulink models, algebraic loops are algebraic constraints. Models with algebraic loops define a system of differential algebraic equations. Simulink does not solve DAEs directly; Simulink solves the algebraic equations (the algebraic loop) numerically for x_a at each step of the ODE solver.

The following Simulink model is equivalent to this system of equations in semi-explicit form:

$$\dot{x} = f(x, x_a, t) = x_a$$
$$0 = g(x, x_a, t) = -x + u - 2x_a.$$



At each step of the ODE solver, the algebraic loop solver must solve the algebraic constraint for x_a before calculating the derivative $\dot{x}$.

Physical Meaning of Algebraic Loops. Algebraic constraints occur when modeling physical systems, often due to the conservation laws of mass and energy. You can also use algebraic constraints to impose design constraints on system responses in a dynamic system.

Choosing a particular coordinate system for a model can also result in an algebraic constraint. In most cases, you can eliminate algebraic loops, as described in "Removing Algebraic Loops" on page 2-48, to produce an ordinary differential equation (ODE). However, this technique is not always practical.

Identifying Algebraic Loops in Your Model

You can highlight algebraic loops when you update, simulate, or debug a model:

- "Algebraic Loop Diagnostic" on page 2-42
- "Highlighting Algebraic Loops Using the Algebraic Loop Diagnostic" on page 2-43
- "Highlighting Algebraic Loops with the ashow Debugger Command" on page 2-44

Algebraic Loop Diagnostic. Simulink detects algebraic loops during simulation initialization, for example, when you update your diagram. You set the **Algebraic loop** diagnostic to report an error or warning if the software detects any algebraic loops in your model.

In the Configuration Parameters dialog box, on the **Diagnostics** pane, set the **Algebraic loop** parameter as follows.

Setting	Simulation Response
`none`	Tries to solve the algebraic loop; reports an error only if it cannot solve the algebraic loop.
`warning`	Algebraic loops result in warnings; tries to solve the algebraic loop; reports an error only if it cannot solve the algebraic loop.
`error`	Algebraic loops stop the initialization.

Note For more information about the **Algebraic loop** parameter, see "Algebraic loop".

Highlighting Algebraic Loops Using the Algebraic Loop Diagnostic. When updating or simulating a model, you can highlight algebraic loops in the Model Editor, as the following example shows:

1. Open the `sldemo_hydcyl` demo model:

   ```
   sldemo_hydcyl
   ```

2. Open the Configuration Parameters dialog box by selecting **Simulation > Configuration Parameters**.

3. On the **Diagnostics** pane, set the **Algebraic loop** parameter to `error`.

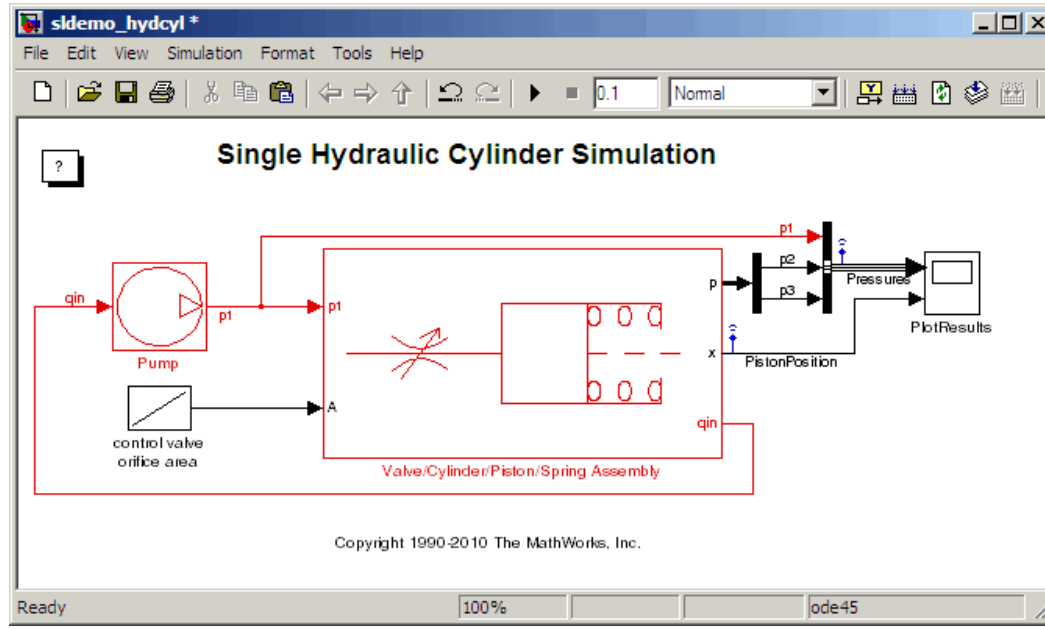
   This setting specifies that the Simulink software stop the simulation and report an error if it finds an algebraic loop in the model.

4. Click **OK** to save the setting.

5. Click the **Start simulation** button.

   The simulation stops during initialization when Simulink detects an algebraic loop. The Diagnostics Viewer displays an error message and lists all the blocks in the model that are part of that algebraic loop.

   In the Model Editor, the software highlights the blocks and signals that constitute the loop in red.



6 To restore the diagram to its original colors, close the Diagnostics Viewer.

7 Close the `sldemo_hydcyl` model without saving the changes.

In the next section, the `ashow` debugger command shows that this model actually has two algebraic loops.

Highlighting Algebraic Loops with the ashow Debugger Command.

When debugging your model, use the `ashow` command to highlight algebraic loops, as in this example:

1 Open the `sldemo_hydcyl` demo model.

By default, the **Algebraic loop** parameter for this model is set to `none`.

2 In the Model Editor, select **Tools > Simulink Debugger** to start the Simulink debugger.

3 Click the **Start/Continue** button to start the debugger.

4 In the MATLAB Command Window, type:

```
ashow
```

The software lists the two algebraic loops in the `sldemo_hydcyl` model and the number of blocks in each loop.

```
Found 2 Algebraic loop(s):
System number#Algebraic loop id, number of blocks in loop
- 0#1, 9 blocks in loop
- 0#2, 4 blocks in loop
```

5 To list the blocks in the first algebraic loop, enter the following command at the debugger prompt:

```
ashow 0#1
```

The software opens the Control Valve Flow subsystem in the Valve/Cylinder/Piston/Spring Assembly subsystem, highlights that algebraic loop in the model, and lists the nine blocks in the algebraic loop:

```
- hydcyl/Valve//Cylinder//Piston//Spring Assembly/Control Valve Flow/IC
- hydcyl/Valve//Cylinder//Piston//Spring Assembly/Control Valve Flow/signed sqrt
- hydcyl/Valve//Cylinder//Piston//Spring Assembly/Control Valve Flow/Product
- hydcyl/Valve//Cylinder//Piston//Spring Assembly/laminar flow pressure drop
- hydcyl/Valve//Cylinder//Piston//Spring Assembly/Sum7
- hydcyl/Pump/IC
- hydcyl/Valve//Cylinder//Piston//Spring Assembly/Control Valve Flow/Sum1 (algebraic variable)
- hydcyl/Pump/Sum1
- hydcyl/Pump/leakage (algebraic variable)
```

6 In the Simulink Debugger window, click **Close**.

7 In the MATLAB Command Window, press **Enter** to restore the default MATLAB command prompt.

Simulink Algebraic Loop Solver

- "How the Algebraic Loop Solver Works" on page 2-46

How the Algebraic Loop Solver Works. When a model contains an algebraic loop, the Simulink software uses a nonlinear solver at each time step to solve the algebraic loop. The solver performs iterations to determine the solution to the algebraic constraint (if possible). As a result, models with algebraic loops can run slower than models without algebraic loops.

For the loop solver to work, it needs one block where the loop solver can break the loop and attempt to solve the loop. The loop solver works only with real double signals. In addition, the loop solver assumes that the algebraic loop function is smoothly changing. (The solver uses a gradient-based search method.)

For example, suppose your model has a Sum block with two inputs (one additive, the other subtractive). If you feed the output of the Sum block to one of the inputs, you create an algebraic loop where all of the blocks include direct feedthrough.

The Sum block computes its output, but the block cannot compute the output without knowing the input. Simulink detects the algebraic loop and solves the loop using an iterative loop. The software computes the correct result in the Sum block example as follows:

$x_a(t) = u(t) / 2.$

Trust-Region and Line-Search Algorithms in the Algebraic Loop Solver. The Simulink algebraic loop solver uses one of two algorithms to solve algebraic loops: trust region and line search. By default, the algebraic loop solver uses the trust-region algorithm.

If the algebraic loop solver cannot solve the algebraic loop, try simulating the model using the other algorithm.

To switch to the trust-region algorithm, at the MATLAB command line, enter:

```
set_param(model_name, 'AlgebraicLoopSolver', 'TrustRegion');
```

For more information about trust-region optimization algorithms, see "Trust-Region Methods for Nonlinear Minimization" in the Optimization Toolbox™ documentation.

To switch to the line-search algorithm, at the MATLAB command line, enter:

```
set_param(model_name, 'AlgebraicLoopSolver', 'LineSearch');
```

For more information about line-search optimization algorithms, see "Line Search" in the Optimization Toolbox documentation.

Limitations of the Algebraic Loop Solver. Algebraic loop solving is an iterative process. The Simulink algebraic loop solver can be successful only if the algebraic loop converges to a definite answer. When the loop fails to converge, or converges too slowly, the simulation exits with an error.

The algebraic loop solver cannot solve algebraic loops that contain any of the following:

- Blocks with discrete-valued outputs
- Blocks with nondouble or complex outputs
- Stateflow charts
- Nonvirtual subsystems

Problems Caused by Algebraic Loops

If your model contains an algebraic loop, you might encounter one or more of the following problems:

- You cannot generate code for a model with algebraic loops.
- The Simulink algebraic loop solver cannot solve the algebraic loop.
- The simulation executes slowly while Simulink is trying to solve the algebraic loop.

  For most models, the algebraic loop solver is computationally expensive for the first time step. Simulink solves subsequent time steps rapidly because a good starting point for x_a is available from the previous time step.

Removing Algebraic Loops

When Not to Remove Algebraic Loops. If you can simulate a model that contains an algebraic loop, you do not need to remove the loop. However, removing algebraic loops can improve the performance of your model.

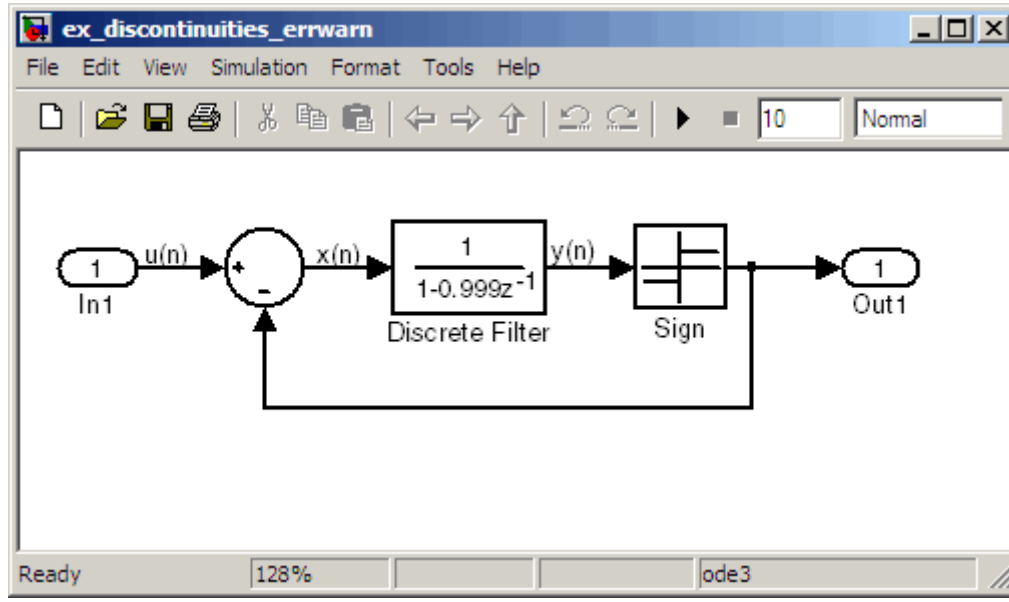
When to Remove Algebraic Loops. If the Simulink software cannot solve the algebraic loop, the software reports an error. If the Simulink algebraic loop solver cannot solve the algebraic loop, there are techniques that you can use to solve the loop manually. The following sections describe some of these techniques.

Creating Initial Guesses Using the IC and Algebraic Constraint Blocks. Your model might contain loops for which the loop solver cannot converge without a good initial guess for the algebraic states. You can specify an initial guess for the algebraic state variables by placing an IC block (normally used to specify an initial condition for a signal) in the algebraic loop.

Another way to specify an initial guess for a signal in an algebraic loop is to use an Algebraic Constraint block.

Avoiding Discontinuities. If your model has discontinuities within an algebraic loop, the algebraic loop solver might not be able to solve it.

For example, the following model attempts to model a leaky integrator using the Discrete Filter block.



The Discrete Filter block defines the difference equation

$$y(n) = x(n) + 0.999y(n - 1),$$

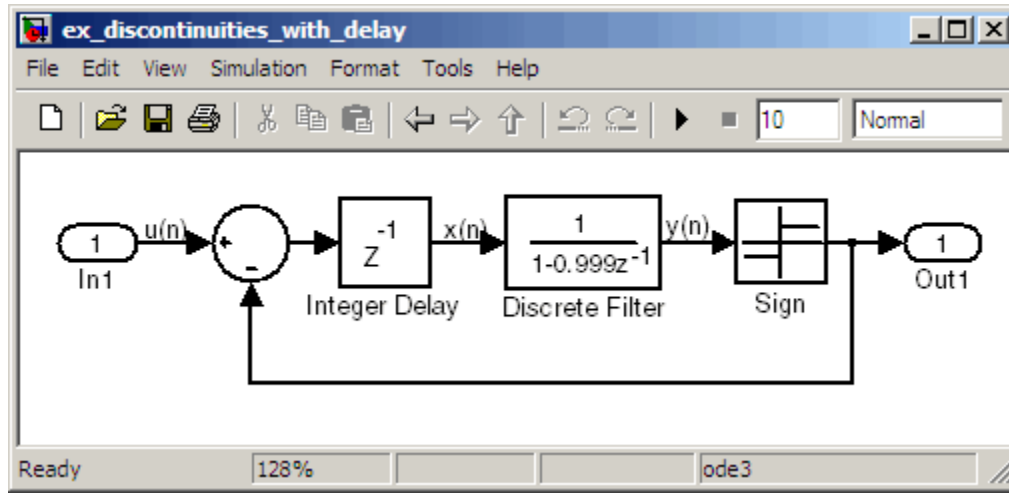
where x represents the input to the Discrete Filter block and y represents the output from the Discrete Filter block. At each time step, the integrator leaks values from the previous iteration. The output of the filter $y(n)$ depends directly on the current time step $x(n)$. The Discrete Filter block has direct feedthrough, which in turn causes the algebraic loop.

If you simulate this model, you see an error message that the algebraic loop solver cannot solve this algebraic loop. The Sign block introduces the discontinuity because it outputs three distinct values (–1, 0, 1). As a result of this discontinuity, the algebraic constraint cannot be differentiated, and the gradient-based algebraic loop solver cannot solve the algebraic constraint.

One way to eliminate this algebraic loop is to add an Integer Delay block with a one-step delay. Adding this block results in an equivalent difference equation that is not direct feedthrough:

$y(n) = x(n– 1) + 0.999y(n – 1)$.

The output $y(n)$ now depends only on input values from the previous time step $x(n – 1)$.



Modifying Direct-Feedthrough Blocks. Some models bundle signals together. This bundling might cause Simulink to detect an algebraic loop, even when one does not exist. If you redirect one or more signals, you remove the algebraic loop.

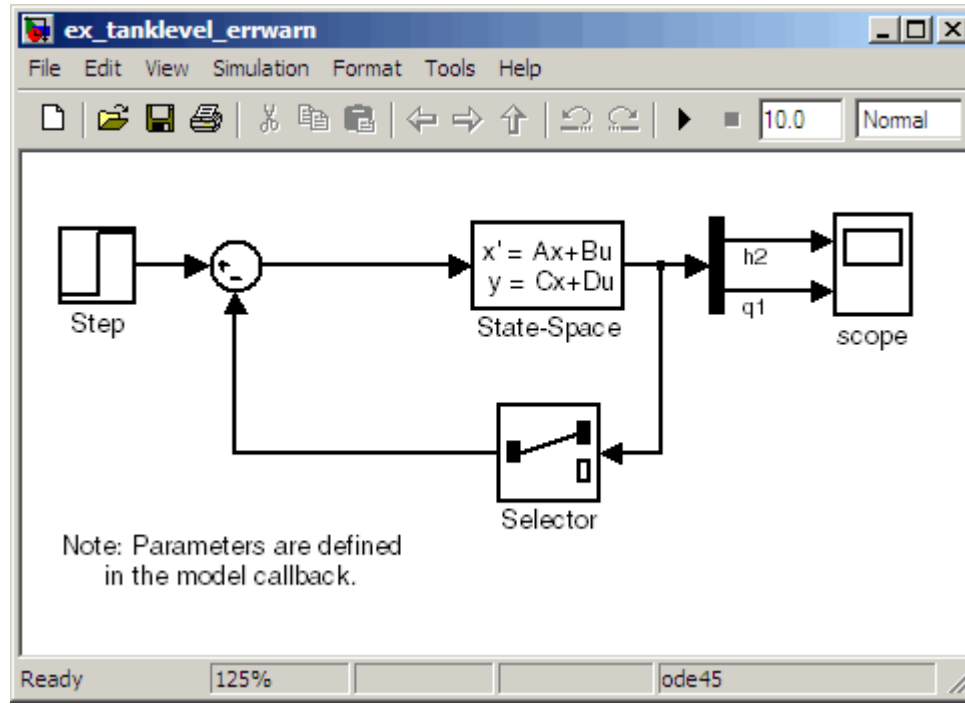
The following linearized model simulates the dynamics of a two-tank system fed by a single pump. In this model:

- Input `q1` is the rate of the fluid flow into the tank from the pump.
- Input `h2` is the height of the fluid in the second tank.
- The State-Space block defines the dynamic response of the tank system to the pump operation:
  - `A: [-c1 0; c1 -c2]`

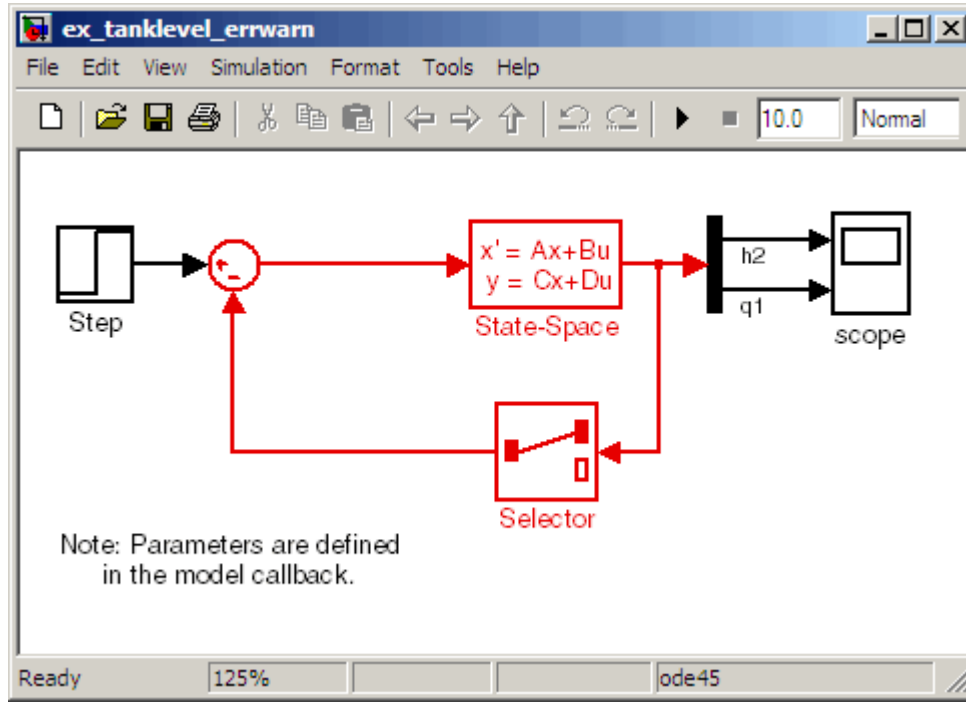
    `c1` and `c2` are flow coefficients. The model callback defines the values for `c1` and `c2`.
  - `B: [1 0]'`

- C: `[0 1; 0 0]`
- D: `[0 1]'`

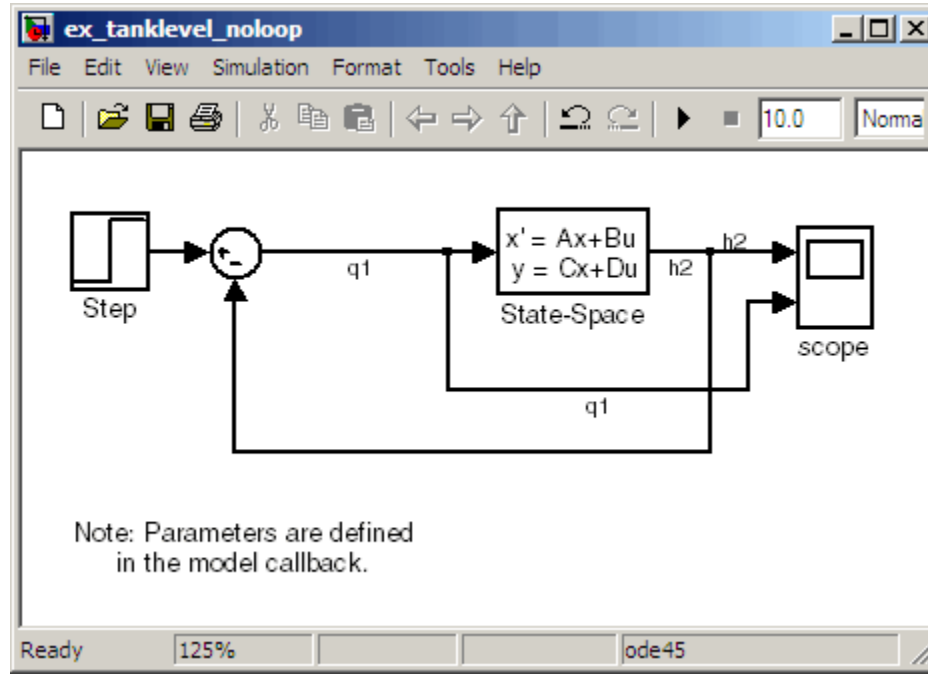
- The output from the State-Space block is a vector that contains `q1` and `h2`.



If you simulate this model with the **Algebraic loop** parameter set to `warn` or `error`, Simulink identifies the algebraic loop.



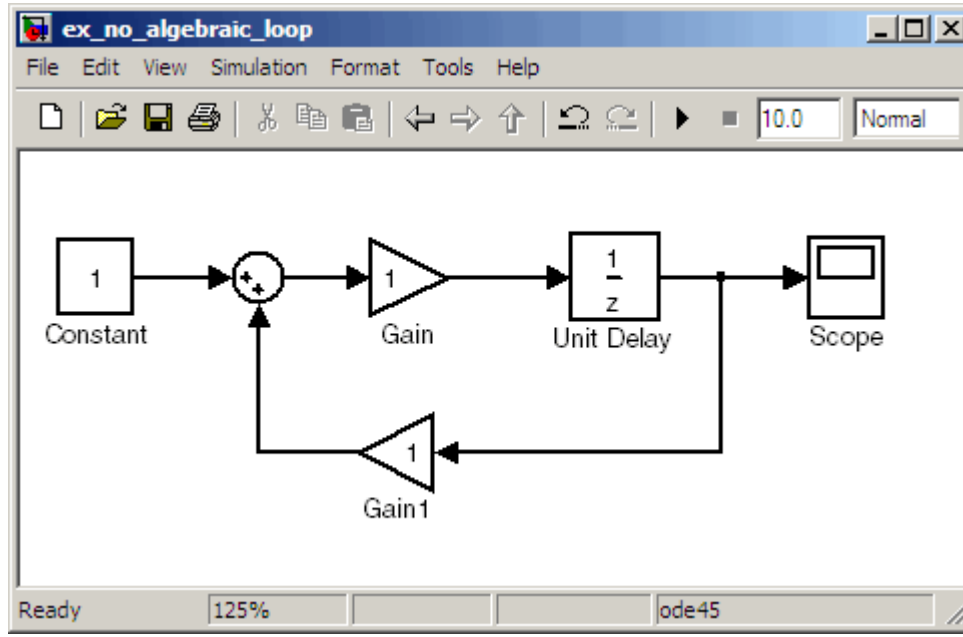
To eliminate this algebraic loop, pass `q1` directly to the scope instead of through the State-Space block. Now, the input (`q1`) does not pass directly to the output (the `D` matrix is 0), so the State-Space block no longer has direct feedthrough. You are now passing a one-element signal to the Selector block, so the Selector block is no longer necessary.



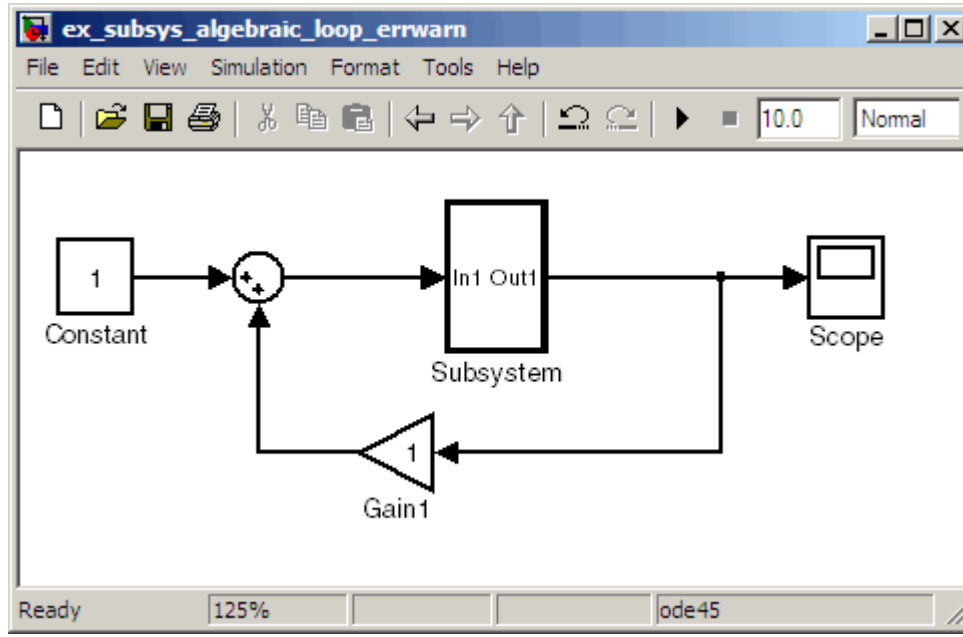
Artificial Algebraic Loops

Definition of an Artificial Algebraic Loop. An *artificial algebraic loop* occurs when an atomic subsystem mimics the behavior of an algebraic loop, even though the contents of the subsystem do not function as an algebraic loop.

For example, the following model does not initially contain an algebraic loop. The model simulates without error.



However, suppose you enclose the Gain and Unit Delay blocks in a subsystem and make the subsystem atomic, as shown.



The model now contains an artificial algebraic loop. The output of the Subsystem block passes through the Gain1 block that has direct feedthrough back to the Sum block.

If you set the **Algebraic loop** parameter to `error`, Simulink stops the simulation with an algebraic loop error.

Identifying Artificial Algebraic Loops. If Simulink reports that your model has an algebraic loop it cannot solve, check to see if you have an atomic subsystem that creates an artificial algebraic loop. You can replace the atomic subsystem with a virtual subsystem, which has no effect on the behavior of the model. If the simulation still fails with an algebraic loop, you have a real algebraic loop.

To convert an atomic subsystem to a virtual subsystem:

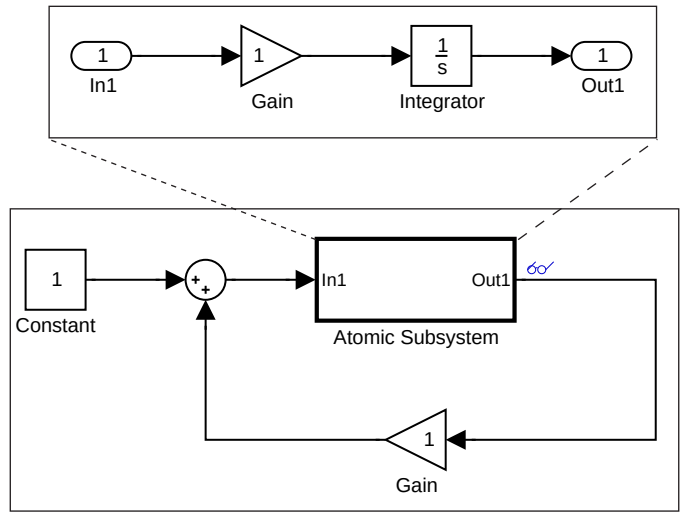
1. Open the model that contains the atomic subsystem.
2. Right-click the atomic subsystem and select **Subsystem Parameters**.

3 Clear the **Treat as atomic unit** parameter.

4 Click **OK** to save the changes and close the dialog box.

5 Save the model.

Eliminating Artificial Algebraic Loops Using Simulink. The following model shows how the Simulink software can remove an artificial algebraic loop. Simulating this model with the **Algebraic loop** parameter set to `error` reveals that the model contains an artificial algebraic loop involving its atomic subsystem.



To eliminate the algebraic loop from the compiled version of this model:

1 Right-click the atomic subsystem and select **Subsystem Parameters**.

2 Select the **Minimize algebraic loop occurrences** parameter.

3 Click **OK** to save the changes and close the Subsystem Parameters dialog box.

4 Simulate the model.

The model now simulates without error.

Simulink can eliminate the algebraic loop involving this atomic subsystem because the atomic subsystem contains a block that does not have direct feedthrough—the Integrator block.

If you remove the Integrator block from the atomic subsystem, the atomic subsystem contains blocks with direct feedthrough. Simulink cannot eliminate the algebraic loop.

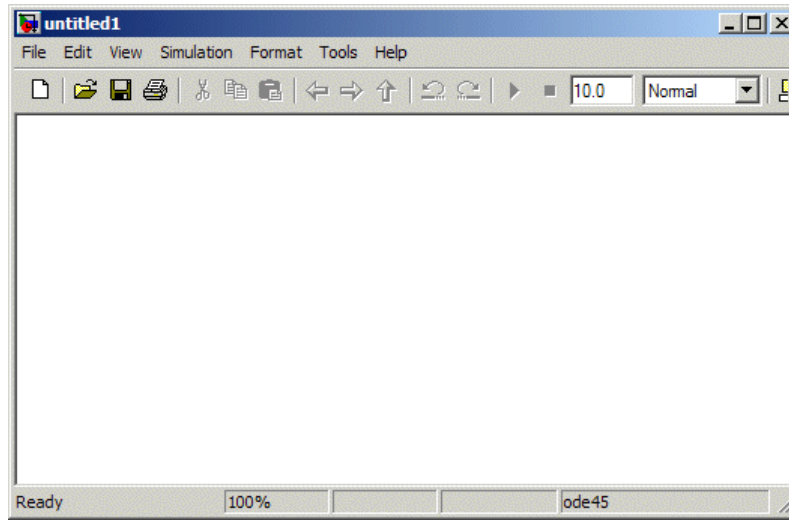
Modeling Dynamic Systems

3

Creating a Model

Creating an Empty Model

To create an empty model, click the **New** button on the Library Browser's toolbar, or choose **New** from the library window's **File** menu and select **Model**. An empty model is created in memory and it is displayed in a new model editor window.



Creating a Model Template

When you create a model, Simulink uses defaults for many configuration parameters. For example, by default new models have a white canvas, the `ode45` solver, and a visible toolbar. If these or other defaults do not meet your needs, you can use the Simulink software model construction commands described in "Model Construction" to write a function that creates a model with the defaults you prefer. For example, the following function creates a model that has a green canvas and a hidden toolbar, and uses the `ode3` solver:

```
function new_model(modelname)
% NEW_MODEL Create a new, empty Simulink model
%    NEW_MODEL('MODELNAME') creates a new model with
%    the name 'MODELNAME'. Without the 'MODELNAME'
%    argument, the new model is named 'my_untitled'.
```

```
if nargin == 0
     modelname = 'my_untitled';
end

% create and open the model
open_system(new_system(modelname));

% set default screen color
set_param(modelname, 'ScreenColor', 'green');

% set default solver
set_param(modelname, 'Solver', 'ode3');

% set default toolbar visibility
set_param(modelname, 'Toolbar', 'off');

% save the model
save_system(modelname);
```

Populating a Model

In this section...

About the Library Browser

Simulink provides the Simulink Library Browser, which you can use to browse, search, and clone blocks from built-in and user libraries to your model. This section summarizes the techniques for using the Library Browser. For additional details, see "Library Browser". For information about creating your own libraries and adding them to the Library Browser, see Chapter 23, "Working with Block Libraries".

Opening the Library Browser

To open the Simulink Library Browser, do one of the following:

- Click the **Library Browser** button  in the toolbar of the MATLAB Desktop or a Simulink Model Editor window
- In the MATLAB Command Window, enter:

```
simulink
```

If you have not already loaded Simulink, a short delay occurs while it loads. The Library Browser opens.

To keep the Library Browser above all other windows on your desktop, select the **Pushpin** button on the browser's toolbar.

Browsing Block Libraries

The **Libraries** pane on the left shows displays a tree-structured folder of the block libraries installed on your system.. Initially the Simulink library is selected and its top level is open. You can scroll the pane and expand and collapse libraries and sublibraries to see what libraries are installed on your system and what blocks they contain.

The contents of the library selected in the **Libraries** pane appear in the **Library** tab to the right of the pane. The contents can be sublibraries, blocks, or a mixture of the two. Each member of the selected library is represented by an icon and a name. A library's icon suggests the purpose of the library. A block's library icon is the same as the block's icon when cloned into a model.

You can open a sublibrary by either selecting it in the **Libraries** pane or double-clicking it in the **Library** tab. To see a block's Block parameters dialog, double-click the block in the Library tab. To get Help for a block, right-click it and select Help from its context menu. The Help text, and the context menu itself, are the same that would appear if you right-clicked an instance of that block in a model.

Searching Block Libraries

To search for library blocks whose names contain a specified character string:

1. Enter the character string in the text field of the Library Browser's **Search** field.

2. Press `Return` or click the tool's **Search** button.

The browser searches all libraries for blocks whose names match the specified string and displays the results in the Library Browser's **Found** pane. The pane shows the blocks from each library separately.

By default, the search finds any substring and is not case-sensitive. You can change these defaults, or enable use of MATLAB regular expressions in the **Search** field, by clicking the **Library Browser Options** button and selecting appropriate commands. You can work with blocks found by **Search** just as you could with blocks found by selecting a library.

Cloning Blocks to Models

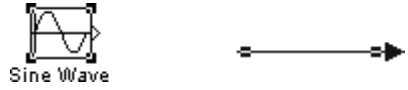
To copy a block from the Library Browser into a model, drag and drop the library block into the model window at the location where you want to create the copy. Simulink copies the block to the model at the point you selected. The resulting block retains a link to its library, so that updates to the source library automatically propagate to all copies. See Chapter 23, "Working with Block Libraries" for information about library links.

Selecting Objects

In this section...

Selecting an Object

To select an object, click it. Small black square handles appear at the corners of a selected block and near the end points of a selected line. For example, the figure below shows a selected Sine Wave block and a selected line.



When you select an object by clicking it, any other selected objects are deselected.

Selecting Multiple Objects

You can select more than one object either by selecting objects one at a time, by selecting objects located near each other using a bounding box, or by selecting the entire model.

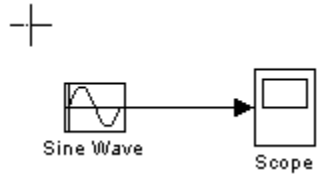
Selecting Multiple Objects One at a Time

To select more than one object by selecting each object individually, hold down the **Shift** key and click each object to be selected. To deselect a selected object, click the object again while holding down the **Shift** key.

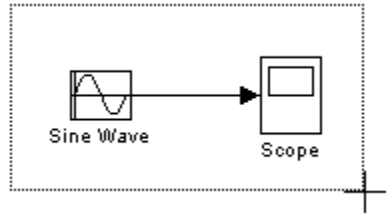
Selecting Multiple Objects Using a Bounding Box

An easy way to select more than one object in the same area of the window is to draw a bounding box around the objects:

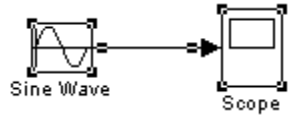
1. Define the starting corner of a bounding box by positioning the pointer at one corner of the box, then pressing and holding down the mouse button. Notice the shape of the cursor.



2 Drag the pointer to the opposite corner of the box. A dotted rectangle encloses the selected blocks and lines.



3 Release the mouse button. All blocks and lines at least partially enclosed by the bounding box are selected.



Selecting All Objects

To select all objects in the active window, select **Select All** from the **Edit** menu. You cannot create a subsystem by selecting blocks and lines in this way. For more information, see “Creating Subsystems” on page 3-37.

Specifying Block Diagram Colors

In this section...

How to Specify Block Diagram Colors

You can specify the foreground and background colors of any block or annotation in a diagram, as well as the diagram's background color. To set the background color of a block diagram, select **Screen color** from the **Format** menu. To set the background color of a block or annotation or group of such items, first select the item or items. Then select **Background color** from the **Format** menu. To set the foreground color of a block or annotation, first select the item. Then select **Foreground color** from the **Format** menu.

In all cases, a menu of color choices is displayed. Choose the desired color from the menu. If you select a color other than **Custom**, the background or foreground color of the diagram or diagram element is changed to the selected color.

Choosing a Custom Color

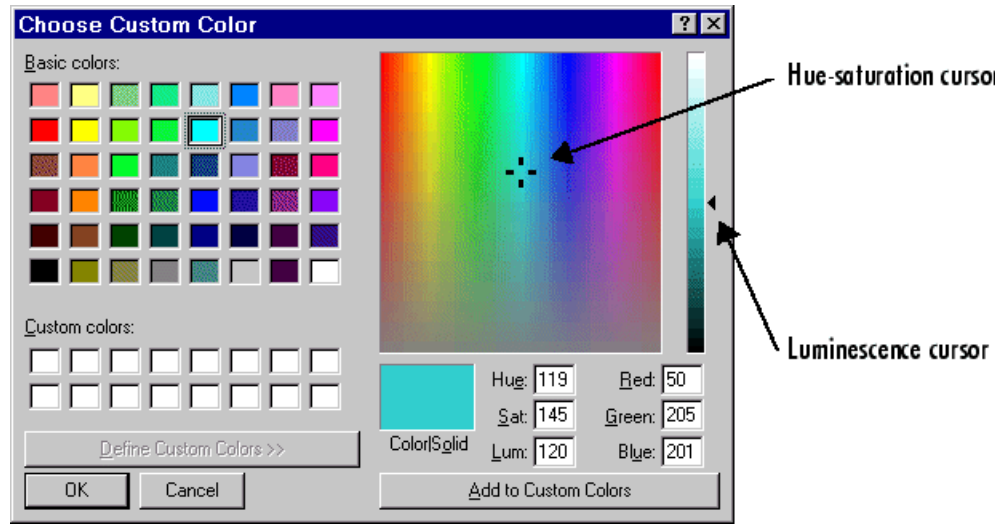
If you choose **Custom**, The Simulink Choose Custom Color dialog box is displayed.

The dialog box displays a palette of basic colors and a palette of custom colors that you previously defined. If you have not previously created any custom colors, the custom color palette is all white. To choose a color from either palette, click the color, and then click the **OK** button.

Defining a Custom Color

To define a custom color, click the **Define Custom Colors** button on the Choose Custom Color dialog box.

The dialog box expands to display a custom color definer.



The color definer allows you to specify a custom color by

- Entering the red, green, and blue components of the color as values between 0 (darkest) and 255 (brightest)
- Entering hue, saturation, and luminescence components of the color as values in the range 0 to 255
- Moving the hue-saturation cursor to select the hue and saturation of the desired color and the luminescence cursor to select the luminescence of the desired color

The color that you have defined in any of these ways appears in the **Color|Solid** box. To redefine a color in the **Custom colors** palette, select the color and define a new color, using the color definer. Then click the **Add to Custom Colors** button on the color definer.

Specifying Colors Programmatically

You can use the `set_param` command at the MATLAB command line or in a MATLAB program to set parameters that determine the background

color of a diagram and the background color and foreground color of diagram elements. The following table summarizes the parameters that control block diagram colors.

Parameter	Determines
`ScreenColor`	Background color of block diagram
`BackgroundColor`	Background color of blocks and annotations
`ForegroundColor`	Foreground color of blocks and annotations

You can set these parameters to any of the following values:

- `'black'`, `'white'`, `'red'`, `'green'`, `'blue'`, `'cyan'`, `'magenta'`, `'yellow'`, `'gray'`, `'lightBlue'`, `'orange'`, `'darkGreen'`
- `'[r,g,b]'`

  where `r`, `g`, and `b` are the red, green, and blue components of the color normalized to the range `0.0` to `1.0`.

For example, the following command sets the background color of the currently selected system or subsystem to a light green color:

```
set_param(gcs, 'ScreenColor', '[0.3, 0.9, 0.5]')
```

Displaying Sample Time Colors

The blocks and lines in your model can be color coded to indicate the sample rates at which the blocks operate.

Color	Use
Black	Continuous sample time
Magenta	Constant sample time
Red	Fastest discrete sample time
Green	Second fastest discrete sample time
Blue	Third fastest discrete sample time
Light Blue	Fourth fastest discrete sample time

Color	Use
Dark Green	Fifth fastest discrete sample time
Orange	Sixth, seventh, eighth, etc., fastest discrete sample time
Yellow	Indicates a block with hybrid sample time, e.g., subsystems grouping blocks and Mux or Demux blocks grouping signals with different sample times, Data Store Memory blocks updated and read by different tasks.
Cyan	Blocks in triggered subsystems
Brown	Variable sample time. See the Pulse Generator block and "How to Specify the Sample Time" on page 4-3 for more information
Gray	Fixed in minor step

To enable the sample time colors feature, select **Sample Time Colors** from the **Format** menu.

The Simulink software does not automatically recolor the model with each change you make to it, so you must select **Update Diagram** from the **Edit** menu to explicitly update the model coloration. To return to your original coloring, disable sample time coloration by again choosing **Sample Time Colors**.

The color that is assigned to each block depends on its sample time relative to other sample times in the model. This means that the same sample time may be assigned different colors in a parent model and in models that it references. (See Chapter 5, "Referencing a Model".)

For example, suppose that a model defines three sample times: `1`, `2`, and `3`. Further, suppose that it references a model that defines two sample times: `2` and `3`. In this case, blocks operating at the `2` sample rate appear as green in the parent model and as red in the referenced model.

It is important to note that Mux and Demux blocks are simply grouping operators; signals passing through them retain their timing information. For

this reason, the lines emanating from a Demux block can have different colors if they are driven by sources having different sample times. In this case, the Mux and Demux blocks are color coded as hybrids (yellow) to indicate that they handle signals with multiple rates.

Similarly, Subsystem blocks that contain blocks with differing sample times are also colored as hybrids, because there is no single rate associated with them. If all the blocks within a subsystem run at a single rate, the Subsystem block is colored according to that rate.

Connecting Blocks

In this section...

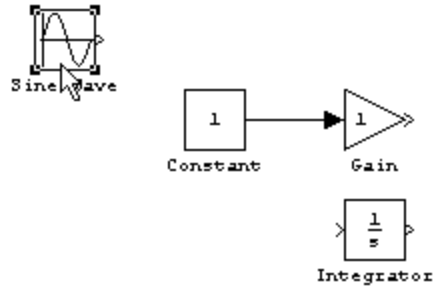
Automatically Connecting Blocks

You can command the Simulink software to connect blocks automatically. This eliminates the need for you to draw the connecting lines yourself. When connecting blocks, the lines are routed around intervening blocks to avoid cluttering the diagram.

Connecting Two Blocks

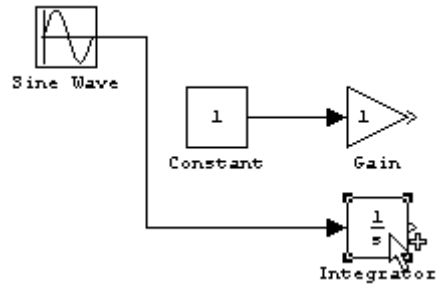
To autoconnect two blocks:

1 Select the source block.

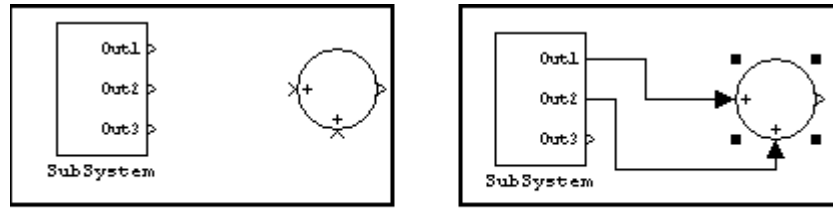


2 Hold down **Ctrl** and left-click the destination block.

The source block is connected to the destination block, and the lines are routed around intervening blocks if necessary.



When connecting two blocks, the Simulink software draws as many connections as possible between the two blocks as illustrated in the following example.



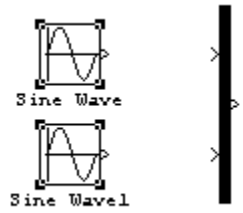
Before autoconnect After autoconnect

Connecting Groups of Blocks

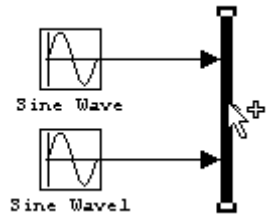
The Simulink software can connect a group of source blocks to a destination block or a source block to a group of destination blocks.

To connect a group of source blocks to a destination block:

1 Select the source blocks.

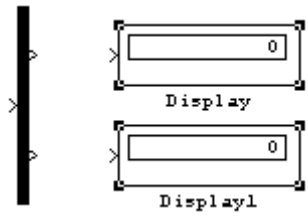


2 Hold down **Ctrl** and left-click the destination block.

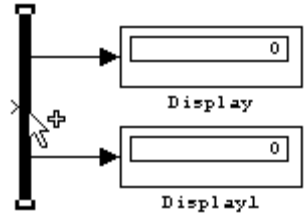


To connect a source block to a group of destination blocks:

1 Select the *destination* blocks.



2 Hold down **Ctrl** and left-click the *source* block.



Manually Connecting Blocks

You can draw lines manually between blocks or between lines and blocks. You might want to do this if you need to control the path of the line or to create a branch line.

Drawing a Line Between Blocks

To connect the output port of one block to the input port of another block:

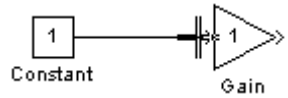
1. Position the cursor over the first block's output port. It is not necessary to position the cursor precisely on the port.

   The cursor shape changes to crosshairs.

2. Press and hold down the mouse button.

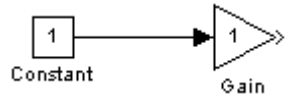
3. Drag the pointer to the second block's input port. You can position the cursor on or near the port or in the block. If you position the cursor in the block, the line is connected to the closest input port.

   The cursor shape changes to double crosshairs.



4 Release the mouse button. The port symbols are replaced by a connecting line with an arrow showing the direction of the signal flow. You can create lines either from output to input, or from input to output.

   The arrow appears at the appropriate input port, and the signal is the same.

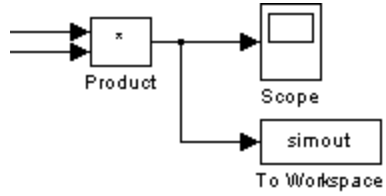


The Simulink software draws connecting lines using horizontal and vertical line segments. To draw a diagonal line, hold down the **Shift** key while drawing the line.

Drawing a Branch Line

A *branch line* is a line that starts from an existing line and carries its signal to the input port of a block. Both the existing line and the branch line represent the same signal. Using branch lines enables you to connect a signal to more than one block.

This example demonstrates the connecting of the Product block output to both the Scope block and the To Workspace block.



To add a branch line:

1 Position the pointer on the line where you want the branch line to start.

2 While holding down the **Ctrl** key, press and hold down the left mouse button.

3 Drag the pointer to the input port of the target block, then release the mouse button and the **Ctrl** key.

You can also use the right mouse button instead of holding down the left mouse button and the **Ctrl** key.

Drawing a Line Segment

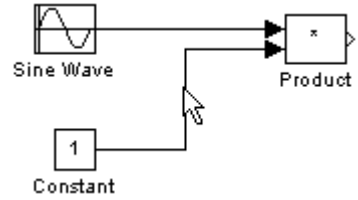
You might want to draw a line with segments exactly where you want them instead of where the Simulink software draws them. Or you might want to draw a line before you copy the block to which the line is connected. You can do either by drawing line segments.

To draw a line segment, you draw a line that ends in an unoccupied area of the diagram. An arrow appears on the unconnected end of the line. To add another line segment, position the cursor over the end of the segment and draw another segment. The segments area drawn as horizontal and vertical lines. To draw diagonal line segments, hold down the **Shift** key while you draw the lines.

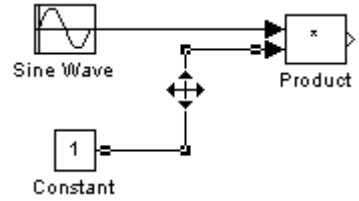
Moving a Line Segment

To move a line segment:

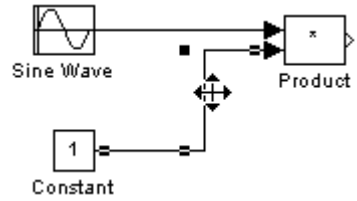
1 Position the pointer on the segment you want to move.



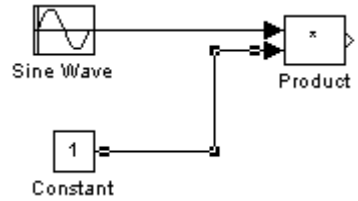
2 Press and hold down the left mouse button.



3 Drag the pointer to the desired location.



4 Release the mouse button.



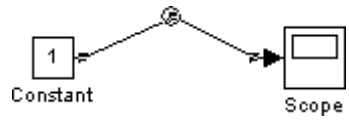
To move the segment connected to an input port, position the pointer over the port and drag the end of the segment to the new location. You cannot move the segment connected to an output port.

Moving a Line Vertex

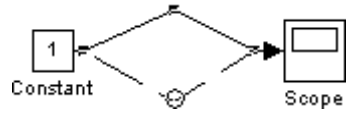
To move a vertex of a line:

1 Position the pointer on the vertex, then press and hold down the mouse button.

The cursor changes to a circle that encloses the vertex.



2 Drag the pointer to the desired location.



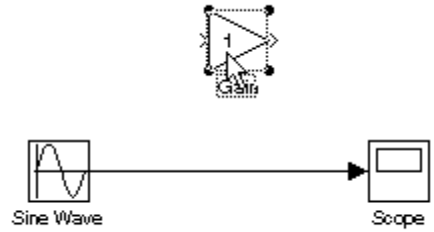
3 Release the mouse button.

Inserting Blocks in a Line

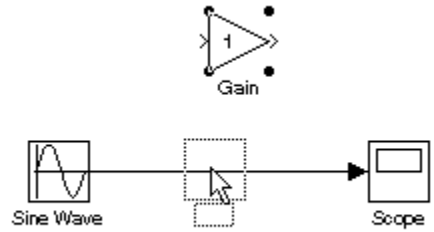
You can insert a block in a line by dropping the block on the line. The Simulink software inserts the block for you at the point where you drop the block. The block that you insert can have only one input and one output.

To insert a block in a line:

1 Position the pointer over the block and press the left mouse button.

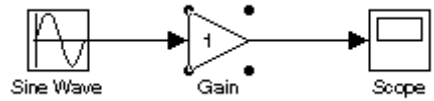


2 Drag the block over the line in which you want to insert the block.



3 Release the mouse button to drop the block on the line.

The block is inserted where you dropped it.



Disconnecting Blocks

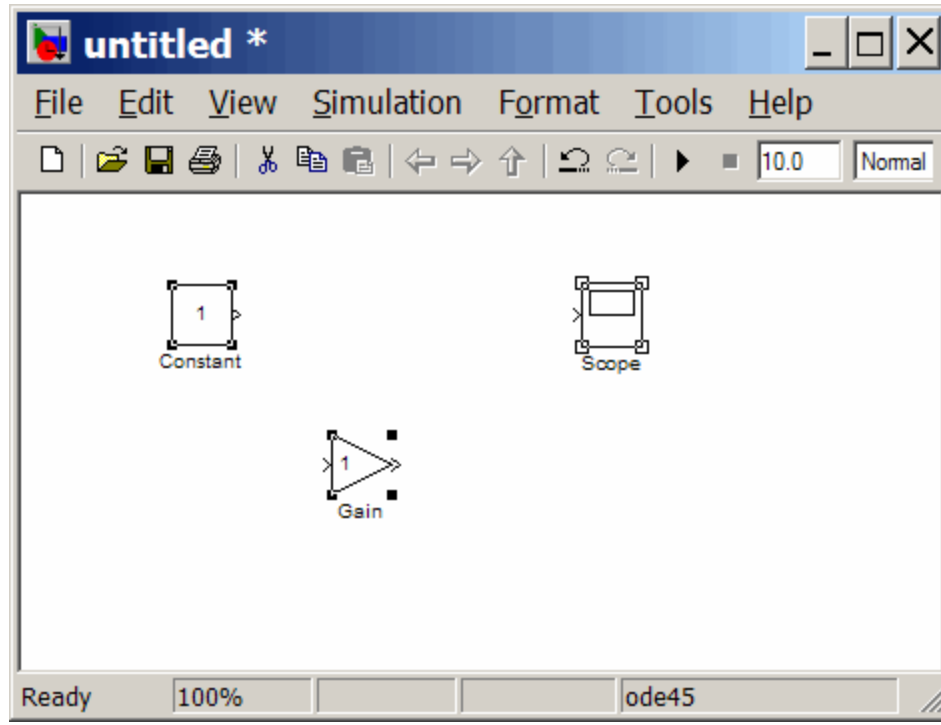
To disconnect a block from its connecting lines, hold down the **Shift** key, then drag the block to a new location.

To disconnect a line from a block's input port, position the mouse pointer over the line's arrowhead. The pointer turns into a circle. Drag the arrowhead away from the block.

Aligning, Distributing, and Resizing Groups of Blocks Automatically

The model editor's **Format** menu includes commands that let you quickly align, distribute, and resize groups of blocks. To align (or distribute or resize) a group of blocks:

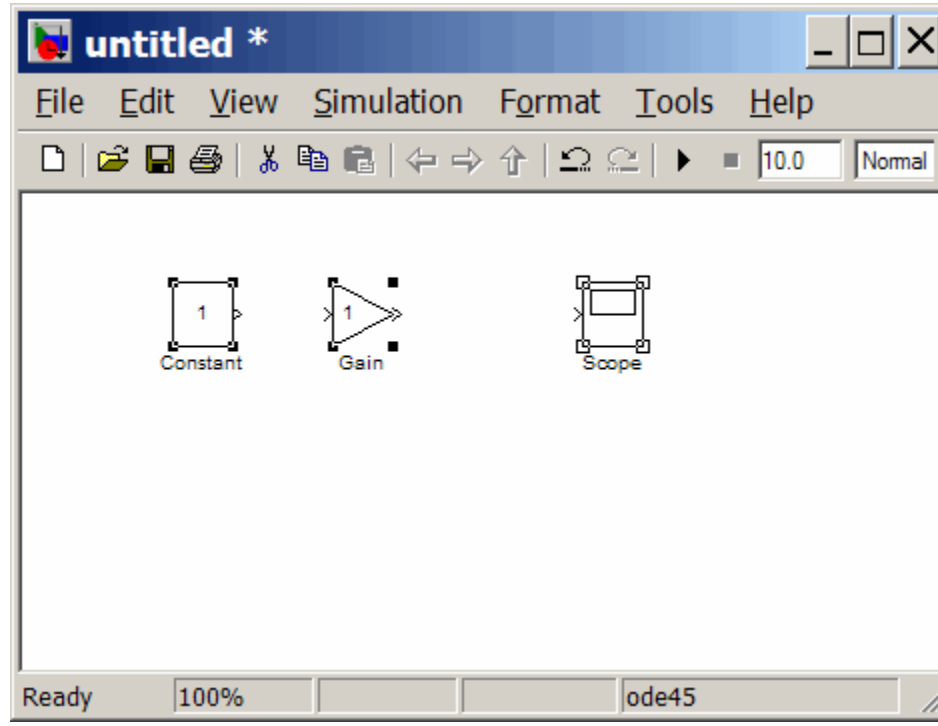
1 Select the blocks that you want to align.



One of the selected blocks displays empty selection handles. The model editor uses this block as the reference for aligning the other selected blocks. If you want another block to serve as the alignment reference, click that block.

2 Select one of the alignment options from the editor's **Format > Align Blocks** menu (or distribution options from the **Format > Distribute**

Blocks or resize options from the **Format > Resize Blocks** menu). For example, selecting **Align Top Edges** aligns the top edges of the selected blocks with the top edge of the reference block.

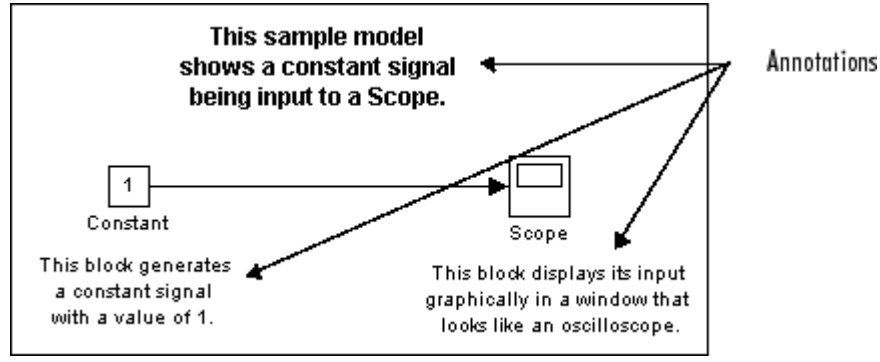


Annotating Diagrams

In this section...

How to Annotate Diagrams

Annotations provide textual information about a model. You can add an annotation to any unoccupied area of your block diagram.



To create a model annotation, double-click an unoccupied area of the block diagram. A small rectangle appears and the cursor changes to an insertion point. Start typing the annotation contents. Each line is centered in the rectangle that surrounds the annotation.

To move an annotation, drag it to a new location.

To edit an annotation, select it:

- To replace the annotation, click the annotation, then double-click or drag the cursor to select it. Then, enter the new annotation.
- To insert characters, click between two characters to position the insertion point, then insert text.
- To replace characters, drag the mouse to select a range of text to replace, then enter the new text.

To delete an annotation, hold down the **Shift** key while you select the annotation, then press the **Delete** or **Backspace** key.

To change an annotation's font, select the annotation, then choose **Font** from the **Format** menu. Select a font and size from the dialog box.

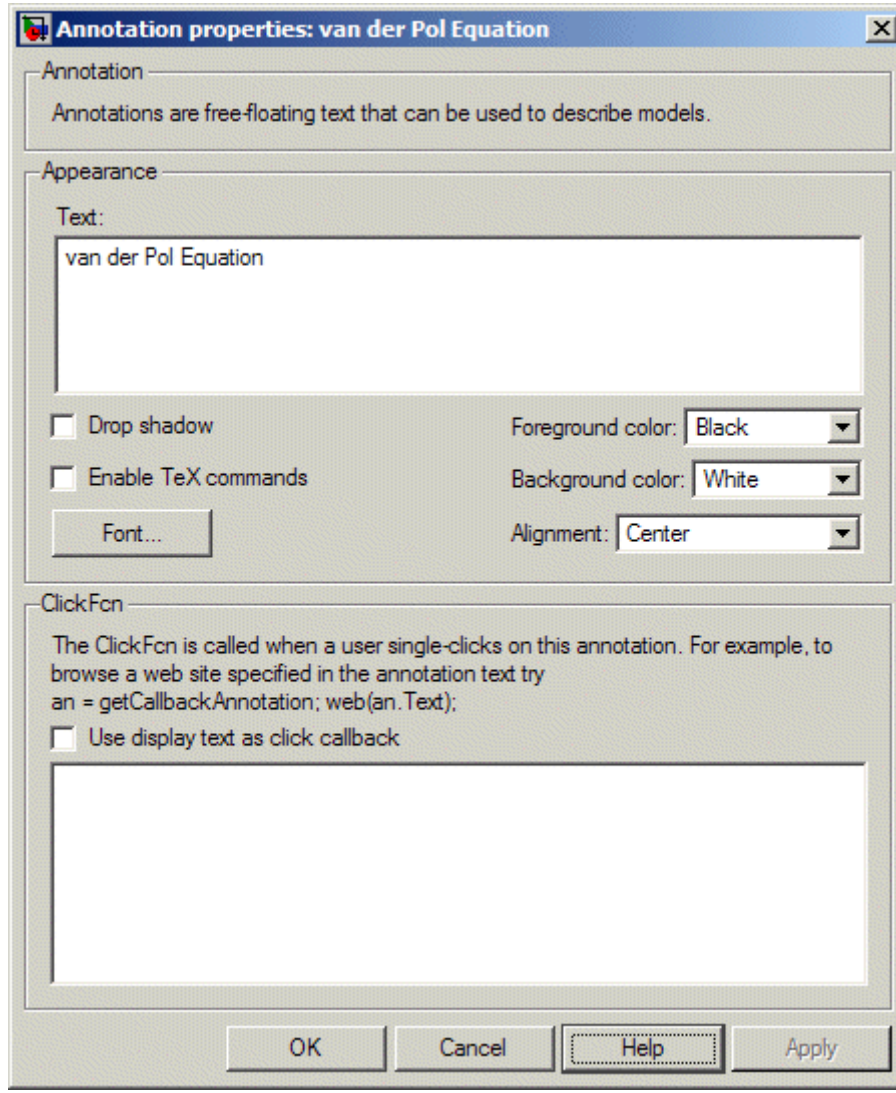
To change the text alignment (e.g., left, center, or right) of the annotation, select the annotation and choose **Text Alignment** from model editor's **Format** or the context menu. Then choose one of the alignment options (e.g., **Center)** from the **Text Alignment** submenu.

Annotations Properties Dialog Box

The Annotation Properties dialog box allows you to specify the contents and format of the currently selected annotation and to associate a click function with the annotation.

To display the Annotation Properties dialog box for an annotation, select the annotation and then select Annotation Properties from model editor's **Edit** or the context menu.

The dialog box appears.



The dialog box includes the following controls.

Text
Displays the current text of the annotation. Edit this field to change the annotation text.

Drop shadow
Checking this option causes a drop shadow to be displayed around the annotation, giving it a 3-D appearance.

Enable TeX commands
Checking this option enables use of TeX formatting commands in this annotation. See "Using TeX Formatting Commands in Annotations" in the online Simulink documentation for more information.

Font
Clicking this button displays a font chooser dialog box. Use the font chooser to change the font used to render the annotation's text.

Foreground color
Specifies the color of the annotation text.

Background color
Specifies the color of the background of the annotation's bounding box.

Alignment
Specifies the alignment of the annotation's text relative to its bounding box.

ClickFcn
Specifies MATLAB code to be executed when a user single-clicks this annotation. The Simulink software stores the code entered in this field with the model. See "Associating Click Functions with Annotations" on page 3-31 for more information.

Use display text as click callback

Checking this option causes the text in the **Text** field to be treated as the annotation's click function. The specified text must be a valid MATLAB expression comprising symbols that are defined in the MATLAB workspace when the user clicks this annotation. See "Associating Click Functions with Annotations" on page 3-31 for more information. Note that selecting this option disables the **ClickFcn** edit field.

Annotation Callback Functions

You can associate the following callback functions with annotations.

Click Function

A click function is a MATLAB function that the Simulink software invokes when a user single-clicks an annotation. You can associate a click function with any of a model's annotations (see "Associating Click Functions with Annotations" on page 3-31). the Simulink software uses the color blue to display the text of annotations associated with click functions. This allows the user to see at a glance which annotations are associated with click functions. Click functions allow you to add hyperlinks and custom command "buttons" to your model's block diagram. For example, you can use click functions to allow a user to display the values of workspace variables referenced by the model or to open related models simply by clicking on annotations displayed on the block diagram. (See Chapter 5, "Referencing a Model".)

Load Function

This function is invoked when it loads the model containing the associated annotation. To associate a load function with an annotation, set the LoadFcn property of the annotation to the desired function (see "Annotations API" on page 3-33).

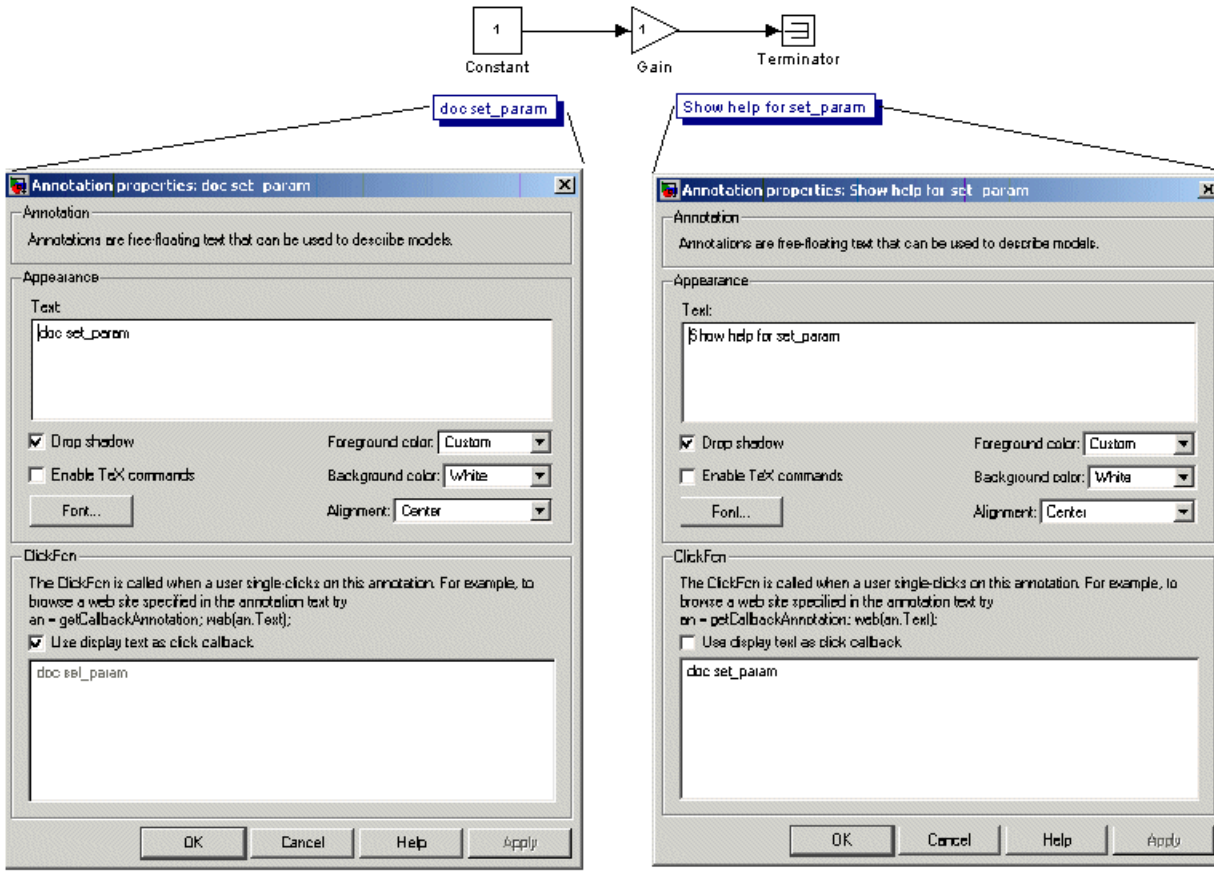
Delete function

This function is invoked before deleting the associated annotation. To associate a delete function with an annotation, set the DeleteFcn property of the annotation to the desired function (see "Annotations API" on page 3-33).

Associating Click Functions with Annotations

Two ways are provided to associate a click function with an annotation via the annotation's properties dialog box (see "Annotations Properties Dialog Box" on page 3-27). You can specify either the annotation itself as the click function or a separately defined function. To specify the annotation itself as the click function, enter a valid MATLAB expression in the dialog box's **Text** field and check the **Use display text** as callback option. To specify a separately defined click function, enter the MATLAB code that defines the click function in the dialog box's **ClickFcn** edit field.

The following model illustrates the two ways to associate click functions with an annotation.



Annotation text as the click function

Separately defined click function

Clicking either of the annotations in this model displays help for the `set_param` command.

Note You can also use MATLAB code to associate a click function with an annotation. See "Annotations API" on page 3-33 for more information.

Selecting and Editing Annotations Associated with Click Functions

Associating an annotation with a click function prevents you from selecting the annotation by clicking on it. You must use drag select the annotation. Similarly, you cannot make the annotation editable on the diagram by clicking its text. To make the annotation editable on the diagram, first drag-select it, then select **Edit Annotation Text** from model editor's **Edit** or the context menu.

Annotations API

An application program interface (API) is provided that enables you to use MATLAB programs to get and set the properties of annotations. The API comprises the following elements:

- `Simulink.Annotation` class

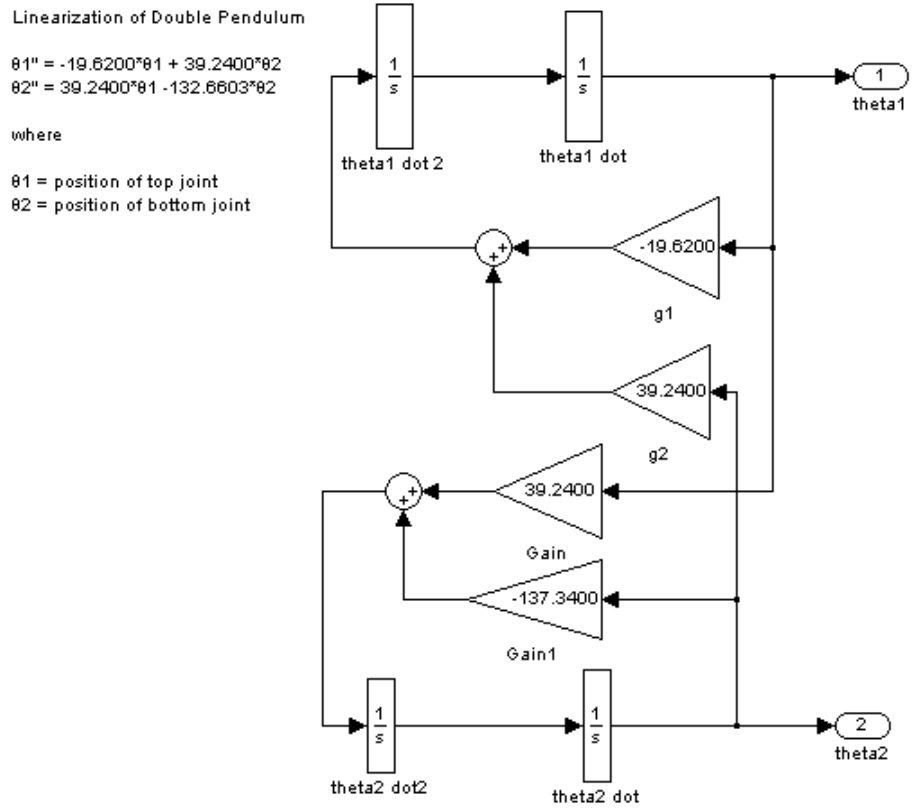
  Allows MATLAB code (for example, annotation load functions) to set the properties of annotations (see "Load Function" on page 3-30)

- `getCallbackAnnotation` function

  Gets the `Simulink.Annotation` object for the annotation associated with the currently executing annotation callback function

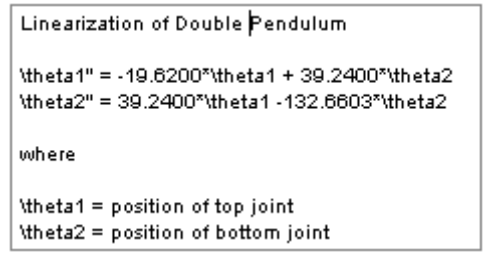
Using TeX Formatting Commands in Annotations

You can use TeX formatting commands to include mathematical and other symbols and Greek letters in block diagram annotations.



To use TeX commands in an annotation:

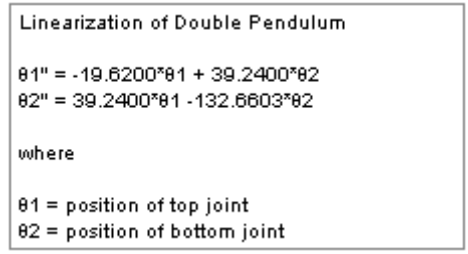
1. Select the annotation.
2. Select **Enable TeX Commands** from model editor's **Format** menu.
3. Enter or edit the text of the annotation, using TeX commands where needed to achieve the desired appearance.



See "Mathematical Symbols, Greek Letters, and TeX Characters" in the MATLAB documentation for information on the TeX formatting commands which are supported.

4 Deselect the annotation by clicking outside it or typing **Esc**.

The formatted text is displayed.



Creating Annotations Programmatically

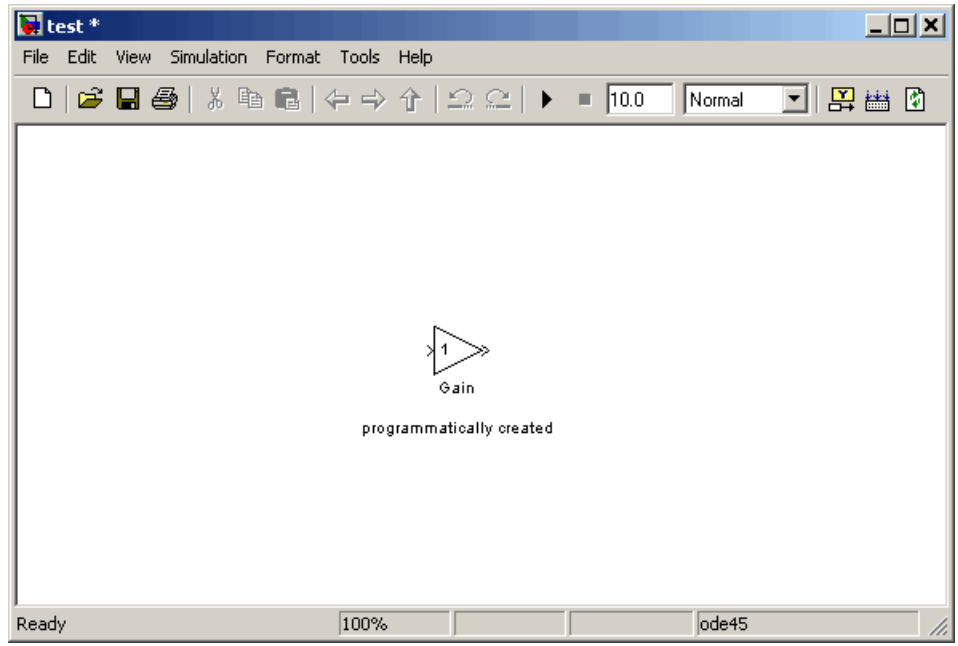
You can use the `add_block` command to create annotations at the command line or in a MATLAB program. Use the following syntax to create the annotation:

```
add_block('built-in/Note','path/text','Position', ...
[center_x, 0, 0, center_y]);
```

where path is the path of the diagram to be annotated, text is the text of the annotation, and [*center_x*, *0*, *0*, *center_y*] is the position of the center of the annotation in pixels relative to the upper left corner of the diagram. For example, the following sequence of commands

```
new_system('test')
open_system('test')
add_block('built-in/Gain', 'test/Gain', 'Position', ...
[260, 125, 290, 155])
add_block('built-in/Note','test/programmatically created', ...
'Position', [550 0 0 180])
```

creates the following model:



To delete an annotation, use the `find_system` command to get the annotation's handle. Then use the `delete` function to delete the annotation, e.g.,

```
delete(find_system(gcs, 'FindAll', 'on', 'type', 'annotation'));
```

Creating Subsystems

In this section...

Why Subsystems are Advantageous

A subsystem is a set of blocks that have been replaced by a single block called a Subsystem block. As your model increases in size and complexity, you can simplify it by grouping blocks into subsystems. Using subsystems has these advantages:

- It helps reduce the number of blocks displayed in your model window.
- It allows you to keep functionally related blocks together.
- It enables you to establish a hierarchical block diagram, where a Subsystem block is on one layer and the blocks that make up the subsystem are on another.

You can create a subsystem in two ways:

- Add a Subsystem block to your model, then open that block and add the blocks it contains to the subsystem window.
- Add the blocks that make up the subsystem, then group those blocks into a subsystem.

A subsystem can be executed conditionally or unconditionally. An unconditionally executed subsystem always executes. A conditionally executed subsystem may or may not execute, depending on the value of an input signal. For information about conditionally executed subsystems, see Chapter 6, "Creating Conditional Subsystems".

Creating a Subsystem by Adding the Subsystem Block

To create a subsystem before adding the blocks it contains, add a Subsystem block to the model, then add the blocks that make up the subsystem:

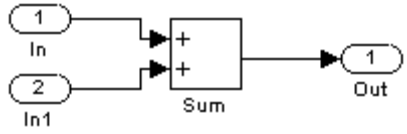
1. Copy the Subsystem block from the Ports & Subsystems library into your model.

2. Open the Subsystem block by double-clicking it.

   The subsystem is opened in the current or a new model window, depending on the model window reuse mode that you selected (see "Window Reuse" on page 3-40).

3. In the empty Subsystem window, create the subsystem. Use Inport blocks to represent input from outside the subsystem and Outport blocks to represent external output.

   For example, the subsystem shown includes a Sum block and Inport and Outport blocks to represent input to and output from the subsystem.



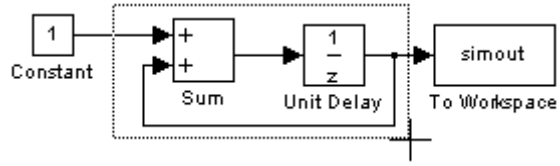
Creating a Subsystem by Grouping Existing Blocks

If your model already contains the blocks you want to convert to a subsystem, you can create the subsystem by grouping those blocks:

1. Enclose the blocks and connecting lines that you want to include in the subsystem within a bounding box. You cannot specify the blocks to be grouped by selecting them individually or by using the **Select All**

command. For more information, see "Selecting Multiple Objects Using a Bounding Box" on page 3-7.

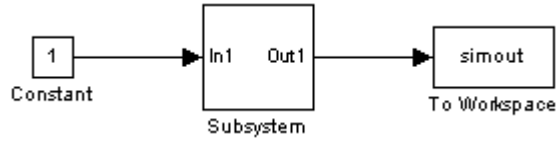
For example, this figure shows a model that represents a counter. The Sum and Unit Delay blocks are selected within a bounding box.



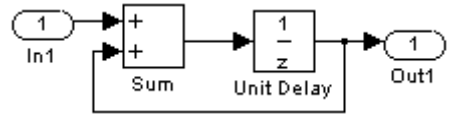
When you release the mouse button, the two blocks and all the connecting lines are selected.

2 Choose **Create Subsystem** from the **Edit** menu. The selected blocks are replaced with a Subsystem block.

This figure shows the model after you choose the **Create Subsystem** command (and resize the Subsystem block so the port labels are readable).



If you open the Subsystem block, the underlying system is displayed, as shown below.



Notice that the Simulink software adds Inport and Outport blocks to represent input from and output to blocks outside the subsystem.

As with all blocks, you can change the name of the Subsystem block. You can also use the masking feature to customize the block's appearance and dialog box. See Chapter 21, "Working with Block Masks".

Undoing Subsystem Creation

To undo creation of a subsystem by grouping blocks, select **Undo** from the **Edit** menu. You can undo creation of a subsystem that you have subsequently edited. However, the **Undo** command does not undo any nongraphical changes that you made to the blocks, such as changing the value of a block parameter or the name of a block. The Simulink software alerts you to this limitation by displaying a warning dialog box before undoing creation of a modified subsystem.

Model Navigation Commands

Subsystems allow you to create a hierarchical model comprising many layers. You can navigate this hierarchy using the Model Browser (see "The Model Browser" on page 8-73) and/or the following model navigation commands:

- **Open Block**

  The **Open Block** command opens the currently selected subsystem. To execute the command, select **Open Block** from either the **Edit** menu or the subsystem's context (right-click) menu, press **Enter**, or double-click the subsystem.

- **Open Block In New Window**

  Opens the currently selected subsystem regardless of the window reuse settings (see "Window Reuse" on page 3-40). To execute the command, select **Open Block In New Window** from the subsystem's context (right-click) menu.

- **Go To Parent**

  The **Go To Parent** command displays the parent of the subsystem displayed in the current window. To execute the command, press **Esc** or select **Go To Parent** from the Simulink software **View** menu.

Window Reuse

You can specify whether the Simulink software model navigation commands use the current window or a new window to display a subsystem or its parent. Reusing windows avoids cluttering your screen with windows. Creating a window for each subsystem allows you to view subsystems side by side with their parents or siblings. To specify your preference regarding window reuse,

select **Preferences** from the **File** menu and then select one of the following **Window reuse type** options listed in the **Preferences** dialog box.

Reuse Type	Open Action	Go to Parent (Esc) Action
`none`	Subsystem appears in a new window.	Parent window moves to the front.
`reuse`	Subsystem replaces the parent in the current window.	Parent window replaces subsystem in current window
`replace`	Subsystem appears in a new window. Parent window disappears.	Parent window appears. Subsystem window disappears.
`mixed`	Subsystem appears in its own window.	Parent window rises to front. Subsystem window disappears.

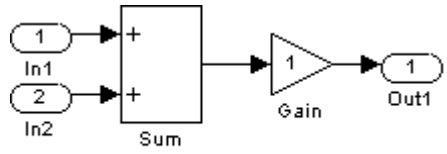
Labeling Subsystem Ports

Simulink labels ports on a Subsystem block. The labels are the names of Inport and Outport blocks that connect the subsystem to blocks outside the subsystem through these ports.

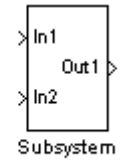
You can hide (or show) the port labels by

- Selecting the Subsystem block, then choosing **Hide Port Labels** (or **Show Port Labels**) from the **Format** menu
- Selecting an Inport or Outport block in the subsystem and choosing **Hide Name** (or **Show Name**) from the **Format** menu
- Selecting the **Show port labels** option in the Subsystem block's parameter dialog

This figure shows two models.



Subsystem with Inport and Outport blocks



Subsystem with labeled ports

The subsystem on the left contains two Inport blocks and one Outport block. The Subsystem block on the right shows the labeled ports.

Controlling Access to Subsystems

You can control user access to subsystems. For example, you can prevent a user from viewing or modifying the contents of a library subsystem while still allowing the user to employ the subsystem in a model.

To restrict access to a library subsystem, open the subsystem's parameter dialog box and set its **Read/Write permissions** parameter to either `ReadOnly` or `NoReadOrWrite`. The first option allows a user to view the contents of the library subsystem but prevents the user from modifying the reference subsystem without first disabling its library link or changing its **Read/Write permissions** parameter to `ReadWrite`. The second option prevents the user from viewing the contents of the library subsystem, modifying the reference subsystem, and changing the reference subsystem's permissions. Note that both options allow a user to use the library subsystem in models by creating links (see Chapter 23, "Working with Block Libraries"). See the Subsystem block in the *Simulink Reference* guide for more information on subsystem access options.

Note You will not receive a response if you attempt to view the contents of a subsystem whose **Read/Write permissions** parameter is set to `NoReadOrWrite`. For example, when double-clicking such a subsystem, the Simulink software neither opens the subsystem nor displays any messages.

Interconverting Subsystems and Block Diagrams

These functions are provided that you can use to interconvert subsystems and block diagrams:

`Simulink.SubSystem.copyContentsToBlockDiagram`
: Copies the contents of a subsystem to an empty block diagram.

`Simulink.BlockDiagram.copyContentsToSubSystem`
: Copies the contents of a block diagram to an empty subsystem.

For more information, see the reference documentation for these functions.

Emptying Subsystems and Block Diagrams

These functions are provided to empty subsystems and block diagrams:

`Simulink.SubSystem.deleteContents`
: Deletes the contents of a subsystem.

`Simulink.BlockDiagram.deleteContents`
: Deletes the contents of a block diagram.

For more information, see the reference documentation for these functions.

Modeling Control Flow Logic

In this section...

Equivalent C Language Statements

You can use block diagrams to model control flow logic equivalent to the following C programming language statements:

- `for`
- `if-else`
- `switch`
- `while`

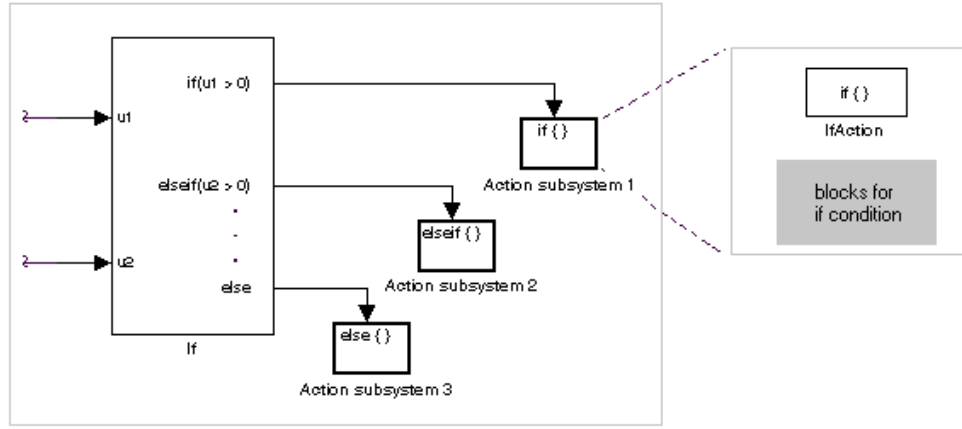
Modeling Conditional Control Flow Logic

You can use the following blocks to model conditional control flow logic.

C Statement	Equivalent Blocks
`if-else`	If, If Action Subsystem
`switch`	Switch Case, Switch Case Action Subsystem

Modeling If-Else Control Flow

The following diagram models `if-else` control flow.



Construct an `if-else` control flow diagram as follows:

- Provide data inputs to the If block for constructing if-else conditions.

  Inputs to the If block are set in the If block properties dialog box. Internally, they are designated as `u1, u2,..., un` and are used to construct output conditions.

- Set output port if-else conditions for the If block.

  Output ports for the If block are also set in its properties dialog box. You use the input values `u1, u2, ..., un` to express conditions for the if, elseif, and else condition fields in the dialog box. Of these, only the if field is required. You can enter multiple elseif conditions and select a check box to enable the else condition.

- Connect each condition output port to an Action subsystem.

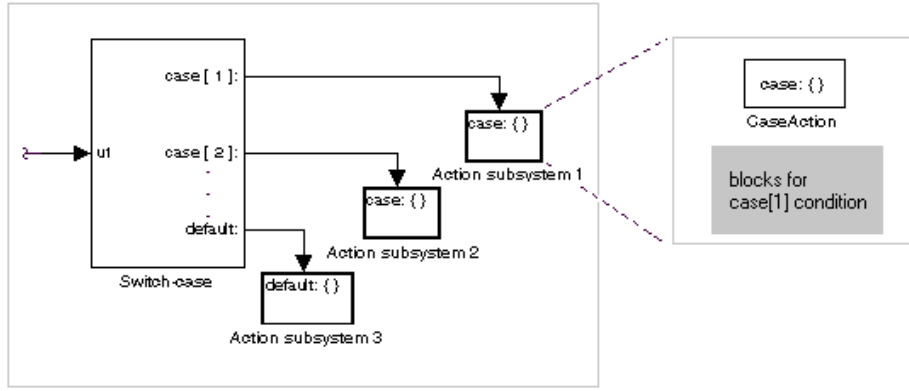
  Each if, elseif, and else condition output port on the If block is connected to a subsystem to be executed if the port's case is true. You create these subsystems by placing an Action Port block in a subsystem. This creates an atomic Action subsystem with a port named Action, which you then connect to a condition on the If block. Once connected, the subsystem takes on the identity of the condition it is connected to and behaves like an enabled subsystem.

For more detailed information, see the If and Action Port blocks.

Note All blocks in an Action subsystem driven by an If or Switch Case block must run at the same rate as the driving block.

Modeling Switch Control Flow

The following diagram models `switch` control flow.



Construct a `switch` control flow statement as follows:

- Provide a data input to the argument input of the Switch Case block.

  The input to the Switch Case block is the argument to the `switch` control flow statement. This value determines the appropriate case to execute. Noninteger inputs to this port are truncated.

- Add cases to the Switch Case block based on the numeric value of the argument input.

  You add cases to the Switch Case block through the properties dialog box of the Switch Case block. Cases can be single or multivalued. You can also add an optional default case, which is true if no other cases are true. Once added, these cases appear as output ports on the Switch Case block.

- Connect each Switch Case block case output port to an Action subsystem.

  Each case output of the Switch Case block is connected to a subsystem to be executed if the port's case is true. You create these subsystems by placing

an Action Port block in a subsystem. This creates an atomic subsystem with a port named Action, which you then connect to a condition on the Switch Case block. Once connected, the subsystem takes on the identity of the condition and behaves like an enabled subsystem. Place all the block programming executed for that case in this subsystem.

For more detailed information, see *Simulink Reference* for the Switch Case and Action Port blocks.

Note After the subsystem for a particular case is executed, an implied break is executed that exits the `switch` control flow statement altogether. The Simulink software `switch` control flow statement implementations do not exhibit "fall through" behavior like C `switch` statements.

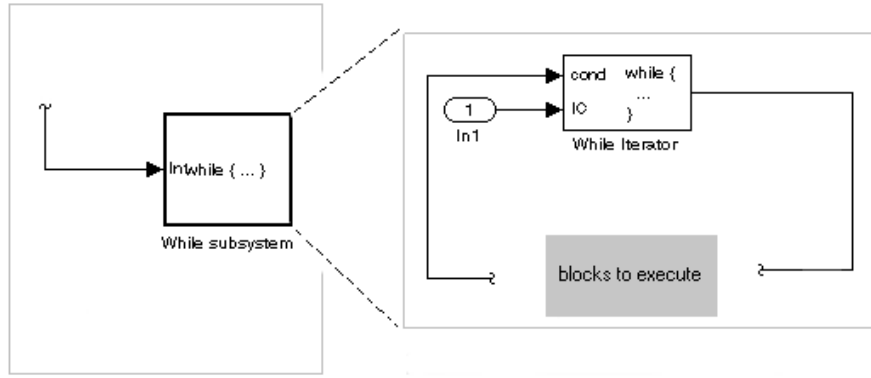
Modeling While and For Loops

The following blocks allow you to model `while` and `for` loops.

C Statement	Equivalent Blocks
`do-while`	While Iterator Subsystem
`for`	For Iterator Subsystem
`while`	While Iterator Subsystem

Modeling While Loops

The following diagram illustrates a `while` loop.



In this example, the Simulink software repeatedly executes the contents of the While subsystem at each time step until a condition specified by the While Iterator block is satisfied. In particular, for each iteration of the loop specified by the While Iterator block, the Simulink software invokes the update and output methods of all the blocks in the While subsystem in the same order that the methods would be invoked if they were in a noniterated atomic subsystem.

Note Simulation time does not advance during execution of a While subsystem's iterations. Nevertheless, blocks in a While subsystem treat each iteration as a time step. As a result, in a While subsystem, the output of a block with states, i.e., a block whose output depends on its previous input, reflects the value of its input at the previous iteration of the `while` loop—not, as one might expect, its input at the previous simulation time step. For example, a Unit Delay block in a While subsystem outputs the value of its input at the previous iteration of the `while` loop—not the value at the previous simulation time step.

Construct a `while` loop as follows:

- Place a While Iterator block in a subsystem.

  The host subsystem's label changes to `while {...}` to indicate that it is modeling a while loop. These subsystems behave like triggered subsystems.

This subsystem is host to the block programming you want to iterate with the While Iterator block.

- Provide a data input for the initial condition data input port of the While Iterator block.

  The While Iterator block requires an initial condition data input (labeled `IC`) for its first iteration. This must originate outside the While subsystem. If this value is nonzero, the first iteration takes place.

- Provide data input for the conditions port of the While Iterator block.

  Conditions for the remaining iterations are passed to the data input port labeled `cond`. Input for this port must originate inside the While subsystem.

- You can set the While Iterator block to output its iterator value through its properties dialog.

  The iterator value is 1 for the first iteration and is incremented by 1 for each succeeding iteration.

- You can change the iteration of the While Iterator block to `do-while` through its properties dialog.

  This changes the label of the host subsystem to `do {...} while`. With a `do-while` iteration, the While Iteration block no longer has an initial condition (IC) port, because all blocks in the subsystem are executed once before the condition port (labeled `cond`) is checked.

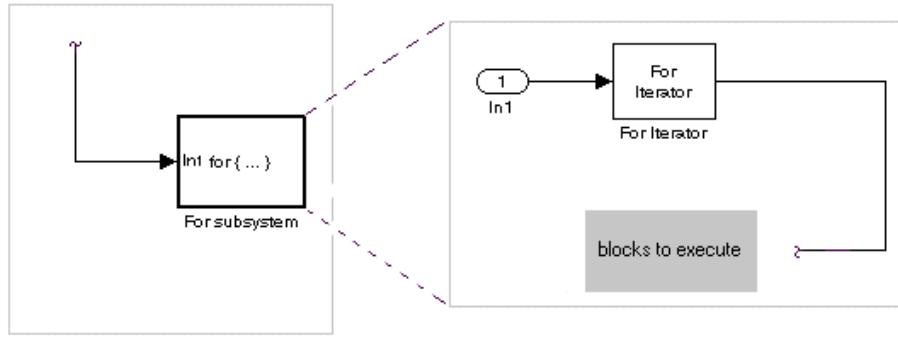
- Create a block diagram in the subsystem that defines the subsystem's outputs.

Note The diagram must not contain blocks with continuous states, e.g., blocks from the Continuous block library, and the sample times of all the blocks must be inherited (`-1`) or constant (`inf`).

For more information, see the While Iterator block.

Modeling For Loops

The following diagram models a `for` loop:



In this example, the Simulink software executes the contents of the For subsystem multiples times at each time step with the number of iterations being specified by the input to the For Iterator block. In particular, for each iteration of the `for` loop, the Simulink software invokes the update and output methods of all the blocks in the For subsystem in the same order that the methods would be invoked if they were in a noniterated atomic subsystem.

Note Simulation time does not advance during execution of a For subsystem's iterations. Nevertheless, blocks in a For subsystem treat each iteration as a time step. As a result, in a For subsystem, the output of a block with states, i.e., a block whose output depends on its previous input, reflects the value of its input at the previous iteration of the `for` loop—not, as one might expect, its input at the previous simulation time step. For example, a Unit Delay block in a For subsystem outputs the value of its input at the previous iteration of the `for` loop—not the value at the previous simulation time step.

Construct a `for` loop as follows:

- Drag a For Iterator Subsystem block from the Library Browser or Library window into your model.

- You can set the For Iterator block to take external or internal input for the number of iterations it executes.

  Through the properties dialog of the For Iterator block you can set it to take input for the number of iterations through the port labeled `N`. This input must come from outside the For Iterator Subsystem.

  You can also set the number of iterations directly in the properties dialog.

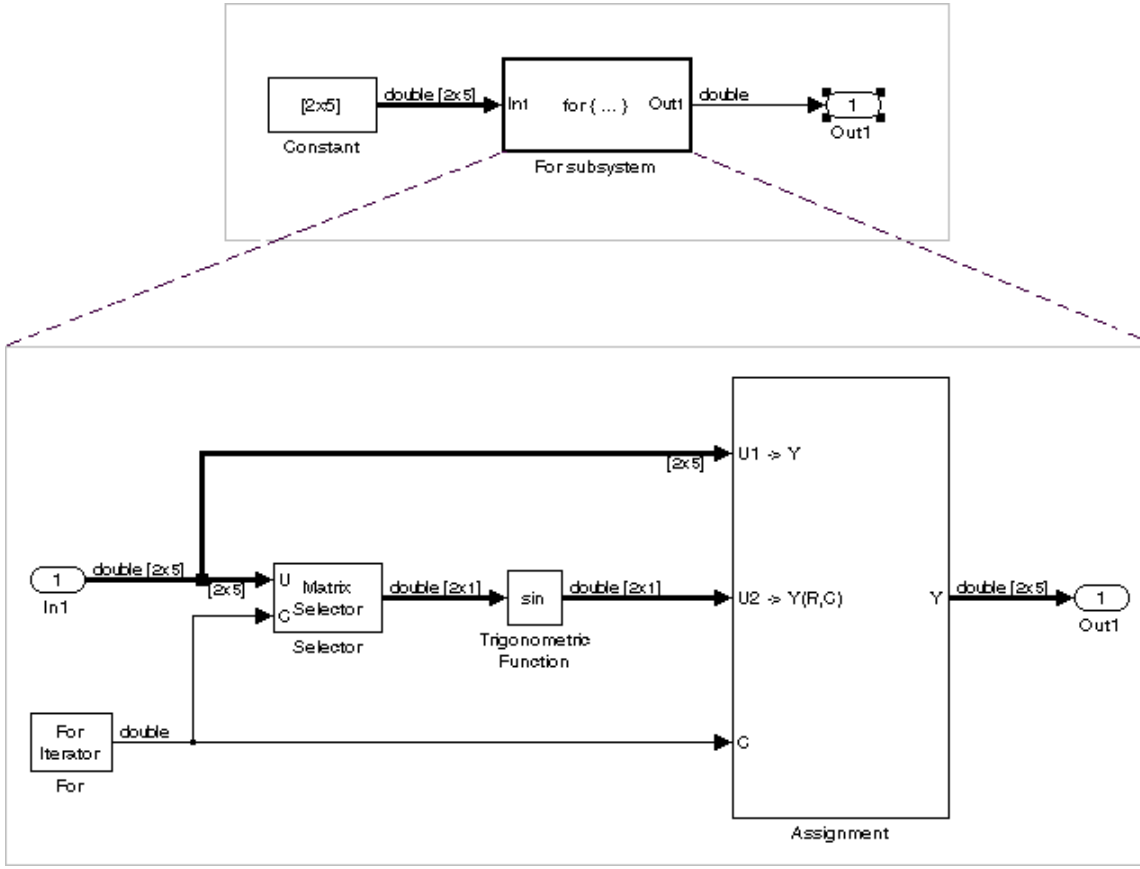
- You can set the For Iterator block to output its iterator value for use in the block programming of the For Iterator Subsystem.

  The iterator value is 1 for the first iteration and is incremented by 1 for each succeeding iteration.

- Create a block diagram in the subsystem that defines the subsystem's outputs.

Note The diagram must not contain blocks with continuous states, e.g., blocks from the Continuous block library, and the sample times of all the blocks must be inherited (`-1`) or constant (`inf`).

The For Iterator block works well with the Assignment block to reassign values in a vector or matrix. This is demonstrated in the following example. Note the matrix dimensions in the data being passed.



The above example outputs the sine value of an input 2-by-5 matrix (2 rows, 5 columns) using a For subsystem containing an Assignment block. The process is as follows:

1. A 2-by-5 matrix is input to the Selector block and the Assignment block.
2. The Selector block strips off a 2-by-1 matrix from the input matrix at the column value indicated by the current iteration value of the For Iterator block.
3. The sine of the 2-by-1 matrix is taken.

4 The sine value 2-by-1 matrix is passed to an Assignment block.

5 The Assignment block, which takes the original 2-by-5 matrix as one of its inputs, assigns the 2-by-1 matrix back into the original matrix at the column location indicated by the iteration value.

The rows specified for reassignment in the property dialog for the Assignment block in the above example are [1,2]. Because there are only two rows in the original matrix, you could also have specified -1 for the rows, i.e., all rows.

Note Experienced Simulink software users will note that the Trigonometric Function block is already capable of taking the sine of a matrix. The above example uses the Trigonometric Function block only as an example of changing each element of a matrix with the collaboration of an Assignment block and a For Iterator block.

Using Callback Functions

In this section...

About Callback Functions

Callback functions are a powerful way of customizing your Simulink model. A *callback* is a function that executes when you perform various actions on your model, such as clicking on a block or starting a simulation. You can use callbacks to execute a MATLAB script or other MATLAB commands. You can use block, port, or model parameters to specify callback functions.

Common tasks you can achieve by using callback functions include:

- Loading variables into the MATLAB workspace automatically when you open your Simulink model
- Executing a MATLAB script by double-clicking on a block
- Executing a series of commands before starting a simulation
- Executing commands when a block diagram is closed

For examples of these tasks, see "Example Callback Function Tasks" on page 3-63.

For related tasks, see

- "Using Model Workspaces" on page 3-67 for loading and modifying variables required by your model
- "Model Dependencies" on page 8-76 for analyzing model and block callbacks, and identifying and packaging files required by your model

Tracing Callbacks

Callback tracing allows you to determine the callbacks the Simulink software invokes and in what order the it invokes them when you open or simulate a model. To enable callback tracing, select the **Callback tracing** option on the Preferences dialog box or execute `set_param(0, 'CallbackTracing', 'on')`. This option causes the callbacks to be listed in the MATLAB Command Window as they are invoked. This option applies to all Simulink models, not just models that are open when the preference is enabled.

Creating Model Callback Functions

You can create model callback functions interactively or programmatically. Use the **Callbacks** pane of the model's Model Properties dialog box (see "Callbacks Pane" on page 3-104) to create model callbacks interactively. To create a callback programmatically, use the `set_param` command to assign a MATLAB expression that implements the function to the model parameter corresponding to the callback (see "Model Callback Functions" on page 3-56).

For example, this command evaluates the variable `testvar` when the user double-clicks the Test block in `mymodel`:

```
set_param('mymodel/Test', 'OpenFcn', testvar)
```

You can examine the `clutch` system (`sldemo_clutch.mdl`) for routines associated with many model callbacks. This model defines the following callbacks:

- `PreLoadFcn`
- `PostLoadFcn`
- `StartFcn`
- `StopFcn`

- `CloseFcn`

Model Callback Functions

The following table describes callback functions associated with models.

Parameter	When Executed
`CloseFcn`	Before the block diagram is closed. Any `ModelCloseFcn` and `DeleteFcn` callbacks set on blocks in the model are called prior to the model's `CloseFcn`. The `DestroyFcn` callback of any blocks in the model is called after the model's `CloseFcn`.
`ContinueFcn`	Before the simulation continues.
`InitFcn`	Called at start of model simulation.
`PauseFcn`	After the simulation pauses.
`PostLoadFcn`	After the model is loaded. Defining a callback routine for this parameter might be useful for generating an interface that requires that the model has already been loaded.
`PostSaveFcn`	After the model is saved.
`PreLoadFcn`	Before the model is loaded. Defining a callback routine for this parameter might be useful for loading variables used by the model.

Parameter	When Executed
	Note In a `PreLoadFcn` callback routine, the `get_param` command does not return the model's parameter values because the model is not yet loaded. In a `PreLoadFcn` routine, `get_param` returns: • The default value for a standard model parameter such as `solver` • An error message for a model parameter added with `add_param` In a `PostLoadFcn` callback routine, however, `get_param` returns the model's parameter values because the model is loaded.
`PreSaveFcn`	Before the model is saved.
`StartFcn`	Before the simulation starts.
`StopFcn`	After the simulation stops. Output is written to workspace variables and files before the `StopFcn` is executed.

Note Beware of adverse interactions between callback functions of models referenced by other models. (See Chapter 5, "Referencing a Model".) For example, suppose that model A references model B and that model A's `OpenFcn` creates variables in the MATLAB workspace and model B's `CloseFcn` clears the MATLAB workspace. Now suppose that simulating model A requires rebuilding model B. Rebuilding B entails opening and closing model B and hence invoking model B's `CloseFcn`, which clears the MATLAB workspace, including the variables created by A's `OpenFcn`.

Creating Block Callback Functions

You can create block callback functions interactively or programmatically. Use the **Callbacks** pane of the block's Block Properties dialog box (see "Callbacks Pane" on page 18-19) to create block callbacks interactively. To create a callback programmatically, use the `set_param` command to assign a MATLAB expression that implements the function to the block parameter corresponding to the callback (see "Block Callback Parameters" on page 3-58).

Note A callback for a masked subsystem cannot directly reference the parameters of the masked subsystem (see Chapter 21, "Working with Block Masks"). The Simulink software evaluates block callbacks in the MATLAB base workspace whereas the mask parameters reside in the masked subsystem's private workspace. A block callback, however, can use `get_param` to obtain the value of a mask parameter, e.g., `get_param(gcb, 'gain')`, where `gain` is the name of a mask parameter of the current block.

Block Callback Parameters

This table lists the parameters for which you can define block callback routines, and indicates when those callback routines are executed. Routines that are executed before or after actions take place occur immediately before or after the action.

Parameter	When Executed
`ClipboardFcn`	When the block is copied or cut to the system clipboard.
`CloseFcn`	When the block is closed using the `close_system` command. The `CloseFcn` is not called when you interactively close the block, when you interactively close the subsystem or model containing the block, or when you close the subsystem or model containing the block using `close_system`.
`ContinueFcn`	Before the simulation continues.

Parameter	When Executed
`CopyFcn`	After a block is copied. The callback is recursive for Subsystem blocks (that is, if you copy a Subsystem block that contains a block for which the `CopyFcn` parameter is defined, the routine is also executed). The routine is also executed if an `add_block` command is used to copy the block.
`DeleteChildFcn`	After a block or line is deleted in a subsystem. If the block has a `DeleteFcn` or `DestroyFcn`, those functions are executed prior to the `DeleteChildFcn`. Only Subsystem blocks have a `DeleteChildFcn` callback.
`DeleteFcn`	After a block is graphically deleted, e.g., when you graphically delete the block, invoke `delete_block` on the block, or close the model containing the block. When the `DeleteFcn` is called, the block handle is still valid and can be accessed using `get_param`. The `DeleteFcn` callback is recursive for Subsystem blocks. If the block is graphically deleted by invoking `delete_block` or by closing the model, after deletion the block is destroyed from memory and the block's `DestroyFcn` is called.
`DestroyFcn`	When the block has been destroyed from memory, e.g., when you invoke `delete_block` on either the block or a subsystem containing the block or close the model containing the block. If the block was not previously graphically deleted, the block's `DeleteFcn` is called prior to the `DestroyFcn`. When the `DestroyFcn` is called, the block handle is no longer valid.
`InitFcn`	Before the block diagram is compiled and before block parameters are evaluated.

Parameter	When Executed

`ErrorFcn`	When an error has occurred in a subsystem. Only Subsystem blocks have a `ErrorFcn` callback. The callback function should have the following form:
	
	`errorMsg = errorHandler(subsys, errorType)`
	
	where `errorHandler` is the name of the callback function, `subsys` is a handle to the subsystem in which the error occurred, `errorType` is a Simulink string indicating the type of error that occurred, and `errorMsg` is a string specifying the error message to be displayed to the user. The following command sets the `ErrorFcn` of the subsystem `subsys` to call the `errorHandler` callback function
	
	`set_param(subsys,'ErrorFcn','errorHandler')`
	
	Do not include the callback function's input arguments in the call to `set_param`. The Simulink software displays the error message `errorMsg` returned by the callback function.

`LoadFcn`	After the block diagram is loaded. This callback is recursive for Subsystem blocks.
`ModelCloseFcn`	Before the block diagram is closed. When the model is closed, the block's `ModelCloseFcn` is called prior to its `DeleteFcn`. This callback is recursive for Subsystem blocks.
`MoveFcn`	When the block is moved or resized.
`NameChangeFcn`	After a block's name and/or path changes. When a Subsystem block's path is changed, it recursively calls this function for all blocks it contains after calling its own `NameChangeFcn` routine.

Parameter	When Executed
`OpenFcn`	When the block is opened. This parameter is generally used with Subsystem blocks. The routine is executed when you double-click the block or when an `open_system` command is called with the block as an argument. The `OpenFcn` parameter overrides the normal behavior associated with opening a block, which is to display the block's dialog box or to open the subsystem.
`ParentCloseFcn`	Before closing a subsystem containing the block or when the block is made part of a new subsystem using the `new_system` command (see `new_system` in the online Simulink software reference) or the **Create Subsystem** item in model editor's **Edit** menu. The `ParentCloseFcn` of blocks at the root model level is not called when the model is closed.
`PauseFcn`	After the simulation pauses.
`PostSaveFcn`	After the block diagram is saved. This callback is recursive for Subsystem blocks.
`PreCopyFcn`	Before a block is copied. The callback is recursive for Subsystem blocks (that is, if you copy a Subsystem block that contains a block for which the `PreCopyFcn` parameter is defined, that routine is also executed). The block's `CopyFcn` is called after all `PreCopyFcn` callbacks are executed, unless the `PreCopyFcn` invokes the `error` command either explicitly or via a command used in any `PreCopyFcn`. The `PreCopyFcn` is also executed if an `add_block` command is used to copy the block.

Parameter	When Executed
`PreDeleteFcn`	Before a block is graphically deleted, e.g., when the user graphically deletes the block or invokes `delete_block` on the block. The `PreDeleteFcn` is not called when the model containing the block is closed. The block's `DeleteFcn` is called after the `PreDeleteFcn` unless the `PreDeleteFcn` invokes the `error` command either explicitly or via a command used in the `PreDeleteFcn`.
`PreSaveFcn`	Before the block diagram is saved. This callback is recursive for Subsystem blocks.
`StartFcn`	After the block diagram is compiled and before the simulation starts. In the case of an S-Function block, `StartFcn` executes immediately before the first execution of the block's `mdlProcessParameters` function. See "S-Function Callback Methods" in the online Simulink software documentation for more information.
`StopFcn`	At any termination of the simulation. In the case of an S-Function block, `StopFcn` executes after the block's `mdlTerminate` function executes. See "S-Function Callback Methods" in the online Simulink software documentation for more information.
`UndoDeleteFcn`	When a block deletion is undone.

Note Do not call the `run` command from within model or block callbacks. Doing so can result in unexpected behavior (such as errors or incorrect results) if a Simulink model is loaded, compiled, or simulated from inside a MATLAB function.

Port Callback Parameters

Block input and output ports have a single callback function parameter, `ConnectionCallback`. This parameter allows you to set callbacks on ports

that are triggered every time the connectivity of these ports changes. Examples of connectivity changes include adding a connection from the port to a block, deleting a block connected to the port, and deleting, disconnecting, or connecting branches or lines to the port.

Use `get_param` to get the port handle of a port and `set_param` to set the callback on the port. The callback function must have one input argument that represents the port handle, but the input argument is not included in the call to `set_param`. For example, suppose the currently selected block has a single input port. The following code fragment sets `foo` as the connection callback on the input port.

```
phs = get_param(gcb, 'PortHandles');
set_param(phs.Inport, 'ConnectionCallback', 'foo');
```

where, `foo` is defined as:

```
function foo(portHandle)
```

Example Callback Function Tasks

The following sections describe simple examples for commonly used callback routines.

Loading Variables Automatically When Opening a Model

You can use the `PreloadFcn` callback to automatically preload variables into the MATLAB workspace when you open your model.

Some variables might be required by parameters in different parts of the Simulink model. For example, if you have a model which contains a Gain block and the gain is specified as `K`, Simulink looks for the variable `K` to be defined. Using the following technique, you can automatically define `K` every time the model is opened.

You can define variables, such as `K`, in a MATLAB script. You can use the `PreLoadFcn` callback to execute the MATLAB script.

To create model callbacks interactively, open the model's Model Properties dialog box and use the **Callbacks** pane to edit callbacks (see "Callbacks Pane" on page 3-104).

To create a callback programmatically, enter the following at the MATLAB command prompt:

```
set_param('mymodelname','PreloadFcn', 'expression')
```

where `expression` is a valid MATLAB command or a MATLAB script that exists in your MATLAB search path.

For example, if your model is called `modelname.mdl` and your variables are defined in a MATLAB script called `loadvar.m`, you would type the following:

```
set_param('modelname','PreloadFcn', 'loadvar')
```

Now save the model. Every time you subsequently open this model, the `loadvar` function will execute. You can see the variables from the `loadvar.m` declared in the MATLAB workspace.

Executing a MATLAB Script by Double-Clicking a Block

You can use the `OpenFcn` callback to automatically execute MATLAB scripts when the you double-clicks a block. MATLAB scripts can perform many different tasks such as defining variables for a block, making a call to MATLAB which brings up a plot of simulated data, or generating a GUI.

The `OpenFcn` overrides the normal behavior which occurs when opening a block (its parameter dialog box is displayed or a subsystem is opened).

To create block callbacks interactively, open the block's Block Properties dialog box and use the **Callbacks** pane to edit callbacks (see "Callbacks Pane" on page 18-19). To create the `OpenFcn` callback programmatically, click the block that you want to add this property to, then enter the following at the MATLAB command prompt:

```
set_param(gcb,'OpenFcn','expression')
```

where `expression` is a valid MATLAB command or a MATLAB script that exists in your MATLAB search path.

The following example shows how to setup the callback to execute a MATLAB script called `myfunction.m` when double clicking a subsystem called `mysubsystem`.

```
set_param('mymodelname/mysubsystem','OpenFcn','myfunction')
```

Executing Commands Before Starting Simulation

You can use the `StartFcn` callback to automatically execute commands before your simulation starts. For example, you can make all of the Scope blocks that exist in a model come to the forefront before running the simulation.

Specifically, you can create a simple MATLAB script named `openscopes.m` and save it on your MATLAB search path, as shown in the following example.

```
% openscopes.m
% Brings scopes to forefront at beginning of simulation.

blocks = find_system(bdroot,'BlockType','Scope');

% Finds all of the scope blocks on the top level of your
 % model to find scopes in subsystems, give the subsystem
 % names. Type help find_system for more on this command.

for i = 1:length(blocks)
  set_param(blocks{i},'Open','on')
end

% Loops through all of the scope blocks and brings them
 % to the forefront
```

After you have created this MATLAB script,, set the `StartFcn` for the model to call the script. For example,

```
set_param('mymodelname','StartFcn','openscopes')
```

Now every time you run the model, all of the Scope blocks should open automatically and be in the forefront.

Using Model Workspaces

In this section...

About Model Workspaces

Each model is provided with its own workspace for storing variable values. The model workspace is similar to the base MATLAB workspace except that:

- Variables in a model workspace are visible only in the scope of the model.

  If both the MATLAB workspace and a model workspace define a variable of the same name, and the variable does not appear in any intervening masked subsystem or model workspaces, the Simulink software uses the value of the variable in the model workspace. A model's workspace effectively provides it with its own name space, allowing you to create variables for the model without risk of conflict with other models.

- When the model is loaded, the workspace is initialized from a data source.

  The data source can be the MDL-file for the model, a MAT-file, a MATLAB file, or MATLAB code stored in the model file (see "Data source" on page 3-72 for more information).

- You can interactively reload and save MAT-file, MATLAB file, and MATLAB code data sources.

- Only `Simulink.Parameter` and `Simulink.Signal` objects for which the storage class is set to `Auto` can reside in a model workspace. You must create all other Simulink data objects in the base MATLAB workspace to ensure the objects are unique within the global Simulink context and accessible to all models.

Note Subclasses of `Simulink.Parameter` and `Simulink.Signal` classes, including `mpt.Parameter` and `mpt.Signal` objects (Real-Time Workshop® Embedded Coder license required), can reside in a model workspace only if their storage class is set to `Auto`.

- In general, parameter variables in a model workspace are not tunable.

  However, you can tune model workspace variables declared as model arguments for referenced models (for more information, see "Using Model Arguments" on page 5-41).

Note When resolving references to variables used in a referenced model, the variables of the referenced model are resolved as if the parent model did not exist. For example, suppose a referenced model references a variable that is defined in both the parent model's workspace and in the MATLAB workspace but not in the referenced model's workspace. In this case, the MATLAB workspace is used. (See Chapter 5, "Referencing a Model".)

Note When you use a workspace variable as a block parameter, Simulink creates a copy of the variable during the compilation phase of the simulation and stores the variable in memory. This can cause your system to run out of memory during simulation, or in the process of generating code. Your system might run out of memory if you have:

- Large models with many parameters
- Models with parameters that have a large number of elements

This issue does not affect the amount of memory that is used to represent parameters in generated code.

Simulink.ModelWorkspace Data Object Class

An instance of this class describes a model workspace. Simulink creates an instance of this class for each model that you open during a Simulink session.

The methods associated with this class can be used to accomplish a variety of tasks related to the model workspace, including:

- Listing the variables in the model workspace
- Assigning values to variables
- Evaluating expressions
- Clearing the model workspace
- Reloading the model workspace from the data source
- Saving the model workspace to a specified MAT-file or MATLAB file
- Saving the workspace to the MAT-file or MATLAB file that the workspace designates as its data source

For more information, see the reference page for the `Simulink.ModelWorkspace` data object class.

Changing Model Workspace Data

The procedure for modifying a workspace depends on the data source of the model workspace.

Changing Workspace Data Whose Source Is the Model File

If the data sources of a model workspace is data stored in the model, you can use Model Explorer (see "The Model Explorer: Overview" on page 8-2) or MATLAB commands to change the model's workspace (see "Using MATLAB Commands to Change Workspace Data" on page 3-70).

For example, to create a variable in a model workspace, using Model Explorer, first select the workspace in the Model Explorer **Model Hierarchy** pane. Then select **MATLAB Variable** from Model Explorer **Add** menu or toolbar. You can similarly use the **Add** menu or toolbar to add a `Simulink.Parameter` object to a model workspace.

To change the value of a model workspace variable, select the workspace, then select the variable in Model Explorer's Contents pane and edit the value displayed in the Contents pane or in Model Explorer **Dialog** pane. To delete a model workspace variable, select the variable in the **Contents** pane and from

the Model Explorer**Edit** menu or toolbar and then select **Delete**. To save the changes, save the model.

Changing Workspace Data Whose Source Is a MAT-File or MATLAB File

You can also use Model Explorer or MATLAB commands to modify workspace data whose source is a MAT-file or MATLAB file. In this case, if you want to make the changes permanent, you must save the changes to the MAT-file or MATLAB file, using the **Save To Source** button on the Model Workspace dialog box (see "Model Workspace Dialog Box" on page 3-71). To discard changes to the workspace, use the **Reinitialize From Source** button on the Model Workspace dialog box.

Changing Workspace Data Whose Source Is MATLAB Code

The safest way to change data whose source is MATLAB code is to edit and reload the source (that is, edit the MATLAB code and then clear the workspace and reexecute the code, using the **Reinitialize From Source** button on the Model Workspace dialog box).

To save and reload alternative versions of the workspace that result from editing the MATLAB code source or the workspace variables themselves, see "Exporting Workspace Variables" on page 8-54 and "Importing Workspace Variables" on page 8-56.

Using MATLAB Commands to Change Workspace Data

To use MATLAB commands to change data in a model workspace, first get the workspace for the currently selected model:

```
hws = get_param(bdroot, 'modelworkspace');
```

This command returns a handle to a `Simulink.ModelWorkspace` object whose properties specify the source of the data used to initialize the model workspace. Edit the properties to change the data source. Use the workspace methods to:

- List, set, and clear variables
- Evaluate expressions in the workspace

- Save and reload the workspace

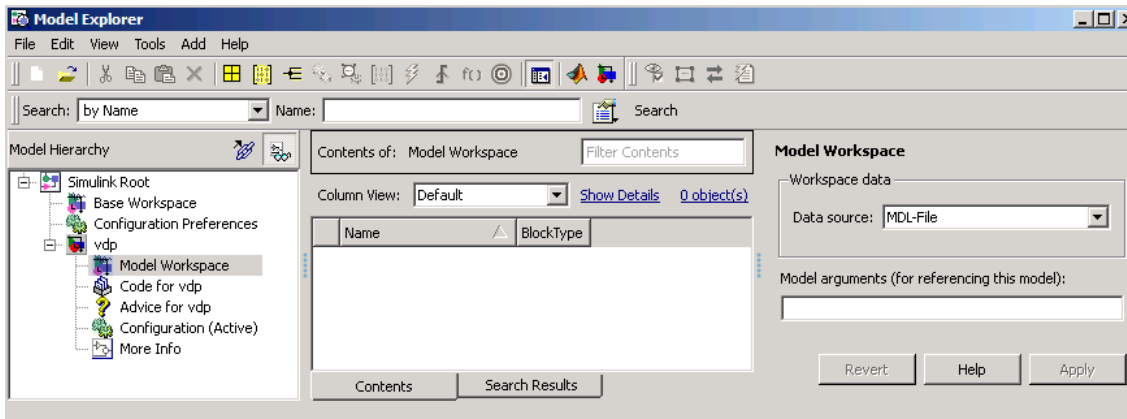
For example, the following MATLAB code creates variables specifying model parameters in the model workspace, saves the parameters, modifies one of them, and then reloads the workspace to restore it to its previous state.

```
hws = get_param(bdroot, 'modelworkspace');
hws.DataSource = 'MAT-File';
hws.FileName = 'params';
hws.assignin('pitch', -10);
hws.assignin('roll', 30);
hws.assignin('yaw', -2);
hws.saveToSource;
hws.assignin('roll', 35);
hws.reload;
```

Model Workspace Dialog Box

The Model Workspace dialog box enables you to specify a data source for a model workspace and to specify model reference arguments. To display the dialog box for a model workspace:

1. Right-click the model workspace in the Model Explorer **Model Hierarchy** pane.



2. Select the **Properties** menu item.

The dialog box contains a **Data source** control and a **Model arguments (for referencing this model)** control.

To use MATLAB commands to change data in a model workspace, see "Using MATLAB Commands to Change Workspace Data" on page 3-70.

Data source

Specifies the data source of this workspace. The options are

- `Mdl-File`

  Specifies that the data source is the model itself.

- `MAT-File`

  Specifies that the data source is a MAT file. Selecting this option causes additional controls to appear (see "MAT-File and MATLAB File Source Controls" on page 3-72).

- `MATLAB File`

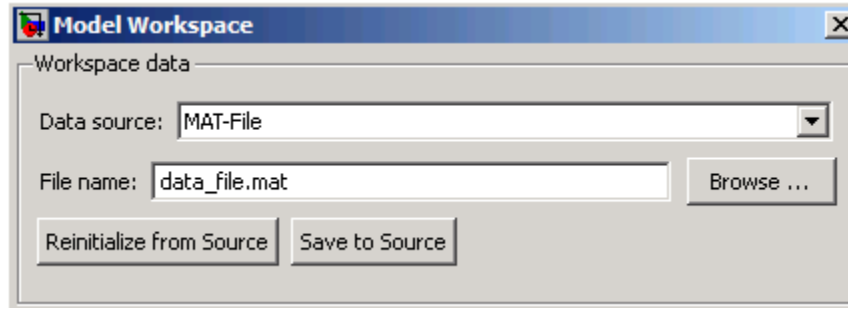
  Specifies that the data source is a MATLAB file. Selecting this option causes additional controls to appear (see "MAT-File and MATLAB File Source Controls" on page 3-72).

- `MATLAB Code`

  Specifies that the data source is MATLAB code stored in the model file. Selecting this option causes additional controls to appear (see "MATLAB Code Source Controls" on page 3-73).

MAT-File and MATLAB File Source Controls

Selecting `MAT-File` or `MATLAB File` as the **Data source** for a workspace causes the Model Workspace dialog box to display additional controls.



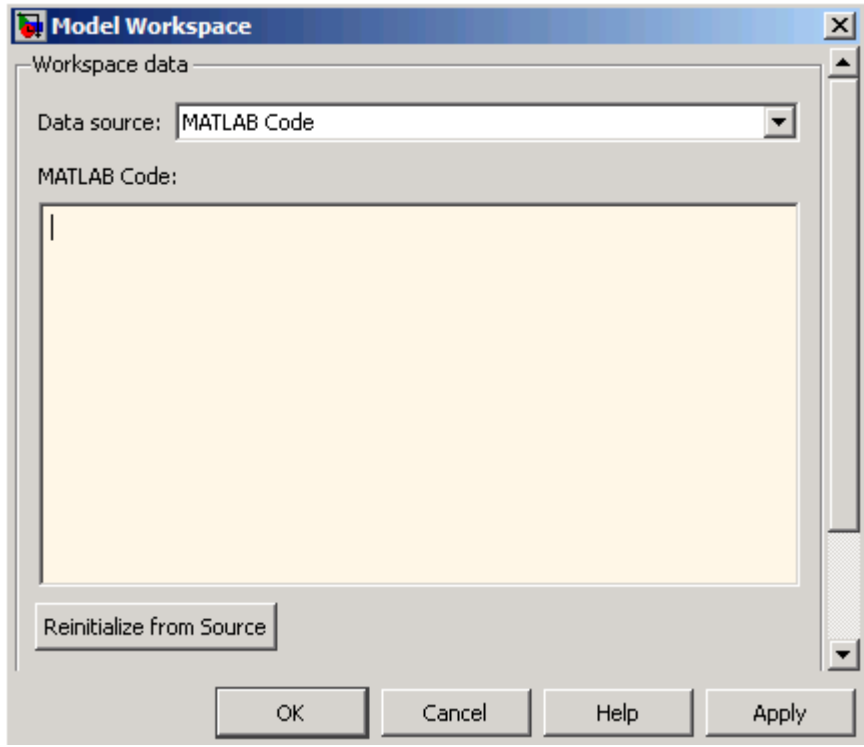
File name. File name or path name of the MAT-file or MATLAB file that is the data source for the selected workspace. If you specify a file name, the name must reside on the MATLAB path.

Reinitialize From Source. Clears the workspace and reloads the data from the MAT-file or MATLAB file specified by the **File name** field.

Save To Source. Save the workspace in the MAT-file or MATLAB file specified by the **File name** field.

MATLAB Code Source Controls

Selecting `MATLAB Code` as the **Data source** for a workspace causes the Model Workspace dialog box to display additional controls.



MATLAB Code. Specifies MATLAB code that initializes the selected workspace. To change the initialization code, edit this field, then select the **Reinitialize from source** button on the dialog box to clear the workspace and execute the modified code.

Reinitialize from Source. Clears the workspace and executes the contents of the **MATLAB Code** field.

Model Arguments (For Referencing This Model)

This field allows you to specify arguments that can be passed to instances of this model referenced by another model. For more information, see "Using Model Arguments" on page 5-41.

Resolving Symbols

In this section...

About Symbol Resolution

When you create a Simulink model, you can use symbols to provide values and definitions for many types of entities in the model. Model entities that can be defined with symbols include block parameters, configuration set parameters, data types, signals, signal properties, and bus architecture.

A symbol that provides a value or definition must be a legal MATLAB identifier. Such an identifier starts with an alphabetic character, followed by alphanumeric or underscore characters up to the length given by the function `namelengthmax`. You can use the function `isvarname` to determine whether a symbol is a legal MATLAB identifier.

A symbol provides a value or definition in a Simulink model by corresponding to some item that:

- Exists in an accessible workspace
- Has a name that matches the symbol
- Provides the required information

The process of searching for and finding an item that corresponds to a symbol is called *resolving* the symbol. The matching item can provide the needed information directly, or it can itself be a symbol, which must then resolve to some other item that provides the information.

When the Simulink software compiles a model, it tries to resolve every symbol in the model, except symbols in MATLAB code that runs in a callback or as part of mask initialization. Depending on the particular case, the item to which a symbol resolves can be a variable, object, or function.

Hierarchical Symbol Resolution

The Simulink software attempts to resolve a symbol by searching through the accessible workspaces in hierarchical order for a MATLAB variable or Simulink object whose name is the same as the symbol. The search path is identical for every symbol. The search begins with the block that uses the symbol, or is the source of a signal that is named by the symbol, and proceeds upward. Except when simulation occurs via the `sim` command, the search order is the following:

1. Any mask workspaces, in order from the block upwards (see "Understanding Mask Parameters" on page 21-19)
2. The model workspace of the model that contains the block (see "Using Model Workspaces" on page 3-67)
3. The MATLAB base workspace (See "MATLAB Workspace")

If the Simulink software finds a matching item in the course of this search, the search terminates successfully at that point, and the symbol resolves to the matching item. The result is the same as if the value of that item had appeared literally instead of the symbol that resolved to the item. An object defined at a lower level shadows any object defined at a higher level.

If no matching item exists on the search path, the Simulink software attempts to evaluate the symbol as a function. If the function is defined and returns an appropriate value, the symbol resolves to whatever the function returned. Otherwise, the symbol remains unresolved, and an error occurs. Evaluation as a function occurs as the final step whenever a hierarchical search terminates without having found a matching workspace variable.

If the model that contains the symbol is a referenced model, and the search reaches the model workspace but does not succeed there, the search jumps directly to the base workspace *without* trying to resolve the symbol in the workspace of any parent model. Thus a given symbol will resolve to the

same item irrespective of whether the model that contains the symbol is a referenced model. See Chapter 5, "Referencing a Model" for information about model referencing.

Specifying Numeric Values with Symbols

Any block parameter that requires a numeric value can be specified by providing a literal value, a symbol, or an expression, which can contain symbols and literal values. Each symbol is resolved separately, as if none of the others existed. Different symbols in an expression can thus resolve to items on different workspaces, and to different types of item.

When a single symbol appears and resolves successfully, its value provides the value of the parameter. When an expression appears, and all symbols resolve successfully, the value of the expression provides the value of the parameter. If any symbol cannot be resolved, or resolves to a value of inappropriate type, an error occurs.

For example, suppose that the **Gain** parameter of a Gain block is given as `cos(a*(b+2))`. The symbol `cos` will resolve to the MATLAB cosine function, and `a` and `b` must resolve to numeric values, which can be obtained from the same or different types of items in the same or different workspaces. If the symbols resolve to numeric values, the value returned by the cosine function becomes the value of the **Gain** parameter.

Specifying Other Values with Symbols

Most symbols and expressions that use them provide numeric values, but the same techniques that provide numeric values can provide any type of value that is appropriate for its context. Another common use of symbols is to name objects that provide definitions of some kind. For example, a signal name can resolve to a signal object (`Simulink.Signal`) that defines the properties of the signal, and a Bus Creator block **Data type** parameter can name a bus object (`Simulink.Bus`) that defines the properties of the bus. Symbols can be used when defining data types, can specify input data sources and logged data destinations, and can serve many other purposes.

From the standpoint of hierarchical symbol resolution, all of these different uses of symbols, whether singly or in expressions, are the same: each symbol is resolved, if possible, independently of any others, and the result becomes

available where the symbol appeared. The only difference between one symbol and another is the specific item to which the symbol resolves and the use made of that item. The only requirement is that every symbol must resolve to something that can legally appear at the location of the symbol.

Limiting Signal Resolution

Hierarchical symbol resolution traverses the complete search path by default. You can truncate the search path by using the **Permit Hierarchical Resolution** option of any subsystem. This option controls what happens if the search reaches that subsystem without resolving to a workspace variable. The **Permit Hierarchical Resolution** values are:

- `All`

  Continue searching up the workspace hierarchy trying to resolve the symbol. This is the default value.

- `None`

  Do not continue searching up the hierarchy.

- `ExplicitOnly`

  Continue searching up the hierarchy only if the symbol specifies a block parameter value, data store memory (where no block exists), or a signal or state that explicitly requires resolution. Do not continue searching for an implicit resolution. See “Explicit and Implicit Symbol Resolution” on page 3-78 for more information.

If the search does not find a match in the workspace, and terminates because the value is `ExplicitOnly` or `None`, the Simulink software evaluates the symbol as a function. The search succeeds or fails depending on the result of the evaluation, as previously described.

Explicit and Implicit Symbol Resolution

Models and some types of model entities have associated parameters that can affect symbol resolution. For example, suppose that a model includes a signal named Amplitude, and that a `Simulink.Signal` object named Amplitude exists in an accessible workspace. If the Amplitude signal’s **Signal name**

must resolve to Simulink signal object option is checked, the signal will resolve to the object. See "Signal Properties Dialog Box" for more information.

If the option is not checked, the signal may or may not resolve to the object, depending on the value of **Configuration Parameters > Data Validity > Signal resolution**. This parameter can suppress resolution to the object even though the object exists, or it can specify that resolution occurs on the basis of the name match alone. See "Diagnostics Pane: Data Validity" > "Signal resolution" for more information.

Resolution that occurs because an option like **Signal name must resolve to Simulink signal object** requires it is called *explicit symbol resolution*. Resolution that occurs on the basis of name match alone, without an explicit specification, is called *implicit symbol resolution*.

MathWorks discourages using implicit symbol resolution except for fast prototyping, because implicit resolution slows performance, complicates model validation, and can have nondeterministic effects.

Consulting the Model Advisor

In this section...

About the Model Advisor

The Model Advisor checks a model or subsystem for conditions and configuration settings that can result in inaccurate or inefficient simulation of the system that the model represents. If you have a Real-Time Workshop or Simulink® Verification and Validation™ license, the Model Advisor can also check for model settings that result in generation of inefficient code or code unsuitable for safety-critical applications. (For more information about using the Model Advisor in code generation applications, see "Getting Advice About Optimizing Models for Code Generation" in the Real-Time Workshop documentation.)

The Model Advisor produces a report that lists the suboptimal conditions or settings that it finds, suggesting better model configuration settings where appropriate. In some cases, the Model Advisor provides mechanisms for automatically fixing warnings and failures or fixing them in batches. For more information on individual checks, see "Model Advisor Checks" in the Simulink, Real-Time Workshop, and Simulink Verification and Validation Reference documentation.

Starting the Model Advisor

You can use any of the following methods to start the Model Advisor.

Note Before starting the Model Advisor, ensure that the current folder is writable. If the folder is not writable, you see an error message when you start the Model Advisor.

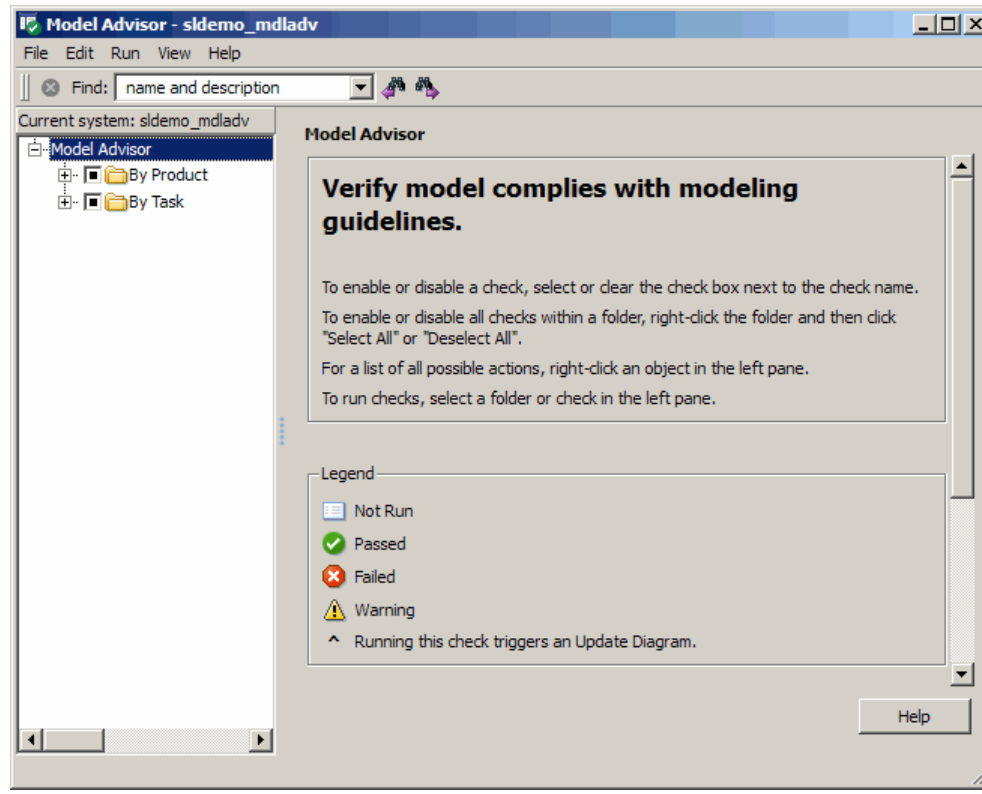
The Model Advisor uses the Simulink project (`slprj`) folder in the current folder to store reports and other information. If this folder does not exist in the current folder, the Model Advisor creates it.

To start the Model Advisor...	For a...	Do this:
From the Model Editor	Model or subsystem	**1** From the **Tools** menu, select **Model Advisor**. The System Selector window opens. **2** Select the model or subsystem of interest. **3** Click **OK**.
From the Model Explorer	Model	In the **Contents** pane, select **Advice for *`model`***, where ***`model`*** is the name of the model that you want to check. (For more information, see "The Model Explorer: Overview" on page 8-2.)

To start the Model Advisor...	For a...	Do this:
From the context menu	Subsystem	Right-click the subsystem that you want to check and select **Model Advisor**.
Programmatically	Model or subsystem	At the MATLAB prompt, enter `modeladvisor(`*`model`*`)`, where *`model`* is a handle or name of the model or subsystem that you want to check. (For more information, see the `modeladvisor` function reference page.)

Overview of the Model Advisor Window

When you start the Model Advisor, the Model Advisor window displays two panes. The left pane lists the folders in the Model Advisor. Expanding the folders displays the available checks. The right pane provides instructions on how to view, enable, and disable checks, and provides a legend explaining the displayed symbols.



From the left pane, you can:

- Select **By Task** to display checks related to specific tasks, such as updating the model to be compatible with the current Simulink version.
- Select some or all of the checks using the check boxes or context menus associated with the checks, and then run an individual check or all selected checks.
- Reset the status of the checks to not run by right-clicking **Model Advisor** in the right pane and selecting `Reset` from the context menu.
- Specify input parameters for some checks to run (for an example, see "Check for proper Merge block usage" in the **Product > Simulink** folder).

After running checks, the Model Advisor displays the results in the right pane. Additionally, the Model Advisor generates an HTML report of the check results, which you can optionally view in a separate browser window by clicking the **Report** link at the folder level.

Note When you open the Model Advisor on a model that you have previously checked, the Model Advisor initially displays the check results generated the last time you checked the model. If you recheck the model, the new results replace the previous results in the Model Advisor window.

To find checks and folders, enter text in **Find** and click the **Find Next** button (). The Model Advisor searches in check names, folder names, and analysis descriptions for the text.

Running Model Advisor Checks

To use the Model Advisor to perform checks on your model and view the check results:

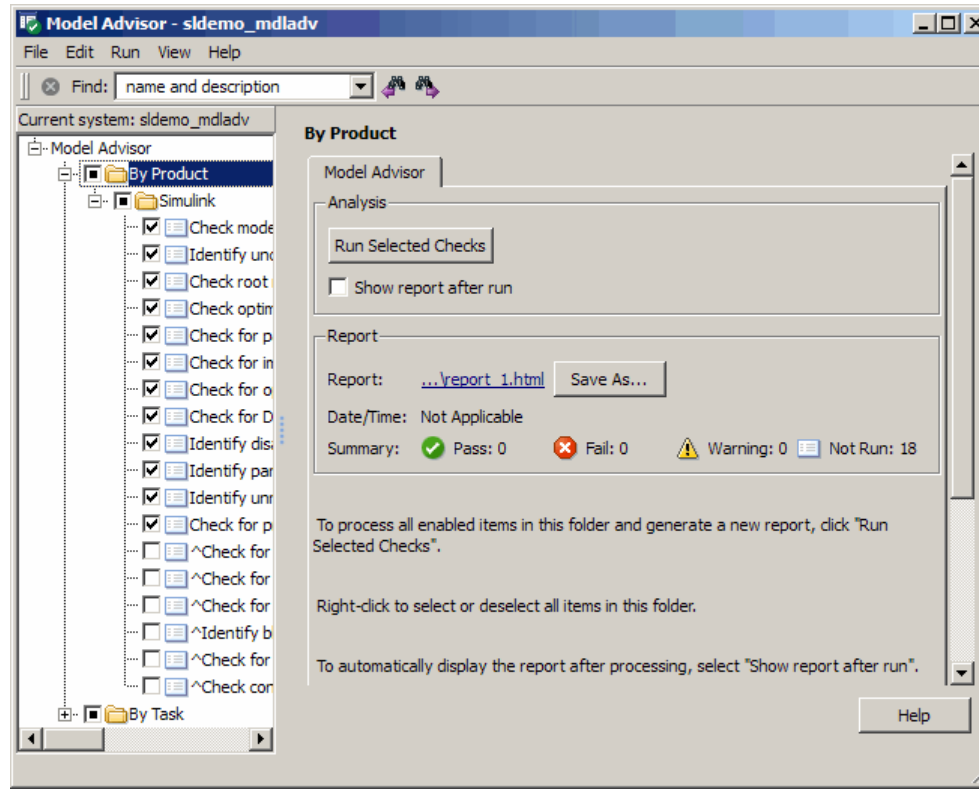
1. Open your model. For example, open the Model Advisor demo: `sldemo_mdladv`.
2. Start the Model Advisor.
   a. From the Model Editor **Tools** menu, select **Model Advisor** .

      The System Selector window opens.

   b. In the System Selector window, select the model or system that you want to review. For example, `sldemo_mdladv` and click **OK**.

      The Model Advisor window opens and displays checks for the `sldemo_mdladv` demo model.
3. In the left pane, expand the **By Product** folder to display the subfolders.
4. In the left pane, expand the **Simulink** folder to display the available checks.

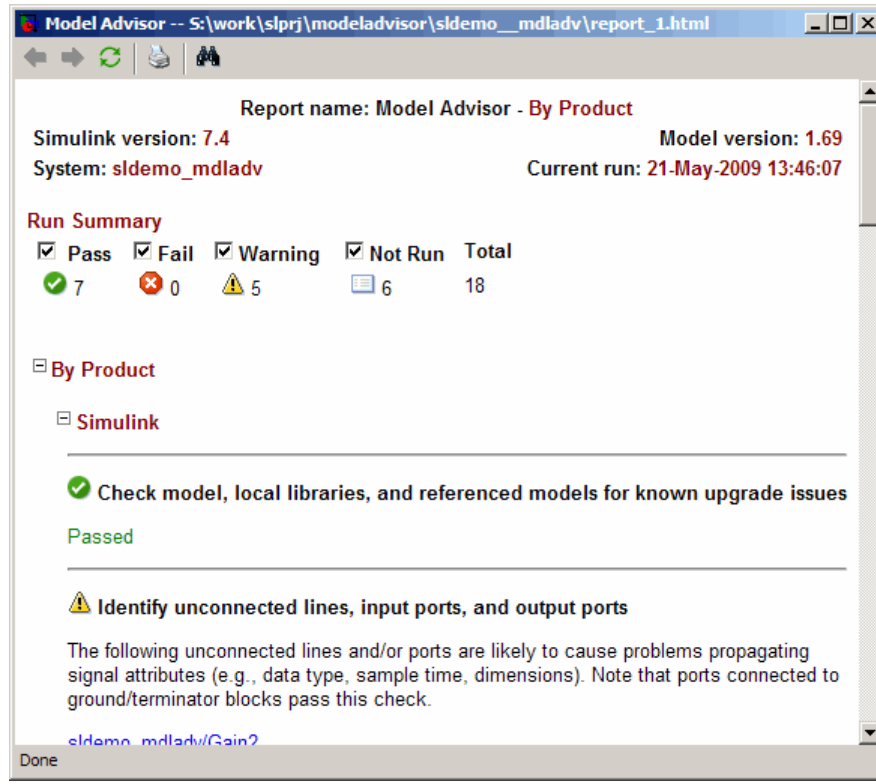
5 Select the **By Product** folder in the left pane. The right pane changes to a **By Product** view.



6 Select the **Show report after run** check box. This option causes an HTML report of check results to appear after you run the checks.

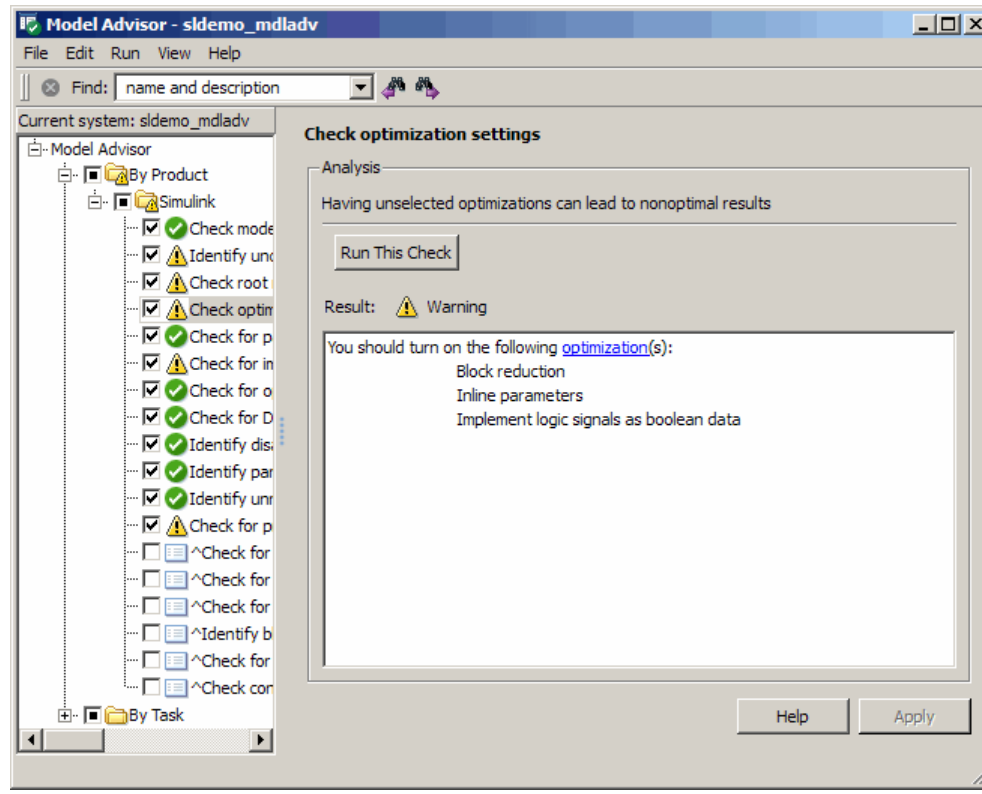
7 Run the selected checks by clicking the **Run Selected Checks** button. After the Model Advisor runs the checks, an HTML report displays the check results in a browser window.

Tip While you can fix warnings and failures through Model Advisor reports, use the Model Advisor window for interactive fixing. Model Advisor reports are best for viewing a summary of checks.



8 Return to the Model Advisor window, which shows the check results.

9 Select an individual check to open a detailed view of the results in the right pane. For example, selecting **Check optimization settings** changes the right pane to the following view. Use this view to examine and exercise a check individually.



10 After reviewing the check results, you can choose to fix warnings or failures as described in "Fixing a Warning or Failure" on page 3-87.

Fixing a Warning or Failure

Checks fail when a model or submodel has a suboptimal condition. A warning result is informational. You can choose to fix the reported issue, or move on to the next task. For more information on why a specific check does not pass, see the "Simulink Checks" documentation.

Caution When you fix a warning or failure, rerun all checks to update the results of all checks. If you do not rerun all checks, the Model Advisor might report an invalid check result.

The Model Advisor provides the following ways to fix warnings and failures:

- Follow the instructions in the Analysis Result box to manually fix any warning or failure. See “Manually Fixing Warnings or Failures” on page 3-88.
- Use the Action box, when available, to automatically fix all failures. See “Automatically Fixing Warnings or Failures” on page 3-89.
- Use the Model Advisor Results Explorer, when available, to batch-fix failures. See “Batch-Fixing Warnings or Failures” on page 3-90.

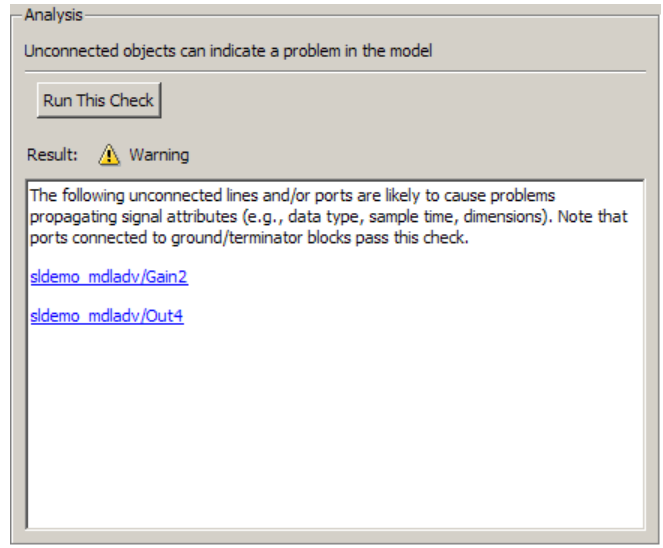
Manually Fixing Warnings or Failures

All checks have an Analysis Result box that describes the recommended actions to manually fix warnings or failures.

To manually fix warnings or failures within a task:

1. Optionally, save a model and data restore point so you can undo the changes that you make. For more information, see “Reverting Changes Using Restore Points” on page 3-92.

2 In the Analysis Result box, review the recommended actions. Use the information to make changes to your model.



3 Rerun the check to verify that it passes.

Caution When you fix a warning or failure, rerun all checks to update the results of all checks. If you do not rerun all checks, the Model Advisor might report an invalid check result.

Automatically Fixing Warnings or Failures

Some checks have an Action box where you can automatically fix failures. The action box applies all of the recommended actions listed in the Analysis Result box.

Caution Review the Analysis Result box before automatically fixing failures to ensure that you want to apply all of the recommended actions. If you do not want to apply all of the recommended actions, do not use this method to fix warnings or failures.

To automatically fix all warnings or failures within a check:

1. Optionally, save a model and data restore point so you can undo the changes that you made by clicking the **Modify All** button. For more information, see "Reverting Changes Using Restore Points" on page 3-92.
2. In the Action box, click **Modify All**.

   The Action Result box displays a table of changes.
3. Rerun the check to verify that it passes.

Caution When you fix a warning or failure, rerun all checks to update the results of all checks. If you do not rerun all checks, the Model Advisor might report an invalid check result.

Batch-Fixing Warnings or Failures

Some checks in the Model Advisor have an **Explore Result** button that starts the Model Advisor Result Explorer. The Model Advisor Result Explorer allows you to quickly locate, view, and change elements of a model.

The Model Advisor Result Explorer, a version of the Model Explorer, helps you to modify only the items that the Model Advisor is checking. For more information about using this window, see "The Model Explorer: Overview" on page 8-2.

If a check does not pass and you want to explore the results and make batch changes:

1. Optionally, save a model and data restore point so you can undo any changes that you make. For more information, see "Reverting Changes Using Restore Points" on page 3-92.

2. In the Analysis box, click **Explore Result**.

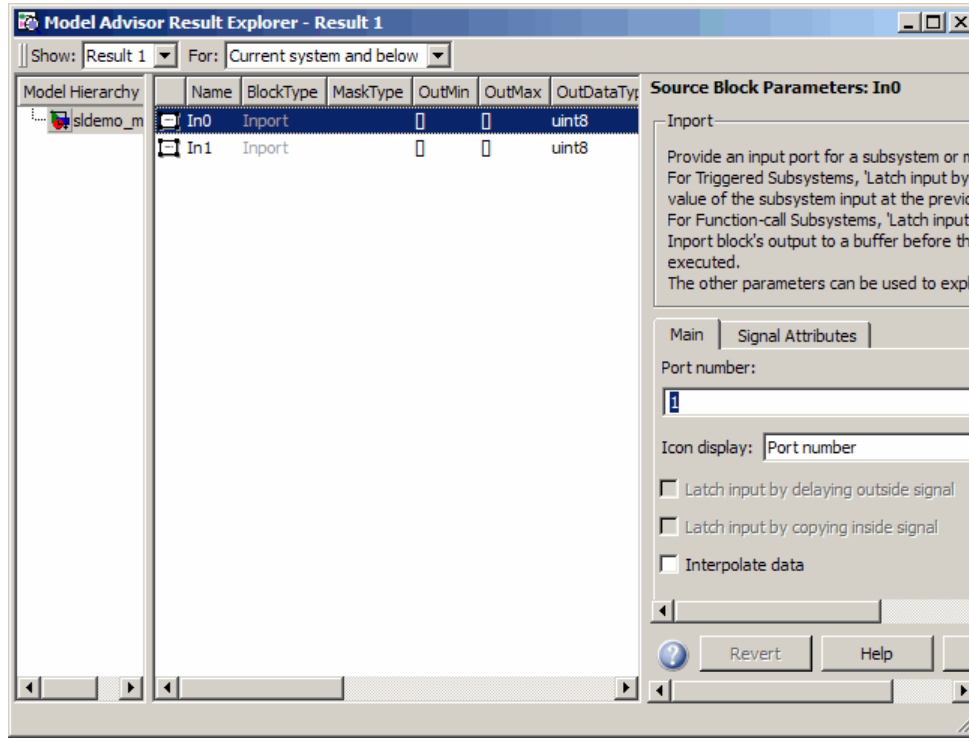
   The Model Advisor Result Explorer window opens.

3. Use the Model Advisor Result Explorer to modify block parameters.

4. In the Model Advisor window, rerun the check to verify that it passes.

Caution When you fix a warning or failure, rerun all checks to update the results of all checks. If you do not rerun all checks, the Model Advisor might report an invalid check result.

In the following example, run **Check root model Inport block specifications** for the `sldemo_mdladv` model. The result is a warning. Clicking the **Explore Result** button opens the Model Advisor Result Explorer window.



Reverting Changes Using Restore Points

The Model Advisor provides a model and data restore point capability for reverting changes that you made in response to advice from the Model Advisor. A *restore point* is a snapshot in time of the model, base workspace, and Model Advisor. The Model Advisor maintains restore points for the model or subsystem of interest through multiple sessions of MATLAB.

Caution A restore point saves only the current working model, base workspace variables, and Model Advisor tree. It does not save other items, such as libraries and referenced submodels.

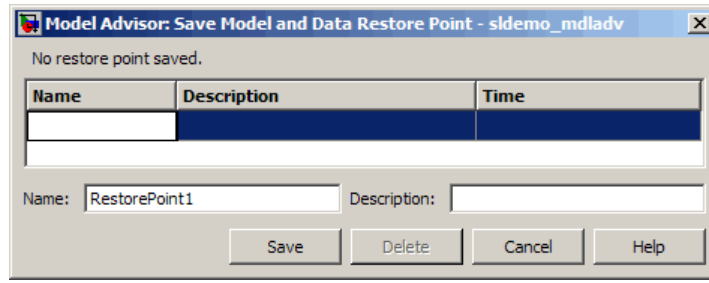
Saving a Restore Point

You can save a restore point and give it a name and optional description, or allow the Model Advisor to automatically name the restore point for you.

To save a restore point with a name and optional description:

1. Go to **File > Save Restore Point As**.

   The Save Model and Data Restore Point dialog box opens.



2. In the **Name** field, enter a name for the restore point.

3. In the **Description** field, you can optionally add a description to help you identify the restore point.

4. Click **Save**.

   The Model Advisor saves a restore point of the current model, base workspace, and Model Advisor status.

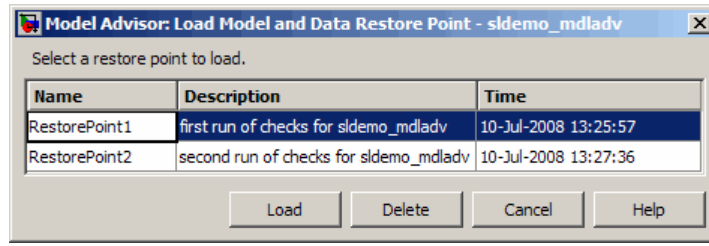
To quickly save a restore point, go to **File > Save Restore Point**. The Model Advisor saves a restore point with the name `autosave`*n*, where *n* is the sequential number of the restore point. If you use this method, you cannot change the name of, or add a description to, the restore point.

Loading a Restore Point

To load a restore point:

1. Optionally, save a model and data restore point so you can undo any changes that you make.
2. Go to **File > Load Restore Point**.

   The Load Model and Data Restore Point dialog box opens.



3. Select the restore point that you want.
4. Click **Load**.

   The Model Advisor issues a warning that the restoration will remove all changes that you made after saving the restore point.
5. Click **Load** to load the restore point you selected.

   The Model Advisor reverts the model, base workspace, and Model Advisor status.

Viewing and Saving Model Advisor Reports

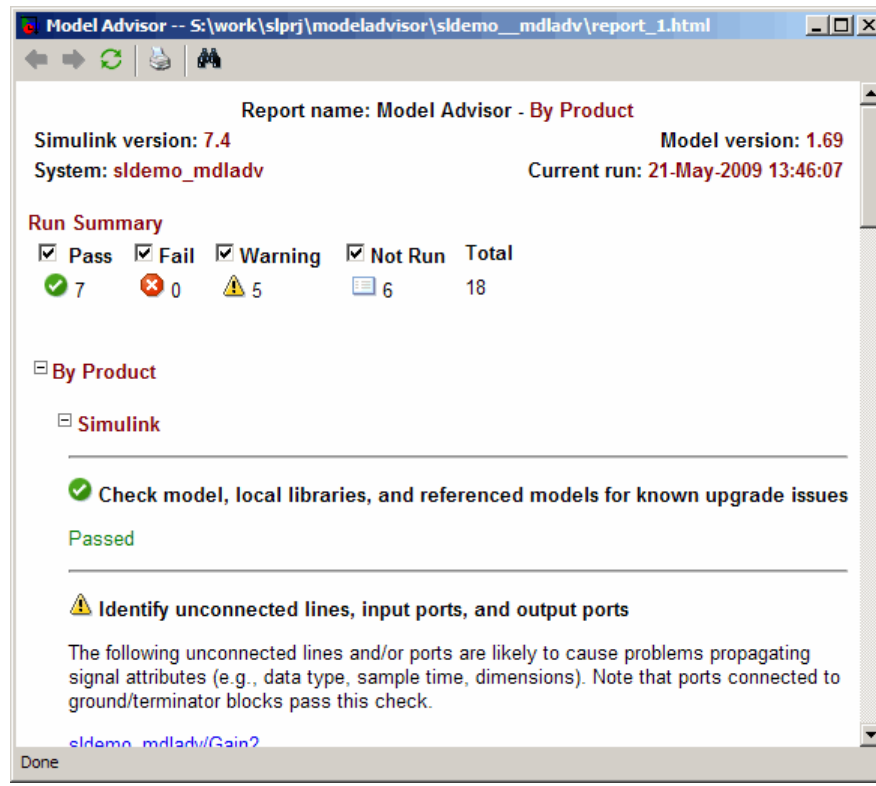
When the Model Advisor runs checks, it generates an HTML report of check results. Each folder in the Model Advisor contains a report for all of the checks in that folder and the subfolders within that folder.

Viewing Model Advisor Reports

You can access any report by selecting a folder and clicking the link in the **Report** box.

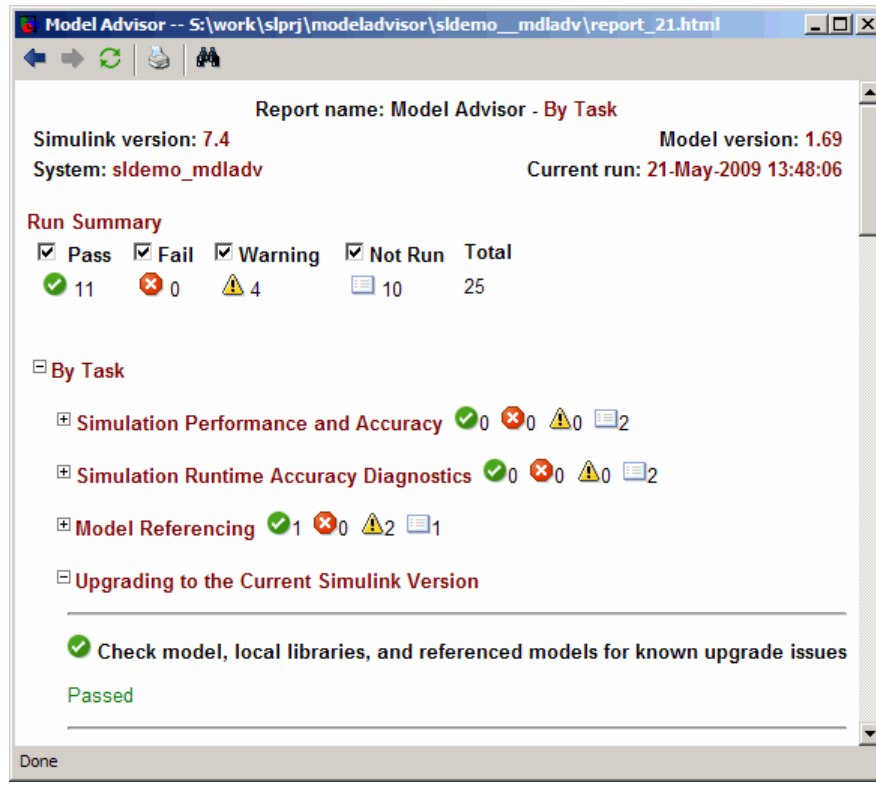
Tip While you can fix warnings and failures through Model Advisor reports, use the Model Advisor window for interactive fixing. Model Advisor reports are best for viewing a summary of checks.

As you run checks, the Model Advisor updates the reports with the latest information for each check in the folder. A message appears in the report when you run the checks at different times. Time stamps indicate when checks have been run. The time of the current run appears at the top right of the report. Checks that occurred during previous runs have a time stamp following the check name.



You can manipulate the report to show only what you are interested in viewing as follows:

- The check boxes next to the Run Summary status allow you to view only the checks with the status that you are interested in viewing. For example, you can remove the checks that have not run by clearing the check box next to the Not Run status.
- Minimize folder results in the report by clicking the minus sign next to the folder name. When you minimize a folder, the report updates to display a run summary for that folder:



Saving Model Advisor Reports

You can archive a Model Advisor report by saving it to a new location. To save a report:

1. In the Model Advisor window, navigate to the folder that contains the report you want to save.
2. Select the folder that you want. The right pane of the Model Advisor window displays information about that folder, including a **Report** box.
3. In the Report box, click **Save As**. A save as dialog box opens.
4. In the save as dialog box, navigate to the location where you want to save the report, and click **Save**. The Model Advisor saves the report to the new location.

Note If you rerun the Model Advisor, the report is updated in the working folder, not in the save location.

You can find the full path to the report in the title bar of the report window. Typically, the report is in the working folder: `slprj/modeladvisor/`*`model_name`*.

Running the Model Advisor Programmatically

If you have a Simulink Verification and Validation license, you can create MATLAB scripts and functions that run the Model Advisor programmatically. For example, you can create a function to check whether your model passes a specified set of the Model Advisor checks every time you open the model or start a simulation or generate code from the model. For more information, see the `ModelAdvisor.run` function in the Simulink Verification and Validation documentation.

Model Advisor Limitations

When you use the Model Advisor to check systems, the following limitations apply:

- If you rename a system, you must restart the Model Advisor to check that system.
- In systems that contain a variant subsystem, the Model Advisor checks only the active subsystem.

For limitations that apply to specific checks, see the Limitations section within the documentation of each check.

Managing Model Versions

In this section...

How Simulink Helps You Manage Model Versions

The Simulink software has these features to help you to manage multiple versions of a model:

- Model File Change Notification helps you manage work with source control operations and multiple users
- As you edit a model, the Simulink software generates version control information about the model, including a version number, who created and last updated the model, and an optional change history. The Simulink software automatically saves these **Version Control Properties** with the model
- The Model Properties dialog box lets you edit some of the version control information stored in the model and select various version control options
- The Model Info block lets you display version control information, including information maintained by an external version control system, as an annotation block in a model diagram
- The Simulink software version control parameters let you access version control information from the MATLAB command line or a MATLAB script
- The **Source Control** submenu of the **File** menu allows you to check models into and out of your source control system. See "Source Control Interface" in the online MATLAB documentation for more information.

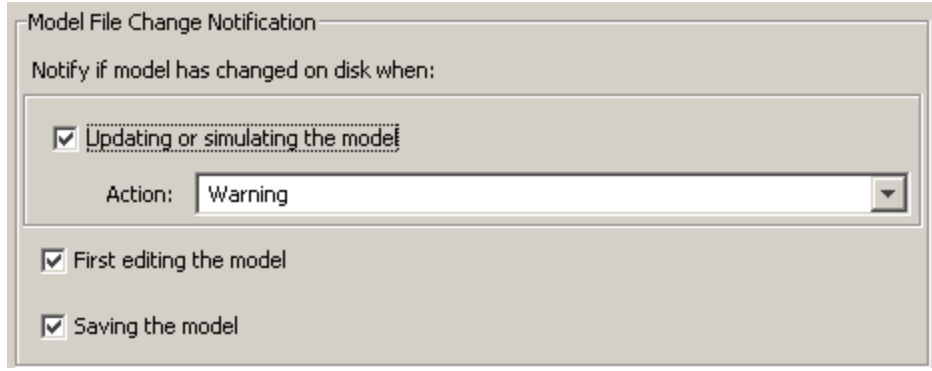
Model File Change Notification

You can use the Simulink Preferences window to specify whether to notify if the model has changed on disk when updating, simulating, editing, or saving the model. This can occur, for example, with source control operations and multiple users.

Note To programmatically check whether the model has changed on disk since it was loaded, use the function `slIsFileChangedOnDisk`.

To access the Simulink Preferences window,

- Select **File > Preferences** in the Simulink product.
- Select **File > Preferences** in MATLAB to open the MATLAB Preferences, then select **Simulink** in the left pane, and click the button **Launch Simulink Preferences**.



The Model File Change Notification options are in the right pane. You can use the three independent options as follows:

- If you select the **Updating or simulating the model** check box, you can choose what form of notification you want from the **Action** list:
  - `Warning` — in the MATLAB command window.

  - `Error` — in the MATLAB command window if simulating from the command line, or if simulating from a menu item, in the Simulation Diagnostics window.
  - `Reload model (if unmodified)` — if the model is modified, you see the prompt dialog. If unmodified, the model is reloaded.
  - `Show prompt dialog` — in the dialog, you can choose to close and reload, or ignore the changes.
- If you select the **First editing the model** check box, and the file has changed on disk, and the block diagram is unmodified in Simulink:
  - Any command-line operation that causes the block diagram to be modified (e.g., a call to `set_param`) will result in a warning:

    ```
    Warning: Block diagram 'mymodel' is being edited but file has
    changed on disk since it was loaded.  You should close and
    reload the block diagram.
    ```

  - Any graphical operation that modifies the block diagram (e.g., adding a block) causes a warning dialog to appear.
- If you select the **Saving the model** check box, and the file has changed on disk:
  - The `save_system` function displays an error, unless the `OverwriteIfChangedOnDisk` option is used.
  - Saving the model by using the menu (**File > Save**) or a keyboard shortcut causes a dialog to be shown. In the dialog, you can choose to overwrite, save with a new name, or cancel the operation.

Specifying the Current User

When you create or update a model, your name is logged in the model for version control purposes. The Simulink software assumes that your name is specified by at least one of the following environment variables: `USER`, `USERNAME`, `LOGIN`, or `LOGNAME`. If your system does not define any of these variables, the Simulink software does not update the user name in the model.

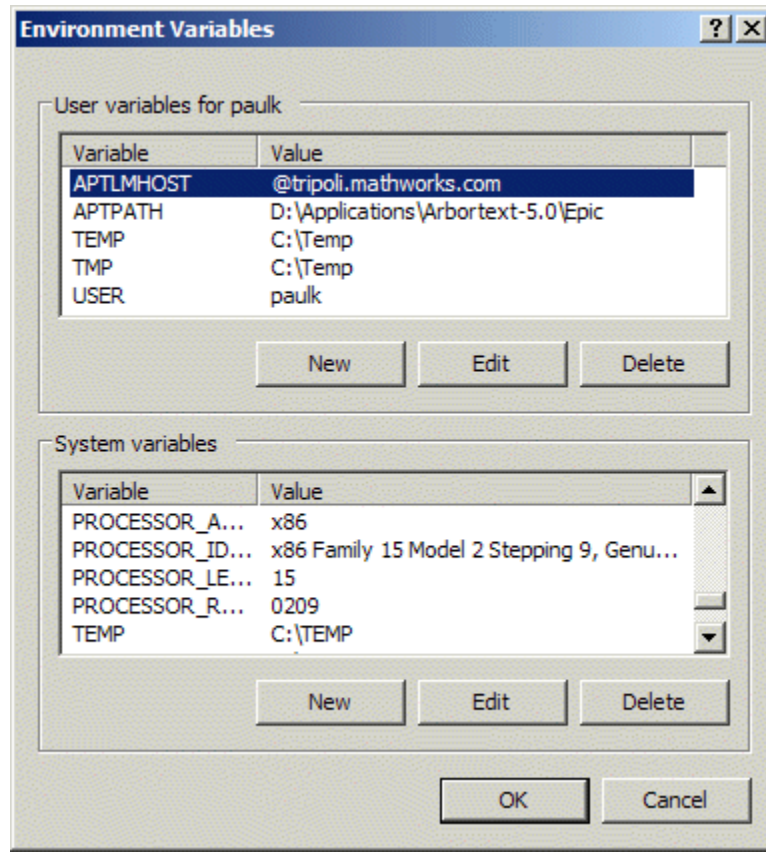
UNIX systems define the `USER` environment variable and set its value to the name you use to log on to your system. Thus, if you are using a UNIX system, you do not have to do anything to enable the Simulink software to identify you as the current user.

Windows systems, on the other hand, might define some or none of the "user name" environment variables that the Simulink software expects, depending on the version of Windows installed on your system and whether it is connected to a network. Use the MATLAB command `getenv` to determine which of the environment variables is defined. For example, enter

```
getenv('user')
```

at the MATLAB command line to determine whether the `USER` environment variable exists on your Windows system. If not, you must set it yourself.

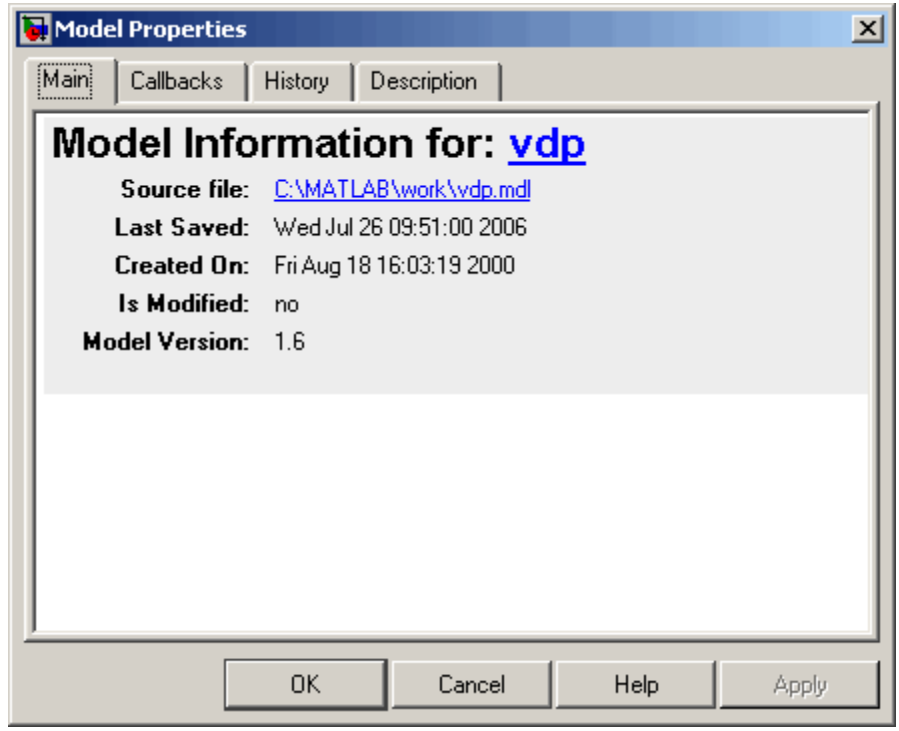
On Windows, use the **Environment** variables pane of the System Properties dialog box to set the `USER` environment variable (if it is not already defined). For Windows XP, access the **Environment** variables pane by clicking the **Environment Variables** button on the **Advanced** pane of the System Properties dialog box.



To display the System Properties dialog box, select **Start > Settings > Control Panel** to open the Control Panel. Double-click the **System** icon. To set the `USER` variable, enter `USER` in the **Variable** field and enter your login name in the **Value** field. Click **Set** to save the new environment variable. Then click **OK** to close the dialog box.

Model Properties Dialog Box

The Model Properties dialog box allows you to set various version control parameters and model callback functions. To display the dialog box, choose **Model Properties** from the **File** menu.



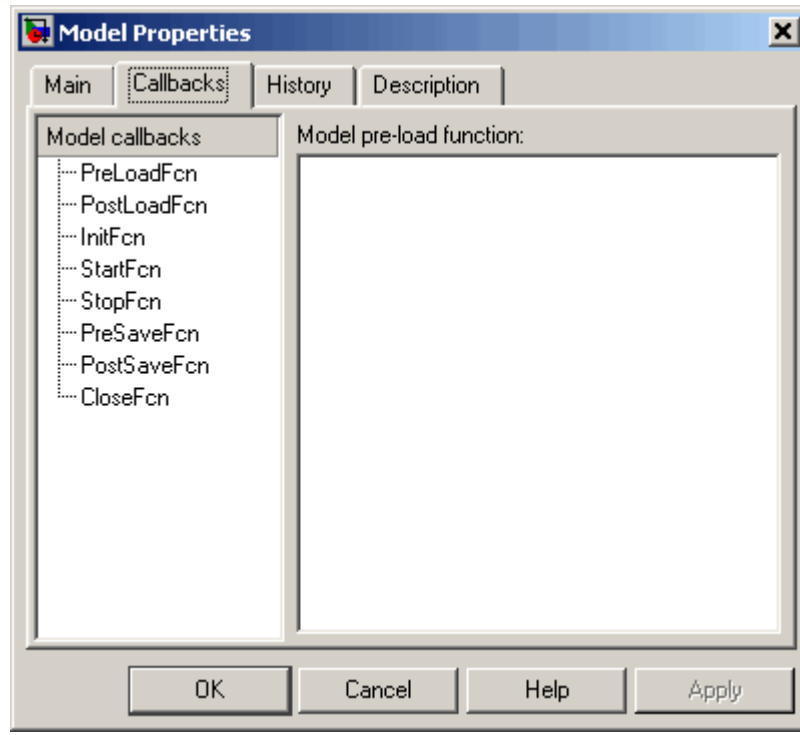
The dialog box includes the following panes.

Main Pane

The **Main** pane summarizes information about the current version of this model.

Callbacks Pane

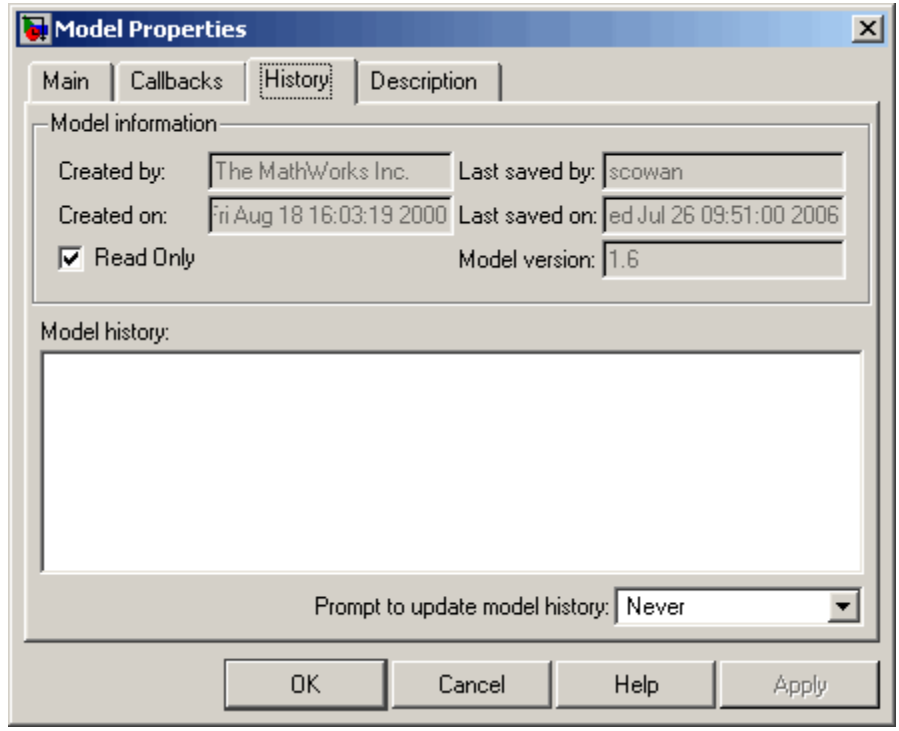
The **Callbacks** pane lets you specify functions to be invoked at specific points in the simulation of the model.



In the left pane, select the callback. In the right pane, enter the name of the function you want to be invoked for the selected callback. See "Creating Model Callback Functions" on page 3-55 for information on the callback functions listed on this pane.

History Pane

The **History** pane allows you to enable, view, and edit this model's change history.



The **History** pane has two control groups: the **Model information** group and the **Model History** group.

Model Information Controls

The contents of the **Model information** control group depend on the state of the **Read Only** check box.

Read Only Check Box Selected. When **Read Only** is selected, the dialog box shows the following fields grayed out.

- **Created by**

  Name of the person who created this model. The Simulink software sets this property to the value of the `USER` environment variable when you create the model.

- **Created on**

  Date and time this model was created.

- **Last saved by**

  Name of the person who last saved this model. The Simulink software sets the value of this parameter to the value of the `USER` environment variable when you save a model.

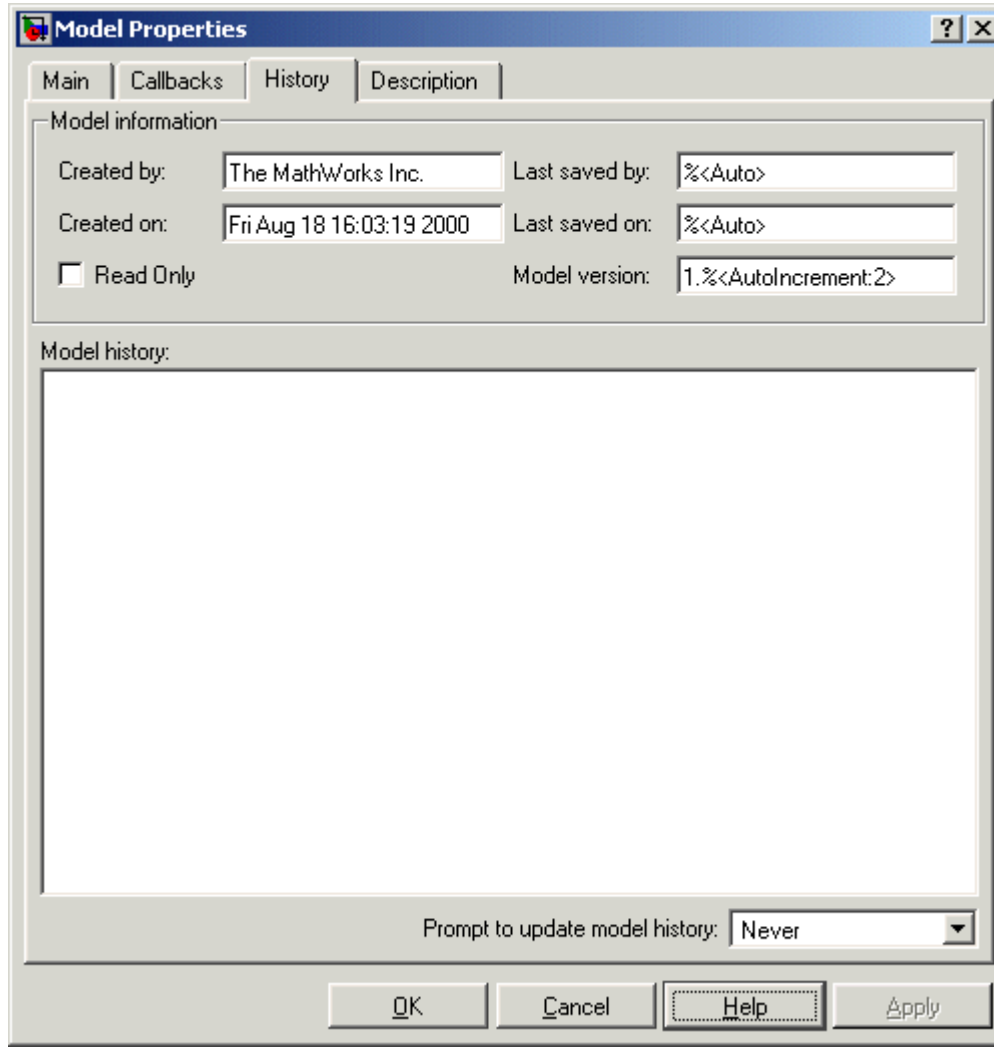
- **Last saved on**

  Date that this model was last saved. The Simulink software sets the value of this parameter to the system date and time whenever you save a model.

- **Model version**

  Version number for this model.

Read Only Check Box Deselected. When **Read Only** is deselected, the dialog box shows the format strings or values for the following fields. You can edit all but the **Created on** field, as described.



- **Created by**

  Name of the person who created this model. The Simulink software sets this property to the value of the `USER` environment variable when you create the model. Edit this field to change the value.

- **Created on**

Date and time this model was created. Do not edit this field.

- **Last saved by**

  Enter a format string describing the format used to display the **Last saved by** value in the **History** pane and the **ModifiedBy** entry in the history log and Model Info blocks. The value of this field can be any string. The string can include the tag `%<Auto>`. The Simulink software replaces occurrences of this tag with the current value of the `USER` environment variable.

- **Last saved on**

  Enter a format string describing the format used to display the **Last saved on** date in the **History** pane and the **ModifiedOn** entry in the history log and the in Model Info blocks. The value of this field can be any string. The string can contain the tag `%<Auto>`. The Simulink software replaces occurrences of this tag with the current date and time.

- **Model version**

  Enter a format string describing the format used to display the model version number in the **Model Properties** pane and in Model Info blocks. The value of this parameter can be any text string. The text string can include occurrences of the tag `%<AutoIncrement:#>` where # is an integer. The Simulink software replaces the tag with an integer when displaying the model's version number. For example, it displays the tag

  ```
  1.%<AutoIncrement:2>
  ```

  as

  ```
  1.2
  ```

  The Simulink software increments # by 1 when saving the model. For example, when you save the model,

  ```
  1.%<AutoIncrement:2>
  ```

  becomes

  ```
  1.%<AutoIncrement:3>
  ```

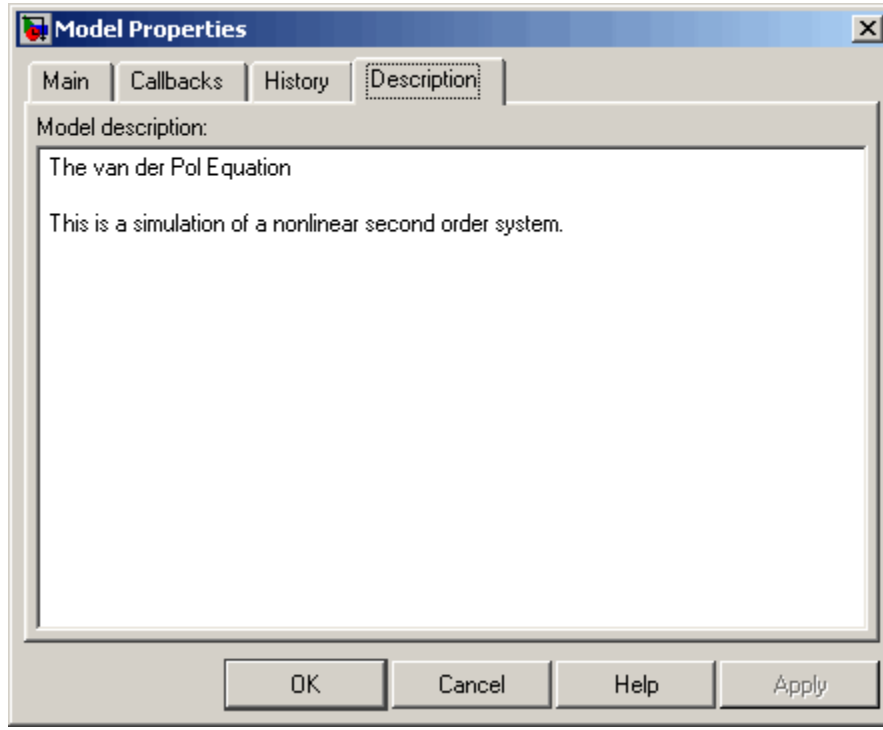
  and the model version number is reported as `1.3`.

Model History Controls

The model history controls group contains a scrollable text field and an option list. The text field displays the history for the model in a scrollable text field. To change the model history, edit the contents of this field. The option list allows you to enable or disable the Simulink software model history feature. To enable the history feature, select `When saving model` from the **Prompt to update model history** list. This causes the Simulink software to prompt you to enter a comment when saving the model. Typically you would enter any changes that you have made to the model since the last time you saved it. This information is stored in the model's change history log. See "Creating a Model Change History" on page 3-111 for more information. To disable the change history feature, select `Never` from the **Prompt to update model history** list.

Model Description Controls

This pane allows you to enter a description of the model. When typing `help` followed by the model name at the MATLAB prompt, the contents of the **Model description** field appear in the Command Window.

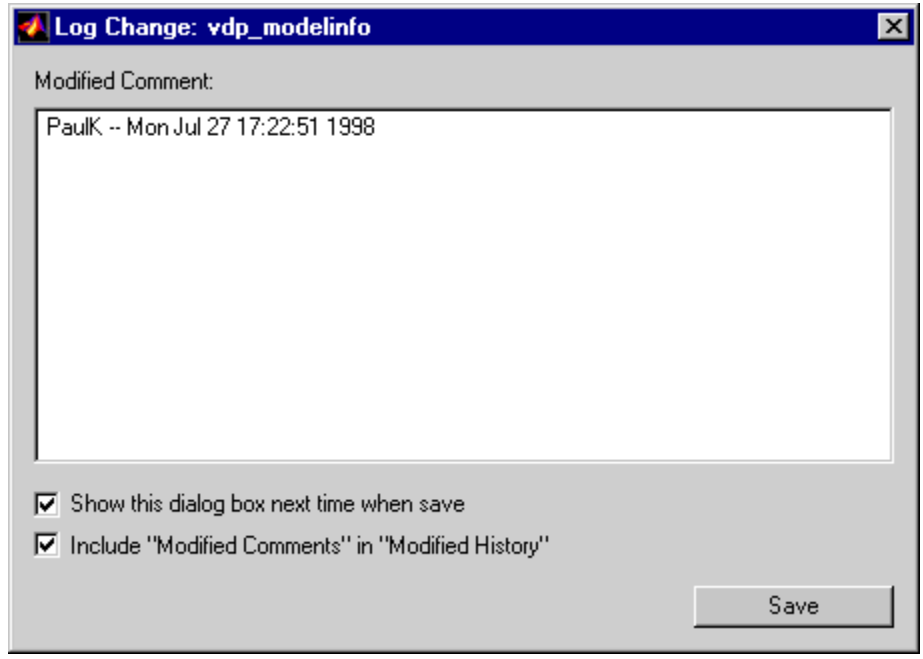


Creating a Model Change History

You can create and store a record of changes to a model in the model itself. The Simulink software compiles the history automatically from comments that you or other users enter when they save changes to a model.

Logging Changes

To start a change history, select `When saving model` from the **Prompt to update model history** list on the **History** pane on the Model Properties dialog box. The next time you save the model, a **Log Change** dialog box is displayed.



To add an item to the model's change history, enter the item in the **Modified Comments** edit field and click **Save**. If you do not want to enter an item for this session, clear the **Include "Modified Contents" in "Modified History"** option. To discontinue change logging, clear the **Show this dialog box next time when save** option.

Version Control Properties

Version control information is stored as model parameters in a model. You can access this information from the MATLAB command line or from a MATLAB script, using the Simulink `get_param` command. The following table describes the model parameters used by Simulink to store version control information.

Property	Description
Created	Date created.
Creator	Name of the person who created this model.

Property	Description
LastModifiedBy	User name of the person who last modified this model.
ModifiedBy	Person who last modified this model.
ModifiedByFormat	Format of the `ModifiedBy` parameter. Value can be any string. The string can include the tag `%<Auto>`. The Simulink software replaces the tag with the current value of the `USER` environment variable.
ModifiedDate	Date modified.
ModifiedDateFormat	Format of the `ModifiedDate` parameter. Value can be any string. The string can include the tag `%<Auto>`. The Simulink software replaces the tag with the current date and time when saving the model.
ModifiedComment	Comment entered by user who last updated this model.
ModifiedHistory	History of changes to this model.
ModelVersion	Version number.
ModelVersionFormat	Format of model version number. Can be any string. The string can contain the tag `%<AutoIncrement:#>` where # is an integer. The Simulink software replaces the tag with # when displaying the version number. It increments # when saving the model.
Description	Description of model.
LastModifiedDate	Date last modified.

Model Discretizer

In this section...

What Is the Model Discretizer?

Model Discretizer selectively replaces continuous Simulink blocks with discrete equivalents. Discretization is a critical step in digital controller design and for hardware in-the-loop simulations.

You can use the Model Discretizer to:

- Identify a model's continuous blocks
- Change a block's parameters from continuous to discrete
- Apply discretization settings to all continuous blocks in the model or selected blocks
- Create configurable subsystems that contain multiple discretization candidates along with the original continuous block(s)
- Switch among the different discretization candidates and evaluate the resulting model simulations

Requirements

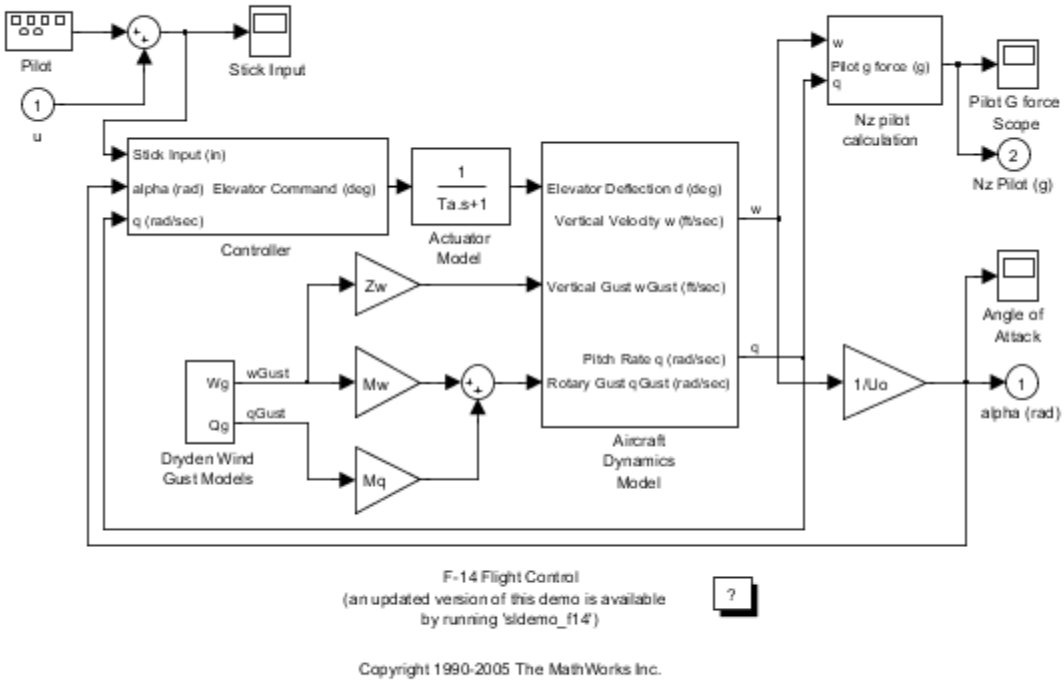
To use Model Discretizer, you must have a Control System Toolbox™ license, Version 5.2 or later.

How to Discretize a Model from the Model Discretizer GUI

To discretize a model:

- Start the Model Discretizer
- Specify the Transform Method
- Specify the Sample Time
- Specify the Discretization Method
- Discretize the Blocks

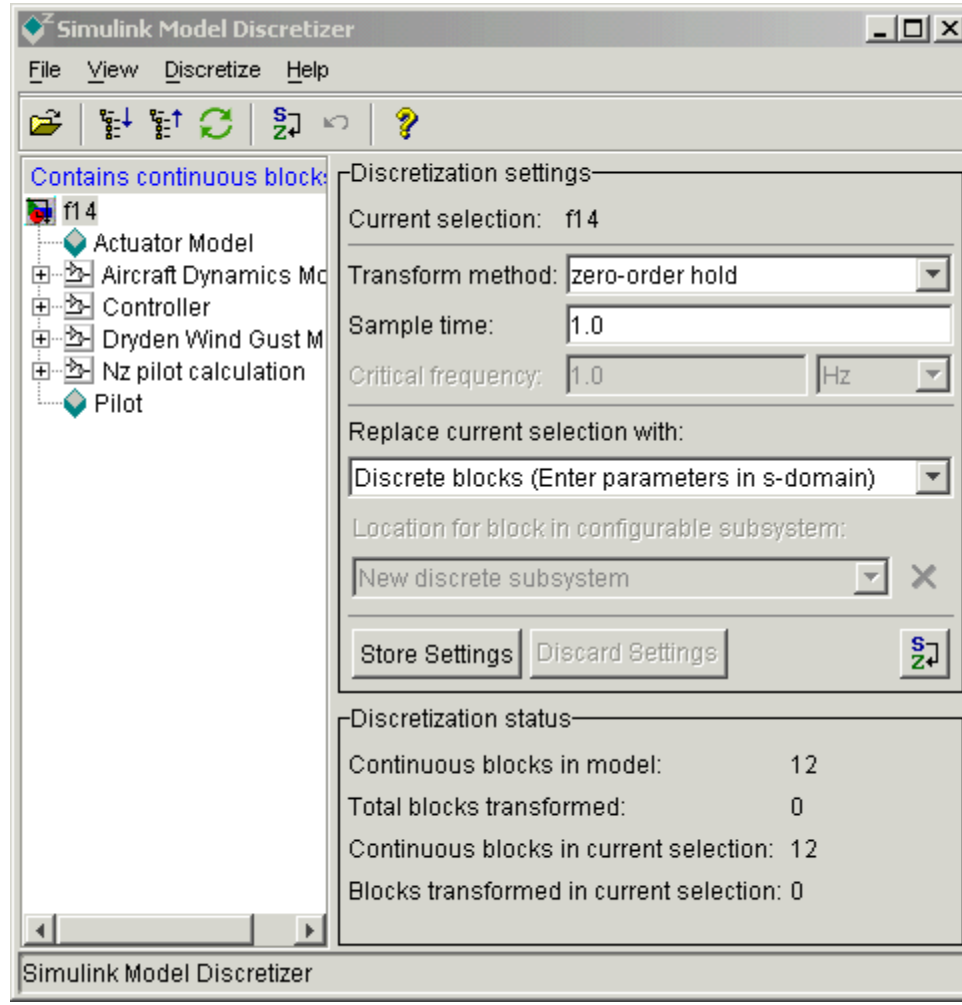
The `f14` model, shown below, demonstrates the steps in discretizing a model.



Start Model Discretizer

To open the tool, select **Tools > Control Design > Model Discretizer** from the model editor's menu bar.

The **Simulink Model Discretizer** appears.



Alternatively, you can open Model Discretizer from the MATLAB Command Window using the `slmdldiscui` function.

The following command opens the **Simulink Model Discretizer** window with the `f14` model:

```
slmdldiscui('f14')
```

To open a new model or library from Model Discretizer, select **Load model** from the **File** menu.

Specify the Transform Method

The transform method specifies the type of algorithms used in the discretization. For more information on the different transform methods, see the Control System Toolbox documentation.

The `Transform method` drop-down list contains the following options:

- `zero-order hold`

  Zero-order hold on the inputs.

- `first-order hold`

  Linear interpolation of inputs.

- `tustin`

  Bilinear (Tustin) approximation.

- `tustin with prewarping`

  Tustin approximation with frequency prewarping.

- `matched pole-zero`

  Matched pole-zero method (for SISO systems only).

Specify the Sample Time

Enter the sample time in the **Sample time** field.

You can specify an offset time by entering a two-element vector for discrete blocks or configurable subsystems. The first element is the sample time and the second element is the offset time. For example, an entry of [1.0 0.1] would specify a 1.0 second sample time with a 0.1 second offset. If no offset is specified, the default is zero.

You can enter workspace variables when discretizing blocks in the s-domain. See “Discrete blocks (Enter parameters in s-domain)” on page 3-119.

Specify the Discretization Method

Specify the discretization method in the **Replace current selection with** field. The options are

- “Discrete blocks (Enter parameters in s-domain)” on page 3-119

  Creates a discrete block whose parameters are retained from the corresponding continuous block.

- “Discrete blocks (Enter parameters in z-domain)” on page 3-120

  Creates a discrete block whose parameters are “hard-coded“ values placed directly into the block’s dialog.

- “Configurable subsystem (Enter parameters in s-domain)” on page 3-121

  Create multiple discretization candidates using s-domain values for the current selection. A configurable subsystem can consist of one or more blocks.

- “Configurable subsystem (Enter parameters in z-domain)” on page 3-122

  Create multiple discretization candidates in z-domain for the current selection. A configurable subsystem can consist of one or more blocks.

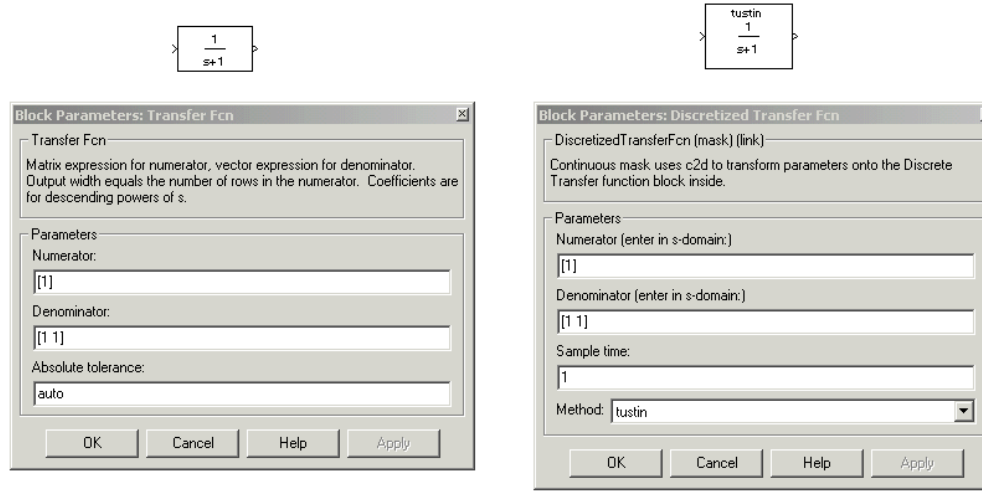
Discrete blocks (Enter parameters in s-domain). Creates a discrete block whose parameters are retained from the corresponding continuous block. The sample time and the discretization parameters are also on the block’s parameter dialog box.

The block is implemented as a masked discrete block that uses `c2d` to transform the continuous parameters to discrete parameters in the mask initialization code.

These blocks have the unique capability of reverting to continuous behavior if the sample time is changed to zero. Entering the sample time as a workspace variable (`'Ts'`, for example) allows for easy changeover from continuous to discrete and back again. See “Specify the Sample Time” on page 3-118.

Note Parameters are not tunable when **Inline parameters** is selected in the model's Configuration Parameters dialog box.

The following figure shows a continuous Transfer Function block next to a Transfer Function block that has been discretized in the s-domain. The **Block Parameters** dialog box for each block appears below the block.

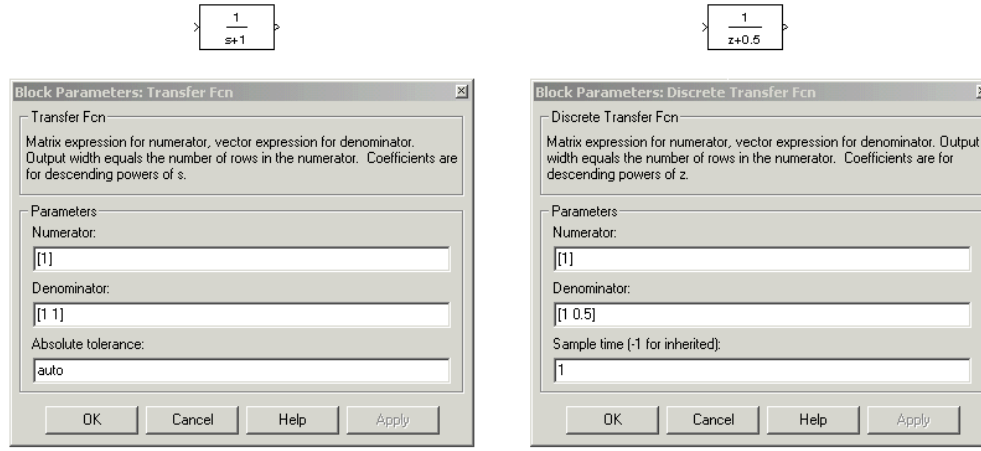


Discrete blocks (Enter parameters in z-domain). Creates a discrete block whose parameters are "hard-coded" values placed directly into the block's dialog box. Model Discretizer uses the `c2d` function to obtain the discretized parameters, if needed.

For more help on the `c2d` function, type the following in the Command Window:

```
help c2d
```

The following figure shows a continuous Transfer Function block next to a Transfer Function block that has been discretized in the z-domain. The Block Parameters dialog box for each block appears below the block.



Note If you want to recover exactly the original continuous parameter values after the Model Discretization session, you should enter parameters in the s-domain.

Configurable subsystem (Enter parameters in s-domain). Create multiple discretization candidates using s-domain values for the current selection. A configurable subsystem can consist of one or more blocks.

The **Location for block in configurable subsystem** field becomes active when this option is selected. This option allows you to either create a new configurable subsystem or overwrite an existing one.

Note The current folder must be writable in order to save the library or libraries for the configurable subsystem option.

Configurable subsystem (Enter parameters in z-domain). Create multiple discretization candidates in z-domain for the current selection. A configurable subsystem can consist of one or more blocks.

The **Location for block in configurable subsystem** field becomes active when this option is selected. This option allows you to either create a new configurable subsystem or overwrite an existing one.

Note The current folder must be writable in order to save the library or libraries for the configurable subsystem option.

Configurable subsystems are stored in a library containing the discretization candidates and the original continuous block. The library will be named `<model name>_disc_lib` and it will be stored in the current . For example a library containing a configurable subsystem created from the `f14` model will be named `f14_disc_lib`.

If multiple libraries are created from the same model, then the filenames will increment accordingly. For example, the second configurable subsystem library created from the `f14` model will be named `f14_disc_lib2`.

You can open a configurable subsystem library by right-clicking on the subsystem in the model and selecting **Link options > Go to library block** from the pop-up menu.

Discretize the Blocks

To discretize blocks that are linked to a library, you must either discretize the blocks in the library itself or disable the library links in the model window.

You can open the library from Model Discretizer by selecting **Load model** from the **File** menu.

You can disable the library links by right-clicking on the block and selecting **Link options -> Disable link** from the pop-up menu.

There are two methods for discretizing blocks.

Select Blocks and Discretize.

1. Select a block or blocks in the Model Discretizer tree view pane.

   To choose multiple blocks, press and hold the **Ctrl** button on the keyboard while selecting the blocks.

   Note You must select blocks from the Model Discretizer tree view. Clicking blocks in the editor does not select them for discretization.

   ---

2. Select **Discretize current block** from the **Discretize** menu if a single block is selected or select **Discretize selected blocks** from the **Discretize** menu if multiple blocks are selected.

   You can also discretize the current block by clicking the **Discretize** button, shown below.

Store the Discretization Settings and Apply Them to Selected Blocks in the Model.

1. Enter the discretization settings for the current block.
2. Click **Store Settings**.

   This adds the current block with its discretization settings to the group of preset blocks.

3. Repeat steps 1 and 2, as necessary.
4. Select **Discretize preset blocks** from the **Discretize** menu.

Deleting a Discretization Candidate from a Configurable Subsystem

You can delete a discretization candidate from a configurable subsystem by selecting it in the **Location for block in configurable subsystem** field and clicking the **Delete** button, shown below.

Undoing a Discretization

To undo a discretization, click the **Undo** discretization button, shown below.

Alternatively, you can select **Undo discretization** from the **Discretize** menu.

This operation undoes discretizations in the current selection and its children. For example, performing the undo operation on a subsystem will remove discretization from all blocks in all levels of the subsystem's hierarchy.

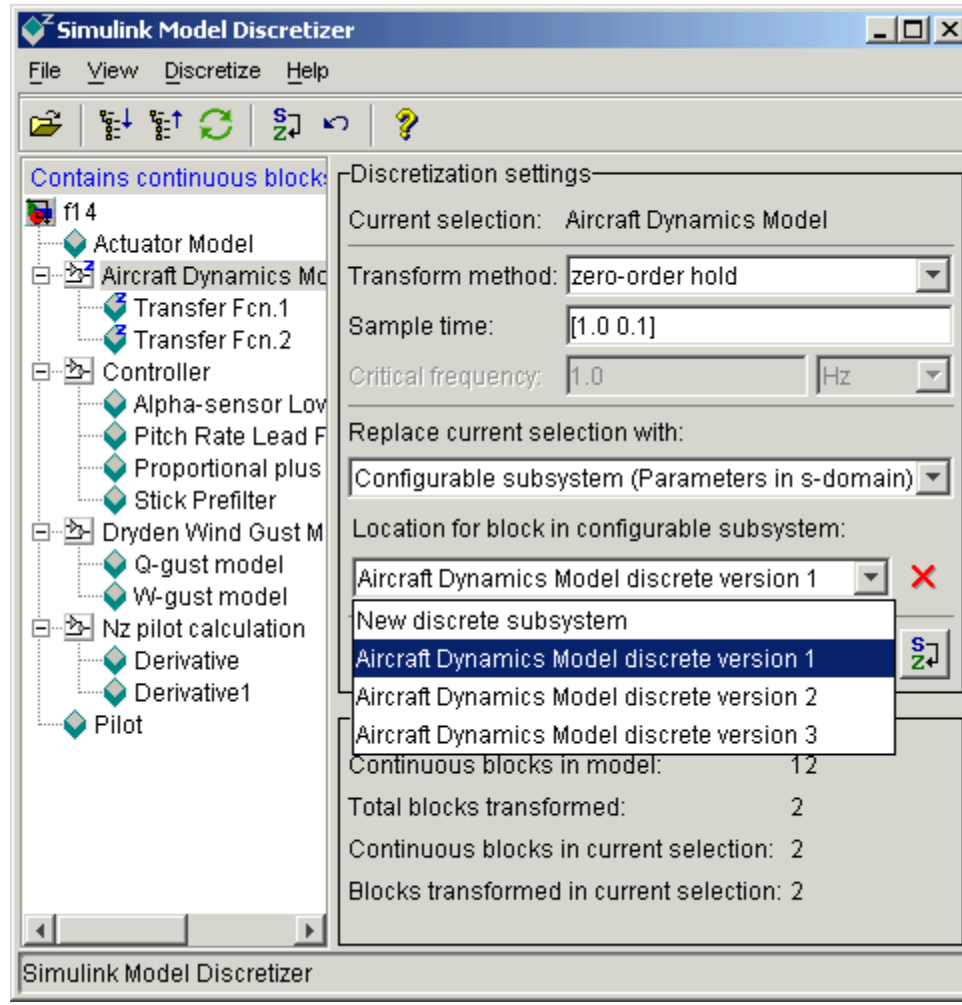
Viewing the Discretized Model

Model Discretizer displays the model in a hierarchical tree view.

Viewing Discretized Blocks

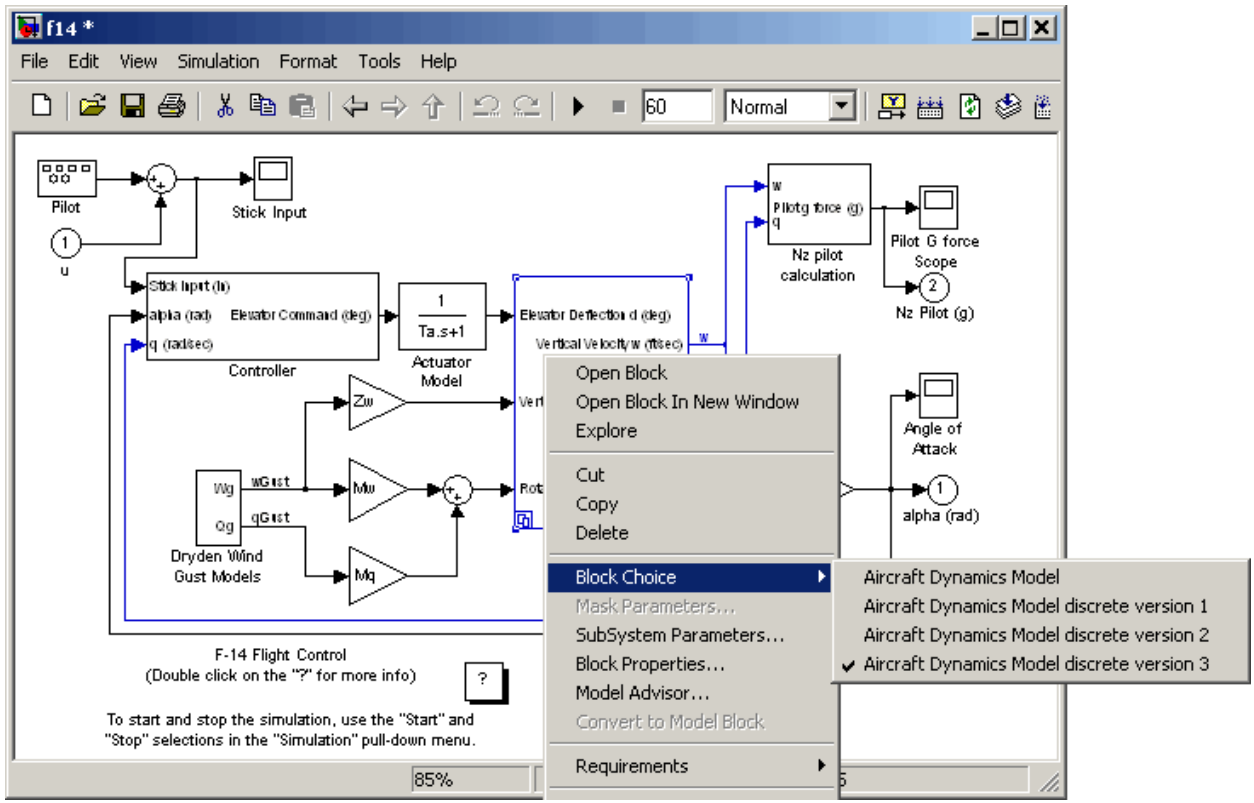
The block's icon in the tree view becomes highlighted with a "**z**" when the block has been discretized.

The following figure shows that the Aircraft Dynamics Model subsystem has been discretized into a configurable subsystem with three discretization candidates.

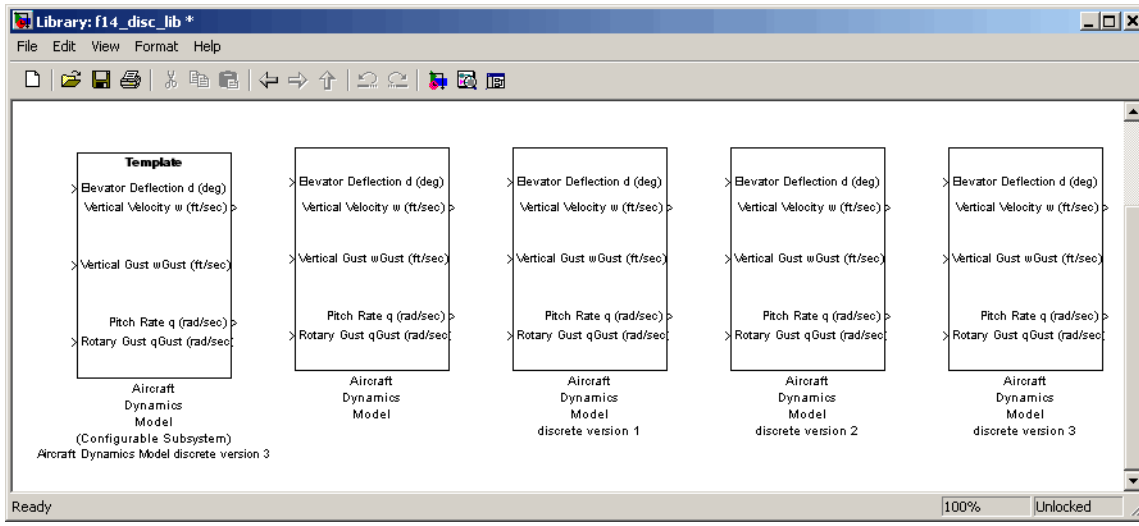


The other blocks in this `f14` model have not been discretized.

The following figure shows the Aircraft Dynamics Model subsystem of the `f14` demo model after discretization into a configurable subsystem containing the original continuous model and three discretization candidates.



The following figure shows the library containing the Aircraft Dynamics Model configurable subsystem with the original continuous model and three discretization candidates.



Refreshing Model Discretizer View of the Model

To refresh Model Discretizer's tree view of the model when the model has been changed, click the **Refresh** button, shown below.

Alternatively, you can select **Refresh** from the **View** menu.

How to Discretize Blocks from the Simulink Model

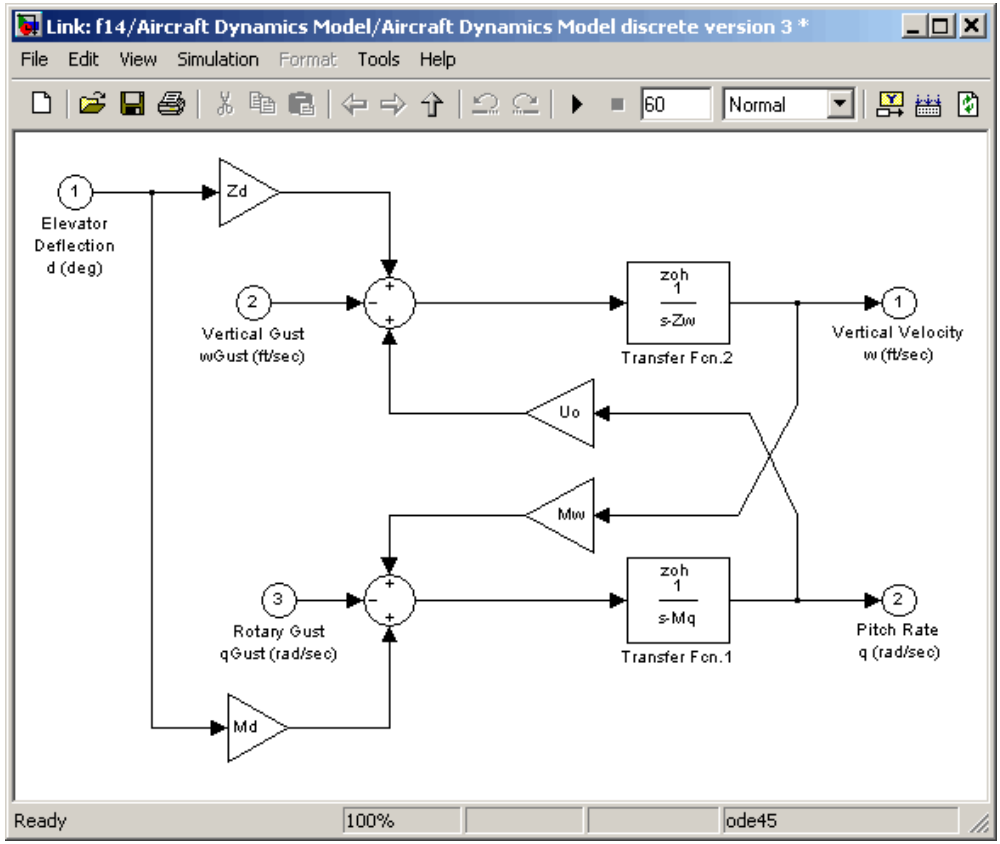
You can replace continuous blocks in a Simulink software model with the equivalent blocks discretized in the s-domain using the Discretizing library.

The procedure below shows how to replace a continuous Transfer Fcn block in the Aircraft Dynamics Model subsystem of the `f14` model with a discretized Transfer Fcn block from the Discretizing Library. The block is discretized

in the s-domain with a zero-order hold transform method and a two second sample time.

1 Open the `f14` model.

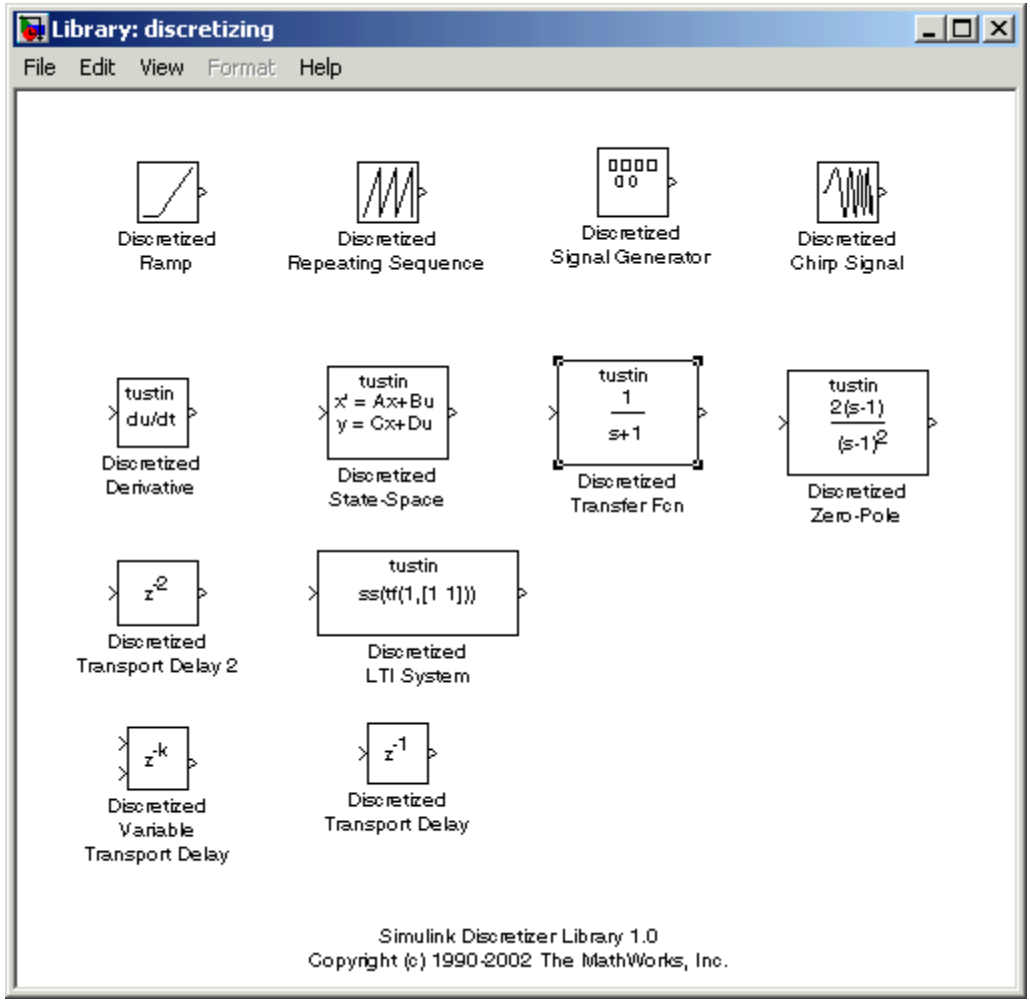
2 Open the Aircraft Dynamics Model subsystem in the `f14` model.



3 Open the Discretizing library window.

Enter `discretizing` at the MATLAB command prompt.

The **Library: discretizing** window opens.

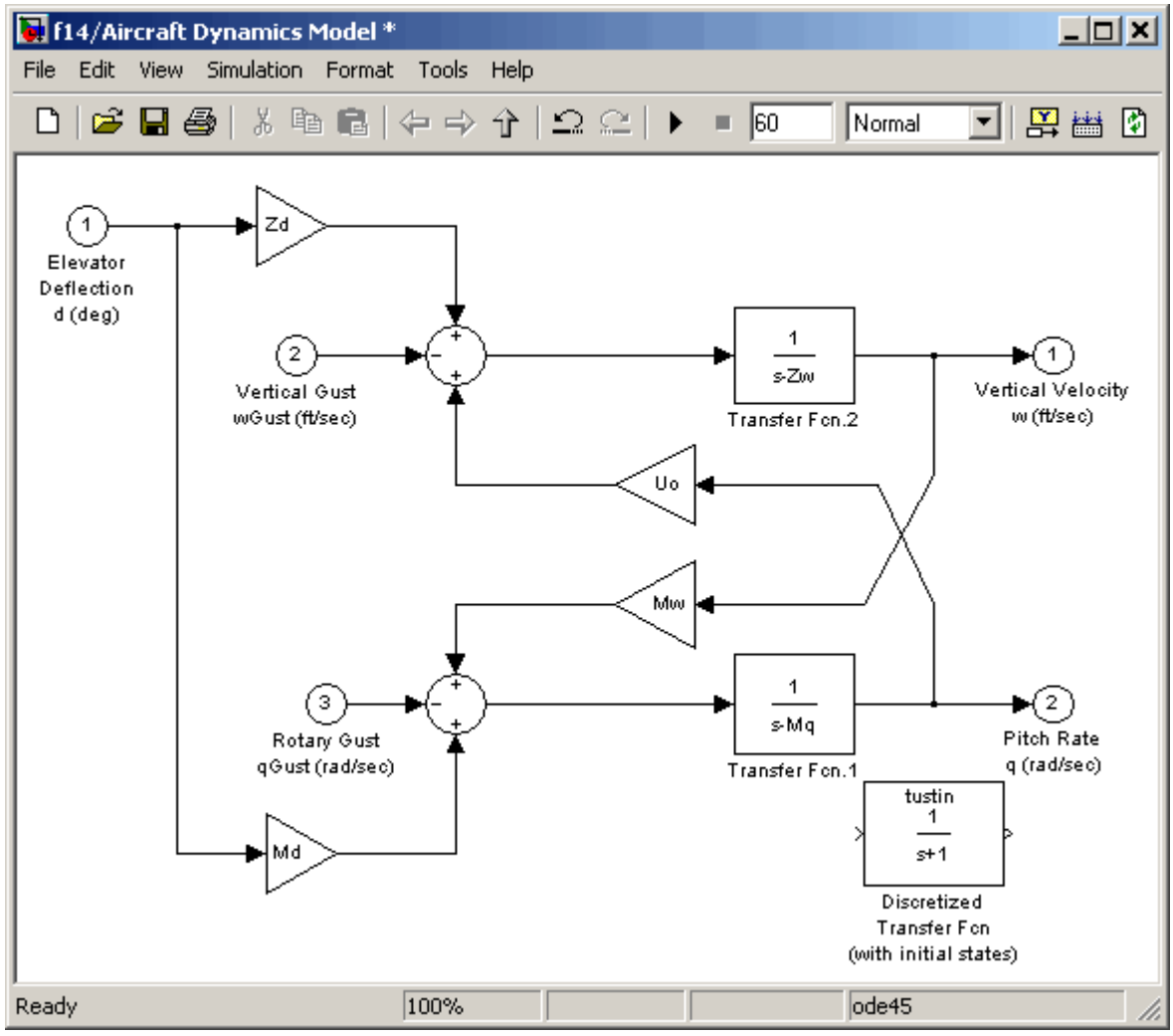


This library contains s-domain discretized blocks.

4 Add the Discretized Transfer Fcn block to the **f14/Aircraft Dynamics Model** window.

a Click the Discretized Transfer Fcn block in the **Library: discretizing** window.

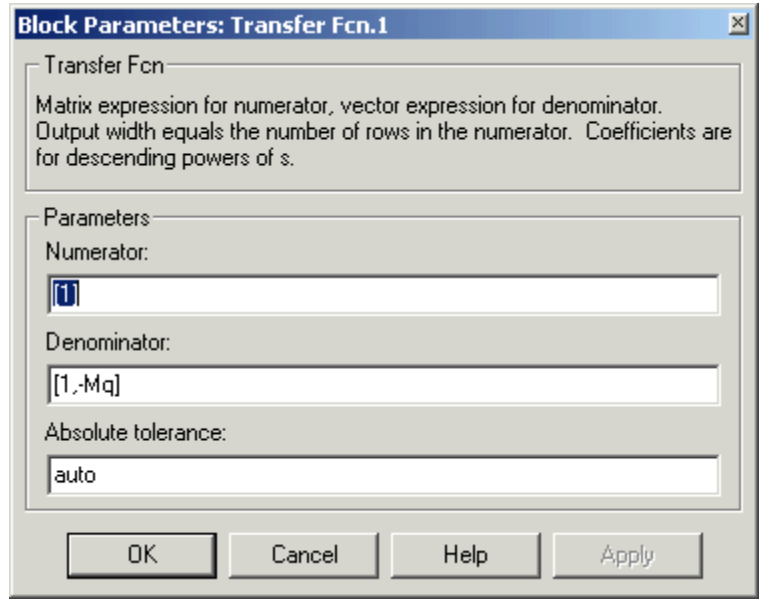
b Drag it into the **f14/Aircraft Dynamics Model** window.



5 Open the parameter dialog box for the Transfer Fcn.1 block.

Double-click the Transfer Fcn.1 block in the **f14/Aircraft Dynamics Model** window.

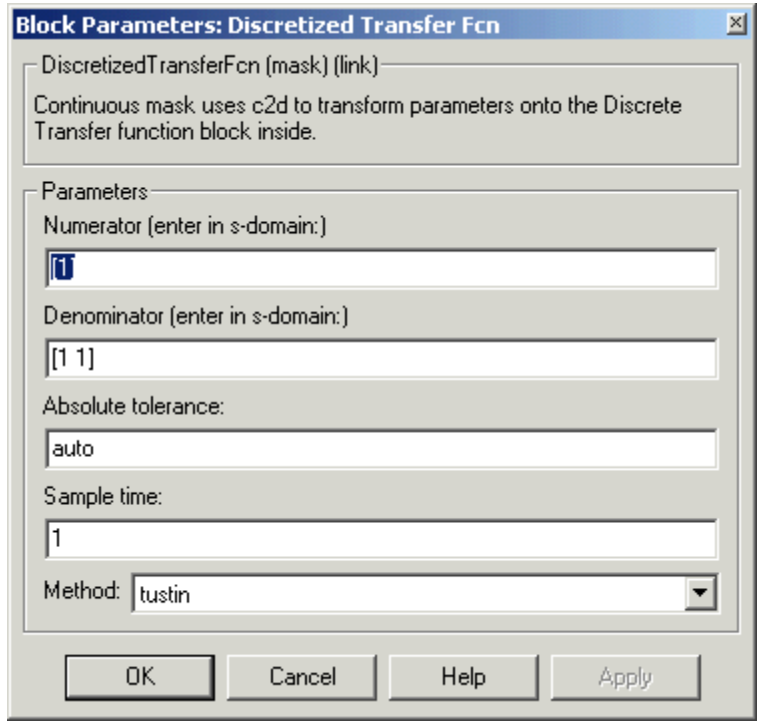
The Block Parameters: Transfer Fcn.1 dialog box opens.



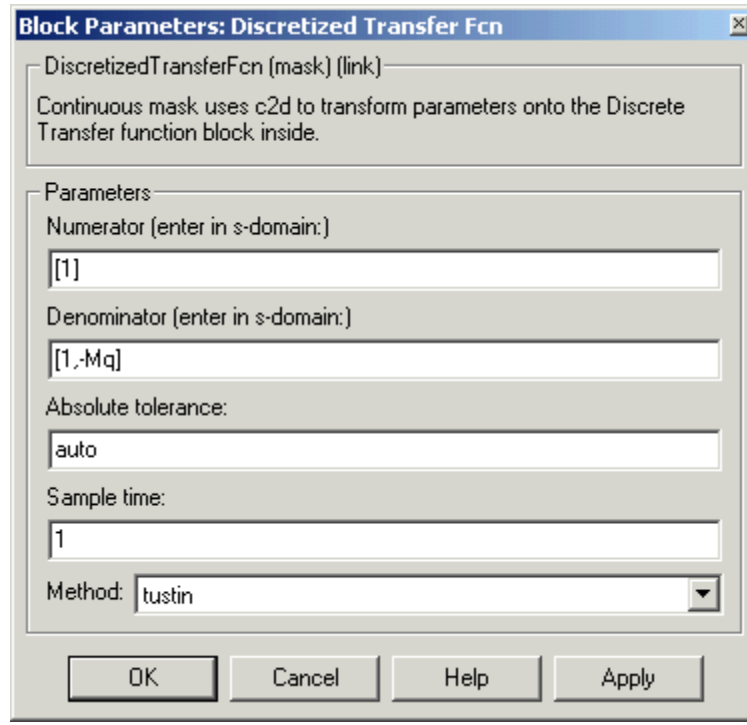
6 Open the parameter dialog box for the Discretized Transfer Fcn block.

Double-click the Discretized Transfer Fcn block in the **f14/Aircraft Dynamics Model** window.

The Block Parameters: Discretized Transfer Fcn dialog box opens.



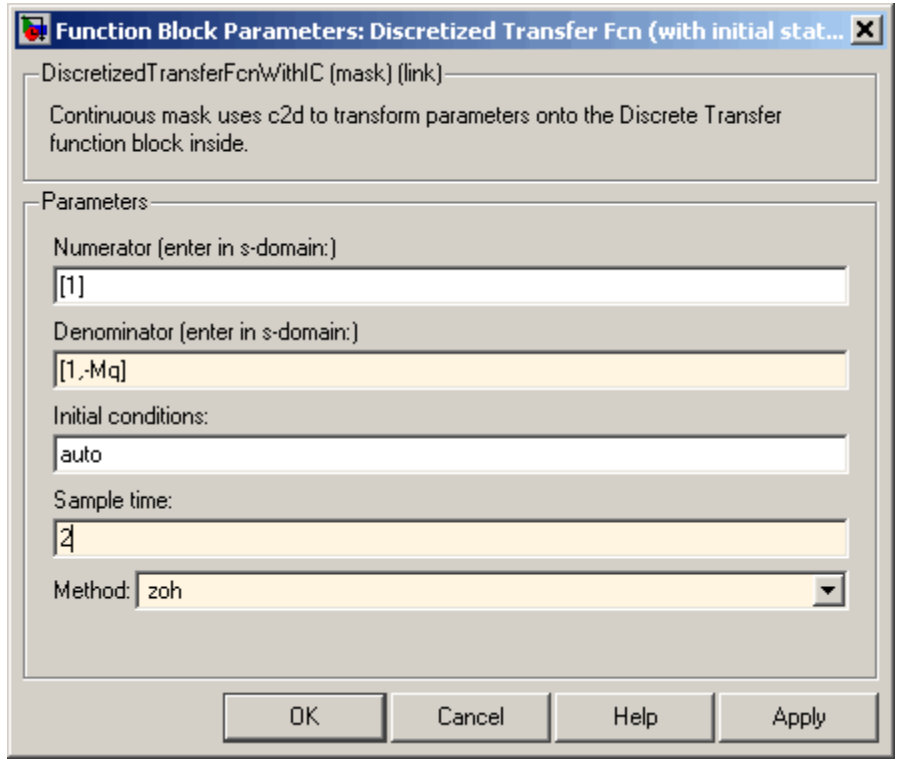
Copy the parameter information from the Transfer Fcn.1 block's dialog box to the Discretized Transfer Fcn block's dialog box.



7 Enter `2` in the **Sample time** field.

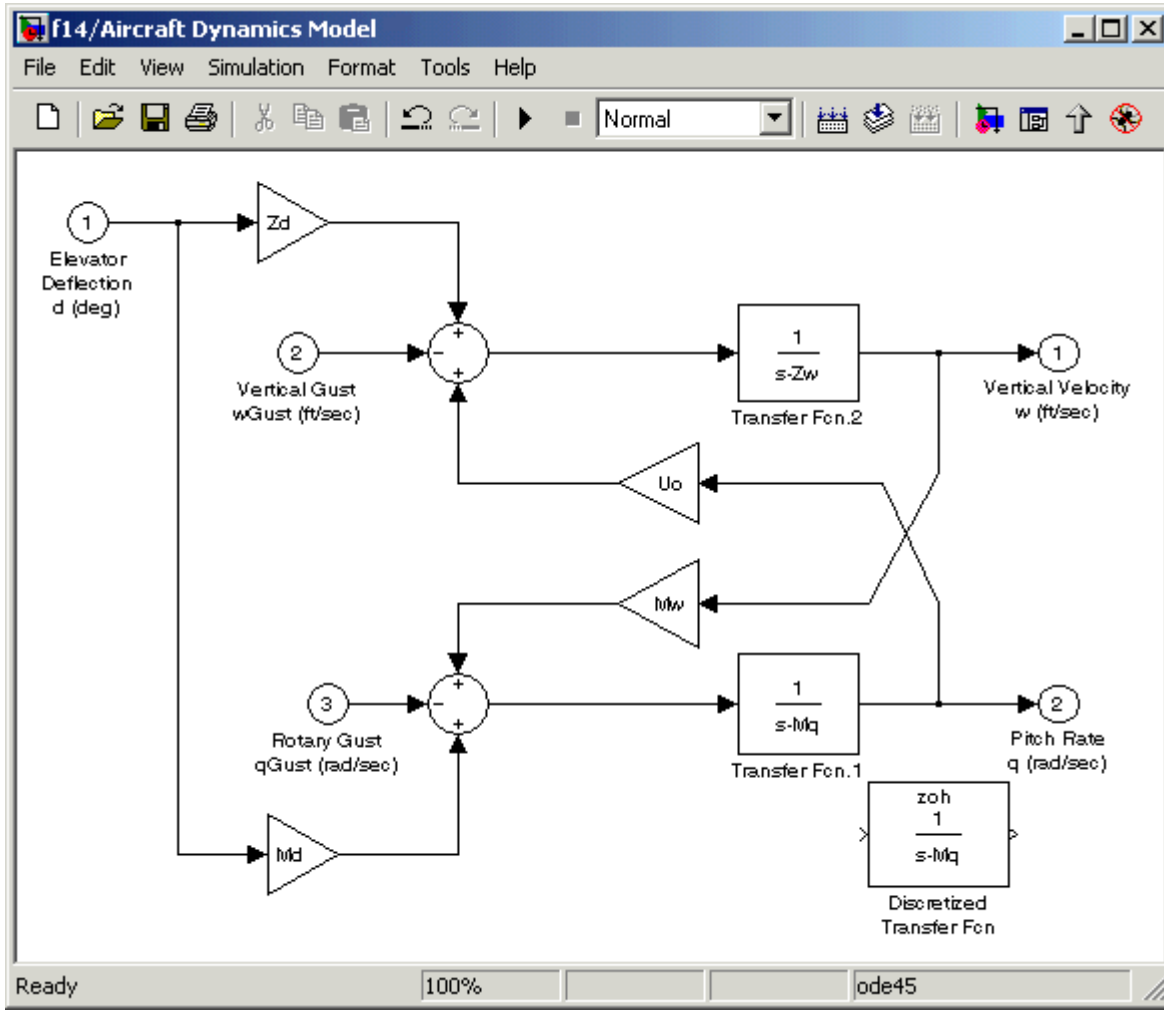
8 Select `zoh` from the **Method** drop-down list.

The parameter dialog box for the Discretized Transfer Fcn now looks like this.



9 Click **OK**.

The **f14/Aircraft Dynamics Model** window now looks like this.

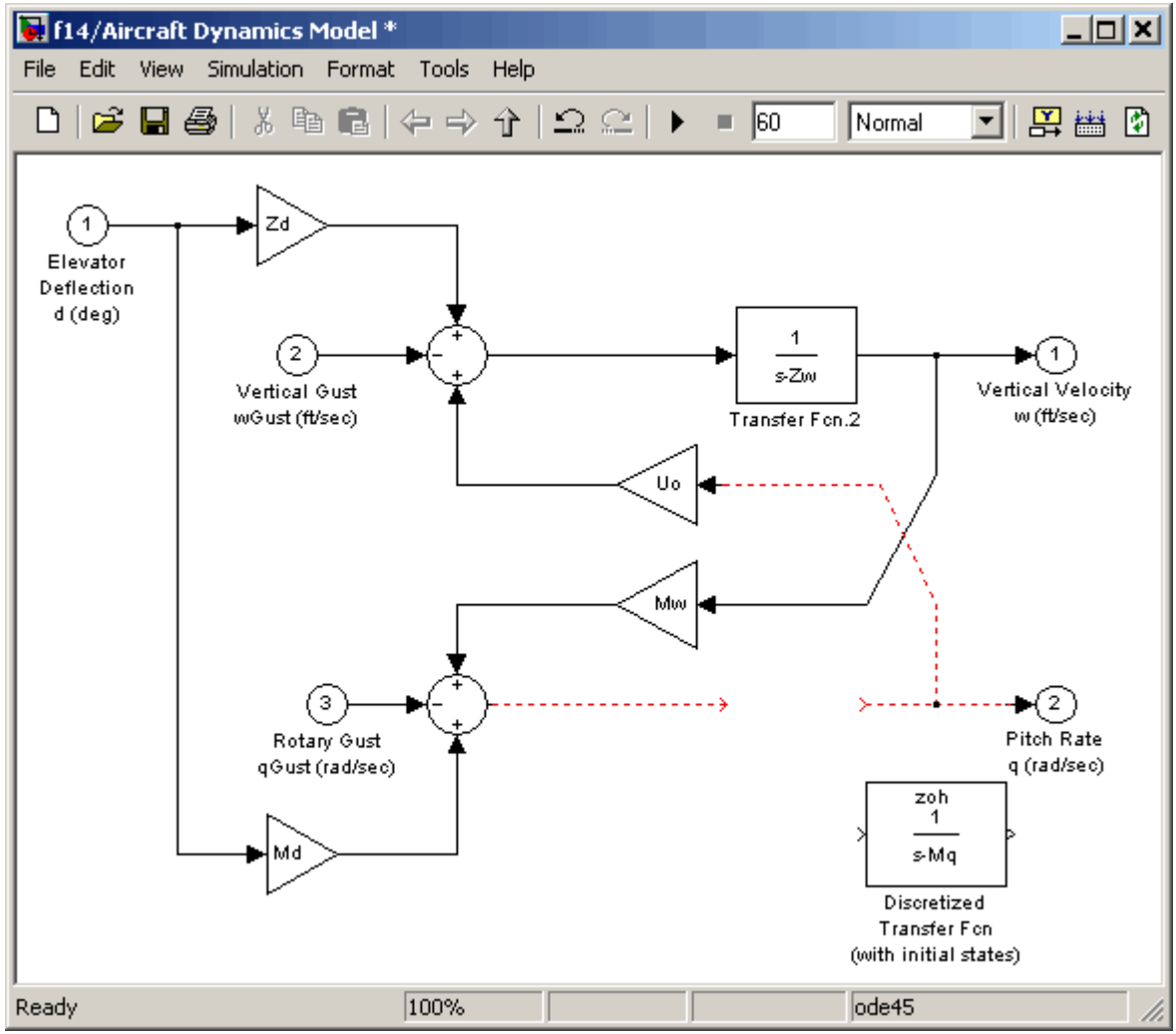


10 Delete the original Transfer Fcn.1 block.

a Click the Transfer Fcn.1 block.

b Press the **Delete** key.

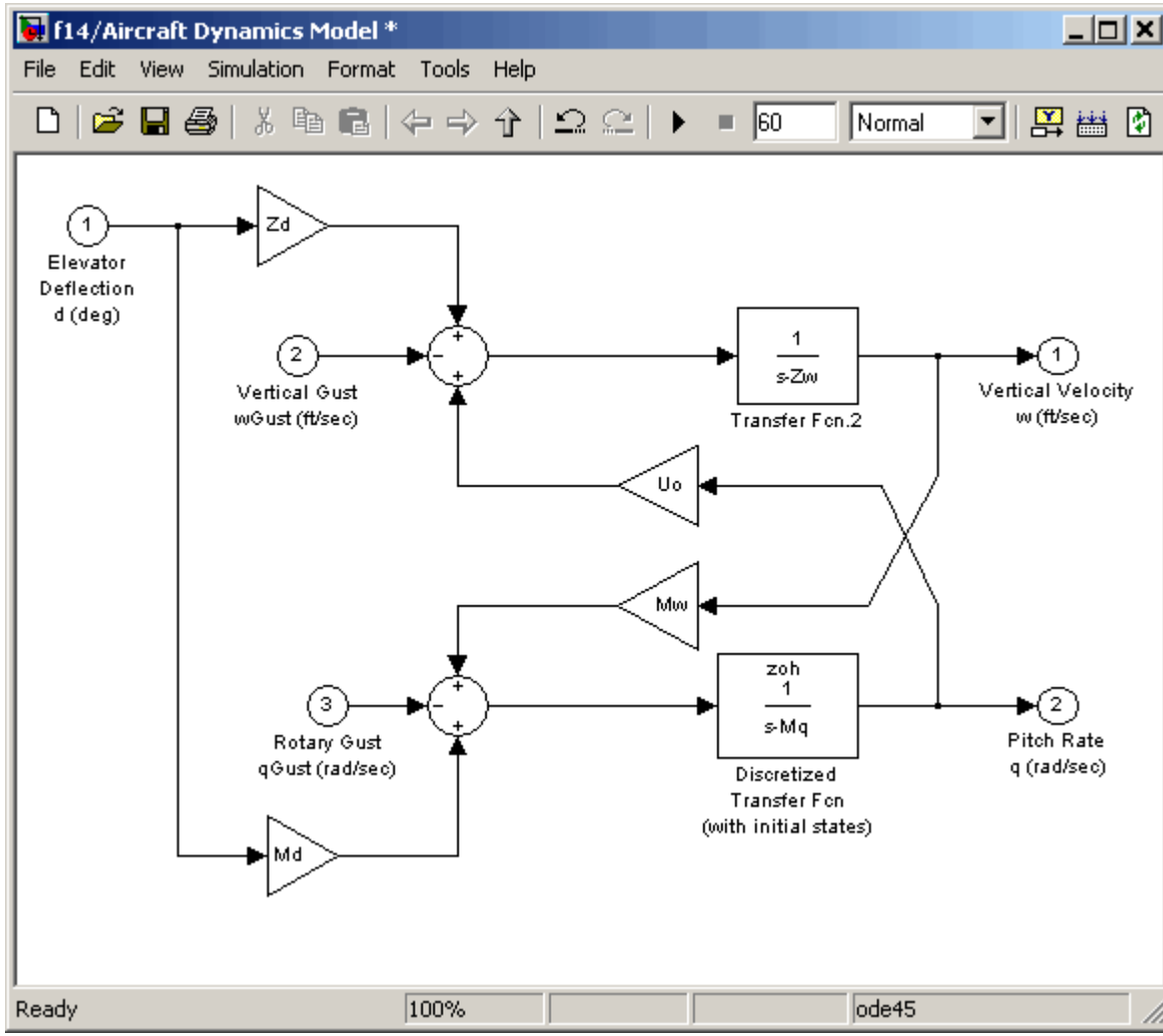
The **f14/Aircraft Dynamics Model** window now looks like this.



11 Add the Discretized Transfer Fcn block to the model.

- **a** Click the Discretized Transfer Fcn block.
- **b** Drag the Discretized Transfer Fcn block into position to complete the model.

The **f14/Aircraft Dynamics Model** window now looks like this.



How to Discretize a Model from the MATLAB Command Window

Use the `sldiscmdl` function to discretize Simulink software models from the MATLAB Command Window. You can specify the transform method, the sample time, and the discretization method with the `sldiscmdl` function.

For example, the following command discretizes the `f14` model in the s-domain with a 1-second sample time using a zero-order hold transform method:

```
sldiscmdl('f14',1.0,'zoh')
```

For more information on the `sldiscmdl` function, see "Model Construction" in the*Simulink Reference*.

4

Working with Sample Times

What Is Sample Time?

The *sample time* of a block is a parameter that indicates when, during simulation, the block produces outputs and if appropriate, updates its internal state. The internal state includes but is not limited to continuous and discrete states that are logged.

Note Do not confuse the Simulink usage of the term sample time with the engineering sense of the term. In engineering, sample time refers to the rate at which a discrete system samples its inputs. Simulink allows you to model single-rate and multirate discrete systems and hybrid continuous-discrete systems through the appropriate setting of block sample times that control the rate of block execution (calculations).

For many engineering applications, you need to control the rate of block execution. In general, Simulink provides this capability by allowing you to specify an explicit `SampleTime` parameter in the block dialog or at the command line. Blocks that do not have a `SampleTime` parameter have an implicit sample time. You cannot specify implicit sample times. Simulink determines them based upon the context of the block in the system. The Integrator block is an example of a block that has an implicit sample time. Simulink automatically sets its sample time to `0`.

Sample times can be port-based or block-based. For block-based sample times, all of the inputs and outputs of the block run at the same rate. For port-based sample times, the input and output ports can run at different rates.

Sample times can also be discrete, continuous, fixed in minor step, inherited, constant, variable, triggered, or asynchronous. The following sections discuss these sample time types, as well as sample time propagation and rate transitions between block-based or port-based sample times. You can use this information to control your block execution rates, debug your model, and verify your model.

How to Specify the Sample Time

In this section...

Designating Sample Times

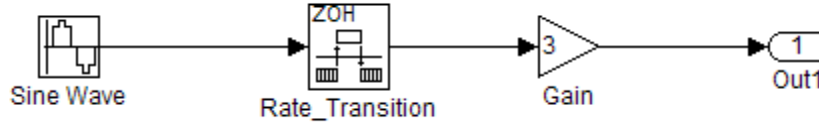
Simulink allows you to specify a block sample time directly as a numerical value or symbolically by defining a sample time vector. In the case of a discrete sample time, the vector is $[T_s, T_o]$ where T_s is the sampling period and T_o is the initial time offset. For example, consider a discrete model that produces its outputs every two seconds. If your base time unit is seconds, you can directly set the discrete sample time by specifying the numerical value of `2` as the `SampleTime` parameter. Because the offset value is zero, you do not need to specify it; however, you can enter `[2,0]` in the **Sample time** field.

For nondiscrete blocks, the components of the vector are symbolic values that represent one of the types in "Types of Sample Time" on page 4-15. The following table summarizes these types and the corresponding sample time values. The table also defines the explicit nature of each sample time type and designates the associated color and annotation. Because an *inherited sample time* is explicit, you can specify it as `[-1, 0]` or as `-1`. Whereas, a triggered sample time is implicit; only Simulink can assign the sample time of `[-1, -1]`. (For more information about colors and annotations, see "How to View Sample Time Information" on page 4-9.)

Designations of Sample Time Information

Sample Time Type	Sample Time	Color	Annotation	Explicit
Discrete	$[T_s, T_o]$	red, green, blue, light blue, dark green, orange	D1, D2, D3, D4, D5, D6, D7,... Di	Yes
Continuous	[0, 0]	black	Cont	Yes
Fixed in minor step	[0, 1]	gray	FiM	Yes
Inherited	[–1, 0]	N/A	N/A	Yes
Constant	[Inf, 0]	magenta	Inf	Yes
Variable	$[-2, T_{vo}]$	brown	V1, V2,... Vi	No
Hybrid	N/A	yellow	N/A	No
Triggered	[–1, –1]	cyan	T	No
Asynchronous	[–1, –n]	purple	A1, A2,... Ai	No

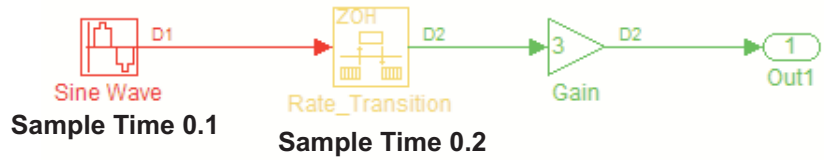
You can use the explicit sample time values in this table to specify sample times interactively or programmatically for either block-based or port-based sample times. The following model, Specify_Sample_Time.mdl, serves as a reference for this section.



Specify_Sample_Time.mdl

In this example, our goal is to set the sample time of the input sine wave signal to `0.1` and to achieve an output sample time of `0.2`. The Rate Transition block serves as a zero-order hold. The resulting block diagram after setting

the sample times and simulating the model is shown in the following figure. (The colors and annotations indicate that this is a discrete model.)



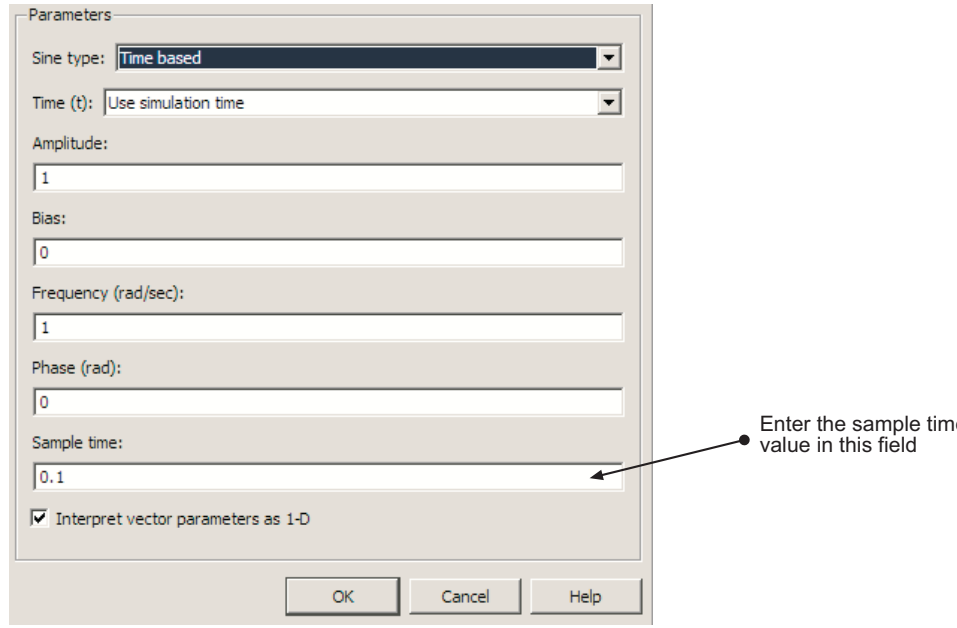
Specify_Sample_Time.mdl after Setting Sample Times

Specifying Block-Based Sample Times Interactively

To set the sample time of a block interactively:

1. In the Simulink model window, double-click the block. The block parameter dialog box opens.
2. Enter the sample time in the **Sample time** field.
3. Click **OK**.

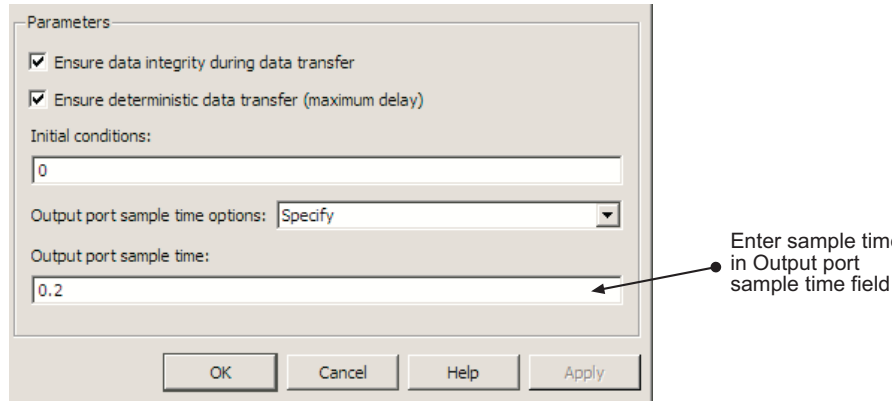
Following is a figure of a parameters dialog box for the Sine Wave block after entering `0.1` in the **Sample time** field.



Specifying Port-Based Sample Times Interactively

The Rate Transition block has port-based sample times. You can set the output port sample time interactively by completing the following steps:

1. Double-click the Rate Transition block. The parameters dialog box opens.
2. Leave the drop-down menu choice of the **Output port sample time options** as `Specify`.
3. Replace the `-1` in the **Output port sample time** field with `0.2`.



4 Click **OK**.

For more information about the sample time options in the Rate Transition parameters dialog box, see the Rate Transition reference page.

Specifying Block-Based Sample Times Programmatically

To set a block sample time programmatically, set its `SampleTime` parameter to the desired sample time using the `set_param` command. For example, to set the sample time of the Gain block in the "Specify_Sample_Time" model to inherited (`-1`), enter the following command:

```
set_param('Specify_Sample_Time/Gain','SampleTime','[-1, 0]')
```

As with interactive specification, you can enter just the first vector component if the second component is zero.

```
set_param('Specify_Sample_Time/Gain','SampleTime','-1')
```

Specifying Port-Based Sample Times Programmatically

To set the output port sample time of the Rate Transition block to `0.2`, use the `set_param` command with the parameter `OutPortSampleTime`:

```
set_param('Specify_Sample_Time/Rate Transition',...
```

```
'OutPortSampleTime', '0.2')
```

Accessing Sample Time Information Programmatically

To access all sample times associated with a model, use the API `Simulink.BlockDiagram.getSampleTimes`.

To access the sample time of a single block, use the API `Simulink.Block.getSampleTimes`.

Specifying Sample Times for a Custom Block

You can design custom blocks so that the input and output ports operate at different sample time rates. For information on specifying block-based and port-based sample times for S-functions, see “Sample Times” .

Determining Sample Time Units

Since the execution of a Simulink model is not dependent on a specific set of units, you must determine the appropriate base time unit for your application and set the sample time values accordingly. For example, if your base time unit is second, then you would represent a sample time of `0.5` second by setting the sample time to `0.5`.

Changing the Sample Time After Simulation Start Time

To change a sample time after simulation begins, you must stop the simulation, reset the `SampleTime` parameter, and then restart execution.

How to View Sample Time Information

In this section...

Viewing Sample Time Display

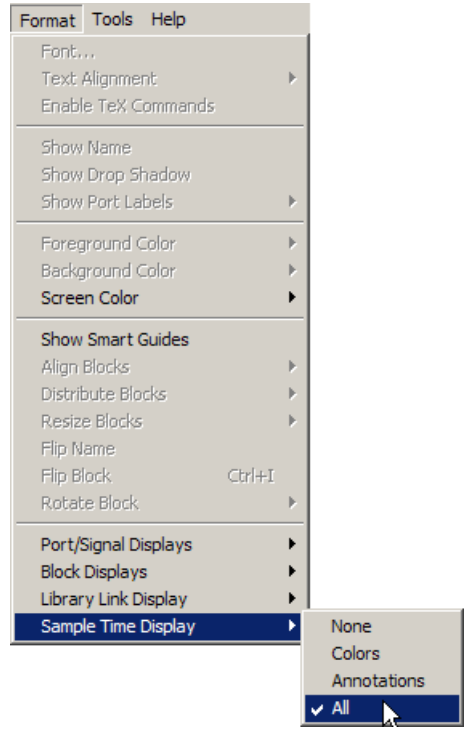
Simulink models can display color coding and annotations that represent specific sample times. As shown in the table Designations of Sample Time Information on page 4-4, each sample time type has one or more colors associated with it. You can display the blocks and signal lines in color, the annotations in black, or both the colors and the annotations. To choose one of these options:

1. In the Simulink model window, select **Format > Sample Time Display**.
2. Select **Colors**, **Annotations**, or **All**.

Selecting **All** results in the display of both the colors and the annotations. Regardless of your choice, Simulink performs an **Update Diagram** automatically. To turn off the colors and annotations:

1. Select **Format > Sample Time Display**.
2. Select **None**.

Simulink performs another **Update Diagram** automatically.



Your Sample Time Display choices directly control the information that the Sample Time Legend displays.

Note The discrete sample times in the table Designations of Sample Time Information on page 4-4 represent a special case. Five colors indicate the fastest through the fifth fastest discrete rate. A sixth color, orange, represents all rates that are slower than the fifth discrete rate. You can distinguish between these slower rates by looking at the annotations on their respective signal lines.

Managing the Sample Time Legend

You can view the Sample Time Legend for an individual model or for multiple models. Additionally, you can prevent the legend from automatically opening when you select options on the **Sample Time Display** menu.

Viewing the Legend

To assist you with interpreting your block diagram, a **Sample Time Legend** is available that contains the sample time color, annotation, description, and value for each sample time in the model. You can use one of three methods to view the legend, but upon first opening the model, you must first perform an **Update Diagram**.

1. In the Simulink model window, select **Edit > Update Diagram**.
2. Select **View > Sample Time Legend** or press **Ctrl +J**.

In addition, whenever you select **Colors**, **Annotations**, or **All** from the **Sample Time Display** menu, Simulink updates the model diagram and opens the legend by default. The legend contents reflect your **Sample Time Display** choices. By default or if you have selected **None** , the legend contains a description of the sample time and the sample time value. If you turn colors on, the legend displays the appropriate color beside each description. Similarly, if you turn annotations on, the annotations appear in the legend.

The legend does not provide a discrete rate for all types of sample times. For asynchronous and variable sample times, the legend displays a link to the block that controls the sample time in place of the sample time value. Clicking one of these links highlights the corresponding block in the block diagram. The rate listed under hybrid and asynchronous hybrid models is “Not Applicable” because these blocks do not have a single representative sample time.

Note The Sample Time Legend displays all of the sample times in the model, including those that are not associated with any block. For example, if the fixed step size is 0.1 and all of the blocks have a sample time of 0.2, then both rates (i.e., 0.1 and 0.2) appear in the legend.

For subsequent viewings of the legend, you must repeat the **Update Diagram** to access the latest known information.

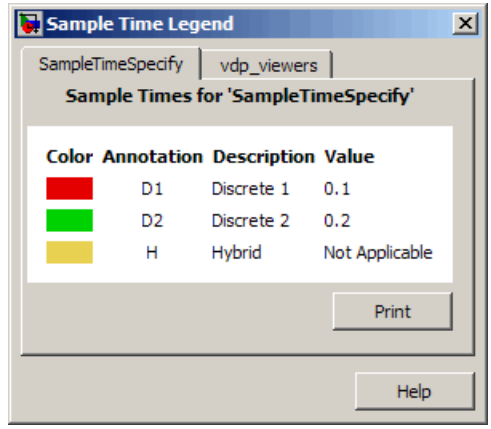
Turning the Legend Off

If you prefer not to view the legend upon selecting **Sample Time Display**:

1. In the Simulink model window, select **File > Preferences**.
2. Scroll to the bottom of the main **Preferences** pane.
3. Clear **Open the Sample Time Legend whenever the Sample Time Display is changed**.

Viewing Multiple Legends

If you have more than one model open and you view the **Sample Time Legend** for each one, a single legend window appears with multiple tabs. Each tab contains the name of the model and the respective legend information. The following figure shows the tabbed legends for SampleTimeSpecify.mdl and vdp_viewers.mdl.

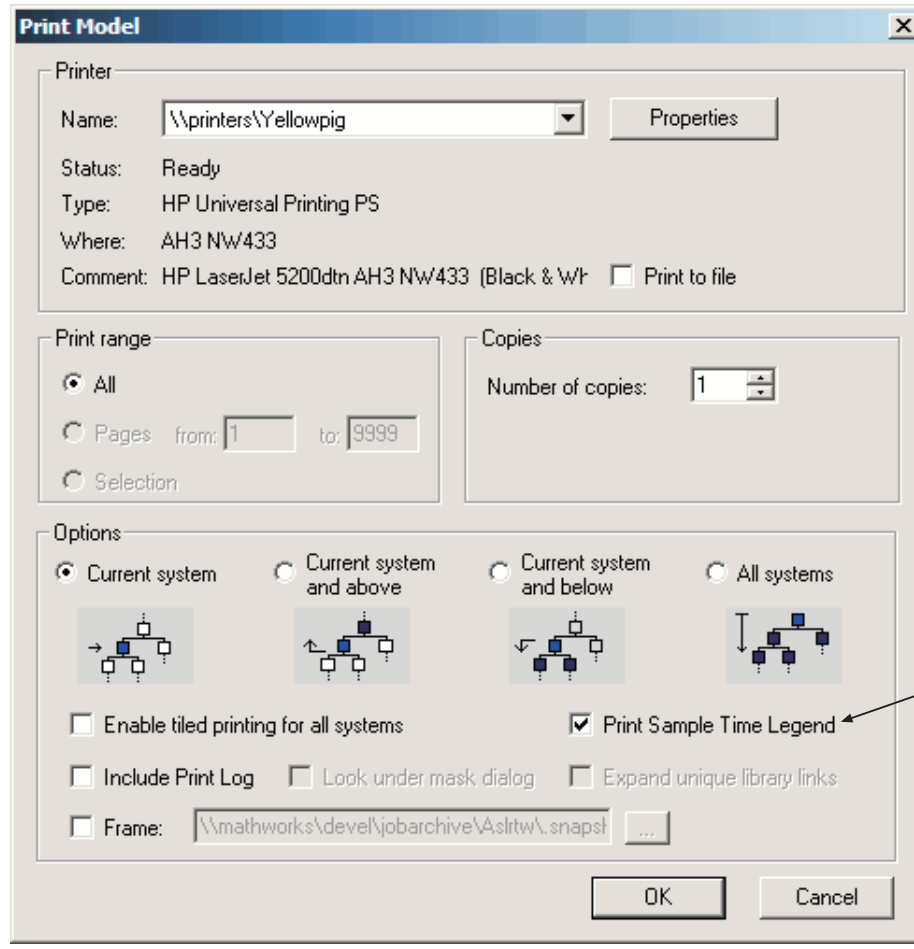


How to Print Sample Time Information

You can print the sample time information in the Sample Time Legend by using either of these methods:

- In the Sample Time Legend window, click **Print**.
- Print the legend from the **Print Model** dialog box:

  1. In the model window, select **File > Print**.
  2. Under **Options**, select the check box beside **Print Sample Time Legend**.
  3. Click **OK**.



Select the Print Sample Time Legend option.

Types of Sample Time

In this section...

Discrete Sample Time

Given a block with a discrete sample time, Simulink executes the block output or update method at times

$$t_n = nT_s + |T_o|$$

where the sample time period T_s is always greater than zero and less than the simulation time, T_{sim}. The number of periods (n) is an integer that must satisfy:

$$0 \le n \le \frac{T_{sim}}{T_s}$$

As simulation progresses, Simulink computes block outputs only once at each of these fixed time intervals of t_n. These simulation times, at which Simulink executes the output method of a block for a given sample time, are referred to as *sample time hits*. Discrete sample times are the only type for which sample time hits are known *a priori*.

If you need to delay the initial sample hit time, you can define an offset, T_o.

The Unit Delay block is an example of a block with a discrete sample time.

Continuous Sample Time

Unlike the discrete sample time, continuous sample hit times are divided into major time steps and minor time steps, where the minor steps represent subdivisions of the major steps (see "Minor Time Steps" on page 2-23). The ODE solver you choose integrates all continuous states from the simulation start time to a given major or minor time step. The solver determines the times of the minor steps and uses the results at the minor time steps to improve the accuracy of the results at the major time steps. However, you see the block output only at the major time steps.

To specify that a block, such as the Derivative block, is continuous, enter [0, 0] or 0 in the **Sample time** field of the block dialog.

Fixed in Minor Step

If the sample time of a block is set to `[0, 1]`, the block becomes *fixed in minor step*. For this setting, Simulink does not execute the block at the minor time steps; updates occur only at the major time steps. This process eliminates unnecessary computations of blocks whose output cannot change between major steps.

While you can explicitly set a block to be fixed in minor step, more typically Simulink sets this condition as either an inherited sample time or as an alteration to a user specification of `0` (continuous). This setting is equivalent to, and therefore converted to, the fastest discrete rate when you use a fixed-step solver.

Inherited Sample Time

If a block sample time is set to [–1, 0] or –1, the sample time is *inherited* and Simulink determines the best sample time for the block based on the block context within the model. Simulink performs this task during the compilation stage; the original inherited setting never appears in a compiled model. Therefore, you never see inherited ([–1, 0]) in the Sample Time Legend. (See "How to View Sample Time Information" on page 4-9.)

Examples of inherited blocks include the Gain and Add blocks.

All inherited blocks are subject to the process of sample time propagation, as discussed in "How Propagation Affects Inherited Sample Times" on page 4-31

Constant Sample Time

Specifying a constant (`Inf`) sample time is a request for an optimization for which the block executes only once during model initialization. Simulink honors such requests if all of the following conditions hold:

- The **Inline parameters** option is enabled in the **Optimization** pane of the Configuration Parameters dialog box.
- The block has no continuous or discrete states.
- The block allows for a constant sample time.
- The block does not drive an output port of a conditionally executed subsystem (see "Enabled Subsystems" on page 6-4).
- The block has no tunable parameters.

One exception is an empty subsystem. A subsystem that has no blocks—not even an input or output block—always has a constant sample time regardless of the status of the conditions listed above.

This optimization process speeds up the simulation by eliminating the need to recompute the block output at each step. Instead, during each model update, Simulink first establishes the constant sample time of the block and then computes the initial values of its output ports. Simulink then uses these values, without performing any additional computations, whenever it needs the outputs of the block.

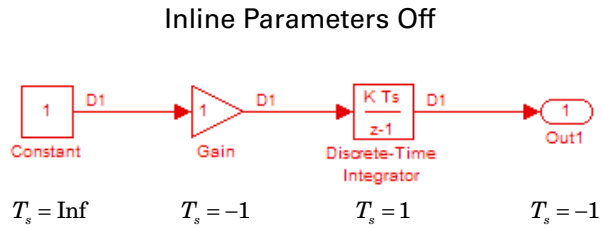
Note The Simulink block library includes several blocks, such as the MATLAB S-Function block, the Level-2 MATLAB S-Function block, and the Model block, whose ports can produce outputs at different sample rates. It is possible for some of the ports of such blocks to have a constant sample time. These ports produce outputs only once—at the beginning of a simulation. Any other ports produce output at their respective sample times.

If Simulink cannot honor the request to use the optimization, then Simulink treats the block as if it had specified an inherited sample time (–1).

One specific case for which Simulink rejects the request is when parameters are tunable. By definition, you can change the parameter values of a block

having tunable parameters; therefore, the block outputs are variable rather than constant. For such cases, Simulink performs sample time propagation (see "How Propagation Affects Inherited Sample Times" on page 4-31) to determine the block sample time.

An example of a Constant block with tunable parameters is shown below. Since the **Inline parameters** option is disabled, the **Constant value** parameter is tunable and the sample time cannot be constant, even if it is set to `Inf`. To ensure accurate simulation results, Simulink treats the sample time of the Constant block as inherited and uses sample time propagation to calculate the sample time. The Discrete-Time Integrator block is the first block, downstream of the Constant block, which does not inherit its sample time. The Constant block, therefore, inherits the sample time of `1` from the Integrator block via backpropagation.



Variable Sample Time

Blocks that use a variable sample time have an implicit `SampleTime` parameter that the block specifies; the block tells Simulink when to run it. The compiled sample time is [–2, T_{vo}] where T_{vo} is a unique variable offset.

The Pulse Generator block is an example of a block that has a variable sample time. Since Simulink supports variable sample times for variable-step solvers only, the Pulse Generator block specifies a discrete sample time if you use a fixed-step solver.

To learn how to write your own block that uses a variable sample time, see "C MEX S-Function Examples".

Triggered Sample Time

If a block is inside of a triggered-type (e.g., function-call, enabled and triggered, or iterator) subsystem, the block may have either a triggered or a constant sample time. You cannot specify the triggered sample time type explicitly. However, to achieve a triggered type during compilation, you must set the block sample time to inherited (–1). Simulink then determines the specific times at which the block computes its output during simulation. One exception is if the subsystem is an asynchronous function call, as discussed in the following section.

Asynchronous Sample Time

An asynchronous sample time is similar to a triggered sample time. In both cases, it is necessary to specify an inherited sample time because the Simulink engine does not regularly execute the block. Instead, a run-time condition determines when the block executes. For the case of an asynchronous sample time, an S-function makes an asynchronous function call.

The differences between these sample time types are:

- Only a function-call subsystem can have an asynchronous sample time. (See "Function-Call Subsystems" on page 6-23.)
- The source of the function-call signal is an S-function having the option SS_OPTION_ASYNCHRONOUS.
- The asynchronous sample time can also occur when a virtual block is connected to an asynchronous S-function or an asynchronous function-call subsystem.
- The asynchronous sample time is important to certain code-generation applications. (See "Handling Asynchronous Events".)
- The sample time is $[-1,-n]$.

For an explanation of how to use blocks to model and generate code for asynchronous event handling, see "Rate Transitions and Asynchronous Blocks".

Determining the Compiled Sample Time of a Block

During the compilation phase of a simulation, Simulink determines the sample time of a block from its `SampleTime` parameter (if it has an explicit sample time), its block type (if it has an implicit sample time), or by its context within the model. This compiled sample time determines the sample rate of a block during simulation. You can determine the compiled sample time of any block in a model by first updating the model and then getting the block `CompiledSampleTime` parameter, using the `get_param` command.

Managing Sample Times in Subsystems

Subsystems fall into two categories: triggered and nontriggered. For triggered subsystems, in general, the subsystem gets its sample time from the triggering signal. One exception occurs when you use a Trigger block to create a triggered subsystem. If you set the block **Trigger type** to **function-call** and the **Sample time type** to **periodic**, the `SampleTime` parameter becomes active. In this case, *you* specify the sample time of the Trigger block, which in turn, establishes the sample time of the subsystem.

The four nontriggered subsystems are virtual, enabled, atomic, and action. Simulink calculates the sample times of virtual and enabled subsystems based on the respective sample times of their contents. The atomic subsystem is a special case in that the subsystem block has a `SampleTime` parameter. Moreover, for a sample time other than the default value of –1, the blocks inside the atomic subsystem can have only a value of `Inf`, –1, or the identical (discrete) value of the subsystem `SampleTime` parameter. If the atomic subsystem is left as inherited, Simulink calculates the block sample time in the same manner as the virtual and enabled subsystems. However, the main purpose of the subsystem `SampleTime` parameter is to allow for the simultaneous specification of a large number of blocks, within an atomic subsystem, that are all set to inherited. Finally, the sample time of the action subsystem is set by the If block or the Switch Case block.

Managing Sample Times in Systems

In this section...

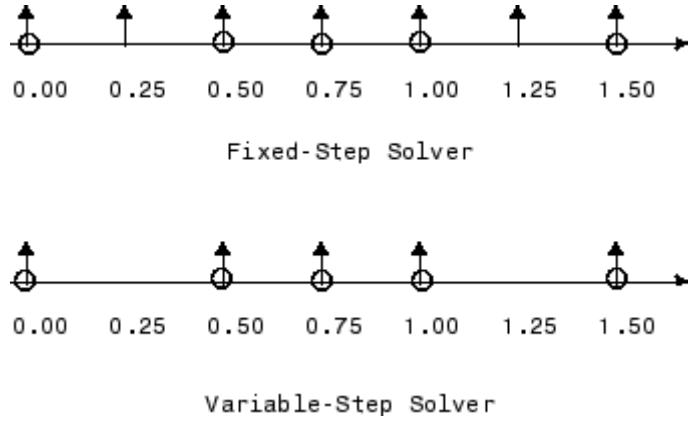
Purely Discrete Systems

A purely discrete system is composed solely of discrete blocks and can be modeled using either a fixed-step or a variable-step solver. Simulating a discrete system requires that the simulator take a simulation step at every sample time hit. For a *multirate discrete system*—a system whose blocks Simulink samples at different rates—the steps must occur at integer multiples of each of the system sample times. Otherwise, the simulator might miss key transitions in the states of the system. The step size that the Simulink software chooses depends on the type of solver you use to simulate the multirate system and on the fundamental sample time.

The *fundamental sample time* of a multirate discrete system is the greatest integer divisor of the actual sample times of the system. For example, suppose that a system has sample times of 0.25 and 0.50 seconds. The fundamental sample time in this case is 0.25 seconds. Suppose, instead, the sample times are 0.50 and 0.75 seconds. The fundamental sample time is again 0.25 seconds.

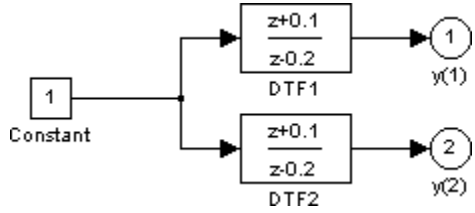
The importance of the fundamental sample time directly relates to whether you direct the Simulink software to use a fixed-step or a variable-step discrete solver to solve your multirate discrete system. A fixed-step solver sets the simulation step size equal to the fundamental sample time of the discrete system. In contrast, a variable-step solver varies the step size to equal the distance between actual sample time hits.

The following diagram illustrates the difference between a fixed-step and a variable-step solver.



In the diagram, the arrows indicate simulation steps and circles represent sample time hits. As the diagram illustrates, a variable-step solver requires fewer simulation steps to simulate a system, if the fundamental sample time is less than any of the actual sample times of the system being simulated. On the other hand, a fixed-step solver requires less memory to implement and is faster if one of the system sample times is fundamental. This can be an advantage in applications that entail generating code from a Simulink model (using Real-Time Workshop). In either case, the discrete solver provided by Simulink is optimized for discrete systems; however, you can simulate a purely discrete system with any one of the solvers and obtain equivalent results.

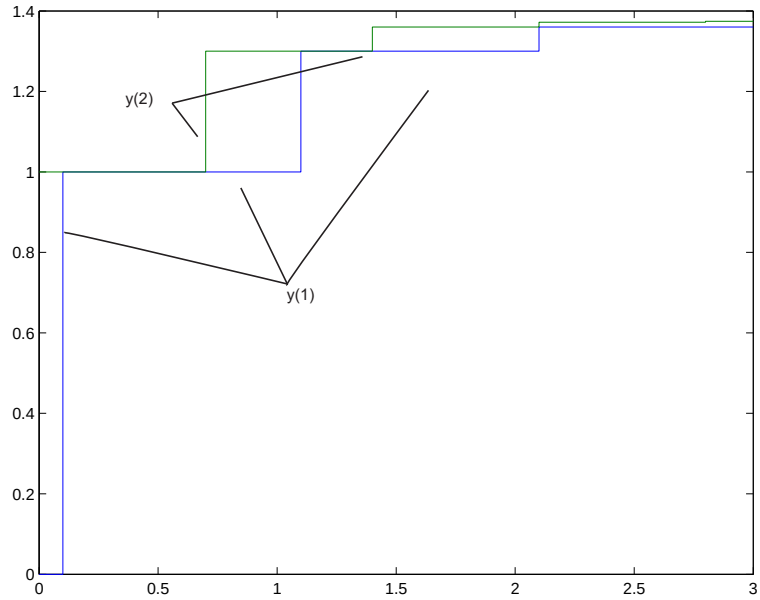
Consider the following example of a simple multirate system. For this example, the DTF1 Discrete Transfer Fcn block's **Sample time** is set to [1 0.1], which gives it an offset of 0.1. The **Sample time** of the DTF2 Discrete Transfer Fcn block is set to 0.7, with no offset.



Running the simulation and plotting the outputs using the `stairs` function

```
[t,x,y] = sim('multirate', 3);
stairs(t,y)
```

produces the following plot.



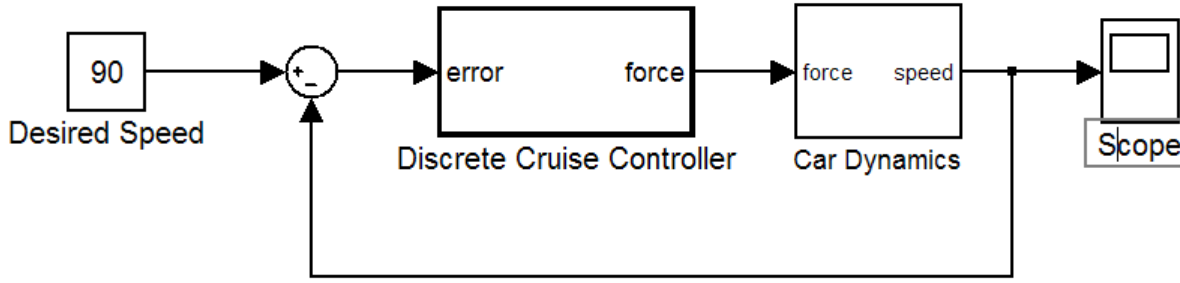
(See Chapter 12, "Running a Simulation Programmatically" for information on the `sim` command.)

As the figure demonstrates, because the DTF1 block has a `0.1` offset, the DTF1 block has no output until `t = 0.1`. Similarly, the initial conditions of the transfer functions are zero; therefore, the output of DTF1, y(1), is zero before this time.

Hybrid Systems

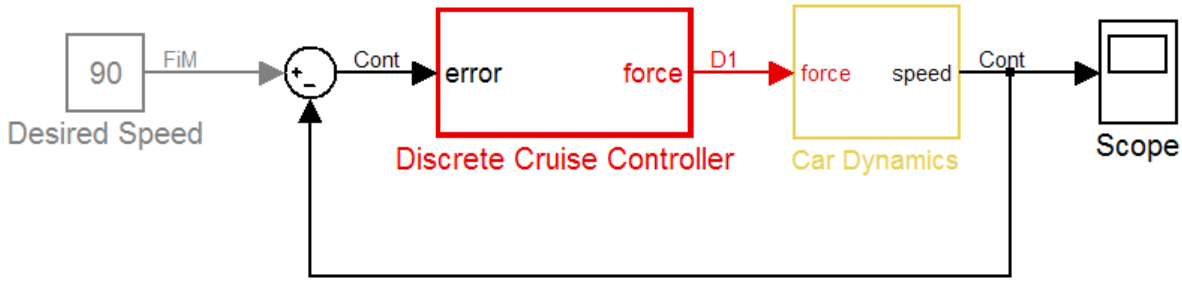
Hybrid systems contain both discrete and continuous blocks and thus have both discrete and continuous states. However, Simulink solvers treat any system that has both continuous and discrete sample times as a hybrid system. For information on modeling hybrid systems, see "Modeling Hybrid Systems" on page 2-8.

In block diagrams, the term hybrid applies to both hybrid systems (mixed continuous-discrete systems) and systems with multiple sample times (multirate systems). Such systems turn yellow in color when you perform an **Update Diagram** with Sample Time Display **Colors** turned 'on'. As an example, consider the following model that contains an atomic subsystem, "Discrete Cruise Controller", and a virtual subsystem, "Car Dynamics".

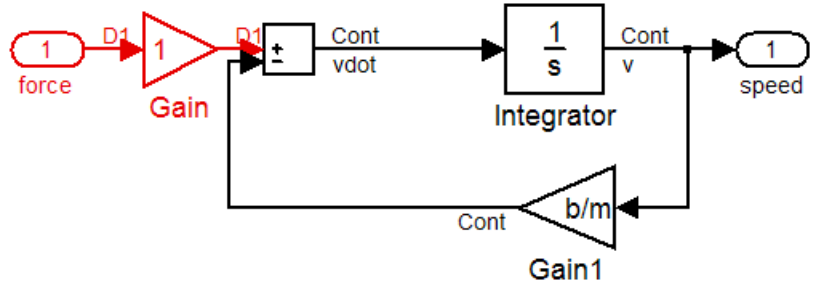


Car Model

With the `Sample Time Display` option set to **All**, an **Update Diagram** turns the virtual subsystem yellow, indicating that it is a hybrid subsystem. In this case, the subsystem is a true hybrid system since it has both continuous and discrete sample times. As shown below, the discrete input signal, D1, combines with the continuous velocity signal, v, to produce a continuous input to the integrator.

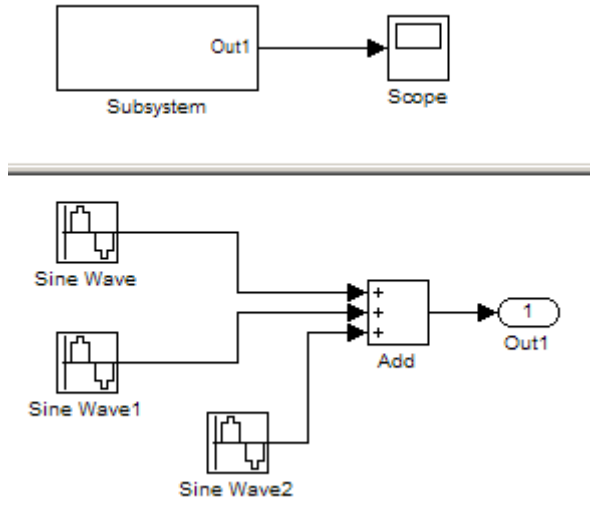


Car Model after an Update Diagram



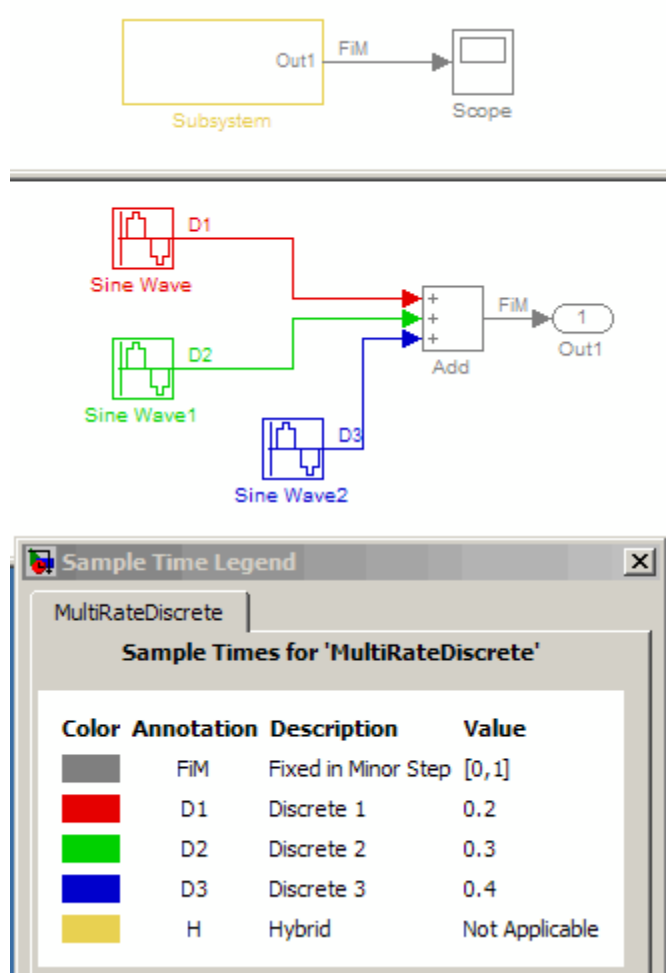
Car Dynamics Subsystem after an Update Diagram

Now consider a multirate subsystem that contains three Sine Wave source blocks, each of which has a unique sample time — 0.2, 0.3, and 0.4, respectively.



Multirate Subsystem

An **Update Diagram** turns the subsystem yellow because the subsystem contains more than one sample time. As shown in the Sample Time Legend, the Sine Wave blocks have discrete sample times D1, D2, and D3 and the output signal is fixed in minor step.



Multirate Subsystem after an Update Diagram

In assessing a system for multiple sample times, Simulink does not consider either constant [inf, 0] or asynchronous [–1, –n] sample times. Thus a subsystem consisting of one block with a constant sample time and one block with a discrete sample time will not be designated as hybrid.

The hybrid annotation and coloring are very useful for evaluating whether or not the subsystems in your model have inherited the correct or expected sample times.

Resolving Rate Transitions

In general, a rate transition exists between two blocks if their sample times differ, that is, if either of their sample-time vector components are different. The exceptions are:

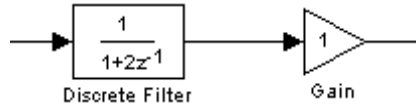
- A constant sample time (`[Inf, 0]`) never has a rate transition with any other rate.
- A continuous sample time (black) and the fastest discrete rate (red) never has a rate transition if you use a fixed-step solver.
- A variable sample time and fixed in minor step do not have a rate transition.

You can resolve rate transitions by inserting rate transition blocks and by using two diagnostic tools. For the single-tasking execution mode, the **Single task rate transition** diagnostic allows you to set the level of Simulink rate transition messages. The **Multitask rate transition** diagnostic serves the same function for multitasking execution mode. These execution modes directly relate to the type of solver in use: Variable-step solvers are always single-tasking; fixed-step solvers may be explicitly set as single-tasking or multitasking.

For a detailed discussion on rate transitions, see “Single-Tasking and Multitasking Execution Modes” and “Handling Rate Transitions”.

How Propagation Affects Inherited Sample Times

During a model update, for example at the beginning of a simulation, Simulink uses a process called sample time propagation to determine the sample times of blocks that inherit their sample times. The figure below illustrates a Discrete Filter block with a sample time period T_s driving a Gain block.



Because the output of the Gain block is the input multiplied by a constant, its output changes at the same rate as the filter. In other words, the Gain block has an effective sample rate equal to the sample rate of the filter. The establishment of such effective rates is the fundamental mechanism behind sample time propagation in Simulink.

Process for Sample Time Propagation

Simulink uses the following basic process to assign sample times to blocks that inherit their sample times:

1. Propagate known sample time information forward.
2. Propagate known sample time information backward.
3. Apply a set of heuristics to determine additional sample times.
4. Repeat until all sample times are known.

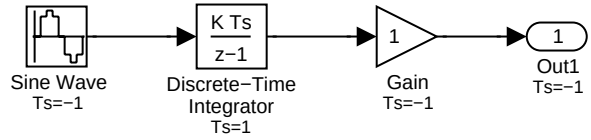
Simulink Rules for Assigning Sample Times

A block having a block-based sample time inherits a sample time based on the sample times of the blocks connected to its inputs, and in accordance with the following rules:

If...	then
all of the inputs have the same sample time and the block can accept that sample time	Simulink assigns the sample time to the block
the inputs have different discrete sample times and all of the input sample times are integer multiples of the fastest input sample time	Simulink assigns the sample time of the fastest input to the block . (This assignment assumes that the block can accept the fastest sample time.)
the inputs have different discrete sample times, some of the input sample times are not integer multiples of the fastest sample time, and the model uses a variable-step solver	Simulink assigns a fixed-in-minor-step sample time to the block.
the inputs have different discrete sample times, some of the input sample times are not integer multiples of the fastest sample time, the model uses a fixed-step solver, and Simulink can compute the greatest common integer divisor (GCD) of the sample times coming into the block,	Simulink assigns the GCD sample time to the block. Otherwise, Simulink assigns the fixed step size of the model to the block.
the sample times of some of the inputs are unknown, or if the block cannot accept the sample time	Simulink determines a sample time for the block based on a set of heuristics.

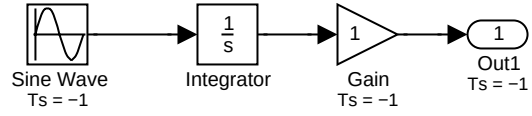
Monitoring Backpropagation in Sample Times

When you update or simulate a model that specifies the sample time of a source block as inherited (–1), the sample time of the source block may be backpropagated; Simulink may set the sample time of the source block to be identical to the sample time specified by or inherited by the block connected to the source block. For example, in the model below, the Simulink software recognizes that the Sine Wave block is driving a Discrete-Time Integrator block whose sample time is 1; so it assigns the Sine Wave block a sample time of 1.



You can verify this sample time setting by selecting **Sample Time Display > Colors** from the Simulink **Format** menu and noting that both blocks are red. Because the Discrete-Time Integrator block looks at its input only during its sample hit times, this change does not affect the results of the simulation, but does improve the simulation performance.

Now replacing the Discrete-Time Integrator block with a continuous Integrator block, as shown below, causes the Sine Wave and Gain blocks to change to continuous blocks. You can test this change by selecting **Update Diagram** from the **Edit** menu to update the colors; both blocks now appear black.



Note Backpropagation makes the sample times of model sources dependent on block connectivity. If you change the connectivity of a model whose sources inherit sample times, you can inadvertently change the source sample times. For this reason, when you update or simulate a model, by default, Simulink displays warnings at the command line if the model contains sources that inherit their sample times.

5

Referencing a Model

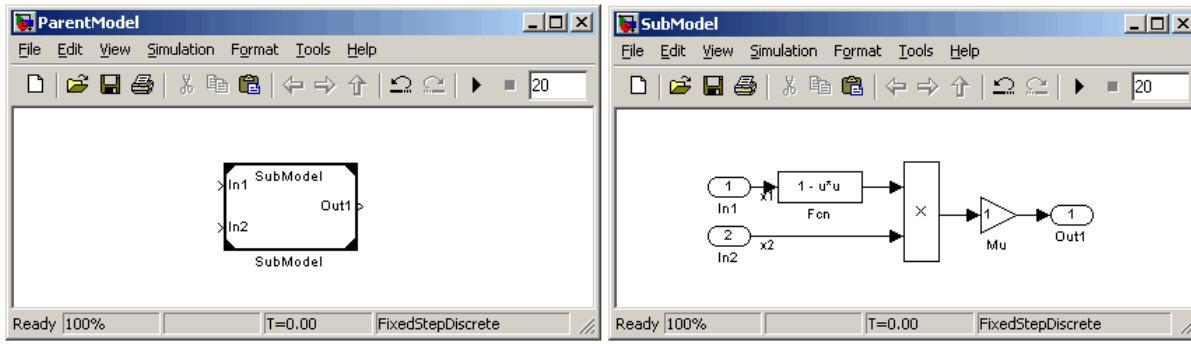
Overview of Model Referencing

In this section...

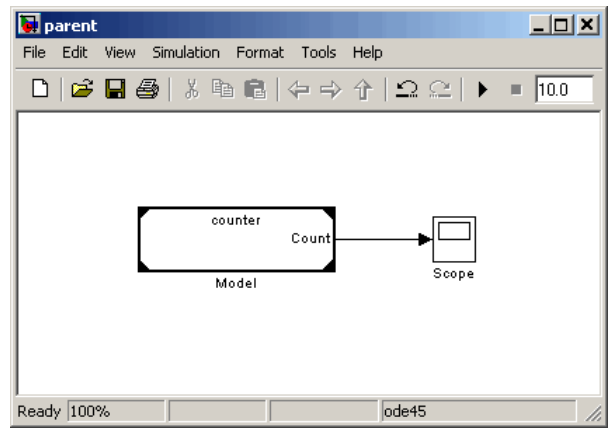
About Model Referencing

You can include one model in another by using Model blocks. Each instance of a Model block represents a reference to another model, called a *referenced model* or *submodel*. For simulation and code generation, the referenced model effectively replaces the Model block that references it. The model that contains a referenced model is its *parent model*. A collection of parent and referenced models constitute a *model reference hierarchy*. A parent model and all models subordinate to it comprise a *branch* of the reference hierarchy.

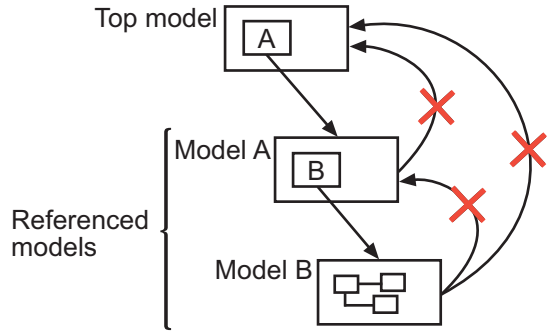
The interface of a referenced model consists of its input and output ports (and trigger port in the case of a function-call model) and its parameter arguments. A Model block displays inputs and outputs corresponding to the root-level inputs and outputs of the model it references. These ports enable you to incorporate the referenced model into the block diagram of the parent model. For example, in the next figure the Model block in the parent model on the left could represent the submodel on the right:



You can use the ports on a Model block to connect the submodel to other elements of the parent model. Connecting a signal to a Model block port has the same effect as connecting the signal to the corresponding port in the submodel.



A referenced model can itself contain Model blocks and thus reference lower-level models, to any depth. The *top model* is the topmost model in a hierarchy of referenced models. Where only one level of model reference exists, the parent model and top model are the same. To prevent cyclic inheritance, a Model block cannot refer directly or indirectly to a model that is superior to it in the model reference hierarchy. This figure shows cyclic inheritance.



A parent model can contain multiple Model blocks that reference the same submodel as long as the submodel does not define global data. The submodel can also appear in other parent models at any level. You can parameterize a referenced model to provide tunability for all instances of the model. Also, you can parameterize a referenced model to let different Model blocks specify different values for variables that define the behavior of the submodel. See "Parameterizing Model References" on page 5-40 for details.

By default, the Simulink software executes a top model interpretively, just as it would if the model did not include submodels. Simulink can execute a referenced model interpretively, as if it were an atomic subsystem, or by compiling the submodel to code and executing the code. See "Referenced Model Simulation Modes" on page 5-12 for details.

You can use a referenced model as a standalone model, if it does not depend on data that is available only from a higher-level model. An appropriately configured model can function as both a standalone model and a referenced model, without changing the model or any entities derived from it.

Referenced Model Advantages

Like subsystems, referenced models allow you to organize large models hierarchically; Model blocks can represent major subsystems. Like libraries, referenced models allow you to use the same capability repeatedly without having to redefine it. However, referenced models provide several advantages that are unavailable with subsystems and/or library blocks:

- **Modular development**

You can develop a referenced model independently from the models that use it.

- **Model Protection**

  You can obscure the contents of a referenced model, allowing you to distribute it without revealing the intellectual property that it embodies.

- **Inclusion by reference**

  You can reference a model multiple times without having to make redundant copies, and multiple models can reference the same model.

- **Incremental loading**

  Simulink loads a referenced model at the point it needs to use the model, which speeds up model loading.

- **Accelerated simulation**

  Simulink can convert a referenced model to code and simulate the model by running the code, which is faster than interactive simulation.

- **Incremental code generation**

  Accelerated simulation requires code generation only if the model has changed since the code was previously generated.

- **Independent configuration sets**

  The configuration set used by a referenced model can differ from the configuration set of its parent or other referenced models.

Masking Model Blocks

You can use the masking facility to create custom dialog boxes and icons for Model blocks. Masked dialog boxes can make it easier to specify additional parameters for Model blocks. For details about masking, see Chapter 21, "Working with Block Masks".

Model Referencing Demos

Simulink includes several demos that illustrate model referencing. To access these demos:

1. In the MATLAB Help browser **Contents** pane, select **Simulink > Demos > Modeling Features > Model Reference**.

   A list of Simulink demos appears on the left side of the Help browser.

2. Select a model reference demo.

The `Introduction to Managing Data with Model Reference` demo introduces the basic concepts and workflow related to managing data with model referencing. To explore these topics in more detail, select the `Detailed Workflow for Managing Data with Model Reference` demo.

In addition, the demo `sldemo_absbrake` (**Simulink > Demos > Automotive Applications > Modeling an Anti-Lock Brake System**) represents a wheel speed calculation as a Model block within the context of an anti-lock braking system (ABS).

Model Referencing Resources

The following are the most commonly needed resources for working with model referencing:

- The Model block, which represents a model that another model references. See the Model block parameters in "Ports & Subsystems Library Block Parameters" for information about accessing a Model block programmatically.
- The **Configuration Parameters > Diagnostics > Model Referencing** pane, which controls the diagnosis of problems encountered in model referencing. See "Diagnostics Pane: Model Referencing" for details.
- The **Configuration Parameters > Model Referencing** pane, which provides options that control model referencing and list files on which referenced models depend. See "Model Referencing Pane" for details.

Creating a Model Reference

A model becomes a submodel when a Model block in some other model references it. Any model can function as a submodel, and such use does not preclude using it as a separate model also. To create a reference to a model (submodel) in another model (parent model):

1. If the folder containing the submodel you want to reference is not on the MATLAB path, add the folder to the MATLAB path.

2. In the submodel:

   - Enable **Configuration Parameters > Optimization > Inline parameters**. You must enable **Inline parameters** for all models in a model reference hierarchy except the top model in the hierarchy. See "Inline Parameter Requirements" on page 5-37 for details.

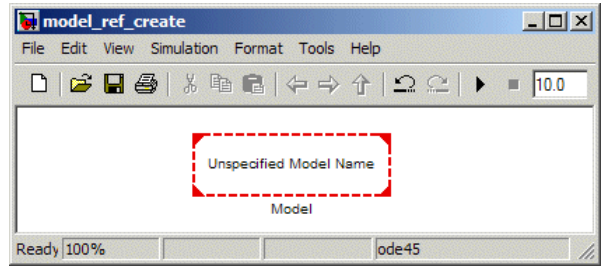
   - Set **Configuration Parameters > Model Referencing > Total number of instances allowed per top model** to:

     - `One`, if the hierarchy uses the model at most once

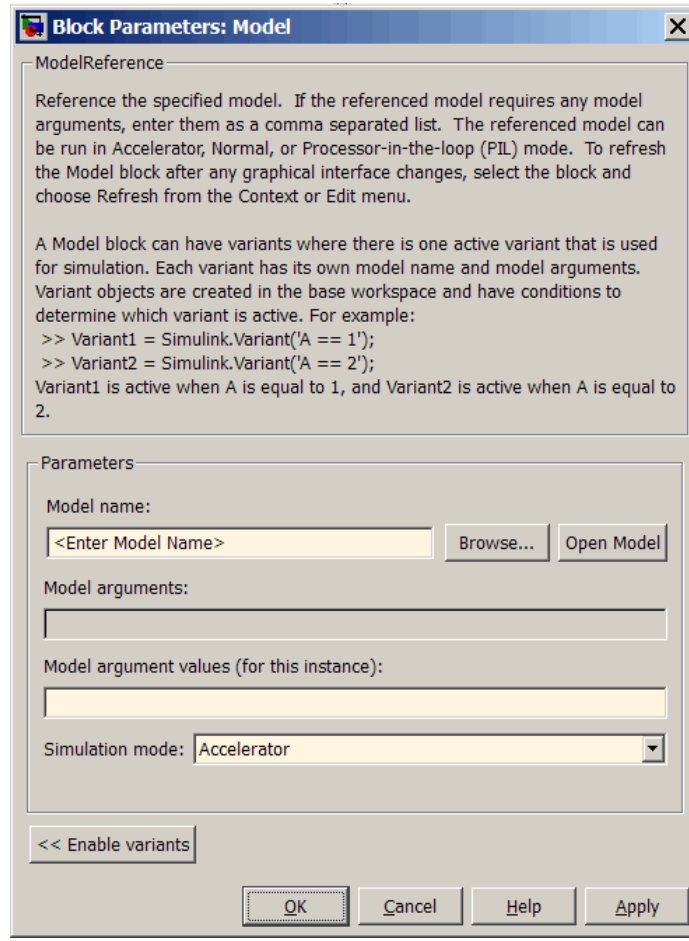
     - `Multiple`, to use the model more than once per top model. To reduce overhead, specify `Multiple` only when necessary.

     - `Zero`, which precludes referencing the model

3. Create an instance of the Model block in the parent model by dragging a Model block instance from the Ports & Subsystems library to the parent model. The new block is initially unresolved (specifies no submodel) and has the following appearance:



4 Open the new Model block's parameter dialog box by double-clicking the Model block. See "Navigating a Model Block" for more about accessing Model block parameters.



5 Enter the name of the submodel in the **Model name** field. This name must contain fewer than 60 characters. (See "Name Length Requirement" on page 5-33.)

- For information about **Model Arguments** and **Model argument values**, see "Using Model Arguments" on page 5-41.

- For information about the **Simulation mode**, see .

6 Click **OK** or **Apply**.

If the referenced model contains any root-level inputs or outputs, Simulink displays corresponding input and output ports on the Model block instance that you have created. Use these ports to connect the referenced model to other ports in the parent model.

A signal that connects to a Model block is functionally the same signal outside and inside the block. Therefore that signal is subject to the restriction that a given signal can have at most one associated signal object. See `Simulink.Signal` for more information. For information about connecting a bus signal to a referenced model, see “Bus Usage Requirements” on page 5-38.

Converting a Subsystem to a Referenced Model

You can convert any atomic subsystem to a referenced model. The conversion requires the model containing the subsystem to have the following configuration parameter settings:

- **Configuration Parameters > Optimization > Inline parameters** must be selected.
- **Configuration Parameters > Diagnostics > Data Validity > Signal resolution** must be `Explicit only`.
- **Configuration Parameters > Diagnostics > Connectivity > Mux blocks used to create bus signals** must be `Error`.

After specifying the indicated parameter values, select **Convert to Model Block** from the context menu of the subsystem. Simulink saves the contents of the subsystem as a new model, then creates and opens an untitled model that contains a Model block whose referenced model is the new model.

Simulink automatically provides a model name that is based on the block name and is unique in the MATLAB path. This name always contains fewer than 60 characters. If an error occurs during the conversion, the outcome depends on the error:

- For some errors, a message box appears that gives you the choice of cancelling or continuing.
- If continuing is impossible, Simulink cancels the conversion without offering a choice to continue.

Even if conversion is successful, you may still need to reconfigure the resulting model to meet your requirements. For example, the **Interpolate data** parameter of each root input port in the new model is selected by default. You can clear the parameter wherever this default is not appropriate. See the Inport block documentation for information about **Interpolate data**.

Once you have successfully converted the subsystem, you can:

- Delete the subsystem block from the source model
- Copy the Model block to the location of the deleted subsystem block

Simulink automatically reconnects all signals. The source model is now a parent model that contains the referenced model.

You can use `Simulink.SubSystem.convertToModelReference` to convert subsystems to model references programmatically. The function provides more capabilities than **Convert to Model Block**, such as the ability to replace a subsystem with an equivalent Model block in a single operation.

Referenced Model Simulation Modes

In this section...

About Referenced Model Simulation Modes

Simulink executes the top model in a model reference hierarchy just as it would if no referenced models existed. All Simulink simulation modes are available to the top model. Simulink can execute a referenced model in any of four modes: Normal, Accelerator, Software-in-the-loop (SIL), or Processor-in-the-loop (PIL).

Normal Mode

Simulink executes a Normal mode submodel interpretively. Normal mode, compared to other simulation modes:

- Requires no delay for code generation or compilation
- Works with more Simulink and Stateflow tools, supporting tools such as:
  - Scopes, port value display, and other output viewing tools
    - Scopes work with Accelerator mode referenced models, but require using the Signal & Scope Manager and adding test points to signals. Adding or removing a test point necessitates rebuilding the SIM target for a model, which can be time-consuming.
  - Model coverage analysis
  - Stateflow debugging and animation
- Provides more accurate linearization analysis
- Supports more S-functions than Accelerator mode does

Normal mode executes slower than Accelerator mode does.

Simulation results for a given model are nearly the same in either Normal or Accelerator mode. Trivial differences can occur due to differences in the optimizations and libraries that you use.

You can use Normal mode with multiple instances of a referenced model. For details, see "Using Normal Mode for Multiple Instances of Referenced Models" on page 5-16.

Accelerator Mode

Simulink executes an Accelerator mode submodel by creating a MEX-file (or *simulation target*) for the submodel, then running the MEX-file. See "Model Reference Simulation Targets" on page 5-28 for more information. Accelerator mode:

- Takes time for code generation and code compilation
- Does not fully support some Simulink tools, such as Model Coverage and the Simulink Debugger.
- Executes faster than Normal mode

Simulation results for a given model are nearly identical in either Normal or Accelerator mode. Trivial differences can occur due to differences in the optimizations and libraries that you use.

Software-in-the-Loop (SIL) Mode

Simulink executes a SIL-mode referenced model by generating production code using the model reference target for the submodel. This code is compiled for, and executed on, the host platform.

With SIL mode, you can:

- Verify generated source code without modifying the original model
- Reuse test harnesses for the original model with the generated source code

SIL mode provides a convenient alternative to PIL simulation when the target hardware is not available.

This option requires Real-Time Workshop® Embedded Coder™ software.

For more information, see "Verifying Generated Code With SIL and PIL Simulations" in the Real-Time Workshop Embedded Coder documentation.

Processor-in-the-Loop (PIL) Mode

Simulink executes a PIL-mode referenced model by generating production code using the model reference target for the submodel. This code is cross-compiled for, and executed on, a target processor or an equivalent instruction set simulator.

With PIL mode, you can:

- Verify deployment object code on target processors without modifying the original model
- Reuse test harnesses for the original model with the generated source code

This option requires Real-Time Workshop Embedded Coder software.

For more information, see "Verifying Generated Code With SIL and PIL Simulations" in the Real-Time Workshop Embedded Coder documentation.

Specifying the Simulation Mode

The Model block for each instance of a referenced model controls its simulation mode. To set or change the simulation mode for a submodel:

1. Access the block parameter dialog box for the Model block. (See "Navigating a Model Block".)
2. Set the **Simulation mode** parameter.
3. Click **OK** or **Apply**.

Mixing Simulation Modes

The following table summarizes the relationship between the simulation mode of the parent model and its submodels.

Parent Model Simulation Mode	Submodel Simulation Modes
Normal	• Submodels can use Normal, Accelerator, SIL, or PIL mode. • A submodel can execute in Normal mode *only* if every model that is superior to it in the hierarchy also executes in Normal mode. A Normal mode path then extends from the top model through the model reference hierarchy down to the Normal mode submodel.
Accelerator	• All subordinate models must also execute in Accelerator mode. • When a Normal mode model is subordinate to an Accelerator mode model, Simulink posts a warning and temporarily overrides the Normal mode specification. • When a SIL-mode or PIL-mode model is subordinate to an Accelerator mode model, an error occurs.
SIL	• All subordinate models also execute in SIL mode regardless of the simulation mode specified by their Model blocks. • The SIL mode Model block uses the model reference targets of the blocks beneath. • Only one Model block, starting at the top of a model reference hierarchy, can execute at a time in SIL mode. See "Simulation Mode Override Behavior in Model Reference Hierarchy".
PIL	• All subordinate models also execute in PIL mode regardless of the simulation mode specified by their Model blocks. • The PIL mode Model block uses the model reference targets of the blocks beneath.

Parent Model Simulation Mode	Submodel Simulation Modes
	• Only one Model block, starting at the top of a model reference hierarchy, can execute at a time in PIL mode. See "Simulation Mode Override Behavior in Model Reference Hierarchy".

For more information about SIL and PIL modes, see in the Real-Time Workshop Embedded Coder documentation:

- "SIL and PIL Code Interfaces"
- "SIL and PIL Simulation Support and Limitations"

Using Normal Mode for Multiple Instances of Referenced Models

You can simulate a model that has multiple references in Normal mode.

Normal Mode Visibility

All instances of the referenced model are part of the simulation. However, Simulink displays only one instance in a model window; that instance is determined by the Normal Mode Visibility setting. Normal mode visibility includes the display of Scope blocks and data port values.

If you do not set Normal Mode Visibility, Simulink picks one instance of each Normal mode model to display.

After a simulation, if you try to open a referenced model from a Model block that has Normal Mode Visibility set to off, Simulink displays a warning.

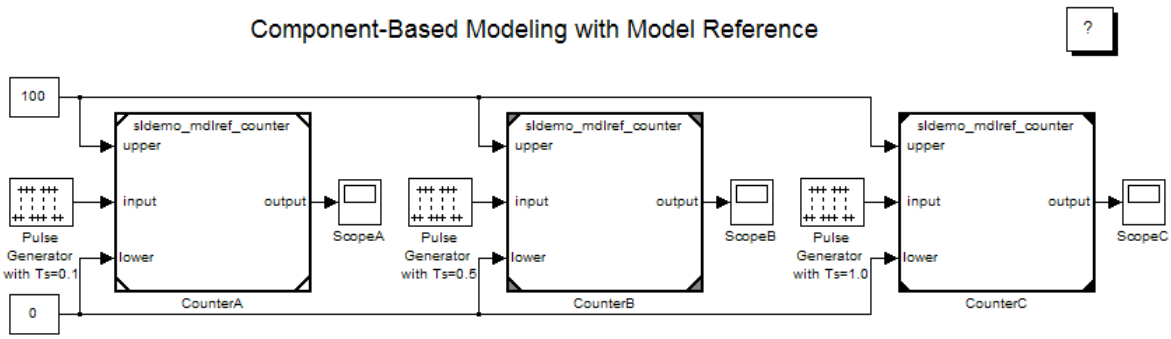
For a description of how to set up your model to control which instance of a referenced model in Normal mode has visibility and to ensure proper simulation of the model, see "Specifying the Instance That Has Normal Mode Visibility" on page 5-19.

Note If you change the Normal Mode Visibility setting for a referenced model, you must simulate the top model in the model reference hierarchy to make use of the new setting.

Examples of a Model with Multiple Referenced Instances in Normal Mode

sldemo_mdlref_basic. The `sldemo_mdlref_basic` demo model has three Model blocks (`CounterA`, `CounterB`, and `CounterC`) that each reference the `sldemo_mdlref_counter` model.

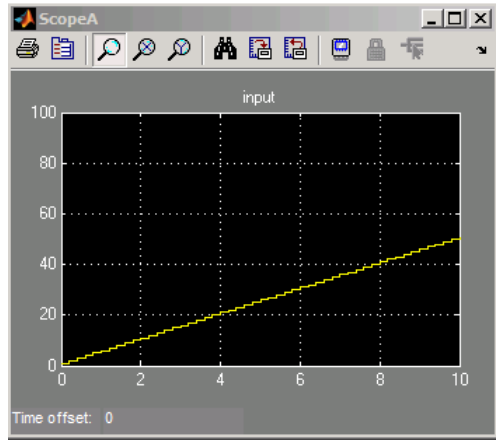
If you update the diagram, the `sldemo_mdlref_basic` displays different icons for each of the three Model blocks that reference `sldemo_mdlref_counter`.



Model Block	Icon Corners	Simulation Mode and Normal Mode Visibility Setting
`CounterA`	White	Normal mode, with Normal Mode Visibility enabled
`CounterB`	Gray corners	Normal mode, with Normal Mode Visibility disabled
`CounterC`	Black corner	Accelerator mode (Normal Mode Visibility is not applicable)

If you do the following steps, then the `ScopeA` block appears as shown below:

1. Simulate `sldemo_mdlref_basic`.
2. Open the `sldemo_mdlref_counter` model.
3. Open the `ScopeA` block.



That `ScopeA` block reflects the results of simulating the `CounterA` Model block, which has Normal Mode Visibility enabled.

If you try to open `mdlref_counter` model from the `CounterB` Model block (for example, by double-clicking the Model block), ScopeA in mdlref_counter still shows the results of the `CounterA` Model block, because that is the Model block with Normal Mode Visibility set to `on`.

sldemo_mdlref_depgraph. The `sldemo_mdlref_depgraph` demo model shows the use of the Model Dependency Viewer for a model that has multiple Normal mode instances of a referenced model. The demo shows what you need to do to set up a model with multiple referenced instances in Normal mode.

Setting Up a Model with Multiple Instances of a Referenced Model in Normal Mode

This section describes how to set up a model to support the use of multiple instances of Normal mode referenced models.

1. Set the **Configuration Parameters > Model Referencing > Total number of instances allowed per top model** parameter to `Multiple`.

   If you cannot use the `Multiple` setting for your model, because of the requirements described in the "Total number of instances allowed per top model" parameter documentation, then you can have only one instance of that referenced model be in Normal mode.

2. For each instance of the referenced model that you want to be in Normal mode, in the block parameters dialog box for the Model block, set the **Simulation Mode** parameter to `Normal`. Ensure that all the ancestors in the hierarchy for that Model block are in Normal mode.

   The corners of icons for Model blocks that are in Normal mode can be white (empty), or gray after you update the diagram or simulate the model.

3. (If necessary) Modify S-functions used by the model so that they work with multiple instances of referenced models in Normal mode. For details, see "Supporting the Use of Multiple Instances of Referenced Models That Are in Normal Mode".

By default, Simulink assigns Normal mode visibility to one of the instances. After you have performed the steps in this section, you can specify a non-default instance to have Normal mode visibility. For details, see "Specifying the Instance That Has Normal Mode Visibility" on page 5-19.

Specifying the Instance That Has Normal Mode Visibility

This section describes how to specify Normal Mode Visibility for an instance other than the one that an instance that Simulink selects automatically.

You need to:

1. (Optionally) "Determine Which Instance Has Normal Mode Visbility" on page 5-20.

2 "Set Normal Mode Visibility" on page 5-21.

3 Simulate the top model to apply the new Normal Mode Visibility settings.

Determine Which Instance Has Normal Mode Visbility. If you do not already know which instance currently has Normal mode visibility, you can determine that by using one of these approaches:

- If you update the diagram and have made no other changes to the model, then you can navigate through the model hierarchy to examine the Model blocks that reference the model that you are interested in. The Model block that has white corners has Normal Mode Visibility enabled.
- When you are editing a model or during compilation, use the `ModelReferenceNormaModeVisiblityBlockPath` parameter.

  If you use this parameter while editing a model, you must update the diagram before you use this parameter.

  The result is a `Simulink.BlockPath` object that points to the Model block that referenced the model that has Normal Mode Visibility enabled. For example:

```
get_param('sldemo_mdlref_basic',...
 'ModelReferenceNormaModeVisiblityBlockPath')

ans =

   Simulink.BlockPath
   Package: Simulink

   Block Path:
      'sldemo_mdlref_basic/CounterA'
```

- For a top model that is being simulated or that is in a compiled state, you can use the `CompiledModelBlockInstancesBlockPath` parameter. For example:

```
a = get_param('sldemo_mdlref_depgraph',...
 'CompiledModelBlockInstancesBlockPath')

a =
```

```
          sldemo_mdlref_F2C: [1x1 Simulink.BlockPath]
       sldemo_mdlref_heater: [1x1 Simulink.BlockPath]
sldemo_mdlref_outdoor_temp: [1x1 Simulink.BlockPath]
```

Set Normal Mode Visibility. To enable Normal Mode Visibility for a different instance of the referenced model than the instance that currently has Normal Mode Visibility, use *one* of these approaches:

- Navigate to the top model and select the **Edit > Model Blocks > Normal Mode Visibility** menu item.

  The Model Block Normal Mode Visibility dialog box appears. That dialog box includes instructions in the right pane. For additional details about the dialog box, see "Working with the Model Block Normal Mode Visibility Dialog Box" on page 5-22.

- From the MATLAB command line, set the `ModelReferenceNormalModeVisibility` parameter.

  For input, you can specify:

  - An array of `Simulink.BlockPath` objects. For example:

    ```
    bp1 = Simulink.BlockPath({'mVisibility_top/Model',  ...
    'mVisibility_mid_A/Model'});
    bp2 = Simulink.BlockPath({'mVisibility_top/Model1', ...
    'mVisibility_mid_B/Model1'});
     bps = [bp1, bp2];
     set_param(topMdl, 'ModelBlockNormalModeVisibility', bps);
    ```

    For details about `Simulink.BlockPath` objects, at the MATLAB command line, enter `help Simulink.BlockPath`).

  - A cell array of cell arrays of strings, with the strings being paths to individual blocks and models. The following example has the same effect as the preceding example (which shows how to specify an array of `Simulink.BlockPath` objects):

    ```
    p1 = {'mVisibility_top/Model',  'mVisibility_mid_A/Model'};
    p2 = {'mVisibility_top/Model1', 'mVisibility_mid_B/Model1'};
    set_param(topMdl, 'ModelBlockNormalModeVisibility', {p1, p2});
    ```

- An empty array, to specify the use of the Simulink default selection of the instance that has Normal mode visibility. For example:

  ```
  set_param(topMdl, 'ModelBlockNormalModeVisibility', []);
  ```

  Using an empty array is equivalent to clearing all the check boxes in the Model Block Normal Mode Visibility dialog box.

Note You cannot change Normal Mode Visibility during a simulation.

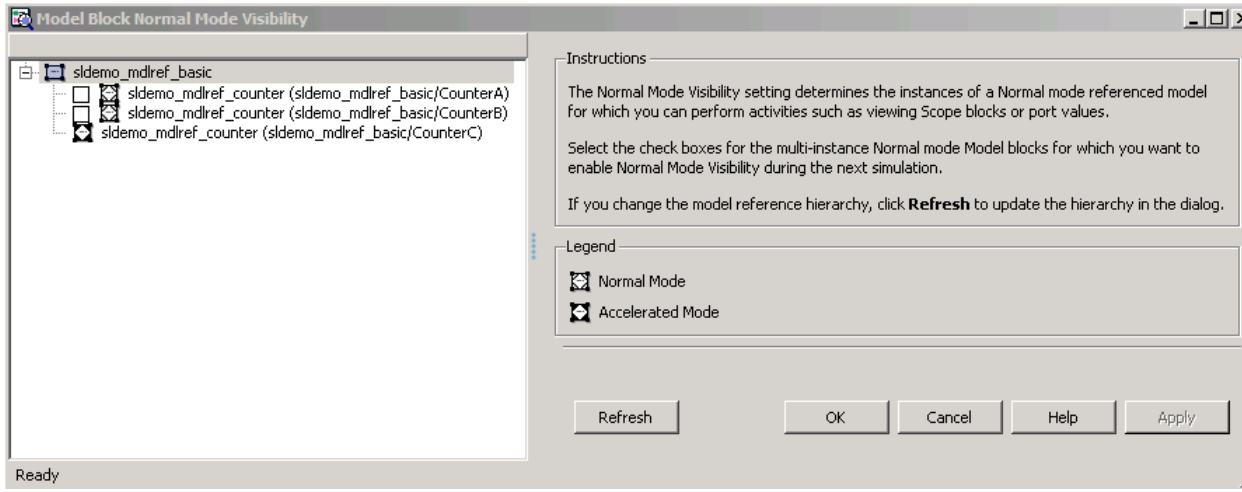
Working with the Model Block Normal Mode Visibility Dialog Box

If you have a model that has multiple instances of a referenced model in Normal mode, you can use the Block Model Normal Mode Visibility dialog box to set Normal Mode Visibility for a specific instance. For a description of Normal mode visibility, see "Normal Mode Visibility" on page 5-16.

Alternatively, you can set the `ModelReferenceNormalModeVisibility` parameter. For information about how to specify an instance of a referenced model that is in Normal mode that is different than the instance automatically selected by Simulink, see "Specifying the Instance That Has Normal Mode Visibility" on page 5-19.

Opening the Model Block Normal Mode Visibility Dialog Box. To open the Model Block Normal Mode Visibility dialog box, navigate to the top model and select the **Edit > Model Blocks > Normal Mode Visibility** menu item.

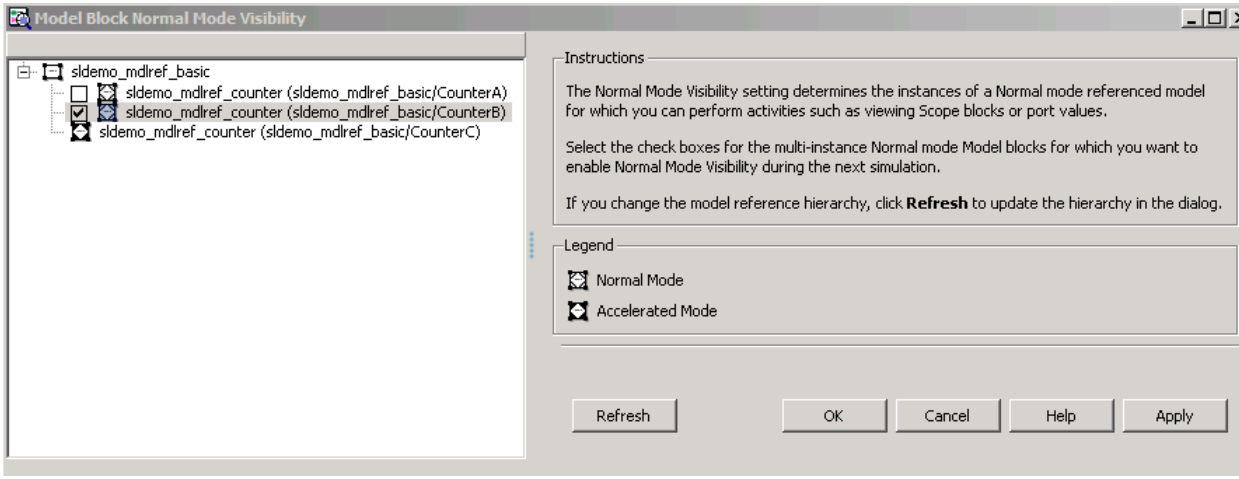
The dialog box for the `sldemo_mdlref_basic` demo model, with the hierarchy pane expanded, looks like this:



The model hierarchy pane shows a partial model hierarchy for the model from which you opened the dialog box. The hierarchy stops at the first Model block that is not in Normal mode. The model hierarchy pane does not display Model blocks that reference protected models.

Selecting a Model for Normal Mode Visibility.

The dialog box shows the complete model block hierarchy for the top model. The Normal mode instances of referenced models have check boxes. Select the check box for the instance of each model that you want to have Normal mode visibility.



When you select a model, Simulink:

- Selects all ancestors of that model
- Deselects all other instances of that model

When a model is deselected, Simulink deselects all children of that model.

Opening a Model from the Model Block Normal Mode Visibility Dialog Box. You can open a model from the Model Block Normal Mode Visibility dialog box by right-clicking the model in the model hierarchy pane and clicking **Open**.

Refreshing the Model Reference Hierararchy. To ensure the model hierarchy pane of the Model Block Normal Mode Visibility dialog box reflects the current model hierarchy, click **Refresh**.

Accelerating a Freestanding or Top Model

You can use Simulink Accelerator mode or Rapid Accelerator mode to achieve faster execution of any Simulink model, including a top model in a model reference hierarchy. For details about Accelerator mode, see the Chapter 17, “Accelerating Models” documentation. For information about Rapid

Accelerator mode, see “Testing and Refining Concept Models With Standalone Rapid Simulations”.

When you execute a top model in Simulink Accelerator mode or Rapid Accelerator mode, all submodels execute in Accelerator mode. For any submodel that specifies Normal mode, Simulink displays an warning message.

Be careful not confuse Accelerator mode execution of a referenced model with:

- Accelerator mode execution of a freestanding or top model, as described in Chapter 17, “Accelerating Models”
- Rapid Accelerator mode execution of a freestanding or top model, as described in “Testing and Refining Concept Models With Standalone Rapid Simulations”

While the different types of acceleration share many capabilities and techniques, they have different implementations, requirements, and limitations.

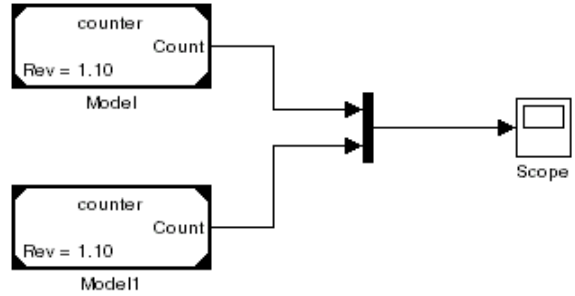
Viewing a Model Reference Hierarchy

Simulink provides tools and functions that you can use to examine a model reference hierarchy:

- **Model Dependency Viewer** — Shows the structure the hierarchy lets you open constituent models. The Referenced Model Instances view displays Model blocks differently to indicate Normal, Accelerator, and PIL modes. See "Using the Model Dependency Viewer" on page 8-101 for more information.
- **`view_mdlrefs` function** — Invokes the Model Dependency Viewer to display a graph of model reference dependencies.
- **`find_mdlrefs` function** — Finds all models directly or indirectly referenced by a given model.

Displaying Version Numbers

To display the version numbers of the models referenced by a model, for the parent model, choose **Format > Block displays > Model block version**. Simulink displays the version numbers in the icons of the corresponding Model block instances.



The version number displayed on a Model block icon refers to the version of the model used to either:

- Create the block
- Refresh the block most recently

See “Managing Model Versions” on page 3-99 and “Refreshing Model Blocks” on page 5-69 for more information.

Model Reference Simulation Targets

In this section...

About Simulation Targets

A *simulation target*, or *SIM target*, is a MEX-file that implements a referenced model that executes in Accelerator mode. Simulink invokes the simulation target as needed during simulation to compute the behavior and outputs of the referenced model. Simulink uses the same simulation target for all Accelerator mode instances of a given referenced model anywhere in a reference hierarchy.

Be careful not to confuse the simulation target of a submodel with any of these other types of target:

- Hardware target — A platform for which Real-Time Workshop generates code
- System target — A file that tells Real-Time Workshop how to generate code for particular purpose
- Rapid Simulation target (RSim) — A system target file supplied with Real-Time Workshop
- Model reference target — A library module that contains Real-Time Workshop code for a referenced model

Simulink creates a simulation target only for a submodel that has one or more Accelerator mode instances in a reference hierarchy. A submodel that executes only in Normal mode always executes interpretively and does not use a simulation target. When one instance of a submodel executes in Normal mode, and one or more instances execute in Accelerator mode:

- Simulink creates a simulation target for the Accelerator mode instances.
- The Normal mode instance does not use that simulation target.

Because Accelerator mode requires code generation, it imposes some requirements and limitations that do not apply to Normal mode. Aside from these constraints, you can generally ignore simulation targets and their details when you execute a referenced model in Accelerator mode. See "Limitations on Accelerator Mode Referenced Models" on page 5-77 for details.

Building Simulation Targets

Simulink by default generates the needed target from the referenced model:

- If a simulation target does not exist at the beginning of a simulation
- When you update a block diagram of a parent model

If the simulation target already exists, Simulink by default checks whether the submodel has changed significantly since the target was last generated. If so, Simulink by default regenerates the target to reflect changes in the model.

You can change this default behavior to modify the rebuild criteria or specify that Simulink always or never rebuilds targets. See "Rebuild options" for details.

To generate simulation targets interactively for Accelerator mode referenced models, do one of these steps:

- Update the model diagram
- Execute the `slbuild` command with appropriate arguments at the MATLAB command line

While generating a simulation target, Simulink displays status messages at the MATLAB command line to enable you to monitor the target generation process. Target generation entails generating and compiling code and linking the compiled target code with compiled code from standard code libraries to create an executable file.

Simulink creates simulation targets in the `slprj` subfolder of the working folder. If `slprj` does not exist, Simulink creates it. Subdirectories in `slprj` provide separate places for simulation code, Real-Time Workshop code, and other files.

Reducing Change Checking Time

You can reduce the time that Simulink spends checking whether any or all simulation targets require rebuilding by setting configuration parameter values as follows:

- In all referenced models throughout the hierarchy, set **Configuration Parameters > Diagnostics > Data Validity > Signal resolution** to `Explicit only`. (See "Signal resolution".)
- For referenced models you want to minimize change checking time, set **Configuration Parameters > Model Referencing > Rebuild options** to `If any changes in known dependencies detected` on the top model. See "Rebuild options".

These parameter values exist in the configuration set of a referenced model, not in the individual Model block, so setting either value for any instance of a referenced model sets it for all instances of that model.

Parallel Building for Large Model Reference Hierarchies

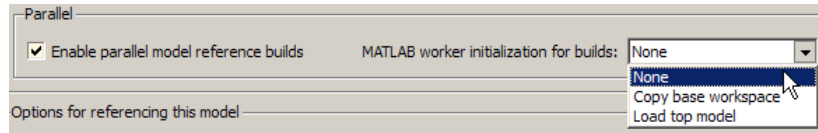
In a parallel computing environment, you can increase the speed of diagram updates for models containing large model reference hierarchies by building referenced models that are configured in Accelerator mode in parallel whenever conditions allow. For example, if you have Parallel Computing Toolbox™ software, updating of each referenced model can be distributed across the cores of a multicore host computer. If you additionally have MATLAB® Distributed Computing Server™ (MDCS) software, updating of each referenced model can be distributed across remote workers in your MATLAB Distributed Computing Server configuration.

To take advantage of parallel building for a model reference hierarchy:

1. Set up a pool of local and/or remote MATLAB workers in your parallel computing environment.
   a. Make sure that Parallel Computing Toolbox software is licensed and installed.
   b. To use remote workers, make sure that MATLAB Distributed Computing Server software is licensed and installed.

c Issue appropriate MATLAB commands to set up the worker pool, for example, `matlabpool 4`.

2 In the Configuration Parameters dialog box, go to the **Model Referencing** pane and select the **Enable parallel model reference builds** option. This selection enables the parameter **MATLAB worker initialization for builds**.



For **MATLAB worker initialization for builds**, select one of the following values:

- `None` if the software should perform no special worker initialization. Specify this value if the child models in the model reference hierarchy do not rely on anything in the base workspace beyond what they explicitly set up (for example, with a model load function).
- `Copy base workspace` if the software should attempt to copy the base workspace to each worker. Specify this value if you use a setup script to prepare the base workspace for all models to use.
- `Load top model` if the software should load the top model on each worker. Specify this value if the top model in the model reference hierarchy handles all of the base workspace setup (for example, with a model load function).

3 Optionally, inspect the model reference hierarchy to determine, based on model dependencies, which models will be built in parallel. For example, you can use the Model Dependency Viewer from the Simulink **Tools** menu.

4 Update your model. Messages in the MATLAB command window record when each parallel or serial build starts and finishes.

The performance gain realized by using parallel builds for updating referenced models depends on several factors, including how many models can be built in parallel for a given model referencing hierarchy, the size of the referenced models, and parallel computing resources such as number of local and/or

remote workers available and the hardware attributes of the local and remote machines (amount of RAM, number of cores, and so on).

The following notes apply to using parallel builds for updating model reference hierarchies:

- For local pools, the host machine should have an appropriate amount of RAM available for supporting the number of local workers (MATLAB sessions) that you plan to use. For example, setting `matlabpool` to 4 results in five MATLAB sessions on your machine, each using approximately 120 MB of memory at startup.
- Remote MDCS workers participating in a parallel build must use a common platform and compiler.
- A consistent MATLAB environment must be set up in each MATLAB worker session as in the MATLAB client session — for example, all shared base workspace variables, MATLAB path settings, and so forth. One approach is to use the `PreLoadFcn` callback of the top model. If you configure your model to load the top model with each MATLAB worker session, its preload function can be used for any MATLAB worker session setup.

Simulink Model Referencing Requirements

In this section...

About Model Referencing Requirements

A model reference hierarchy must satisfy various Simulink requirements, as described in this section. Some limitations also apply, as described in "Simulink Model Referencing Limitations" on page 5-73.

Name Length Requirement

The name of a referenced model must contain fewer than 60 characters, exclusive of the `.mdl` suffix. An error occurs if the name of a referenced model is too long.

Configuration Parameter Requirements

A referenced model uses a configuration set in the same way that any other model does, as described in "Setting Up Configuration Sets" on page 9-2. By default, every model in a hierarchy has its own configuration set. Each model uses its configuration set the same way that it would if the model executed independently.

Because each model can have its own configuration set, configuration parameter values can be different in different models. Furthermore, some parameter values are intrinsically incompatible with model referencing. Simulink's response to an inconsistent or unusable configuration parameter depends on the parameter:

- Where an inconsistency has no significance, or a trivial resolution exists that carries no risk, Simulink ignores or resolves the inconsistency without posting a warning.

- Where a nontrivial and possibly acceptable solution exists, Simulink resolves the conflict silently; resolves it with a warning; or generates an error. See "Model configuration mismatch" for details.
- Where no acceptable resolution is possible, Simulink generates an error. Change some or all parameter values to eliminate the problem.

Manually eliminating all configuration parameter incompatibilities can be tedious when:

- A model reference hierarchy contains many submodels that have incompatible parameter values
- A changed parameter value must propagate to many submodels

You can control or eliminate such overhead by using configuration references to assign an externally stored configuration set to multiple models. See "Referencing Configuration Sets" on page 9-14 for details.

Note Configuration parameters on the Real-Time Workshop pane of the Configuration Parameters dialog do not affect simulation in either Normal or Accelerated mode. Real-Time Workshop parameters affect only code generation by Real-Time Workshop itself. Accelerated mode simulation requires code generation to create a simulation target. Simulink uses default values for all Real-Time Workshop parameters when generating the target, and restores the original parameter values after code generation is complete.

The tables in the following sections list Configuration parameter options that can cause problems if set:

- In certain ways, as indicated in the table
- Differently in a referenced model than in a parent model

Where possible, Simulink resolves violations of these requirements automatically, but most cases require changes to the parameters in some or all models.

Configuration Requirements for All Referenced Model Simulation

Dialog Box Pane	Option	Requirement
Solver	**Start time**	The start time of the top model and all referenced models must be the same, but need not be zero.
	Stop time	Simulink uses **Stop time** of the top model for simulation, overriding any differing **Stop time** in a submodel.
	Type **Solver**	The **Type** and **Solver** of the top model apply throughout the hierarchy. See "Solver Requirements" on page 5-36.
Data Import/Export	**Initial state**	Can be `on` for the top model, but must be `off` for a referenced model.
Optimization	**Inline parameters**	Can be `on` or `off` for a top model, but must be `on` for a referenced model. See "Inline Parameter Requirements" on page 5-37.
	Application lifespan (days)	Must be the same for top and referenced models.

Dialog Box Pane	Option	Requirement
Model Referencing	**Total number of instances allowed per top model**	Must not be `Zero` in a referenced model. Specifying `One` rather than `Multiple` is preferable or required in some cases. See "Model Instance Requirements" on page 5-37.
Hardware Implementation	**Embedded hardware** options	All values must be the same for top and referenced models.

Solver Requirements. Model referencing works with both fixed-step and variable-step solvers. All models in a model reference hierarchy use the same solver, which is always the solver specified by the top model. An error occurs if the solver type specified by the top model is incompatible with the solver type specified by any submodel.

Top Model Solver Type	Submodel Solver Type	Compatibility
Fixed Step	Fixed Step	Allowed
Variable Step	Variable Step	Allowed
Variable Step	Fixed-step	Allowed unless the submodel is multi-rate and specifies both a discrete sample time and a continuous sample time
Fixed Step	Variable Step	Error

If an incompatibility exists between the top model solver and any submodel solver, one or both models must change to use compatible solvers. For information about solvers, see "Solvers" on page 2-21 and "Choosing a Solver" on page 11-9.

Inline Parameter Requirements. Simulink requires enabling **Configuration Parameters > Optimization > Inline parameters** (see "Inline parameters") for all referenced models in a reference hierarchy. The top model can enable or disable inline parameters. If a referenced model disables inlined parameters, and you try to simulate the parent model:

- For a Normal mode submodel, Simulink generates an error and cancels the build. All models and compiled files remain unchanged after the failed build.
- For an Accelerator mode submodel, Simulink temporarily enables inline parameters, posts no warning, and builds the model. Inline parameters remain disabled after the build completes.

Simulink ignores tunable parameter specifications in the **"Model Parameter Configuration Dialog Box"** for both the top model and referenced models. Do not use this dialog box to override the inline parameters optimization for selected parameters to permit them to be tuned. Instead, see "Parameterizing Model References" on page 5-40 for alternate techniques.

Model Instance Requirements. A referenced model must specify that it is available to be referenced, and whether it can be referenced at most once or can have multiple instances. **Configuration Parameters > Model Referencing > Total number of instances allowed per top model** provides this specification. See "Total number of instances allowed per top model" for more information. The possible values for this parameter are:

- `Zero` — A model cannot reference this model. An error occurs if a reference to the model occurs in another model.
- `One` — A model reference hierarchy can reference the model at most once. An error occurs if more than one instance of the model exists. This value is sometimes preferable or required.
- `Multiple` — A model hierarchy can reference the model more than once, if it contains no constructs that preclude multiple reference. An error occurs if the model cannot be multiply referenced, even if only one reference exists.

Setting **Total number of instances allowed per top model** to `Multiple` for a model that is referenced only once can reduce execution efficiency slightly. However, this setting does not affect data values that result from

simulation or from executing code Real-Time Workshop generates. Specifying `Multiple` when only one model instance exists avoids having to change or rebuild the model when reusing the model:

- In the same hierarchy
- Multiple times in a different hierarchy

Some model properties and constructs require setting **Total number of instances allowed per top model** to `One`. For details, see "General Reusability Limitations" on page 5-74 and "Accelerator Mode Reusability Limitations" on page 5-77.

Model Structure Requirements

The following requirements relate to the structure of a model reference hierarchy independently of configuration parameter requirements.

Signal Propagation Requirements

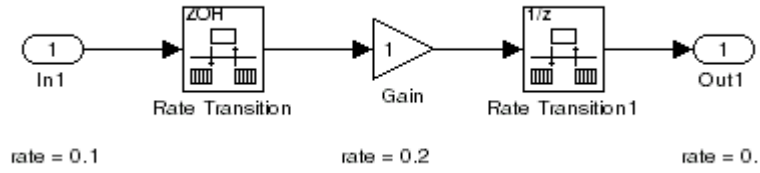
The signal name must explicitly appear on any signal line connected to an Outport of a referenced model. A signal connected an unlabeled line to an Outport of a referenced model cannot propagate out of the Model block to the parent model.

Bus Usage Requirements

A bus that propagates between a parent model and a referenced model must be nonvirtual. Use the same bus object to specify the properties of the bus in both the parent and the referenced model. Define the bus object in the MATLAB workspace. See "About Composite Signals" on page 30-2 for more information.

Sample Time Requirements

The first nonvirtual block connected to a root-level Inport or Outport of a referenced model must have the same sample time as the port to which it connects. You can use Rate Transition blocks to match input and output sample times as illustrated in the following diagram.


1
In1
ZOH
Rate Transition
1
Gain
1/z
Rate Transition1
1
Out1
rate = 0.1
rate = 0.2
rate = 0.1

Parameterizing Model References

In this section...

Introduction

A parameterized referenced model obtains values that affect the behavior of the referenced model from some source outside the model. Changing the values changes the behavior of the model, without recompiling the model.

Due to the constraints described in "Inline Parameter Requirements" on page 5-37, you cannot use the Model Parameter Configuration dialog box to parameterize referenced models. Simulink provides three other techniques that you can use to parameterize referenced models:

- Global nontunable parameters
- Global tunable parameters
- Model arguments

Global parameters work the same way with referenced models that they do with any other model construct. Each global parameter has the same value in every instance of a referenced model that uses it. Model arguments allow you to provide different values to each instance of a referenced model. Each instance can then behave differently from the others. The effect is analogous to calling a function more than once with different arguments in each call.

Global Nontunable Parameters

A *global nontunable parameter* is a MATLAB variable or a `Simulink.Parameter` object whose storage class is `auto`. The parameter can exist in the MATLAB workspace or any model workspace visible to all referenced models that use the parameter.

Using a global nontunable parameter in a referenced model sets the parameter value before the simulation begins. This allows you to control the behavior of the referenced model. All instances of the model use the same value. You cannot change the value during simulation, but you can change it between one simulation and the next. The change requires rebuilding the model in which the change occurs, but not any models that it references. See "Specifying Parameter Values" on page 19-6 for details.

Global Tunable Parameters

A *global tunable parameter* is a `Simulink.Parameter` object whose storage class is other than `auto`. The parameter exists in the MATLAB workspace.

Using a global tunable parameter in a referenced model allows you to control the behavior of the referenced model by setting the parameter value. All instances of the model use the same value. You can change the value during simulation or between one simulation and the next. The change does not require rebuilding the model in which the change occurs, or any models that it references. See "Using Tunable Parameters" on page 19-13 for details.

To reference a model that uses tunable parameters defined with the "Model Parameter Configuration Dialog Box", change the model to implement tunability another way. To facilitate this task, Simulink provides a command that converts tunable parameters specified in the Model Parameter Configuration dialog box to global tunable parameters. See `tunablevars2parameterobjects` for details.

Using Model Arguments

Model arguments let you parameterize references to the same model so that each instance of the model behaves differently. Without model arguments, a variable in a referenced model has the same value in every instance of the model. Declaring a variable to be a model argument allows each instance of the model to use a different value for that variable.

To create model arguments for a referenced model:

1. Create MATLAB variables in the model workspace.

2. Add the variables to a list of model arguments associated with the model.

3 Specify values for those variables separately in each Model block that references the model

The values specified in the Model block replace the values of the MATLAB variables for that instance of the model.

A referenced model that uses model arguments can also appear as a top model or a standalone model. No Model block then exists to provide model argument values. The model uses the values of the MATLAB variables themselves, as defined in the model workspace. Thus, you can use the same model without change as a top model, a standalone model, and a parameterized referenced model.

The demo model `sldemo_mdlref_datamngt` demonstrates techniques for using model arguments. The demo passes model argument values to referenced models through masked Model blocks. Such masking can be convenient, but is independent of the definition and use of model arguments themselves. See for information about masking.

The rest of this section describes techniques for declaring and using model arguments to parameterize a referenced model independently of any Model block masking. The steps are:

- Create MATLAB variables in the model workspace.
- Register the variables to be model arguments.
- Assign values to those arguments in Model blocks.

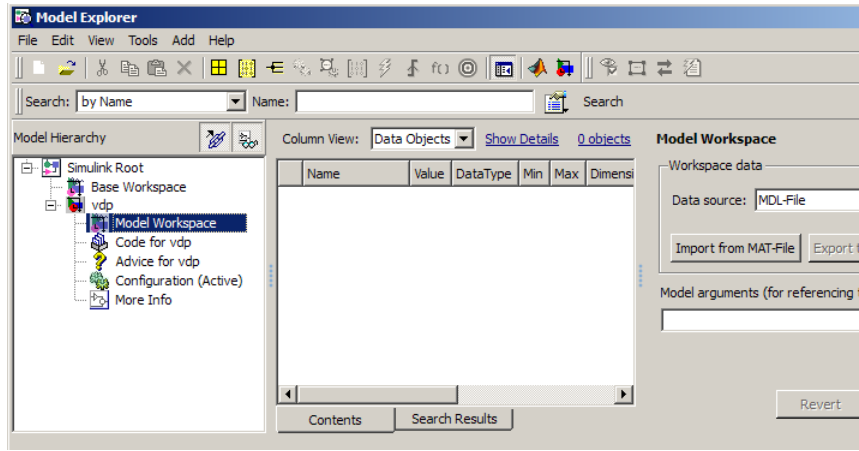
Creating the MATLAB Variables

To create MATLAB variables for use as model arguments:

1 Open the model for which you want to define model arguments.

2 Open the Model Explorer.

3 In the Model Explorer **Model Hierarchy** pane, select the workspace of the model:



4 From Model Explorer's **Add** menu, select **MATLAB Variable**.

   A new MATLAB variable appears in the **Contents** pane with a default name and value.

5 In the **Contents** pane:

   a Change the default name of the new MATLAB variable to a name that you want to declare as a model argument.

   b If you also use the model as a top or standalone model, specify the value for that variable for use in that context. This value must be numeric.

   c If the variable type does not match the dimensions and complexity of the model argument, specify a value that has the correct type. This type must be numeric.

6 Repeat adding and naming MATLAB variables until you have defined all the variables that you need.

Registering the Model Arguments

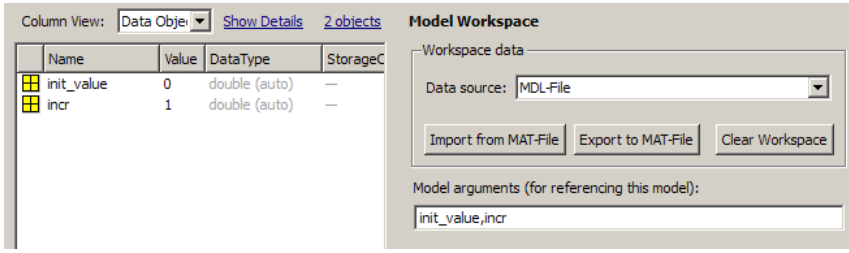
To register MATLAB variables as model arguments:

1 Again, in the Model Explorer **Model Hierarchy** pane, select the workspace of the model.

The Dialog pane displays the Model Workspace dialog.

2 In the Model Workspace dialog, enter the names of the MATLAB variables that you want to declare as model arguments. Use a comma-separated list in the **Model arguments** field.

For example, suppose you added two MATLAB variables named `init_value` and `incr`, and you declared them to be model arguments. The **Contents** and **Dialog** panes of the Model Explorer could look like this:

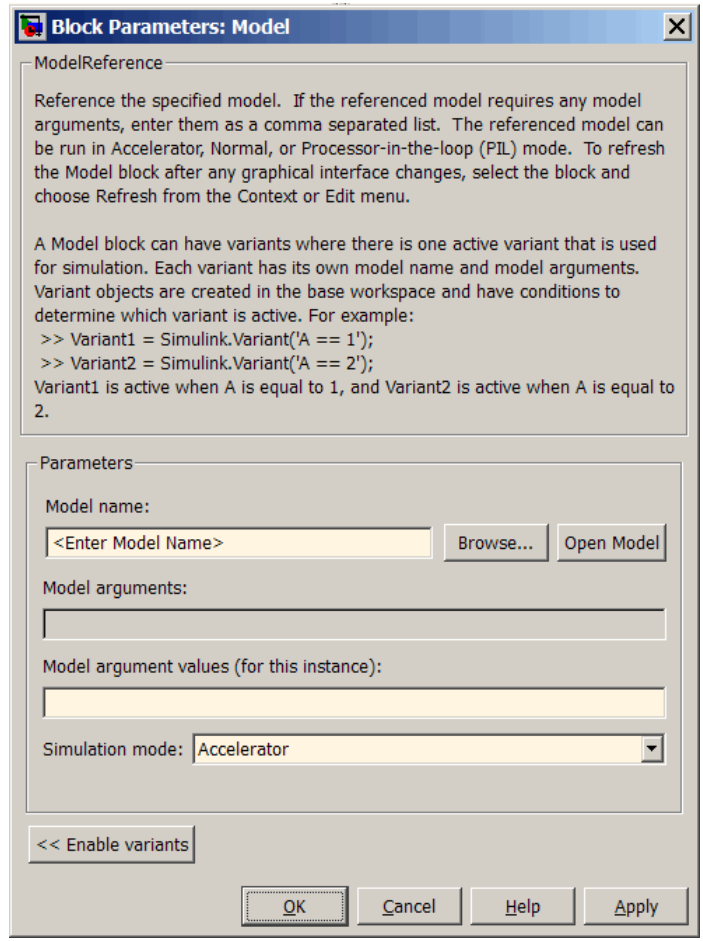


3 Click **Apply** to confirm the entered names.

Assigning Model Argument Values

If a model declares model arguments, assign values to those arguments in each Model block that references the model. Failing to assign a value to a model argument causes an error: the value of the model argument does *not* default to the value of the corresponding MATLAB variable. That value is available only to a standalone or top model. To assign values to the arguments of a referenced model:

1 Open the parameter dialog box of the Model block by right-clicking the block and choosing **Model Reference Parameters** from the context menu.



The second field, **Model arguments**, specifies the same MATLAB variables, in the same order, that you previously typed into the **Model arguments** field of the Model Workspace dialog. This field is not editable. It provides a reminder of which model arguments need values assigned, and in what order.

2 In the **Model argument values** field, enter a comma-delimited list of values for the model arguments that appear in the **Model arguments** field. Simulink assigns the values to arguments in positional order, so they must appear in the same order as the corresponding arguments.

You can enter the values as literal values, variable names, MATLAB expressions, and Simulink parameter objects. Any symbols used resolve to values as described in "Hierarchical Symbol Resolution" on page 3-76. All values must be numeric (including objects with numeric values).

The value for each argument must have the same dimensions and complexity as the MATLAB variable that defines the model argument in the model workspace. The data types need not match. If necessary, the Simulink software casts a model argument value to the data type of the corresponding variable.

3 Click **OK** or **Apply** to confirm the values for the Model block.

When the model executes in the context of that Model block, the **Model arguments** have the values specified in the **Model argument values** field of the Model block.

Defining Triggered Models

In this section...

About Triggered Models

Use a Trigger block to insert a trigger port in a model. Add a trigger port to a model if you want to use an external signal to trigger the execution of that model. You can add a trigger port to a root-level model or to a subsystem.

This section focuses on models that contain a trigger port with an edge-based (`rising`, `falling`, or `either`) trigger type. You can use trigger ports in other ways. You can create:

- A function-call subsystem with a Trigger block. Use a function-call subsystem to have certain blocks control the execution of a referenced model during a time step, using a function-call signal. Examples of such blocks are a Function-Call Generator or an appropriately configured custom S-function block. See "Defining Function-Call Models" on page 5-51.
- A triggered subsystem by adding a trigger port to a subsystem. See "Triggered Subsystems" on page 6-14.
- A combined triggered and enabled subsystem. See "Triggered and Enabled Subsystems" on page 6-18.

Triggered Model Demo

To view a demo that illustrates how you can use trigger ports in referenced models, from the `Introduction to Managing Data with Model Reference`

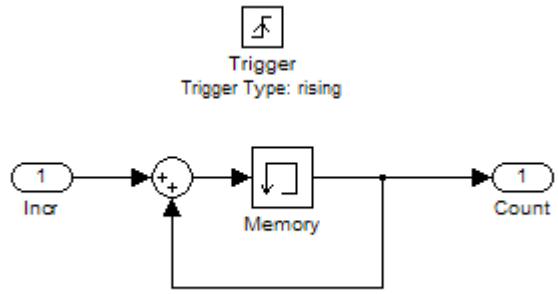
demo, select the `Detailed Workflow for Managing Data with Model Reference` demo, and see the "Top Model: Scheduling Calls to the Referenced Model" section.

Creating a Triggered Model

To create a triggered model:

1. Insert a Trigger block at the root level of a model.
2. Set the **Trigger type** parameter of the Trigger block to `rising`, `falling`, or `either`.
3. Create and connect other blocks to implement the model.

   The following model includes a Trigger block in a root-level model.



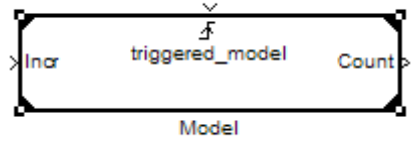
4. Ensure that your model satisfies the conditions for triggered models. See "Triggered Model Block Requirements" on page 5-49.

Referencing a Triggered Model

To reference a triggered model:

1. Add a Model block to the model that you want to reference the triggered model. See "Creating a Model Reference" on page 5-7 for details.

   The top of the Model block displays a trigger port icon, which corresponds to the trigger port in the referenced model.



2 Create and connect other blocks to implement the parent model.

3 Ensure that the referencing model satisfies the conditions for model referencing. See "Simulink Model Referencing Requirements" on page 5-33 and "Simulink Model Referencing Limitations" on page 5-73 for details.

Triggered Model Block Requirements

A referenced model with a trigger port must meet the following requirements, in addition to the requirements that every referenced model must meet:

- Do not include an Enable port in the referenced model.
- The signal attributes of the trigger port in the referenced model must be consistent with the input that the Model block provides to that trigger port.

Simulating a Triggered Model

Use Normal, Accelerator, or Rapid Accelerator mode to simulate a referenced model that contains a triggered port.

You can run a standalone simulation of a referenced model. A standalone simulation is useful for unit testing, because it provides consistent data across simulations, in terms of data type, dimension, and sample time. In the Trigger block, in the **Signal Attributes** pane of the Block Parameters dialog box, specify values to lock down the signal data type, dimension, and sample time.

To run a standalone simulation of a referenced model with a trigger port, specify the inputs using the **Configuration Parameters > Data Import/Export > Input** parameter. The following conditions apply when you use the "Input" parameter for trigger port inputs:

- Make the last data input corresponds to the trigger input.

- If you do not provide any input values, the simulation uses zero as the default values.

For details about how to specify the input, see “Importing Data from a Workspace” on page 27-21.

You can log data to determine which signal triggered the model to run. For the Trigger block, in the **Main** pane of the Block Parameters dialog box, select **Show output port**.

Code Generation for Referenced Triggered Models

You can build model reference RTW and SIM targets for referenced models that contain a trigger port. You cannot generate standalone RTW or PIL code. For information about code generation for referenced models, see “Reusable Code and Referenced Models” and “Generating Code for a Referenced Model”.

Defining Function-Call Models

In this section...

About Function-Call Models

Simulink allows certain blocks to control execution of a referenced model during a time step, using a function-call signal. Examples of such blocks are a Function-Call Generator or an appropriately configured custom S-function. See "Function-Call Subsystems" on page 6-23 for more information. A referenced model that you can invoke in this way is a *function-call model*.

Function-Call Model Demo

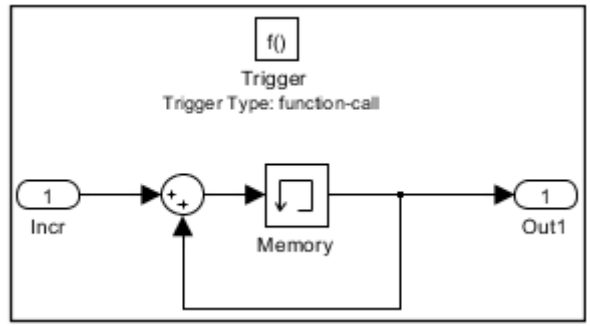
To view a function-call model demo, execute sldemo_mdlref_fcncall at the MATLAB command line, or:

1. In the MATLAB Help browser Contents pane, click **Simulink**.
2. Expand **Demos**.
3. Select **Modeling Features > Model Reference > Model Reference Function-Call**

Creating a Function-Call Model

To create a function-call model:

1. Insert a Trigger block at the root level of the model.
2. Set the **Trigger type** parameter of the Trigger block to `function-call`.
3. Create and connect any other blocks required to implement the model.



4 Ensure that the model satisfies the conditions imposed on function-call models. See "Function-Call Model Requirements" on page 5-53 for details.

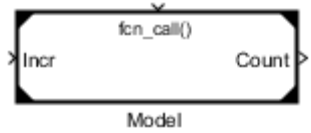
You can now simulate the function-call model either by itself or by running a model that references the function-call model directly or indirectly.

Referencing a Function-Call Model

To create a reference to a function-call model:

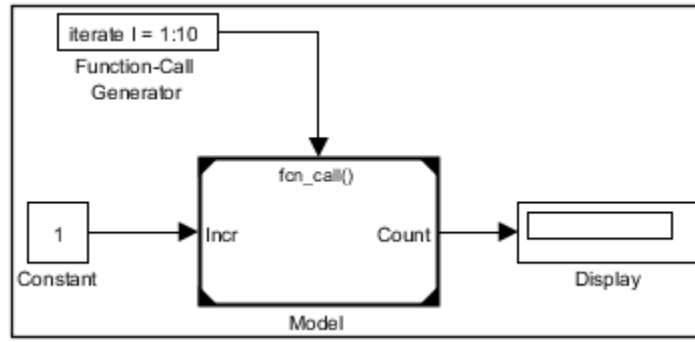
1 Create a Model block in the referencing model that references the function-call model. See "Creating a Model Reference" on page 5-7 for details.

   The top of the Model block displays a function-call port corresponding to the function-call trigger port in the function-call model.



2 Connect a Stateflow chart, Function-Call Generator block, or other function-call-generating block to the function-call port of the Model block. The signal connected to the port must be scalar.

3 Connect the Model blocks inputs and outputs if any to the appropriate blocks in the parent model.



4. Create and connect any other blocks required to implement the parent model.

5. Ensure that the referencing model satisfies the conditions for a model to reference other models. See "Simulink Model Referencing Requirements" on page 5-33 and "Simulink Model Referencing Limitations" on page 5-73 for details.

You can now simulate the model that references the function-call model.

Function-Call Model Requirements

To be a function-call model, a referenced model must meet the following requirements in addition to the requirements that every referenced model must meet.

- A function-call model cannot have an outport driven only by Ground blocks, including hidden Ground blocks inserted by Simulink. To meet this requirement, do the following:

  1. Insert a Signal Conversion block into the signal connected to the outport.
  2. Enable the **Exclude this block from 'Block reduction' optimization** option of the inserted block.

- The referencing model must trigger the function-call model at the rate specified by the **Configuration Parameters > Solver** `'Fixed-step size'` option if the function-call model meets both these conditions:

  - It specifies a fixed-step solver

- It contains one or more blocks that use absolute or elapsed time

  Otherwise, the referencing model can trigger the function-call model at any rate.

- A function-call model must not have direct internal connections between its root-level input and output ports. Simulink does not honor the `None` and `Warning` settings for the **Invalid root Inport/Outport block connection** diagnostic for a referenced function-call model. It reports all invalid root port connections as errors.
- If the **Sample time type** is `periodic`, the sample-time period must not contain an offset.
- The signal connected to a function-call port of a Model block must be scalar.

Protecting Referenced Models

In this section...

About Protected Models

A *protected model* is a referenced model that eliminates all block and line information. Protecting a model does not use encryption technology. You can distribute a protected model without revealing the intellectual property that it embodies. When simulated, a protected model gives the same results that its source model does when referenced in Accelerator mode.

You can use a protected model much as you could any other referenced model. Simulink tools work with protected models to the extent possible given that contents of the model are hidden. For example, the Model Explorer and the Model Dependency Viewer show the hierarchy under an ordinary referenced model, but not under a protected model. You cannot log signals in a protected model, because the log could reveal information about the protected model contents.

Some referenced model require object definitions or tunable parameters that are defined in the MATLAB base workspace. For those models, the protected version may need some of those same definitions when it executes as part of a third-party model. Simulink provides techniques for identifying and obtaining the needed data, and then packaging it with the protected model for delivery.

Protecting a model requires a Real-Time Workshop license, which makes code generation capabilities available for use internally when creating the

protected version of the model. A third party that receives the model does not need a Real-Time Workshop license to use the model. Also, a third party cannot use Real-Time Workshop to generate code for the model or any model that references it.

The Model Protection Facility

The *Model Protection facility* is a set of Simulink commands, tools, and techniques that you can use to:

- Protect a referenced mode
- Identify definitions that it needs
- Package the model and any definitions for delivery to a third party

The receiver can then unpackage and use the protected model and any definitions.

To see a demo of the Model Protection facility, access MATLAB Help browser and choose **Simulink > Demos > Modeling Features > Model Reference > Model Reference Protected Models**

The Model Protection facility is not an integrated unit like a viewer or editor, and has only a command-line interface. To begin using the facility, you execute a `protect` command in the MATLAB base workspace. See the `Simulink.ModelReference.protect` reference page for complete information about the `protect` command. The syntax of the command is:

```
[harnessHandle, neededVars] = Simulink.ModelReference.protect
(model, 'Param', Val, ...)
```

You can use the `protect` command and its arguments to:

- Specify the model to protect. See “Protecting a Referenced Model” on page 5-58.
- Specify the folder in which the `protect` command is to place the protected model. See “Specifying an Output Folder” on page 5-58.

- Create a *harness model*, which contains a Model block that is preconfigured to work with the protected model. See "Creating a Harness Model" on page 5-59.
- Obtain a list that includes the names of all base workspace entities that the model needs in order to run. See "Obtaining Object and Variable Names" on page 5-59.

For simplicity, "Protecting a Referenced Model" on page 5-58 shows you how to use each of these capabilities separately when protecting a model. In practice, you can use any of the capabilities at the same time, and specify optional argument pairs in any order.

After you have created or obtained all the components that you intend to provide to the receiver, you can package them for delivery as described in "Packaging a Protected Model" on page 5-61. The receiver of the model needs instructions for unpacking the components and using them in a model. The necessary instructions appear in "Using a Protected Model" on page 5-62.

Model Protection Requirements

Protecting a model requires meeting all requirements listed in "Simulink Model Referencing Requirements" on page 5-33, as well as the following:

- You must have a Real-Time Workshop license, which you can obtain via `http://www.mathworks.com`.
- Your platform and your version of Simulink must match the platform and version of Simulink that the protected model uses.
- The model you protect must be available on the MATLAB path and have no unsaved changes.
- The model you protect cannot reference any subordinate protected model directly or indirectly.

Model protection is also subject to certain limitations, as described in "Model Protection Limitations" on page 5-64.

Protecting a Referenced Model

If you need nothing but the protected model itself, with no harness model or list of names, simply specify the source model to the `protect` command.

- Be sure that the model you protect and the model hierarchy that contains it:
  1. Meet the "Model Protection Requirements" on page 5-57
  2. Respect the "Model Protection Limitations" on page 5-64 .
- In the MATLAB Command Window, execute:

```
Simulink.ModelReference.protect(model)
```

The *`model`* is the name or handle of the protected model, or the full path to the protected model. If the Model block uses variants, only the active variant is protected. See Chapter 7, "Modeling Variant Systems", for more information.

The `protect` command creates a protected version of the model and stores it by default in the current working folder. You can change this default as described in "Specifying an Output Folder" on page 5-58. The protected model has the same name as the source model, with the suffix `.mdlp`. In the MATLAB Browser, a small image of a lock appears in the upper left corner of the icon for a protected model.

Never change the name of a protected model. If you rename a protected model, or change its suffix, the model is unusable until you restore its original name and suffix. You also cannot change a protected model internally in any way: any internal change destroys the usability of the file.

Specifying an Output Folder

To specify a folder other than the current working folder to contain the protected model, use the optional `Path` argument:

```
Simulink.ModelReference.protect(model, 'Path', pathname)
```

where *`pathname`* is a fully qualified pathname of an accessible writeable folder. The command stores the protected model in the indicated folder.

Creating a Harness Model

When the `protect` command protects a model, it can also create a *harness model*. This model contains a Model block that set up to work with the protected model. This Model block:

- Names the protected model as its referenced model.
- Has the same number of input and output ports as the protected model
- Defines any model reference arguments that the protected model uses, but provides no values

To create a harness model when protecting a model, specify the optional `Harness` argument as `true`. The `protect` command returns the handle of the harness model in the first output argument:

```
[harnessHandle] = Simulink.ModelReference.protect(model, 'Harness', true)
```

The harness model opens as a new untitled model that contains only the described Model block. This block, and any other Model block that references a protected model, shows a small image of a lock in its upper left corner. You can:

- Save the harness model under any name and use it as needed
- Use the handle in *`harnessHandle`* to manipulate the model programmatically
- Copy the Model block into another model, where it functions as the interface to the protected model

See “Packaging a Protected Model” on page 5-61 for more about how to use a harness model and the Model block that it contains.

Obtaining Object and Variable Names

Some referenced models require objects or tunable parameters that are defined in the MATLAB base workspace. Executing the protected version of such a referenced model requires that same entity if it is:

- A global tunable parameter
- A global Data Store Memory

- Any of the following objects used by a signal that connects to a root-level model Inport or Outport:
  - `Simulink.Signal`
  - `Simulink.Bus`
  - `Simulink.Alias`
  - `Simulink.NumericType` that is an alias

When you protect a model, you must obtain the definitions of all necessary base workspace entities and ship them along with the model. The necessary steps for obtaining the definitions are:

- Obtain candidate names
- Prune unneeded names
- Save workspace definitions

See "Packaging a Protected Model" on page 5-61 for information about how to ship the base workspace definitions.

Obtaining Candidate Names. When the `protect` command executes, it always generates a cell array that includes the names of all base workspace entities that the protected model needs. You can obtain this array by accepting the second return value when you execute the command:

```
[~, neededVars] = Simulink.ModelReference.protect(model)
```

The tilde (~) operator discards the first argument, or you could accept it if you create a harness model at the same time. The returned cell array *`neededVars`* includes the name of every needed base workspace entity.

Pruning Unnecessary Names. The cell array *`neededVars`* might also include the names of base workspace entities that the protected model does not need. For example, *`neededVars`* could contain names of workspace objects that define signals that do not connect to any root I/O port within the protected model. The protected version of the model does not need the corresponding definitions, because they do not specify anything about its interface to other model entities.

Leaving unnecessary names in *neededVars*:

- Risks disclosing intellectual property
- Adds unnecessary definitions to the model of the receiver
- Increases the likelihood of a name conflict with that model

Because you cannot change a protected model, resolving such a conflict would require the model of the receiver to change.

To remove unnecessary names, edit the cell array *neededVars*. Delete any names that do not correspond to definitions that serve the protected model in one of the capacities listed under "Obtaining Object and Variable Names" on page 5-59. If you are not sure which names are extra, you can remove any doubtful cases and later test to see whether any missing definitions result.

Saving Workspace Definitions. The cell array derived in the previous steps contains only the names of base workspace entities. The protected model needs the definitions themselves, in a separate file that you can ship along with the model. To create this file, execute:

```
save(myFile.mat, neededVars{:})
```

where *myFile* is any file (or path) name, and *neededVars* is the (possibly pruned) second return value of the `protect` command. The `{:}` operator converts the cell array *neededVars* into a list of comma-separated names, which become arguments to `save`. When the command executes, it evaluates each name, thus obtaining the corresponding definition from the base workspace, and stores all the definitions in *myFile*`.mat`. The receiver of the protected model can then restore the base workspace definitions by loading *myFile*`.mat`.

Packaging a Protected Model

A protected model consists of the model itself, optionally a harness model, and any needed definitions saved in a MAT file, as described in "Saving Workspace Definitions" on page 5-61. The Model Protection facility does not require packaging these files in any specific way. For example, they could be:

- Provided as three separate files

- Combined into a ZIP or other container file
- Packaged using a manifest. See “Exporting Files in a Manifest” on page 8-89.
- Provided in some other standard or proprietary format specified by the receiver

Whichever approach you use to package a protected model, be sure the receiver of the package has the information necessary retrieve the original files. One approach to consider is to use the Simulink Manifest Tools, as described in “Model Dependencies” on page 8-76.

Testing a Protected Model

To test a protected model, you enact the same sequence that the receiver will enact, as described in “Using a Protected Model” on page 5-62. Since you are also the supplier, both the original and the protected model might exist on the MATLAB path. If the**Model name** field of a Model block names the model without providing a suffix, the unprotected (`.mdl`) version will take precedence over the protected (`.mdlp`) model. This occurs regardless of the relative positions of the versions on the MATLAB path. Explicitly specify the `.mdlp` suffix in the **Model name** field of Model block if you need to override this default when testing a protected model.

If you want to ensure that the protected model gives the same results as the source model, you can create a parent model that contains two Model blocks. One Model block references the source model, in Accelerator mode, and the other references the protected model. You can then log the outputs of the blocks and compare the logged data to see that the two versions of the block behave identically. See “Logging Signals” on page 27-3 for more information.

Using a Protected Model

Using a protected model does not require a Real-Time Workshop license. Using a protected model requires that the model:

- Be available somewhere on the MATLAB path.
- Be referenced by a Model block in a model that executes in Normal mode.

- Receive from the Model block the values needed by any defined model arguments.
- Connect via the Model block to input and output signals that match the input and output signals of the protected model.

A typical workflow for meeting these requirements is:

1. If necessary, unpack the files according to any accompanying directions.
2. If there is a MAT-file containing workspace definitions, load that MAT-file.
3. If there is a harness model, copy the Model block into a Normal-mode model.
4. Connect signals to the Model block that match its input and output port requirements.
5. Provide any needed model argument values. See "Assigning Model Argument Values" on page 5-44.

Now you can simulate the model that references the protected model. The simulation produces the same outputs that it did when used in Accelerator mode in the source model. Many variations on these instructions are possible, such as:

- Use your own Model block rather than the Model block in the harness model.
- Start with the harness model, add more constructs to it, and use it in your model.
- Use the protected model as a variant, as described in Chapter 7, "Modeling Variant Systems".
- Apply a mask to the Model block that references the protected model. See Chapter 21, "Working with Block Masks".
- Configure a callback function such as **LoadFcn** to load the MAT file automatically. See "Using Callback Functions" on page 3-54.

To facilitate locating protected models:

- The MATLAB Folder Browser shows a small image of a lock in the upper left corner of the icon of a protected model.
- A Model block that references a protected model shows a small image of a lock in the upper left corner of the block icon.
- When the Model block **Browse** button shows a protected model, the `.mdlp` suffix and lock icon appear.

When you change a Model block to reference a protected model, the **Simulation mode** of the block becomes `Accelerator` and you cannot change it.

Model Protection Limitations

Protected models are subject to all limitations listed in "Limitations on All Model Referencing" on page 5-73 and "Limitations on Accelerator Mode Referenced Models" on page 5-77. The following limitations also apply to protected models.

- A model that you protect cannot use a non-inlined S-function directly or indirectly.
- Simulating a protected model requires that all models superior to it execute in Normal mode.

Protected models must also meet certain requirements, as described in "Model Protection Requirements" on page 5-57.

Inheriting Sample Times

In this section...

How Sample-Time Inheritance Works for Model Blocks

The sample times of a Model block are the sample times of the model that it references. If the referenced model must run at specific rates, the model specifies the required rates. Otherwise, the referenced model inherits its sample time from the parent model.

Placing a Model block in a triggered, function call, or iterator subsystem relies on the ability to inherit sample times. Additionally, allowing a Model block to inherit sample time maximizes its reuse potential. For example, a model might fix the data types and dimensions of all its input and output signals. You could reuse the model with different sample times (for example, discrete at 0.1 or discrete at 0.2, triggered, and so on).

Conditions for Inheriting Sample Times

A referenced model inherits its sample time if the model:

- Does not have any continuous states
- Specifies a fixed-step solver and the **Fixed-step size** is `auto`
- Contains no blocks that specify sample times (other than inherited or constant)
- Does not contain any S-functions that use their specific sample time internally

- Has only one sample time (not counting constant and triggered sample time) after sample time propagation
- Does not contain any blocks, including Stateflow charts, that use absolute time, as listed in "Blocks That Depend on Absolute Time" on page 5-66
- Does not contain any blocks whose outputs depend on inherited sample time, as listed in "Blocks Whose Outputs Depend on Inherited Sample Time" on page 5-68.

You can use a referenced model that inherits its sample time anywhere in a parent model. By contrast, you cannot use a referenced model that has intrinsic sample times in a triggered, function call, or iterator subsystem. To avoid rate transition errors, ensure that blocks connected to a referenced model with intrinsic samples times operate at the same rates as the referenced model.

Determining Sample Time of a Referenced Model

To determine whether a referenced model can inherit its sample time, set the **Periodic sample time constraint** on the **Solver** configuration parameters dialog pane to `Ensure sample time independent`. If the model is unable to inherit sample times, this setting causes Simulink to display an error message when building the model. See "Periodic sample time constraint" for more about this option.

To determine the intrinsic sample time of a referenced model, or the fastest intrinsic sample time for multirate referenced models:

1. Update the model that references the model
2. Select a Model block within the parent model
3. Enter the following at the MATLAB command line:

```
get_param(gcb, 'CompiledSampleTime')
```

Blocks That Depend on Absolute Time

The following Simulink blocks depend on absolute time, and therefore preclude a referenced model from inheriting sample time:

- Backlash (only when the model uses a variable-step solver and the block uses a continuous sample time)
- Chirp Signal
- Clock
- Derivative
- Digital Clock
- Discrete-Time Integrator (only when used in triggered subsystems)
- From File
- From Workspace
- Pulse Generator
- Ramp
- Rate Limiter
- Repeating Sequence
- Signal Generator
- Sine Wave (only when the **Sine type** parameter is `Time-based`)
- Stateflow (only when the chart uses the reserved word `t` to reference time)
- Step
- To File
- To Workspace (only when logging to `StructureWithTime` format)
- Transport Delay
- Variable Time Delay
- Variable Transport Delay

Some blocks other than Simulink blocks depend on absolute time. See the documentation for the blocksets that you use.

Blocks Whose Outputs Depend on Inherited Sample Time

Using a block whose output depends on an inherited sample time in a referenced model can cause simulation to produce unexpected or erroneous results. For this reason, when building a submodel that does not need to run at a specified rate, Simulink checks whether the model contains any blocks whose outputs are functions of the inherited simulation time. This includes checking S-Function blocks. If Simulink finds any such blocks, it specifies a default sample time. Simulink displays an error if you have set the **Configuration Parameters > Solver > Periodic sample time constraint** to `Ensure sample time independent`. See "Periodic sample time constraint" for more about this option.

The outputs of the following built-in blocks depend on inherited sample time. The outputs of these blocks preclude a referenced model from inheriting its sample time from the parent model:

- Discrete-Time Integrator
- From Workspace (if it has input data that contains time)
- Probe (if probing sample time)
- Rate Limiter
- Sine Wave

Simulink assumes that the output of an S-function does not depend on inherited sample time unless the S-function explicitly declares the contrary. See *Developing S-Functions* for information on how to create S-functions that declare whether their output depends on their inherited sample time.

To avoid simulation errors with referenced models that inherit their sample time, do not include S-functions in the referenced models that fail to declare whether their output depends on their inherited sample time. By default, Simulink warns you if your model contains such blocks when you update or simulate the model. See "Unspecified inheritability of sample time" for details.

Refreshing Model Blocks

Refreshing a Model block updates its internal representation to reflect changes in the interface of the model that it references. For example, refresh a Model block if its referenced model has gained or lost a port. When more than one Model block references a model whose interface has changed, refresh all the Model blocks. Changes that do not affect a the interface of a referenced model to its parent do not require refreshing the block.

To refresh all Model blocks in a model, select **Refresh Model Blocks** from the **Edit** menu of the model. To update a specific Model block, select **Refresh** from the context menu of the Model block. You can also refresh a model by starting a simulation or generating code.

Simulink provides diagnostics that you can use to detect changes in the interfaces of referenced models that could require refreshing the Model blocks that reference them. The diagnostics include:

- **"Model block version mismatch"**
- **"Port and parameter mismatch"**

Using S-Functions with Model Referencing

In this section...

S-Function Support for Model Referencing

Each kind of S-function provides its own level of support for model referencing.

Type of S-Function	Support for Model Referencing
Level-1 MATLAB S-function	Not supported
Level-2 MATLAB S-function	• Supports Normal and Accelerator mode • Accelerator mode requires a TLC file
Handwritten C MEX S-function	• Supports Normal and Accelerator mode • May be inlined with TLC file
S-Function Builder	Supports Normal and Accelerator mode
Legacy Code Tool	Supports Normal and Accelerator mode

Sample Times

Simulink software assumes that the output of an S-function does not depend on an inherited sample time unless the S-function explicitly declares a dependence on an inherited sample time.

You can control inheriting sample time by using `ssSetModelReferenceSampleTimeInheritanceRule` in different ways,

depending on whether an S-function permits or precludes inheritance. For details, see "Inherited Sample Time for Referenced Models".

S-Functions with Accelerator Mode Referenced Models

For a referenced model that executes in Accelerator mode, set the **Configuration Parameteres > Model Referencing > Total number of instances allowed per top model** to `One` if the model contains an S-function that is either:

- Inlined, but has not set the `SS_OPTION_WORKS_WITH_CODE_REUSE` flag
- Not inlined

Inlined S-Functions with Accelerator Mode Referenced Models

For Accelerator mode referenced models, if the referenced model contains an S-function that should be inlined using a Target Language Compiler file, the S-function must use the `ssSetOptions` macro to set the `SS_OPTION_USE_TLC_WITH_ACCELERATOR` option in its `mdlInitializeSizes` method. The simulation target does not inline the S-function unless the S-function sets this option.

A referenced model cannot use noninlined S-functions in the following cases:

- The model uses a variable-step solver.
- Real-Time Workshop generated the S-function.
- The S-function supports use of fixed-point numbers as inputs, outputs, or parameters.
- The model is referenced more than once in the model reference hierarchy. To work around this limitation, use Normal mode.
- The S-function uses string parameters.

Using C S-Functions in Normal Mode Referenced Models

Under certain conditions, when a C S-function appears in a referenced model that executes in Normal mode, successful execution is impossible. For details, see "Using S-Functions in Normal Mode Referenced Models".

Use the `ssSetModelReferenceNormalModeSupport` SimStruct function to specify whether an S-function can be used in a Normal mode referenced model.

You may need to modify S-functions that are used by a model so that the S-functions work with multiple instances of referenced models in Normal mode. The S-functions must indicate explicitly that they support multiple `exec` instances. For details, see "Supporting the Use of Multiple Instances of Referenced Models That Are in Normal Mode".

Protected Models

A protected model cannot use non-inlined S-functions directly or indirectly.

Real-Time Workshop Considerations

A referenced model in Accelerator mode cannot use S-functions generated by the Real-Time Workshop software.

Noninlined S-functions in referenced models are supported when generating Real-Time Workshop code.

The Real-Time Workshop S-function target does not support model referencing.

For general information about using Real-Time Workshop and model referencing, see "Creating Model Components".

Simulink Model Referencing Limitations

In this section...

Introduction

The following Simulink limitations apply to model referencing. In addition, a model reference hierarchy must satisfy all the requirements listed in "Simulink Model Referencing Requirements" on page 5-33.

Limitations on All Model Referencing

Index Base Limitations

In two cases, Simulink does not propagate 0-based or 1-based indexing information to referenced-model root-level ports connected to blocks that:

- Accept indexes (such as the Assignment block)
- Produce indexes (such as the For Iterator block)

These two cases are:

- If a root-level input port of the referenced model is connected to index inputs in the model that have different 0-based or 1-based indexing settings, Simulink does not set the 0-based or 1-based indexing property of the root-level Inport.
- If a root-level output port of the referenced model is connected to index outputs in the model that have different 0-based or 1-based indexing settings, Simulink does not set the 0-based or 1-based indexing property of the root-level Outport.

An Assignment block is an example of a block that accepts indexes. The For Iterator block is an example of a block that produces indexes.

In these cases, the lack of propagation can cause Simulink to fail to detect incompatible index connections.

General Reusability Limitations

If a referenced model has any of the following properties, the model must specify **Configuration Parameters > Model Referencing > Total number of instances allowed per top model** as `One`. No other instances of the model can exist in the hierarchy. If you do not set the parameter correctly, or if more than one instance of the model exists in the hierarchy, an error occurs. The properties are:

- The model contains any To File blocks, to avoid multiple instances writing to the same file
- The model references another model which is set to single instance
- The model contains a state or signal with non-auto storage class
- The model uses any of the following Stateflow constructs:
  - Stateflow graphical functions
  - Machine-parented data

Block Mask Limitations

- Mask callbacks cannot add Model blocks or change Model block name or simulation mode. Violating this requirement generates an error.
- If a mask specifies the name of the model referenced by a Model block, the mask must provide directly the name of the referenced model. Evaluating a workspace variable does not provide the name.
- The mask workspace of a Model block is not visible to the model that it references. Any variable used by the referenced model must resolve to a workspace defined in the referenced model, or to the MATLAB base workspace.

See for information about creating and using block masks.

Simulink Tool Limitations

- Working with the Simulink Debugger in a parent model, you can set breakpoints at Model block boundaries. Setting those breakpoints allows you to look at the input and output values of the Model block. However, you cannot set a breakpoint inside the submodel that the Model block references. See Chapter 16, "Simulink Debugger" for more information.

Stateflow Limitations

- A model that contains a Stateflow chart cannot be referenced multiple times in the same model reference hierarchy if:
  - The Stateflow chart contains exported graphical functions.
  - The Stateflow model contains machine-parented data.

Other Limitations

- Referenced models cannot use asynchronous rates internally. However, a function-call model referenced in a top model can be triggered by an asynchronous source within the top model. See "Defining Function-Call Models" on page 5-51 for more information.
- A referenced model can input or output only those user-defined data types that are fixed-point or defined by `Simulink.DataType` or `Simulink.Bus` objects.
- You cannot place in an iterator subsystem Model blocks referencing models that contain assignment blocks that are not in an iterator subsystem.
- In a configurable subsystem with a Model block, during model update (for example, mask initialization), do not change the subsystem selected by the configurable subsystem.
- If you want to initialize the states of a model that references other models with states, specify the initial states in structure format.
- The Model Browser does not display Model blocks in its tree view. Use the Model Explorer to browse a referenced model hierarchy.

- A referenced model cannot directly access the signals in a multi-rate bus. Connecting Multi-Rate Buses to Referenced Models describes a technique for overcoming this limitation.
- A continuous sample time cannot be propagated to a Model block that is sample-time independent.
- Goto and From blocks cannot cross model reference boundaries.
- You cannot print a referenced model from a top model.

Limitations on Normal Mode Referenced Models

Normal Mode Visibility for Multiple Instances of a Referenced Model

You can simulate a model that has multiple instances of a referenced model that are in Normal mode. All of the instances of the referenced model are part of the simulation. However, Simulink displays only one of the instances in a model window; that instance is determined by the Normal Mode Visibility setting. Normal Mode Visibility includes the display of Scope blocks and data port values.

For a description of how to set up your model to control which instance of a referenced model in Normal mode has visibility and to ensure proper simulation of the model, see .

Simulink Profiler

Enabling the Simulink Profiler on a parent model does not enable profiling for referenced models. You must enable profiling separately for each submodel. See “Capturing Performance Data” on page 17-29.

Limitation with Sim Viewing Devices in Rapid Accelerator Mode

When set to Normal mode, a Model block with a sim viewing device is not updated during Rapid Accelerator simulation.

Limitations on Accelerator Mode Referenced Models

Customization Limitations

- Some restrictions exist on grouped custom storage classes in referenced models. See "Custom Storage Class Limitations" for details.
- Simulation target code generation for referenced models does not support data type replacement.

Data Logging Limitations

To Workspace blocks, Scope blocks, and all types of runtime display, such as Port Values Display, have no effect when specified in referenced models executing in Accelerator mode. The result during simulation is the same as if the constructs did not exist.

Accelerator Mode Reusability Limitations

If a referenced model has any of the following properties, and the model executes in Accelerator mode, the model must specify **Configuration Parameters > Model Referencing > Total number of instances allowed per top model** as `One`. No other instances of the model can exist in the hierarchy, in either Normal mode or Accelerator mode. If the parameter is not set correctly, or more than one instance of the model exists in the hierarchy, an error occurs. The properties are:

- The model contains a subsystem that is marked as function
- The model contains an S-function that is:
  - Inlined but has not set the option `SS_OPTION_WORKS_WITH_CODE_REUSE`
  - Not inlined
- The model contains a function-call subsystem that:
  - Has been forced by Simulink to be a function
  - Is called by a wide signal

S-Function Limitations

- If a referenced model contains an S-function that should be inlined using a Target Language Compiler file, the S-function must use the `ssSetOptions` macro to set the `SS_OPTION_USE_TLC_WITH_ACCELERATOR` option in its `mdlInitializeSizes` method. The simulation target does not inline the S-function unless the S-function sets this option.
- The Real-Time Workshop S-function target does not support model referencing.
- A referenced model cannot use noninlined S-functions in the following cases:
  - The model uses a variable-step solver.
  - Real-Time Workshop generated the S-function.
  - The S-function supports use of fixed-point numbers as inputs, outputs, or parameters.
  - The model is referenced more than once in the model reference hierarchy. To work around this limitation:
    1. Make copies of the referenced model.
    2. Assign different names to the copies.
    3. Reference a different copy at each location that needs the model.
- The S-function uses string parameters.

Simulink Tool Limitations

- Simulink tools that require access to the internal data or configuration of a model (including Model Coverage, the Report Generator, the Simulink Debugger, and the Simulink Profiler) have no effect on referenced models executing in Accelerator mode. Specifications made and actions taken by such tools are ignored and effectively do not exist.

Stateflow Limitations

A Stateflow chart in a referenced model that executes in Accelerator mode cannot call MATLAB functions.

Subsystem Limitations

If you generate code for an atomic subsystem as a reusable function, inputs or outputs that connect the subsystem to a referenced model can affect code reuse. See "Reusable Code and Referenced Models" for details.

Target Limitations

- The Real-Time Workshop `grt_malloc` targets do not support model referencing.
- The Real-Time Workshop S-function target does not support model referencing.

Other Limitations

- When you create a model, you cannot use that model as an Accelerator mode referenced model until you have saved the model to disk. You can work around this limitation by setting the model to Normal mode, as described in "Specifying the Simulation Mode" on page 5-14.
- When the `sim` command executes a referenced model in Accelerator mode, the source workspace is always the MATLAB base workspace.
- Accelerator mode does not support the **External mode** option. If you enable the option, Accelerator mode ignores it.

Limitations on PIL Mode Referenced Models

- Only one branch (top model and all subordinates) in a model reference hierarchy can execute in PIL mode.
- If you create a model, you cannot use that model as a PIL mode referenced model until you have saved the model to disk. You can work around this limitation by setting the model to Normal mode, as described in "Specifying the Simulation Mode" on page 5-14.

For more information, in the Real-Time Workshop Embedded Coder documentation, see "Creating Model Components".

6

Creating Conditional Subsystems

About Conditional Subsystems

A subsystem is a set of blocks that have been replaced by a single block called a Subsystem block. This chapter describes a special kind of subsystem whose execution can be externally controlled. For information that applies to all subsystems, see "Creating Subsystems" on page 3-37.

A *conditional subsystem*, also known as a *conditionally executed subsystem*, is a subsystem whose execution depends on the value of an input signal. The signal that controls whether a subsystem executes is called the *control signal*. The signal enters the Subsystem block at the *control input*.

Conditional subsystems can be very useful when you are building complex models that contain components whose execution depends on other components. The following types of conditional subsystems are supported:

- An *enabled subsystem* executes while the control signal is positive. It starts execution at the time step where the control signal crosses zero (from the negative to the positive direction) and continues execution while the control signal remains positive. Enabled subsystems are described in more detail in "Enabled Subsystems" on page 6-4.
- A *triggered subsystem* executes once each time a trigger event occurs. A trigger event can occur on the rising or falling edge of a trigger signal, which can be continuous or discrete. Triggered subsystems are described in more detail in "Triggered Subsystems" on page 6-14.
- A *triggered and enabled subsystem* executes once on the time step when a trigger event occurs if the enable control signal has a positive value at that step. See "Triggered and Enabled Subsystems" on page 6-18 for more information.
- A *control flow subsystem* executes one or more times at the current time step when enabled by a control flow block that implements control logic similar to that expressed by programming language control flow statements (e.g., `if-then`, `while`, `do`, and `for`. See "Modeling Control Flow Logic" on page 3-44 for more information.

Note The Simulink software imposes restrictions on connecting blocks with a constant sample time to the output port of a conditional subsystem. See "Using Blocks with Constant Sample Times in Enabled Subsystems" on page 6-11 for more information.

For examples of conditional subsystems, see:

- Simulink Subsystem Semantics
- Triggered Subsystems
- Enabled Subsystems
- Advanced Enabled Subsystems

Enabled Subsystems

In this section...

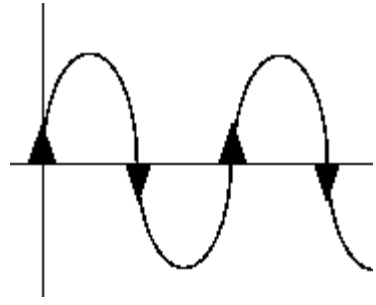
What Are Enabled Subsystems?

Enabled subsystems are subsystems that execute at each simulation step where the control signal has a positive value.

An enabled subsystem has a single control input, which can be scalar or vector valued.

- If the input is a scalar, the subsystem executes if the input value is greater than zero.
- If the input is a vector, the subsystem executes if *any* of the vector elements is greater than zero.

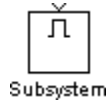
For example, if the control input signal is a sine wave, the subsystem is alternately enabled and disabled, as shown in this figure. An up arrow signifies enable, a down arrow disable.



The Simulink software uses the zero-crossing slope method to determine whether an enable event is to occur. If the signal crosses zero and its slope is positive, then the subsystem becomes enabled. If the slope is negative at the zero crossing, then the subsystem becomes disabled. Note that a subsystem is only enabled or disabled at major time steps. Therefore, if zero-crossing detection is turned off and the signal crosses zero during a minor time step, then the subsystem will not become enabled (or disabled) until the next major time step.

Creating an Enabled Subsystem

You create an enabled subsystem by copying an Enable block from the Ports & Subsystems library into a subsystem. An enable symbol and an enable control input port is added to the Subsystem block.



Setting Initial Conditions for an Enabled Subsystem

You can set the initial output of an enabled subsystem using the subsystems Outport blocks. The initial output value can be either explicitly specified, or inherited from its input signal.

Specifying Initial Conditions. To specify the initial output value of the subsystem:

1. Double-click each Outport block in the subsystem to open its dialog box.
2. Select `Dialog` in the **Source of initial output value** drop-down list.
3. Specify the **Initial output** parameter.

If you select `Dialog`, you can also specify what happens to the output when the subsystem is disabled. For more information, see the next section: “Setting Output Values While the Subsystem Is Disabled” on page 6-7.

Inheriting Initial Conditions. The initial output value of the subsystem can be inherited from the following sources:

- Output port of another conditionally executed subsystem
- Merge block (with Initial output specified)
- Function-Call Model Reference block
- Constant block (simplified initialization mode only)
- IC block (simplified initialization mode only)

The procedure you use to inherit the initial conditions of the subsystem differs depending on whether you are using classic initialization mode or simplified initialization mode.

To inherit initial conditions in classic initialization mode:

1. Double-click each Outport block in the subsystem to open its dialog box.
2. Select `Dialog` in the **Source of initial output value** drop-down list.
3. Set the **Initial output** parameter to `[]` (empty matrix).
4. Click **OK**.

Note For all other driving blocks, specify an explicit initial output value.

To inherit initial conditions in simplified initialization mode:

1. Double-click each Outport block in the subsystem to open its dialog box.
2. Select `Input signal` in the **Source of initial output value** drop-down list.
3. Click **OK**.

   The **Initial output** and **Output when disabled** parameters are disabled, and the values are both inherited from the input signal.

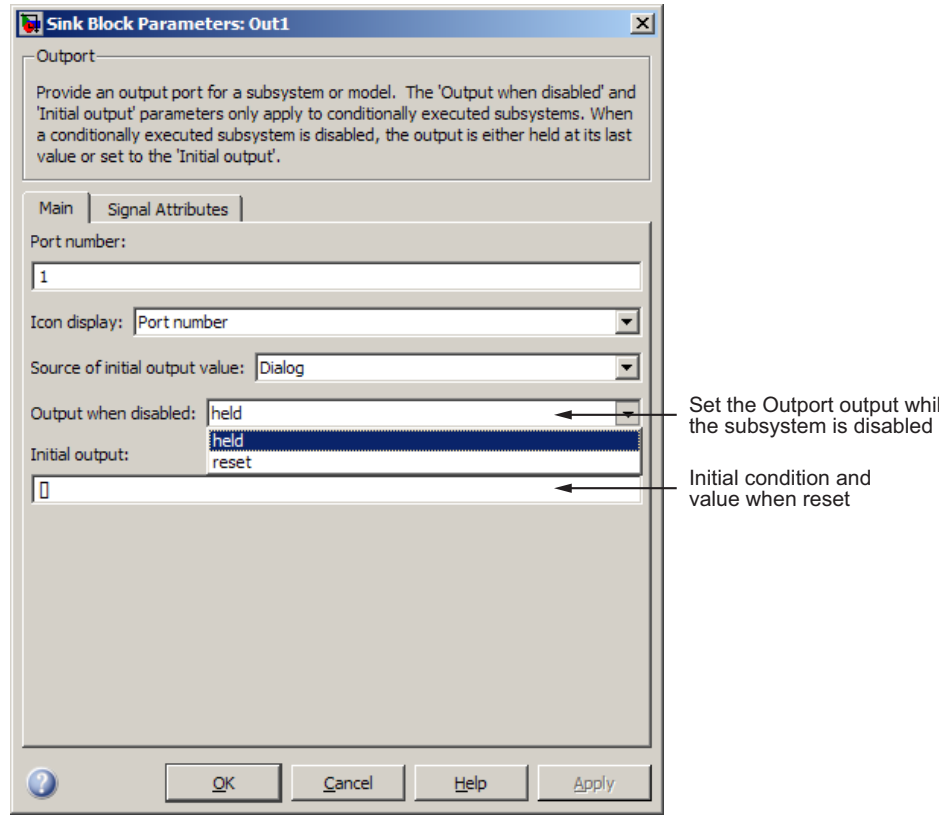
For more information on classic and simplified initialization mode, see "Underspecified initialization detection".

Setting Output Values While the Subsystem Is Disabled

Although an enabled subsystem does not execute while it is disabled, the output signal is still available to other blocks. While an enabled subsystem is disabled, you can choose to hold the subsystem outputs at their previous values or reset them to their initial conditions.

Open each Outport block's dialog box and select one of the choices for the **Output when disabled** parameter, as shown in the following dialog box:

- Choose `held` to maintain the most recent value.
- Choose `reset` to revert to the initial condition. Set the **Initial output** to the initial value of the output.



Note If you are connecting the output of a conditionally executed subsystem to a Merge block, set **Output when disabled** to `held` to ensure consistent simulation results.

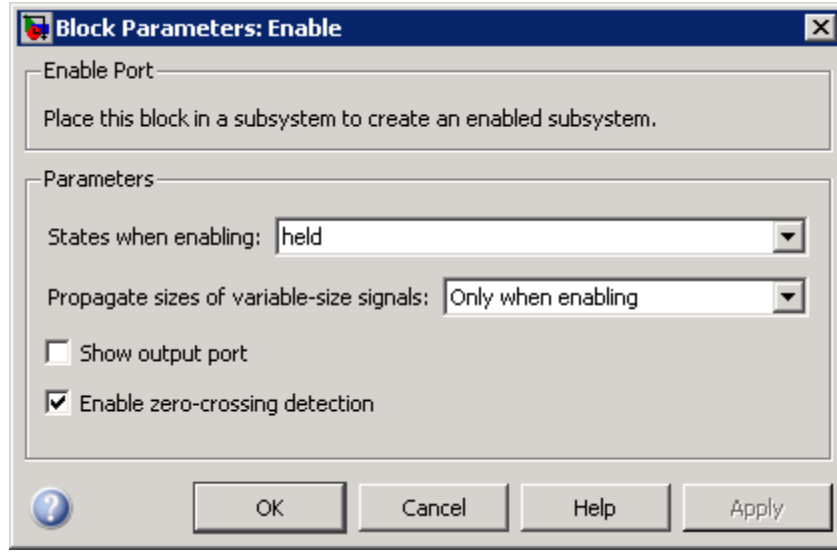
If you are using simplified initialization mode, you must select `held` when connecting a conditionally executed subsystem to a Merge block. For more information, see "Underspecified initialization detection".

Setting States When the Subsystem Becomes Enabled

When an enabled subsystem executes, you can choose whether to hold the subsystem states at their previous values or reset them to their initial conditions.

To do this, open the Enable block dialog box and select one of the choices for the **States when enabling** parameter:

- Choose `held` to cause the states to maintain their most recent values.
- Choose `reset` to cause the states to revert to their initial conditions.

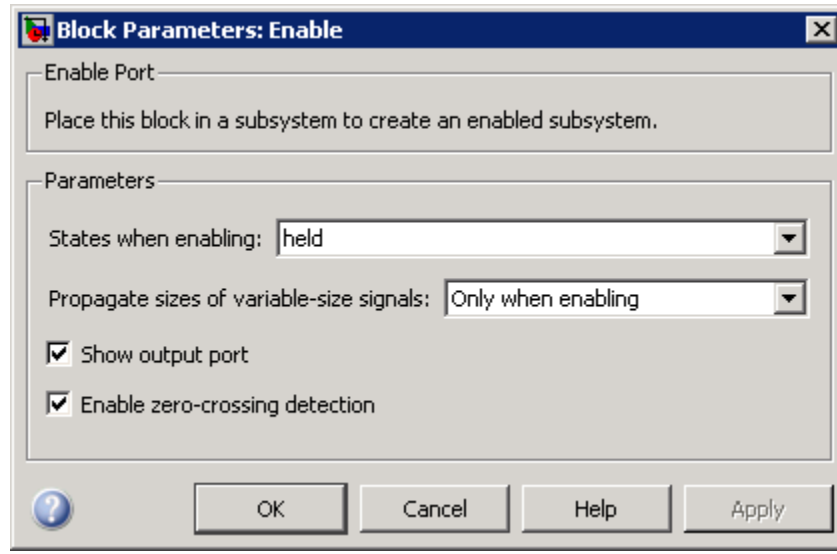


Note If you are using simplified initialization mode, subsystem elapsed time is always reset on first execution after becoming enabled, whether or not the subsystem is configured to reset on enable.

For more information on simplified initialization mode, see "Underspecified initialization detection".

Outputting the Enable Control Signal

An option on the Enable block dialog box lets you output the enable control signal. To output the control signal, select the **Show output port** check box.



This feature allows you to pass the control signal down into the enabled subsystem, which can be useful where logic within the enabled subsystem is dependent on the value or values contained in the control signal.

Blocks an Enabled Subsystem Can Contain

An enabled subsystem can contain any block, whether continuous or discrete. Discrete blocks in an enabled subsystem execute only when the subsystem

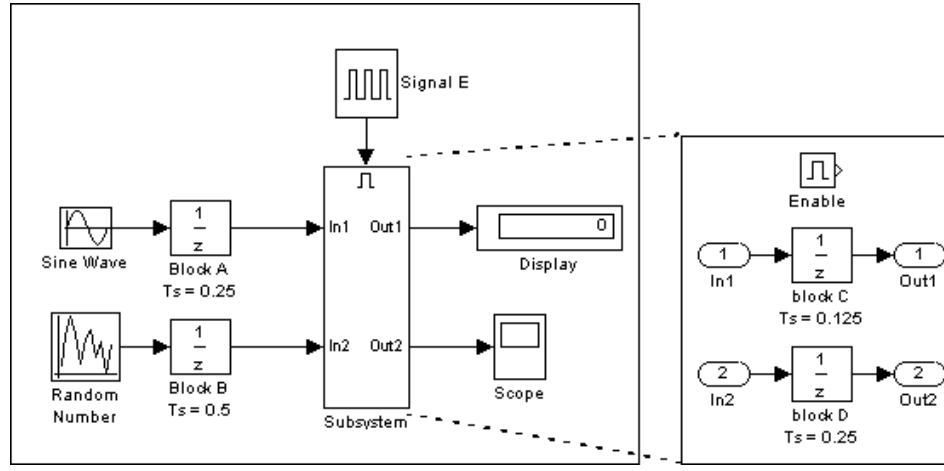
executes, and only when their sample times are synchronized with the simulation sample time. Enabled subsystems and the model use a common clock.

Note Enabled subsystems can contain Goto blocks. However, only state ports can connect to Goto blocks in an enabled subsystem. See the demo model, `clutch`, for an example of how to use Goto blocks in an enabled subsystem.

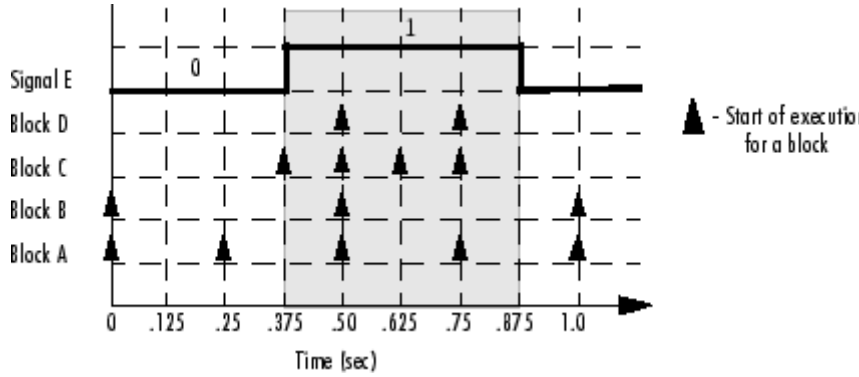
For example, this system contains four discrete blocks and a control signal. The discrete blocks are

- Block A, which has a sample time of 0.25 second
- Block B, which has a sample time of 0.5 second
- Block C, within the enabled subsystem, which has a sample time of 0.125 second
- Block D, also within the enabled subsystem, which has a sample time of 0.25 second

The enable control signal is generated by a Pulse Generator block, labeled Signal E, which changes from 0 to 1 at 0.375 second and returns to 0 at 0.875 second.



The chart below indicates when the discrete blocks execute.



Blocks A and B execute independently of the enable control signal because they are not part of the enabled subsystem. When the enable control signal becomes positive, blocks C and D execute at their assigned sample rates until the enable control signal becomes zero again. Note that block C does not execute at 0.875 second when the enable control signal changes to zero.

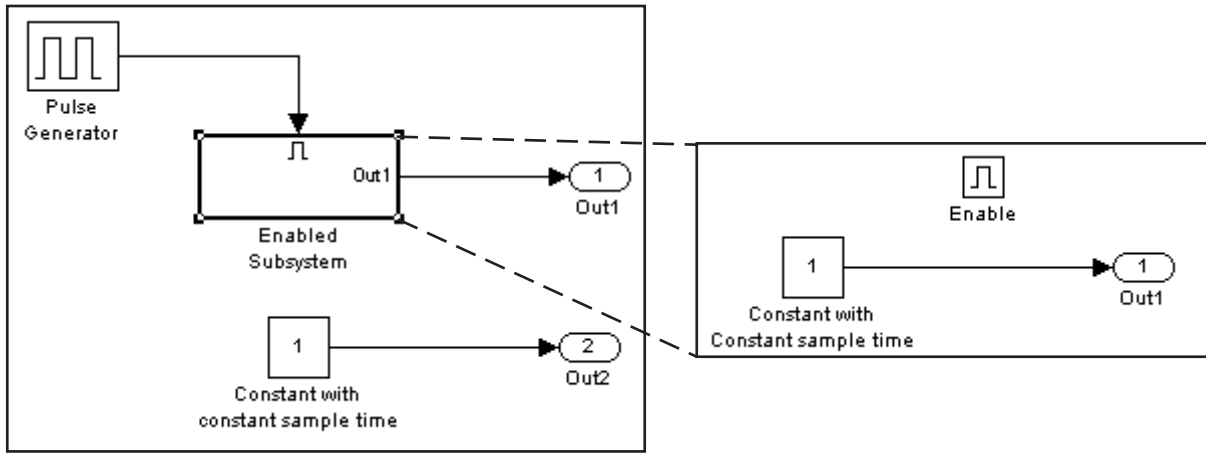
Using Blocks with Constant Sample Times in Enabled Subsystems

Certain restrictions apply when you connect blocks with constant sample times (see “Constant Sample Time” on page 4-17) to the output port of a conditional subsystem.

- An error appears when you connect a Model or S-Function block with constant sample time to the output port of a conditional subsystem.
- The sample time of any built-in block with a constant sample time is converted to a different sample time, such as the fastest discrete rate in the conditional subsystem.

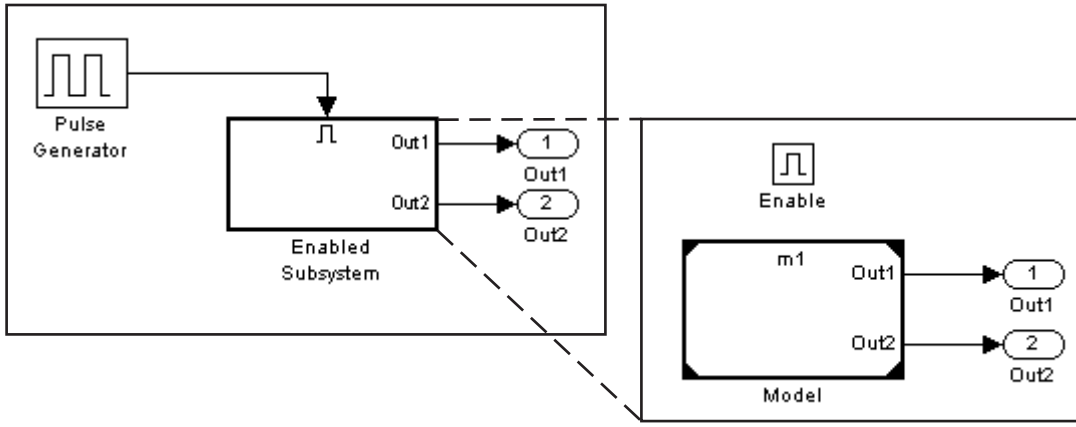
To avoid the error or conversion, either manually change the sample time of the block to a non-constant sample time or use a Signal Conversion block. The example below shows how to use the Signal Conversion block to avoid these errors.

Consider the following model `m1.mdl`.



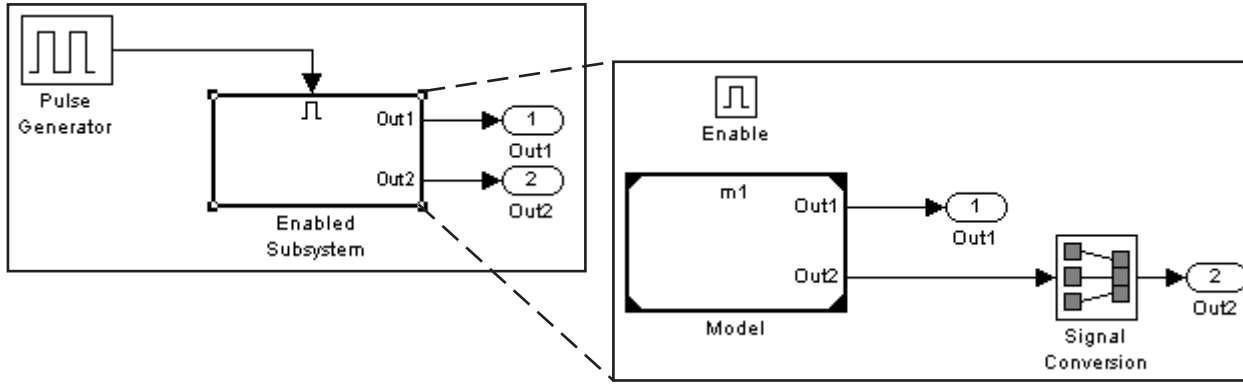
The two Constant blocks in this model have constant sample times. When you simulate the model, the Simulink software converts the sample time of the Constant block inside the enabled subsystem to the rate of the Pulse Generator. If you simulate the model with sample time colors displayed (see "Displaying Sample Time Colors" on page 3-12), the Pulse Generator and Enabled Subsystem blocks are colored red. However, the Constant and Outport blocks outside of the enabled subsystem are colored magenta, indicating that these blocks still have a constant sample time.

Suppose the model above is referenced from a Model block inside an enabled subsystem, as shown below. (See Chapter 5, "Referencing a Model".)



An error appears when you try to simulate the top model, indicating that the second output of the Model block may not be wired directly to the enabled subsystem output port because it has a constant sample time. (See Chapter 5, "Referencing a Model".)

To avoid this error, insert a Signal Conversion block between the second output of the Model block and the enabled subsystem's Outport block.



This model simulates with no errors. With sample time colors displayed, the Model and Enabled Subsystem blocks are colored yellow, indicating that these are hybrid systems, that is, systems that contain multiple sample times.

Triggered Subsystems

In this section...

What Are Triggered Subsystems?

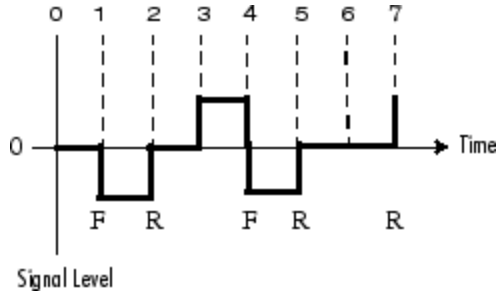
Triggered subsystems are subsystems that execute each time a trigger event occurs.

A triggered subsystem has a single control input, called the *trigger input*, that determines whether the subsystem executes. You can choose from three types of trigger events to force a triggered subsystem to begin execution:

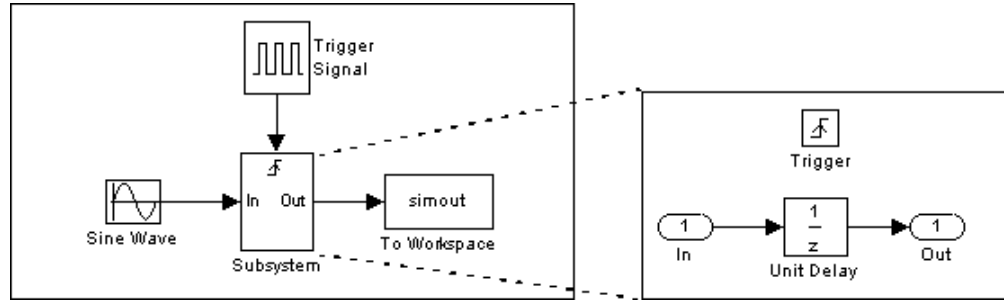
- `rising` triggers execution of the subsystem when the control signal rises from a negative or zero value to a positive value (or zero if the initial value is negative).
- `falling` triggers execution of the subsystem when the control signal falls from a positive or a zero value to a negative value (or zero if the initial value is positive).
- `either` triggers execution of the subsystem when the signal is either rising or falling.

Note For discrete systems: If after rising, a signal remains at zero for more than one time step, then and only then, does the subsequent rising of the signal constitute a trigger event. Similarly, a falling trigger event occurs only if there are at least two time steps between two occurrences of the signal falling. This trigger event scheme eliminates false triggers caused by control signal sampling.

For example, in the following timing diagram for a discrete system, a rising trigger (R) does not occur at time step 3 because the signal has remained at zero for only one time step when the rise occurs.



A simple example of a triggered subsystem is illustrated.



In this example, the subsystem is triggered on the rising edge of the square wave trigger control signal.

Using Model Referencing Instead of a Triggered Subsystem

You can use triggered ports in referenced models. Add a trigger port to a referenced model to create a simpler, cleaner model than when you include either:

- A triggered subsystem in a referenced model
- A Model block in a triggered subsystem

For information about using trigger ports in referenced models, see “Defining Triggered Models” on page 5-47.

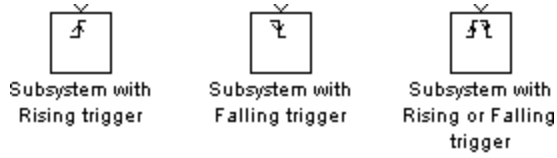
To convert a subsystem to use model referencing, see “Converting a Subsystem to a Referenced Model” on page 5-10.

Creating a Triggered Subsystem

You create a triggered subsystem by copying the Trigger block from the Ports & Subsystems library into a subsystem. The Simulink software adds a trigger symbol and a trigger control input port to the Subsystem block.

To select the trigger type, open the Trigger block dialog box and select one of the choices for the **Trigger type** parameter.

Different symbols appear on the Trigger and Subsystem blocks to indicate rising and falling triggers (or either). This figure shows the trigger symbols on Subsystem blocks.



Outputs and States Between Trigger Events

Unlike enabled subsystems, triggered subsystems always hold their outputs at the last value between triggering events. Also, triggered subsystems cannot reset their states when triggered; states of any discrete blocks are held between trigger events.

Outputting the Trigger Control Signal

An option on the Trigger block dialog box lets you output the trigger control signal. To output the control signal, select the **Show output port** check box.

In the **Output data type** field, you specify the data type of the output signal as `auto`, `int8`, or `double`. The `auto` option causes the data type of the output signal to be the data type (either `int8` or `double`) of the port to which the signal connects.

Blocks That a Triggered Subsystem Can Contain

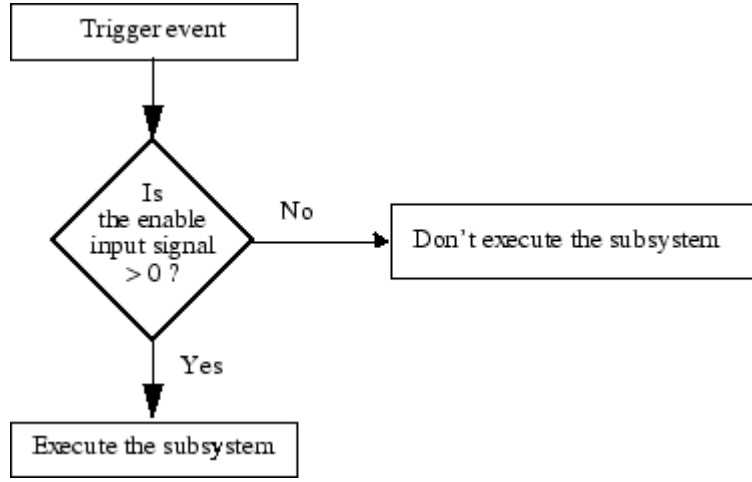
All blocks in a triggered subsystem must have either inherited (`-1`) or constant (`inf`) sample time. This is to indicate that the blocks in the triggered subsystem run only when the triggered subsystem itself runs, for example, when it is triggered. This requirement means that a triggered subsystem cannot contain continuous blocks, such as the Integrator block.

Triggered and Enabled Subsystems

In this section...

What Are Triggered and Enabled Subsystems?

A third kind of conditional subsystem combines both types of conditional execution. The behavior of this type of subsystem, called a *triggered and enabled* subsystem, is a combination of the enabled subsystem and the triggered subsystem, as shown by this flow diagram.



A triggered and enabled subsystem contains both an enable input port and a trigger input port. When the trigger event occurs, the enable input port is checked to evaluate the enable control signal. If its value is greater than zero, the subsystem is executed. If both inputs are vectors, the subsystem executes if at least one element of each vector is nonzero.

The subsystem executes once at the time step at which the trigger event occurs.

Creating a Triggered and Enabled Subsystem

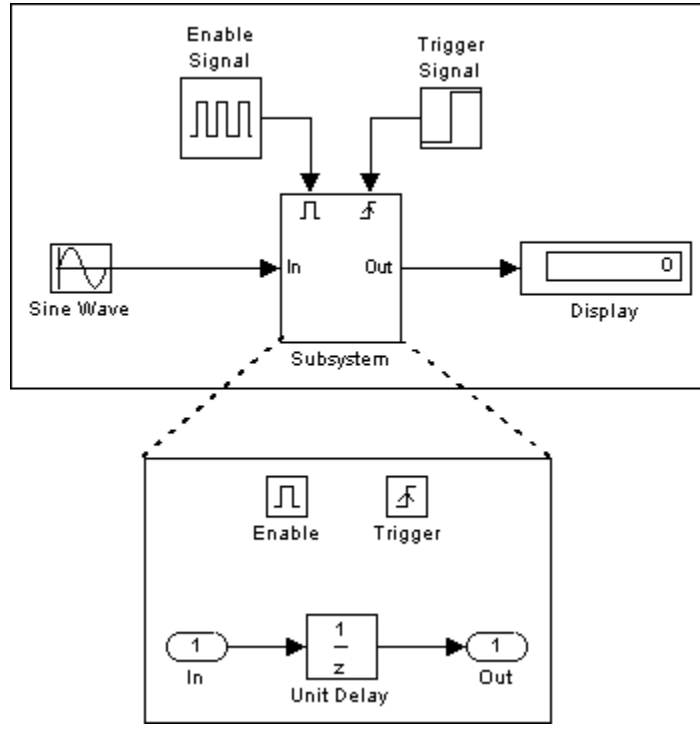
You create a triggered and enabled subsystem by dragging both the Enable and Trigger blocks from the Ports & Subsystems library into an existing subsystem. The Simulink software adds enable and trigger symbols and enable and trigger and enable control inputs to the Subsystem block.

You can set output values when a triggered and enabled subsystem is disabled as you would for an enabled subsystem. For more information, see “Setting Output Values While the Subsystem Is Disabled” on page 6-7. Also, you can specify what the values of the states are when the subsystem is reenabled. See “Setting States When the Subsystem Becomes Enabled” on page 6-8.

Set the parameters for the Enable and Trigger blocks separately. The procedures are the same as those described for the individual blocks.

A Sample Triggered and Enabled Subsystem

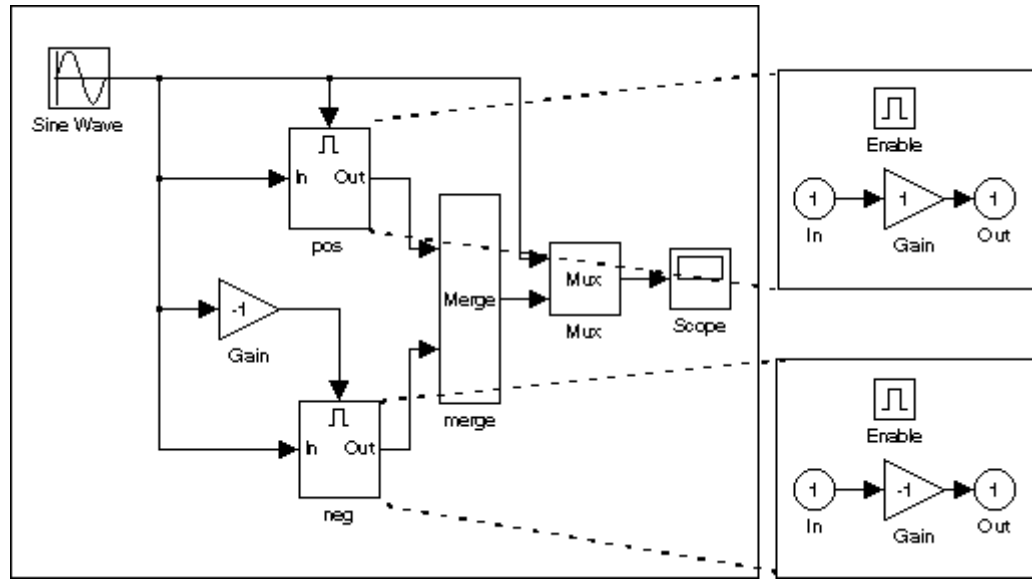
A simple example of a triggered and enabled subsystem is illustrated in the following model.



Creating Alternately Executing Subsystems

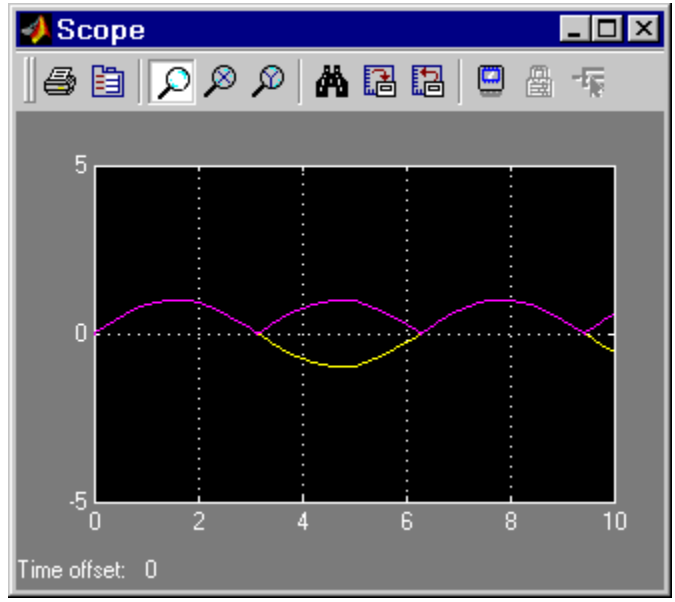
You can use conditional subsystems in combination with Merge blocks to create sets of subsystems that execute alternately, depending on the current state of the model.

The following figure shows a model that uses two enabled blocks and a Merge block to model a full-wave rectifier – a device that converts AC current to pulsating DC current.



The block labeled “pos” is enabled when the AC waveform is positive; it passes the waveform unchanged to its output. The block labeled “neg” is enabled when the waveform is negative; it inverts the waveform. The Merge block passes the output of the currently enabled block to the Mux block, which passes the output, along with the original waveform, to the Scope block.

The Scope creates the following display.



Function-Call Subsystems

A function-call subsystem is a subsystem that another block can invoke directly during a simulation. It is analogous to a function in a procedural programming language. Invoking a function-call subsystem is equivalent to invoking the output methods (see "Block Methods" on page 2-16) of the blocks that the subsystem contains in sorted order (see "How Simulink Determines the Sorted Order" on page 18-45). The block that invokes a function-call subsystem is called the function-call initiator. Stateflow, Function-Call Generator, and S-function blocks can all serve as function-call initiators.

To create a function-call subsystem, drag a Function-Call Subsystem block from the Ports & Subsystems library into your model and connect a function-call initiator to the function-call port displayed on top of the subsystem. You can also create a function-call subsystem from scratch by first creating a Subsystem block in your model and then creating a Trigger block in the subsystem and setting the Trigger block's **Trigger type** to `function-call`.

You can configure a function-call subsystem to be triggered (the default) or periodic by setting the **Sample time type** of its Trigger port to be `triggered` or `periodic`, respectively. A function-call initiator can invoke a triggered function-call subsystem zero, once, or multiple times per time step. The sample times of all the blocks in a triggered function-call subsystem must be set to inherited (`-1`).

A function-call initiator can invoke a periodic function-call subsystem only once per time step and must invoke the subsystem periodically. If the initiator invokes a periodic function-call subsystem aperiodically, the simulation is halted and an error message displayed. The blocks in a periodic function-call subsystem can specify a noninherited sample time or inherited (`-1`) sample time. All blocks that specify a noninherited sample time must specify the sample time. For example, if one block specifies `0.1` as the sample time, all other blocks must specify a sample time of `0.1` or `-1`. If a function-call initiator invokes a periodic function-call subsystem at a rate that differs from the sample time specified by the blocks in the subsystem, the simulation halts and an error message appears.

For more information about function-call subsystems, see "Function-Call Subsystems" in "Writing S-Functions" in the online documentation.

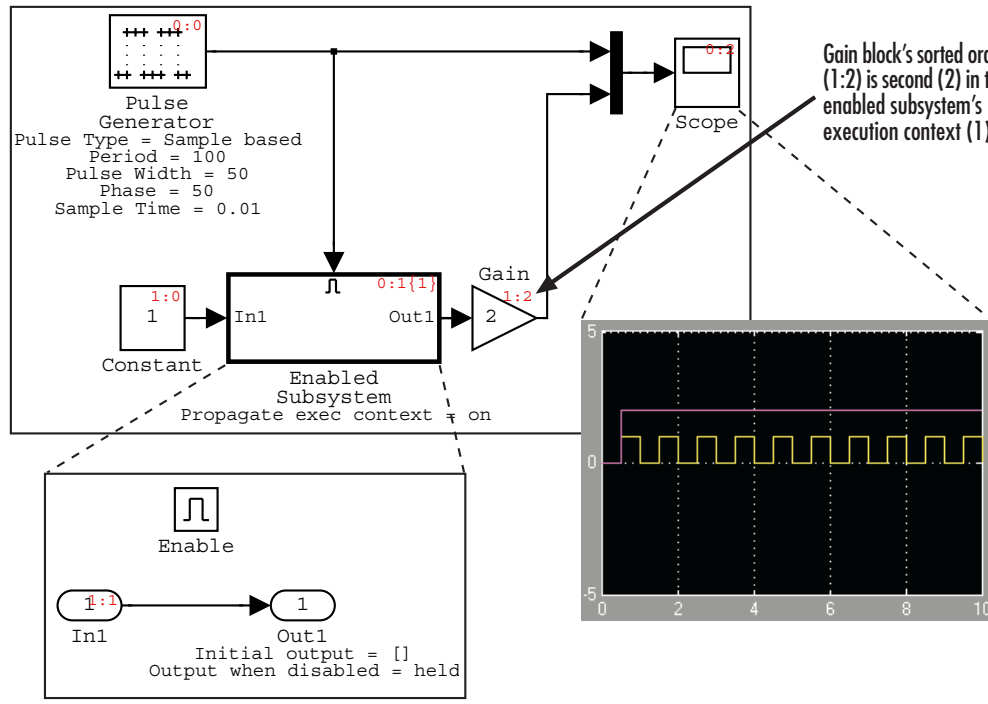
Conditional Execution Behavior

In this section...

What Is Conditional Execution Behavior?

To speed simulation of a model, by default the Simulink software avoids unnecessary execution of blocks connected to Switch, Multiport Switch, and of conditionally executed blocks, a behavior called *conditional execution (CE)* behavior. You can disable this behavior for all Switch and Multiport Switch blocks in a model, or for specific conditional subsystems. See "Disabling Conditional Execution Behavior" on page 6-28.

The following model illustrates conditional execution behavior.



The outputs of the Constant block and Gain blocks are computed only while the enabled subsystem is enabled (that is, at time steps 0.5 to 1.0, 1.5 to 2.0, and so on). This is because the output of the Constant block is required and the input of the Gain block changes only while the enabled subsystem is enabled. When CE behavior is off, the outputs of the Constant and Gain blocks are computed at every time step, regardless of whether the outputs are needed or change.

In this example, the enabled subsystem is regarded as defining an execution context for the Constant and Gain blocks. Although the blocks reside graphically in the model's root system, the Simulink software invokes the blocks' methods during simulation as if the blocks reside in the enabled subsystem. This is indicated in the sorted order labels displayed on the diagram for the Constant and Gain blocks. The notations list the subsystem's (id = 1) as the execution context for the blocks even though the blocks exist graphically at the model's root level (id = 0).

Propagating Execution Contexts

In general, the Simulink software defines an *execution context* as a set of blocks to be executed as a unit. At model compilation time, the Simulink software associates an execution context with the model's root system and with each of its nonvirtual subsystems. Initially, the execution context of the root system and each nonvirtual subsystem is simply the blocks that it contains.

When compiling, each block in the model is examined to determine whether it meets the following conditions:

- Its output is required only by a conditional subsystem or its input changes only as a result of the execution of a conditionally executed.
- The subsystem's execution context can propagate across its boundaries.
- The output of the block is not a testpoint (see "Working with Test Points" on page 29-61).
- The block is allowed to inherit its conditional execution context.

  The Simulink software does not allow some built-in blocks, e.g., the Delay block, ever to inherit their execution context. Also, S-Function blocks can inherit their execution context only if they specify the `SS_OPTION_CAN_BE_CALLED_CONDITIONALLY` option.
- The block is not a multirate block.
- Its sample time is inherited (`-1`).

If a block meets these conditions and execution context propagation is enabled for the associated conditional subsystem (see "Disabling Conditional Execution Behavior" on page 6-28), the Simulink software moves the block into the execution context of the subsystem. This ensures that the block's methods are executed during the simulation loop only when the corresponding conditional subsystem executes.

Note Execution contexts are not propagated to constant sample time blocks.

Behavior for Switch Blocks

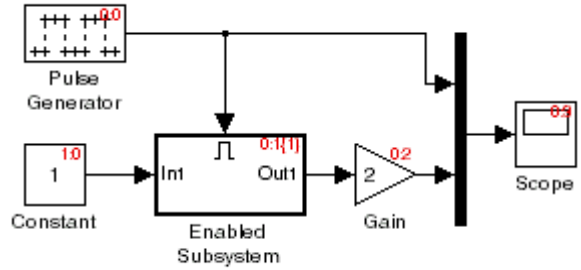
This behavior treats the input branches of a Switch or Multiport Switch block as invisible, conditional subsystems, each of which has its own execution context that is enabled only when the switch's control input selects the corresponding data input. As a result, switch branches execute only when selected by switch control inputs.

Displaying Execution Contexts

To determine the execution context to which a block belongs, select **Block Displays > Sorted order** from the model window **Format** menu. The sorted order index for each block in the model is displayed in the upper-right corner of the block. The index has the format `s:b`, where *s* specifies the subsystem to whose execution context the block belongs and *b* is an index that indicates the block's sorted order in the subsystem's execution context, e.g., 0:0 indicates that the block is the first block in the root subsystem's execution context.

If a bus is connected to the block's input, the block's sorted order is displayed as **s**:B, e.g., 0:B indicates that the block belongs to the root system's execution context and has a bus connected to its input.

The sorted order index of conditional subsystems is expanded to include the system ID of the subsystem itself in curly brackets as illustrated in the following figure.



In this example, the sorted order index of the enabled subsystem is `0:1{1}`. The `0` indicates that the enabled subsystem resides in the model's root system. The first `1` indicates that the enabled subsystem is the second block on

the root system's sorted list (zero-based indexing). The 1 in curly brackets indicates that the system index of the enabled subsystem itself is 1. Thus any block whose system index is 1 belongs to the execution context of the enabled subsystem and hence executes when it does. For example, the Constant block's index, 1:0, indicates that it is the first block on the sorted list of the enabled subsystem, even though it resides in the root system.

Disabling Conditional Execution Behavior

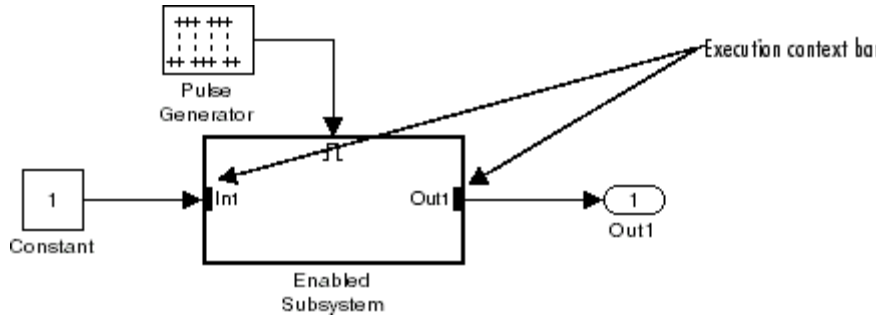
To disable conditional execution behavior for all Switch and Multiport Switch blocks in a model, turn off the **Conditional input branch execution** optimization on the **Optimization** pane of the Configuration Parameters dialog box (see "Optimization Pane"). To disable conditional execution behavior for a specific conditional subsystem, clear the **Propagate execution context across subsystem boundary** check box on the subsystem parameter dialog box.

Even if this option is enabled, a subsystem's execution context cannot propagate across its boundaries under either of the following circumstances:

- The subsystem is a triggered subsystem with a latched input port.
- The subsystem has one or more output ports that specify an initial condition, for example, whose initial condition is other than `[]`. In this case, a block connected to the subsystem's output cannot inherit the subsystem's execution context.

Displaying Execution Context Bars

Simulink software can optionally display bars next to the ports of subsystems across which execution contexts cannot propagate, for example, on subsystems from which no block can inherit its execution context.



To display the bars, select **Execution Context Indicator** from model editor's **Format > Block Displays** menu.

7

Modeling Variant Systems

Overview of Variant Systems

Many applications require the ability to customize a model to fit different specifications, without replacing or duplicating the model. For example, a design engineer has a model that simulates a car. Various models of a car can have many similarities, yet differ in specific ways such as: fuel usage, engine size, or emission standards.

Simulink provides several techniques to customize a model to fit different applications through design and simulation. Two modeling components for implementing a variant system are the Model Variants block and the Variant Subsystem block.

A Model Variants block references two or more models, where the referenced model used during simulation is the active variant. A Variant Subsystem block consists of a set of subsystems, where the subsystem used during simulation is the active variant. Each variant, inactive or active, is associated with a variant object. The evaluation of the variant objects determine the active variant. You can parameterize the variant object by making it dependent on the values of variables and objects in the base MATLAB workspace. For a quick overview, see "Model Variants Block Overview" on page 7-4 and "Variant Subsystem Block Overview" on page 7-17.

You can programmatically switch the active variant by modifying the values of variant control variables in the base workspace, or by manually overriding the variant selection on the block parameter dialog box. Both variant models and variant subsystems implement variants using a similar workflow. For more information, see "Variants Workflow" on page 7-3.

For other techniques to customize a model for different specifications, see:

- "Tunable Parameters" on page 2-9 to change base workspace data values
- Configurable Subsystem block to select from alternate subsystems available in a library
- to use a mask to change a subsystem
- "Parameterizing Model References" on page 5-40 to change the arguments to a parameterized referenced model

Variants Workflow

You can implement a variant system in your model by using the Model Variants block or the Variant Subsystem block. Both components use a similar workflow. One high-level workflow for implementing variants is:

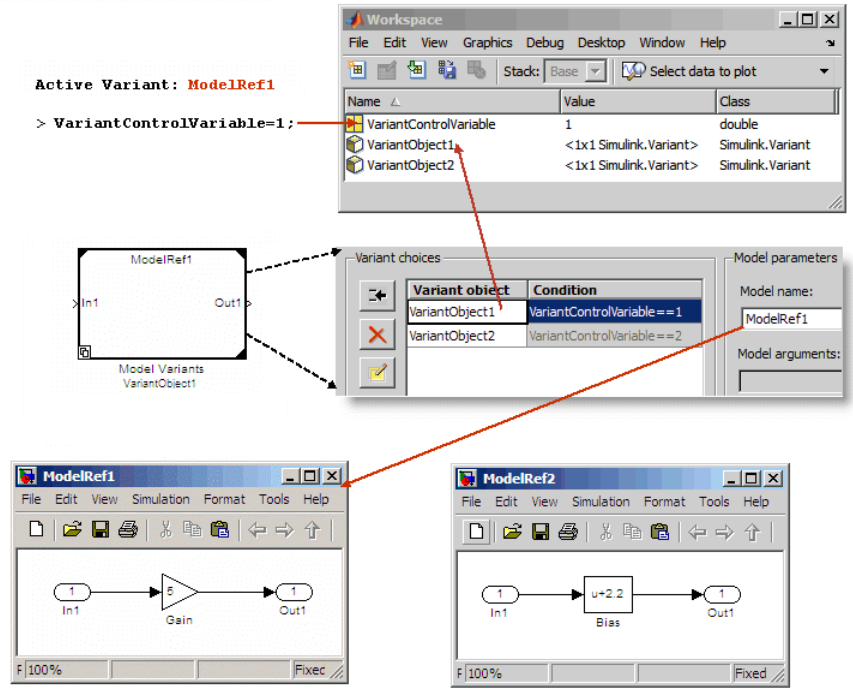
1. Select either the Model Variants block or the Variant Subsystem block for your application. For more information, see "Using the Model Variants Block" on page 7-4 and "Using the Variant Subsystem Block" on page 7-17.
2. Create the variants: subsystems or referenced models.
3. Create and associate a variant object with each variant.
4. Create and modify the variant control variables to select the active variant.
5. Simulate using the active variant.
6. Modify the variant specification to select another variant and simulate again.
7. Generate code for the active variant or all variants, depending on your application.
8. Save variant control variables and variant objects from the base workspace as described in "Exporting Workspace Variables" on page 8-54.

Using the Model Variants Block

In this section...

Model Variants Block Overview

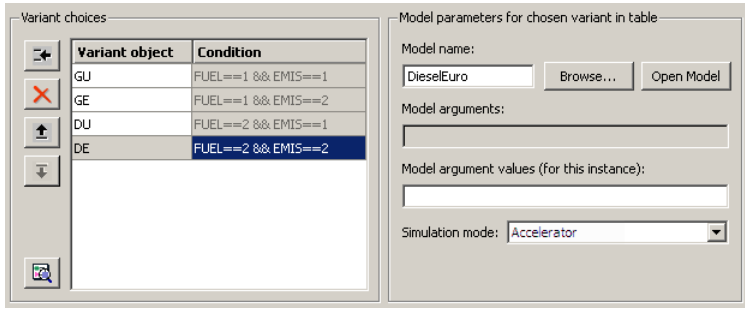
Model Variants provide multiple implementations for a referenced model where only one implementation is active during simulation. You can programmatically swap out the active implementation with another implementation without modifying the model.



A Model Variants block consists of multiple referenced models such that:

- Each variant has a variant object associated with it.
- When compiling the model, Simulink tests the variant condition specified by each variant object. The variant whose variant object condition is `true` becomes the active variant.
- Only one variant can be the active variant for a Model Variants block.
- The active variant is the referenced model used for simulation.

The associations are defined in the Model Reference Parameter dialog box, in the **Variant choices** table.



The Model Variants block parameters specification must include at least:

- The name of a variant object, in the **Variant object** column of the **Variant choices** table.
- The name of a referenced model, in the **Model Name** field of the **Model parameters** section.
- A simulation mode, in the **Simulation mode** field of the **Model parameters** section.
- If a referenced model has arguments, then specify values in the **Model argument values** field of the **Model parameters** section.

Instructions for configuring model variants are in “Example: Implementing a Model Variants Block” on page 7-9.

Model Variants Block Requirements

Model Variants blocks must satisfy the requirements listed in “Simulink Model Referencing Requirements” on page 5-33 and the limitations listed in “Simulink Model Referencing Limitations” on page 5-73. You can nest Model Variants blocks to any level. When you compile the model or generate code for it, the hierarchy resulting from nesting must satisfy all applicable requirements and limitations. The “Model Variants Block Limitations” on page 7-15 section lists the few exceptions. Additional requirements and limitations that apply to only code generation appear in “Limitations on Generating Code for Variants”.

You can enable or suppress warning messages about mismatches between a Model Variants block and its referenced model by setting diagnostics on the "Diagnostics Pane: Model Referencing".

Example of a Model Variants Block

The example model, `AutoMRVar.mdl`, provides an implementation of the following application:

- An automobile that can use either a diesel or a gasoline engine
- The engine must meet either the European or American (USA) emission standard

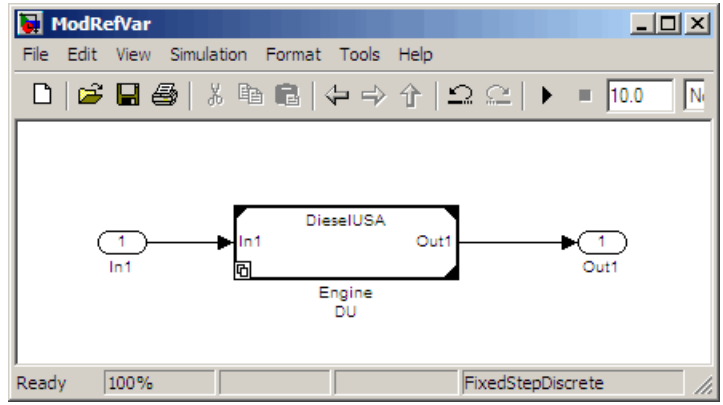
`AutoMRVar` implements the automobile application using the Model Variants block, named `Engine`. The `Engine` block consists of a set of four referenced models. Each referenced model represents one permutation of engine fuel and emission standards.

To view the `AutoMRVar`, do one of the following:

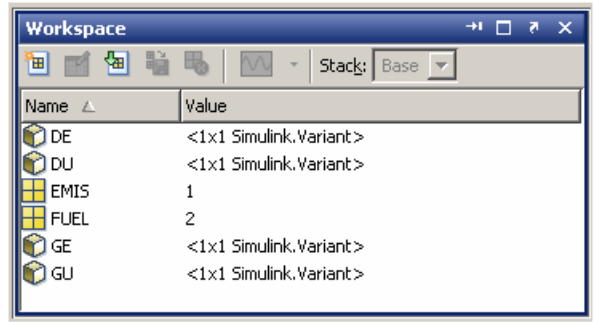
- Click `AutoMRVar.mdl`
- In the MATLAB command window, execute:

```
addpath([docroot '/toolbox/simulink/ug/examples/variants/mdlref/']);
open('AutoMRVar.mdl');
```

The example model opens.



- The icon  appears in the lower-left corner to indicate that the block uses variants.
- The name of the variant that was active the last time the model was saved appears at the top of the block.
- When the active variant is changed and you call an **Update Diagram**, the variant block name changes.
- When you open the example model, a callback function loads a MAT file that populates the base workspace with the variables and objects that the model uses. The base workspace contains the variant control variables and variant objects:



Example: Implementing a Model Variants Block

Create a Model Containing a Model Variants Block

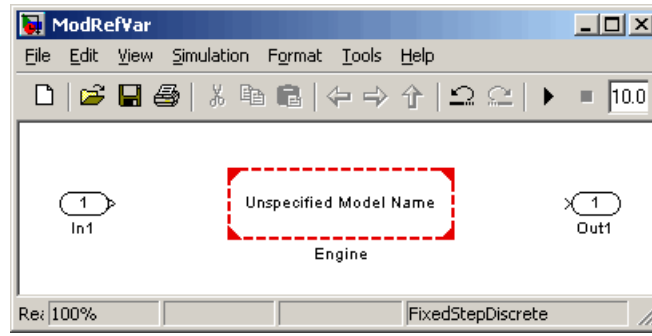
This section illustrates how to create the example model, `AutoMRVar.mdl`. You can apply the operations to your own model, or you can use this section as a tutorial for `AutoMRVar.mdl`.

1. If you are creating your own model, close `AutoMRVar` and clear your workspace. Open a new model and name it `ModRefVar.mdl`.

2. From the Simulink Library Browser, add the following blocks:

   - **Simulink > Commonly Used Blocks > Inport block**
   - **Simulink > Commonly Used Blocks > Outport block**
   - **Simulink > Ports and Subsystems > Model Variants block**

   Name the Model Variants block, `Engine`. `ModRefVar` now looks like the following figure.



3. Save the model in a writable working folder.

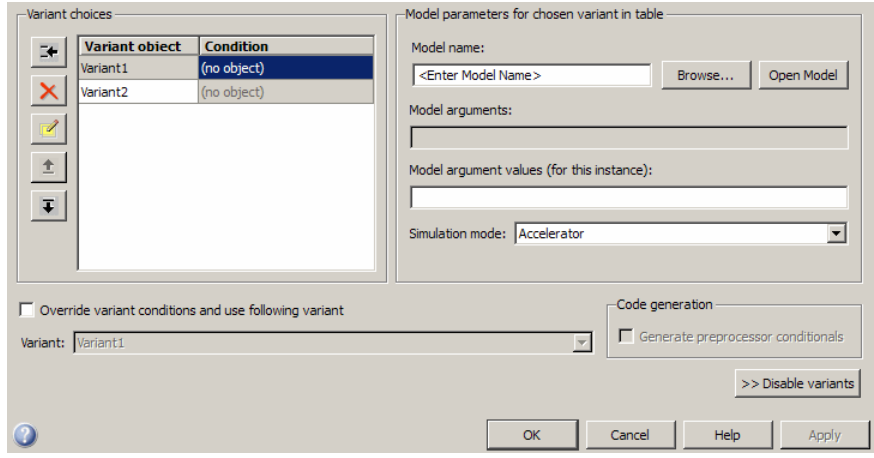
4. Create your models to be referenced as variants of the Model Variants block. For this example, the referenced models are: `DieselEuro`, `DieselUSA`, `GasolEuro`, `GasolUSA`. They are already on the MATLAB path and do not need any changes. For more information, see "Model Variants Block Requirements" on page 7-6 and "Model Variants Block Limitations" on page 7-15.

Configuring the Model Variants Block

To configure your Model Variants block, `Engine`, do the following:

1. From the model diagram window, right-click the `Engine` block, and select **Model Reference Parameters** or select **Edit > Model Reference Parameters**.

   The Model Variants block parameters dialog box opens.



2. To create a variant object, do the following:

   a. In the **Variant object** column of the **Variant choices** table, double-click the default `Variant1` variant object. Type the name of the variant object, `GU`. For an existing variant object, Simulink retrieves the variant condition for the object as soon as you press **Enter** or click away from the **Variant object**.

   b. Click the **Create/Edit selected variant** button  to create a variant object for the selected variant choice. The Simulink.Variant parameter dialog box opens.

   c. Specify the **Condition** for the variant object as `FUEL==1 && EMIS==1`. Click **Apply** and **OK**.

3 To associate the variant object, GU, with a referenced model, do the following:

   a In the **Variant choices** section, select `GU`.

   b In the **Model parameters for chosen variant in table**, to the right of the **Model name** field, select the **Browse** button .

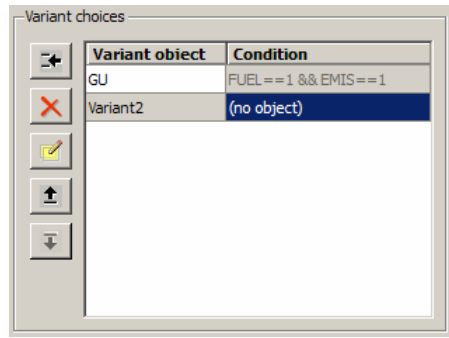
   c Select the model, `GasolUSA.mdl`, and click **Open**. The model name appears in the **Model name** parameter field. An alternative is to type the name of the model in the **Model name** field. (Specify a protected model with a `.mdlp` extension. See "Protecting Referenced Models" on page 5-55)

   d Specify the value of the **Simulation mode**. If you are building the `AutoMRVar` model, select `Normal` mode. (All simulation modes work with model variants. See .)

   e Click **Apply** to associate the referenced model with its variant object.

4 To add another variant, click the **Add a new variant** button 

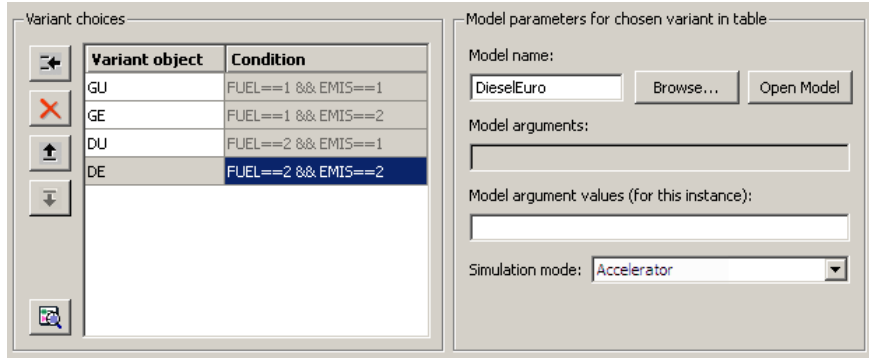
   A new **Variant choices** row appears below the other variant choices.



5 Repeat steps 2–4, until you have specified all referenced models and their associated variant objects for the `Engine` block. The complete specifications for `ModRefVar.mdl` are listed in the following table.

Variant Object	Variant Condition	Model Name	Simulation Mode
GU	FUEL==1 && EMIS==1	GasolUSA.mdl	Normal
GE	FUEL==1 && EMIS==2	GasolEuro.mdl	Normal
DU	FUEL==2 && EMIS==1	DieselUSA.mdl	Normal
DE	FUEL==2 && EMIS==2	DieselEuro.mdl	Normal

The `ModRefVar.mdl` dialog box now looks like the following figure.



6 Click **Apply** or **OK**. For information about the other buttons on the left side of the dialog box, see "Modifying Variant Subsystem Specifications" on page 7-25.

7 Connect the Model Variants block to the Inport and Outport blocks.

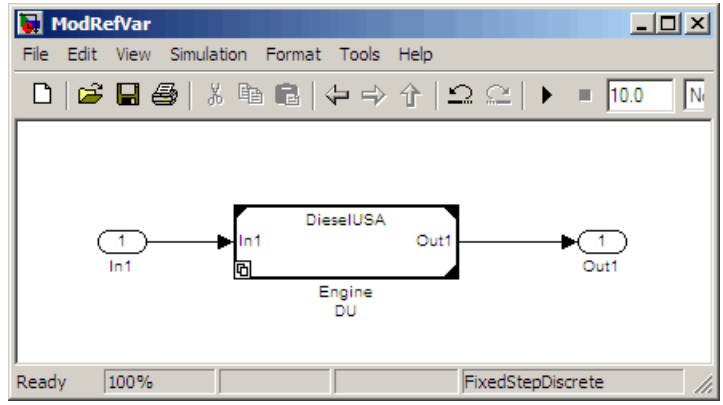
Note Until you define FUEL and EMIS in the base workspace, the model diagram does not update the active variant (in this case, a referenced model) or the active variant object.

Create Variant Control Variables

At the MATLAB command line or in the base workspace, create variant control variables, `EMIS` and `FUEL`. Depending on the values of `EMIS` and `FUEL`, you can see which variant is the active variant.

Variant Control Variables	Variant Object	Active Variant (Model Block or Subsystem Block)
`FUEL=1` and `EMIS=1`	`GU`	`GasolUSA`
`FUEL=1` and `EMIS=2`	`GE`	`GasolEuro`
`FUEL=2` and `EMIS=1`	`DU`	`DieselUSA`
`FUEL=2` and `EMIS=2`	`DE`	`DieselEuro`

Specify `FUEL=2` and `EMIS=1` in the base workspace. When the variant control variables are these values, then the variant condition associated with the variant object `DU` is `true`. Therefore, the active variant is `DieselUSA.mdl`.



Simulate the Model

Make the MATLAB command window visible so that you can see the messages it displays, then simulate the model `AutoMRVar`. Because FUEL = 2 and EMIS = 1, the variant object that evaluates to `true` is `DU`. Variant object `DU` is associated with `DieselUSA.mdl`. Therefore, the model `AutoMRVar`

uses `DieselUSA` as its referenced model during simulation. In the command window, MATLAB displays:

```
Using variant model: DieselUSA.mdl
```

Save Variant Components

Variant control variables and variant objects exist in the base workspace. If you want to reload variant control variables or variant objects with your model, you must save them to a MAT-file. For more information, see "Exporting to MAT-Files".

Further Topics for Model Variants Specifications

- "Disabling and Enabling Model Variants" on page 7-14
- "Parameterizing Model Variants" on page 7-15
- "Override Variant Conditions" on page 7-32
- "Model Variants Block Limitations" on page 7-15
- "Code Generation of Variants" on page 7-37

Disabling and Enabling Model Variants

Once you enable variants, they remain enabled until you explicitly disable them. You can close and reopen the Model Variants block without affecting the variant specification. To disable variants from your Model or Model Variants block:

1. Right-click the block and select **ModelReference Parameters** to open the block parameters dialog box.
2. Select the **Disable Variants** button. Disabling variants:
   - Hides the Block parameter dialog box for variants
   - Leaves the active variant as the model name and the execution environment when the variants were disabled
   - Subsequent changes to variant control variables, variant conditions, and other models, other than the current model, do not effect the behavior of the Model Variants block

3 If you decide to re-enable variants, select the **Enable Variants** button. The following occurs:

- The Model or Model Variants block specifications are the same as they were before.
- The Model or Model Variants block selects a variant according to the current base workspace variables and conditions.

Parameterizing Model Variants

You can parameterize any or all variants of the Model Variants block. You can parameterize some variants but choose not to parameterize others. You can also parameterize different variants differently from one another.

To parameterize a variant (referenced model), of a Model Variants block, specify the necessary values in the **Model parameters** section using the **Model argument values** field. The values are the same as if the model were an ordinary referenced model and no variants existed. For more information, see "Parameterizing Model References" on page 5-40.

Model Variants Block Limitations

- A Model Variants block can log only those signals that the referenced model specifies as logged. To enable logging:

  1 Right-click the Model Variants block.

  2 From the menu, select **Log Referenced Signals**.

  3 In the dialog box that opens, select **Log signals as specified by the referenced model**.

  To enable logging programmatically, use the `DefaultDataLogging` parameter.

- During model compilation, evaluation of variant objects occur before the model `InitFcn` callback is called. Therefore, do not modify the condition of the variant object in the `InitFcn` callback.
- A Model Variants block and its referenced models must satisfy all the requirements listed in "Simulink Model Referencing Limitations" on page 5-73.

Model Variants Demo

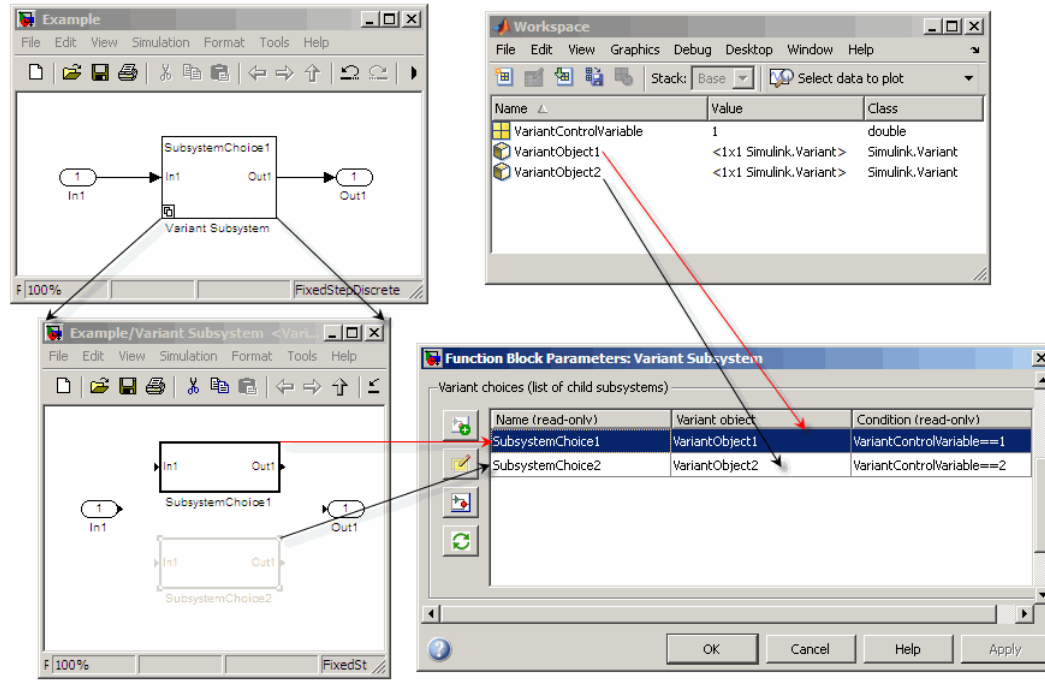
To see a demo that shows how to define a variant model in Simulink , open the MATLAB Help browser and run: `Simulink > Demos > Modeling Features > Model Reference > Model Reference Variants`.

Using the Variant Subsystem Block

In this section...

Variant Subsystem Block Overview

A variant subsystem provides multiple implementations for a subsystem where only one implementation is active during simulation. You can programmatically swap out the active implementation with another implementation without modifying the model. The figure below gives an overview of a Variant Subsystem block implementation.



A Variant Subsystem block consists of multiple subsystems such that:

- Each subsystem has a variant object associated with it.
- The subsystem whose variant object condition is `true` becomes the active variant.
- A Variant Subsystem block can have only one active variant.
- The active variant is the subsystem used for simulation.

The specifications of the Variant Subsystem block parameters dialog box must include at least:

- The name of a variant object, in the **Variant object** column of the **Variant choices** table.
- The variant object must have a conditional expression that evaluates to `true` or `false`.

- Only one variant object can evaluate to `true`.

Instructions for configuring a variant subsystem are in "Example: Implementing a Variant Subsystem Block" on page 7-21.

Variant Subsystem Requirements

A Variant Subsystem block must meet the following requirements:

- The Inport, Outport, and Connection Port blocks in the Variant Subsystem block must be identical to the corresponding inports and outports of its child subsystems.
- Inside the Variant Subsystem block diagram, you cannot create any lines connecting blocks.

You can nest Variant Subsystem blocks to any level. The hierarchy resulting from nesting must satisfy all applicable requirements and limitations when you compile the model or generate code for it.

Additional requirements and limitations that apply to only code generation appear in "Generating Code for Variant Systems".

Example of a Variant Subsystem Block

The example model, `AutoSSVar.mdl`, provides an implementation of the following application:

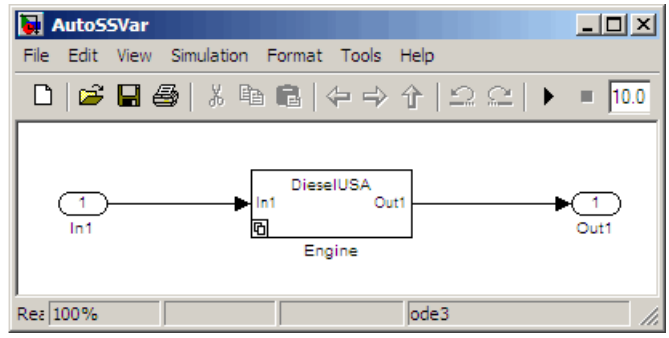
- An automobile that can use either a diesel or a gasoline engine
- The engine must meet either the European or American (USA) emission standard

The example model, `AutoSSVar`, implements the application using a Variant Subsystem block, named `Engine`. The `Engine` block consists of a set of four subsystems. Each subsystem represents one permutation of engine fuel and emission standards. To open `AutoSSVar`, do one of the following:

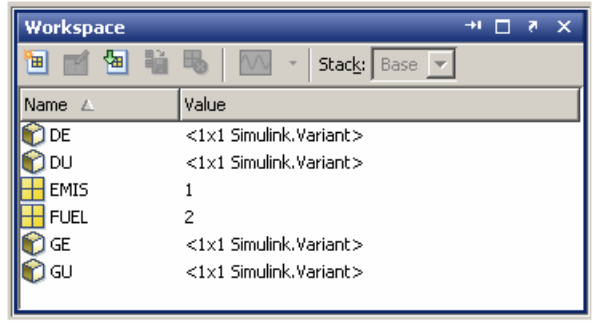
- Click `AutoSSVar.mdl`
- In the MATLAB command window, execute:

```
addpath([docroot '/toolbox/simulink/ug/examples/variants/mdlref/']);
open('AutoSSVar.mdl');
```

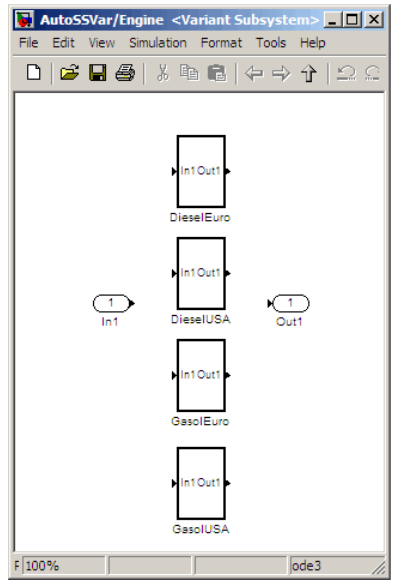
The example model opens



- An icon  appears in the lower-left corner to indicate that the block uses variants.
- The name of the variant that was active the last time the model was saved appears at the top of the block.
- When the active variant is changed and you call an **Update Diagram**, the variant block name changes.
- When you open the example model, a callback function loads a MAT file that populates the base workspace with the variables and objects that the model uses. The base workspace contains the variant control variables and variant objects:



Double-click the Variant Model block, `Engine`, to view the child subsystems.



Notice that there are no connections in the subsystem diagram for a Variant Subsystem block. The only blocks allowed in the Variant Subsystem block diagram are Inport, Outport, and Subsystem blocks. If you are generating code for a Variant Subsystem block, see "Restrictions on Code Generation of a Variant Subsystem" in the Real-Time Workshop Embedded Coder documentation.

Example: Implementing a Variant Subsystem Block

Create the Example Model Containing a Variant Subsystem Block

This section illustrates how to create the example model, `AutoSSVar.mdl`. You can apply the procedures to your own model, or you can use this section as a tutorial for `AutoSSVar.mdl`.

1 If you are creating your own model, close `AutoSSVar` and clear your workspace. Open a new model and name it `SubSysVar.mdl`.

2 From the Simulink Library Browser, add the following blocks:

- **Simulink > Commonly Used Blocks > Inport block**
- **Simulink > Commonly Used Blocks > Outport block**
- **Simulink > Ports and Subsystems > Variant Subsystem block**

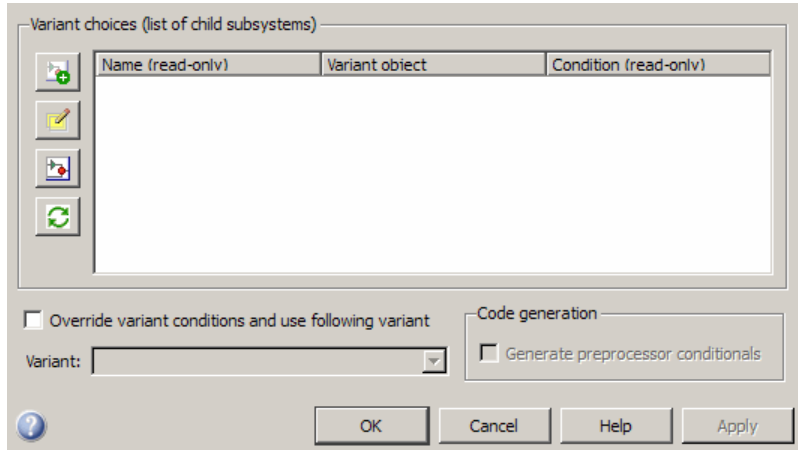
Name the Variant Subsystem block, `Engine`.

3 Save the model in a writable working folder.

Configuring the Variant Subsystem Block

To configure your variant subsystem, do the following:

1 Right-click the Variant Subsystem block, `Engine`, and select **Subsystem Parameters** or from the Model diagram window, select **Edit > Subsystem Parameters**. The Variant Subsystem block parameters dialog box opens.

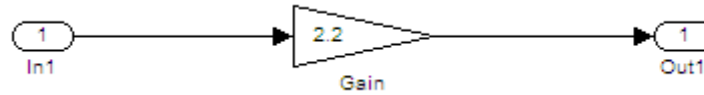


2 Create a subsystem choice in the Variant Subsystem block. In the **Variant choices** table, click the **Create and add a new subsystem choice** button  . A new variant choice appears in the table and a new Subsystem block appears in the Variant Subsystem block diagram window. Configure the subsystem as follows:

a Name the subsystem `DieselEuro`.

b Open the Subsystem block parameter dialog and select the **Treat as atomic unit** parameter.

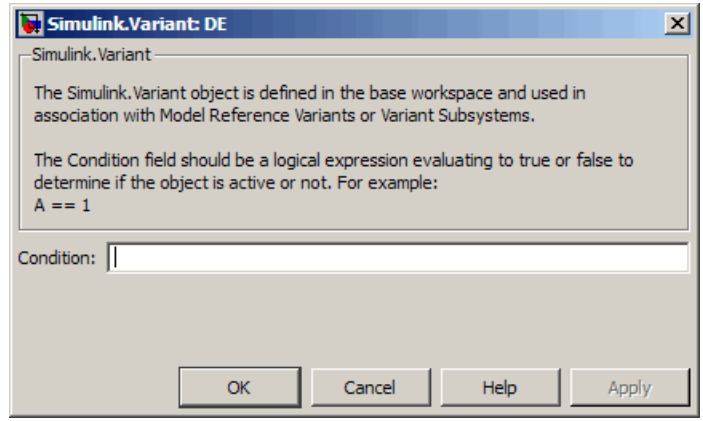
c Double-click the subsystem and create it as follows



d Specify the **Gain** as `2.2`.

3 In the **Variant choices** table in the Variant Subsystem parameter dialog box, double-click the **Variant object** field in the row of the subsystem you just configured. Specify the name for the variant object, for example, for `DieselEuro` the variant object is `DE`.

4 Click the **Create/Edit selected variant object** button  . The Simulink.Variant parameter dialog opens.

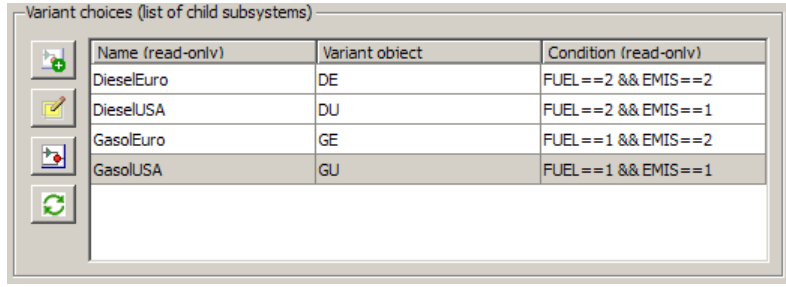


5 Specify the **Condition** for variant object, DE, as `FUEL==2 && EMIS==2`. Click **Apply** and **OK**. The **Variant choices** table is updated with the new variant object, which is now associated with the `DieselEuro`. Simulink also created the variant object as a `Simulink.Variant` object in the base workspace. If you use a variant control variable in the Condition expression, you must create the variant control variables in the base workspace.

6 Repeat Steps 2–5 for the remaining subsystems in the `Engine` block with the following specification:

Subsystem Name	Gain Value	Variant Object	Variant Condition
`DieselUSA`	2.1	`DU`	`FUEL==2 && EMIS==1`
`GasolEuro`	1.2	`GE`	`FUEL==1 && EMIS==2`
`GasolUSA`	1.1	`GU`	`FUEL==1 && EMIS==1`

The `Engine` block parameter dialog box now looks like this:



See "Modifying Variant Subsystem Specifications" on page 7-25 for information about the other buttons on the left side of the dialog.

7 Click **Apply** or **OK**.

8 Connect the Variant Subsystem block, `Engine`, to the Inport and Outport blocks (you can do this at any time after the first subsystem specification exists).

Create and Specify the Variant Control Variables

At the MATLAB command line or in the base workspace, create the variant control variables as in "Variant Control Variable Implementation" on page 7-34. Depending on the values of `EMIS` and `FUEL`, you can see which variant is the active variant.

Variant Control Variables	Variant Object	Active Variant (Subsystem Block)
FUEL=1 and EMIS=1	GU	GasolUSA
FUEL=1 and EMIS=2	GE	GasolEuro
FUEL=2 and EMIS=1	DU	DieselUSA
FUEL=2 and EMIS=2	DE	DieselEuro

In the base workspace or at the MATLAB command line, assign `FUEL = 2` and `EMIS = 1`. The variant object that evaluates to `true` is `DU`. Variant object `DU` is associated with subsystem, `DieselUSA`. Therefore, the model `SubSysVar` uses `DieselUSA` as the active subsystem during simulation. The completed model `SubSysVar.mdl` now looks like `AutoSSVar.mdl`.

Simulate the Model

Make the MATLAB command window visible so that you can see the messages it displays, then simulate the model `SubSysVar`. Because `FUEL = 2` and `EMIS = 1`, MATLAB displays:

```
Using variant subsystem: DieselUSA
```

Save Variant Components

Variant control variables and variant objects exist in the base workspace. If you want to reload variant control variables or variant objects with your model, you must save them to a MAT-file. For more information, see "Exporting to MAT-Files".

Further Topics for Variant Subsystem Specifications

- "Modifying Variant Subsystem Specifications" on page 7-25
- "Override Variant Conditions" on page 7-32
- "Code Generation of Variants" on page 7-37

Modifying Variant Subsystem Specifications

- You can create and modify variant control variables at the MATLAB Command Window or in the base workspace of the Model Explorer.

- You can create and modify variant objects before and after simulations at the MATLAB Command Window, in the base workspace of the Model Explorer, or in the Variant Subsystem block parameter dialog box.
- You can make a child subsystem inactive in the Variant Subsystem block parameter dialog box, by commenting out the variant object in the **Variant choices** table.

The following table describes the functionality of the buttons on the **Variant choices** table that you use to modify the variant specifications of a Variant Subsystem block.

To...	Click...
Create and add a new subsystem choice: Place a new subsystem choice in the table and creates a new subsystem block in the Variant Subsystem block diagram.	
Create/Edit selected variant object:Create a Simulink.Variant object in the base workspace and opens the Simulink.Variant object parameter dialog box to specify the variant **Condition**.	
Open selected subsystem choice: Open the Subsystem block diagram for the selected row in the **Variant choices** table.	
Refresh dialog information from Variant Subsystem block contents: Update the **Variant choices** table according to the Subsystem block's configuration and values of the variant object in the base workspace.	

Create a New Variant for a Variant Subsystem in the Variant Choices Table

1. Click the **Create and Add a New Subsystem Choice** button. A new row appears in the table and a new Subsystem block is added to the Variant Subsystem block diagram.
2. Double-click the new Subsystem block and create and configure the subsystem.

3 Follow the instructions for “Create a Variant Object in the Variant Choices Table” on page 7-27 to associate a variant object with the new subsystem choice.

Create a Variant Object in the Variant Choices Table

1 In the **Variant choices** table, select the row of the variant object to create.

2 To modify the name of the variant object, type the name, and press **Enter**.

3 With the row selected, click the **Create/Edit variant object** button. A new `Simulink.Variant` object is created in the base workspace, with the name that you specified, and the Simulink.Variant parameter dialog box opens.

4 Specify the **Condition** for the variant object.

5 In the Simulink.Variant parameter dialog box, click **Apply** and **OK** .

6 In the Variant Subsystem block parameter dialog box, click **Apply** and **OK**.

Edit the Selected Variant Object in the Variant Choices Table

1 In the Variant choices table, select the row of the variant object to modify.

2 Click the **Create/Edit variant object** button. The Simulink.Variant parameter dialog opens.

3 Specify the **Condition** for the variant object.

4 In the Simulink.Variant parameter dialog box, click **Apply** and **OK**.

5 In the Variant Subsystem block parameter dialog box, click **Apply** and **OK**.

Comment Out a Child Subsystem in the Variant Choices Table

To ignore a subsystem for simulation and code generation, you can comment out the variant object in the Variant Choices table.

1 In the Variant choices table, double-click the name of the variant object.

2 Add a '%' to the beginning of the variant object name.

3 Click **Apply** and **OK**.

Variant Subsystem Demo

To see a demo that shows how to define a variant subsystem in Simulink, open the MATLAB Help browser and run: `Simulink > Demos > Modeling Features > Subsystems > Variant Subsystems`.

Variant Objects

What is a Variant Object?

A variant object is an instance of the Simulink.Variant class that you define in the base workspace. The variant object can have any unique legal name. The value of the variant object specifies a variant condition.

Each variant object corresponds to a different simulation environment. When compiling the model, Simulink tests the variant condition specified by each variant object. The variant object whose variant condition is `true` designates the active variant. The active variant determines which variant is used during simulation. You must organize the variant objects for a Variant Model or a Variant Subsystem such that when the model is compiled only one variant condition is true based on the current base workspace values.

The example model, `AutoMRVar.mdl`, uses four variant objects, one for each of the four environments defined by the permutations of fuel and emission standards. The variant conditions and the objects that contain them are:

Variant Object	Variant Condition
`GU`	`(FUEL==1 && EMIS==1)`
`GE`	`(FUEL==1 && EMIS==2)`
`DU`	`(FUEL==2 && EMIS==1)`
`DE`	`(FUEL==2 && EMIS==2)`

For example, in the base workspace, if `FUEL=2` (Diesel), and `EMIS=1` (USA), the third variant object `DU` is `true`, and the rest are `false`. Techniques for defining variant objects are described in "Variant Object Implementation" on page 7-30.

Note You cannot use the same variant object more than once in the same variant block, because a conflict occurs when that variant condition is `true`. The same type of conflict occurs in a variant block where two different variant objects both evaluate to `true`. For more information, see "Variant Object Reuse" on page 7-31.

Variant Object Implementation

There are three techniques for defining variant objects for your applications. Choose the technique that compliments your workflow.

- **In the Block parameters dialog box:** For either the Model Variants block or the Variant Subsystem block, in the **Variant choices** table of the parameters dialog box:

  1. Select the row for a variant choice. Type in the name of the variant object, for example, `DU`.
  2. Click the **Create/Edit selected variant** button  to create a variant object for the selected variant choice. The Simulink.Variant parameter dialog box opens.
  3. Specify the **Condition** for the variant object, for example, `FUEL=2 && EMIS==1`.
  4. Click **Apply** and **OK**.

  The variant object is created in the base workspace.

- **In the Model Explorer:**

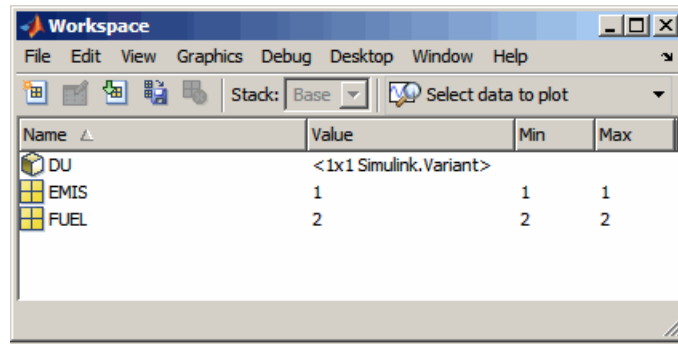
  1. Select the `Base Workspace`.
  2. Select **Add > Simulink.Variant**.

     A new variant object named `Variant` appears in the base workspace.
  3. Click the new variant object and change its name. For example, `DU`.
  4. In the right pane, specify the Condition of the variant object. For example, for `DU`, enter `FUEL==2 && EMIS==1`. *Do not* surround the condition with parentheses or single quotes. (Only the MATLAB API requires parentheses or single quotes.)

- **In the MATLAB Command Window:** Enter (or paste from this page):

```
DU=Simulink.Variant('FUEL==2 && EMIS==1')
```

Each technique results in the following in the base workspace.



Variant Object Reuse

For simplicity, the example models, `AutoMRVar` and `AutoSSVar`, show only one variant block. A variant block refers to a Model Variants block or a Variant Subsystem block.

Some applications have multiple variant blocks that might reuse some of the same variant objects associated with their variants (referenced models or subsystems). For example, a model or subsystem of an automobile might include many capabilities that change depending on the applicable fuel and emission standards. To meet those different requirements using variants, you can use the same variant object in multiple variant blocks. To do this, associate the variant object with the same, or a different, variant in each of the variant blocks. The variant blocks change their selected variants in synchrony as variant control variable values change. The separate uses of the variant object do not affect one another.

Other applications might associate multiple variant objects to one variant in a Model Variants block. To do this, you can assign each of the variant objects to a different parameterization or execution mode of the referenced model variant. The separate uses of the referenced model do not affect one another.

Reusing variant objects, subsystems and referenced models allows you to globally reconfigure a model hierarchy to suit different environments by doing nothing more than changing variant control variable values. No matter how many simulation environments you define, selecting an environment requires only setting variable or parameter values appropriately in the base workspace.

Variant Condition

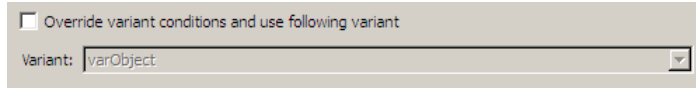
A variant condition is the value of the variant object. It is a Boolean expression that can include:

- MATLAB variables defined in the base workspace, for example, variant control variables.
- Simulink parameter objects defined in the base workspace
- scalar variables
- enumerated values
- operators ==, !=, &&, ||, ~
- parantheses for grouping

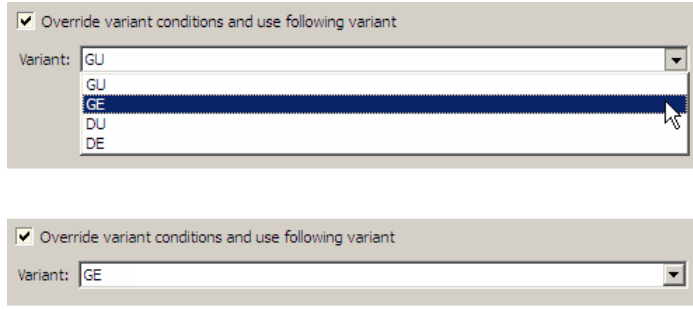
Note You can define the variant condition using a Simulink.Parameter object of enumerated type. Doing so provides meaningful names and improves the readability of the conditions.

Override Variant Conditions

The bottom left portion of the Model Variants and Variant Subsystem block parameters dialog boxes provide the "Override variant conditions and use following variant" parameter, which allows you to specify one variant as the active variant.



1. Select the parameter **Override variant conditions and use following variant**. The "Variant" parameter becomes enabled.
2. Click the **Variant** drop-down list and select a variant object from the list.



3 After you make the change, click **Apply** or **OK** after you make the change. The variant object that you specified becomes the active variant, overriding all other specifications that determine which variant is active. The variant remains active until you either select a different **Variant** from the drop-down list, or clear **Override variant conditions and use following variant**.

Variant Control Variable

A variant control variable used in simulation can be a MATLAB variable, or a `Simulink.Parameter` object that resides in the base workspace. You can define variant control variables in the MATLAB Command Window or the Model Explorer. You use variant control variables to specify the condition of a variant object. Before compiling or simulating, you set the variant control variables to values that specify the environment in which you want to simulate.

The example model, `AutoMRVar.mdl`, uses two variant control variables: `FUEL` and `EMIS`. The values for the variables in the example and the (arbitrarily assigned) meanings of those values are in the following table.

Variant Control Variable	Value	Meaning
`FUEL`	1	gasoline
	2	diesel
`EMIS`	1	USA
	2	European

Techniques for defining variant control variables are described in "Variant Control Variable Implementation" on page 7-34.

A variant control variable for code generation must be a Simulink parameter that meets the requirements described in "Generating Code for Variant Systems".

Variant Control Variable Implementation

At the MATLAB Command Window or in the Model Explorer, create variant control variables:

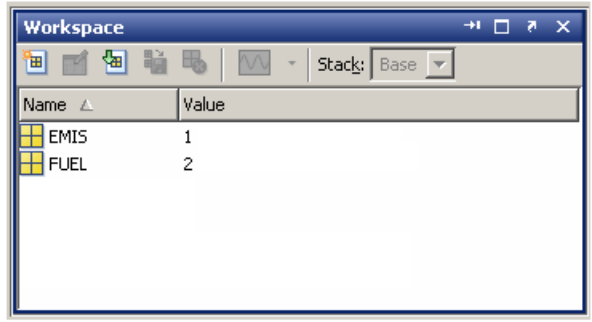
- **In the MATLAB Command Window**: Enter (or paste from this page):

```
EMIS = 1
FUEL = 2
```

- **In the Model Explorer:**

  1. Select the `Base Workspace`.
  2. Select **Add > MATLAB Variable**.
  3. Name the variable and specify its value.

Each technique results in the following variant control variables in the base workspace.



See also "Using Enumerated Types for Variant Control Variable Values" on page 7-35.

Using Enumerated Types for Variant Control Variable Values

You can use enumerated types to give meaningful names to the integers that you use as values of variant control variables. For more information about defining and using enumerated types, see Chapter 26, "Enumerations and Modeling". For example, suppose you defined the following enumerated class, whose elements represent vehicle properties:

```
classdef(Enumeration) VarParams < Simulink.IntEnumType
  enumeration
    gasoline(1)
    diesel(2)
    USA(1)
    European(2)
  end
end
```

With the class `VarParams` defined, you can use meaningful names to specify variant control variables and variant conditions. For example, you can substitute names for the integers for variant control variables `EMIS` and `FUEL`.

```
EMIS = VarParams.USA
FUEL = VarParams.diesel
```

Using the techniques described in "Variant Objects" on page 7-29, the variant objects are:

```
GU=Simulink.Variant('FUEL==VarParams.gasoline && EMIS==VarParams.USA')
GE=Simulink.Variant('FUEL==VarParams.gasoline && EMIS==VarParams.European')
DU=Simulink.Variant('FUEL==VarParams.diesel && EMIS==VarParams.USA')
DE=Simulink.Variant('FUEL==VarParams.diesel && EMIS==VarParams.European')
```

Specifying meaningful names rather than integers as the values of variant control variables facilitates creating complex variant specifications. It also clarifies the generated code, which contains the names of the values rather than integers.

Active Variant

What is an Active Variant?

The active variant is the variant used when simulating your model. An active variant can be either a referenced model of a Model Variants block or a subsystem of a Variant Subsystem block. The active variant is determined by which variant object condition evaluates to `true` at compile time.

Select the Active Variant for Simulation

The conditions of the variant objects determine which variant is the active variant. If you defined the variant object conditions using variant control variables defined in the base workspace, then you can simply modify the values of the variant control variables to select the active variant.

Another method for selecting the active variant is to override the variant conditions and manually select one active variant. For more information, see “Override Variant Conditions” on page 7-32.

Code Generation of Variants

The Real-Time Workshop software only generates code for the active variant.

The Real-Time Workshop Embedded Coder software generates code for only the active variant when **Override variant conditions and use following variant** is selected. The Real-Time Workshop Embedded Coder software can also generate code for all specified variants of a variant block. The generated code for each variant is surrounded by C preprocessor conditionals, `#if`, `#elif`, and `#endif`. Therefore, selection of the active variant occurs at C compile time and preprocessor conditionals determine which sections of the code to execute. For complete information about generating code for variants, see “Generating Code for Variant Systems” in the Real-Time Workshop Embedded Coder documentation.

Reference

In this section...

Custom Storage Classes

Reference information for Simulink classes used in implementing variants:

- Simulink.Parameter for variant control variables
- Simulink.Variant for variant objects

Blocks

Reference information for blocks used in implementing variants:

- Model Variants block
- Variant Subsystem block

8

Exploring, Searching, and Browsing Models

The Model Explorer: Overview

In this section...

Introduction to the Model Explorer

Use the Model Explorer to quickly view, modify, and add elements of Simulink models, Stateflow charts, and workspace variables. The Model Explorer provides several ways for you to focus on specific elements (for example, blocks, signals, and properties) without your having to navigate through the model diagram or chart.

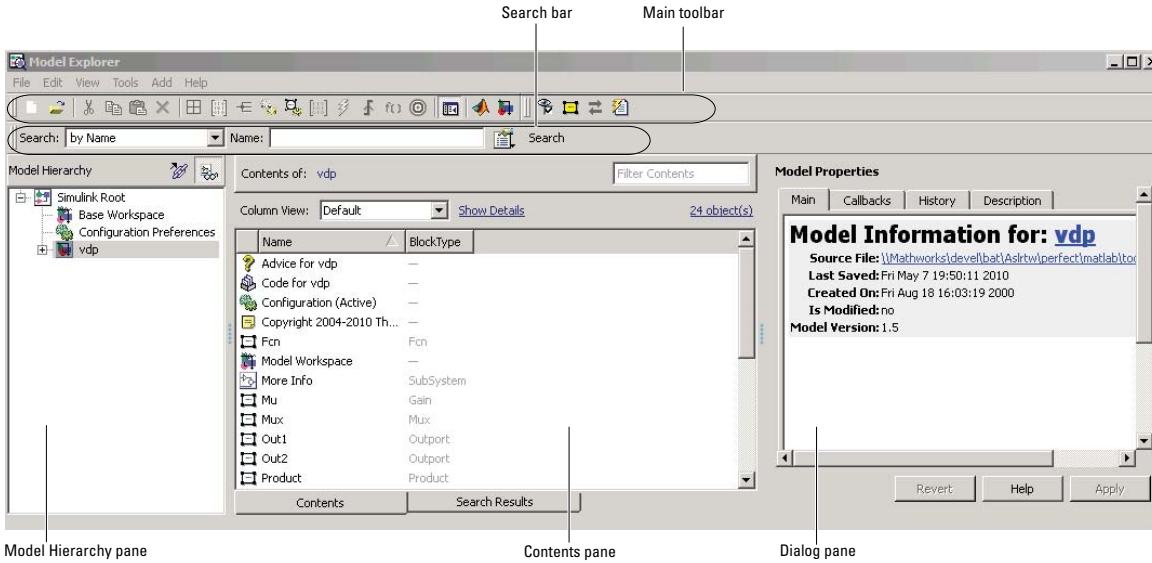
Opening the Model Explorer

To open the Model Explorer, use one of these approaches:

- From the Simulink model editor **View** menu, select **Model Explorer** or select the Model Explorer icon  from the toolbar.
- In an open model in the Simulink model editor, right-click a block and from the context menu, select **Explore**.
- In an open Stateflow chart, right-click in the drawing area and from the context menu, select **Explore**.
- At the MATLAB command line, enter `daexplr`.

Model Explorer Components

By default, the Model Explorer opens with three panes (**Model Hierarchy**, **Contents**, and **Dialog**), a main toolbar, and a search bar.



Component	Purpose	Documentation
Main toolbar	Execute Model Explorer commands	"The Main Toolbar" on page 8-4
Search bar	Perform a search within the context of the selected node in **Model Hierarchy** pane.	"The Model Explorer: Search Bar" on page 8-58
Model Hierarchy pane	Navigate and explore model, chart, and workspace nodes	"The Model Explorer: Model Hierarchy Pane" on page 8-9
Contents pane	Display and modify model or chart objects	"The Model Explorer: Contents Pane" on page 8-18
Dialog pane	View and change the details of object properties	"The Model Explorer: Dialog Pane" on page 8-64

The Main Toolbar

The main toolbar at the top of the Model Explorer provides buttons you click to perform Model Explorer operations. Most of the toolbar buttons perform actions that you can also perform using Model Explorer menu items.

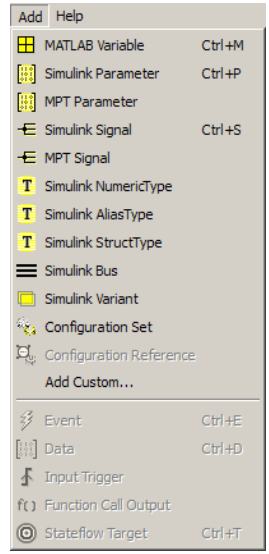
The toolbar buttons in the following table perform actions that you cannot perform using Model Explorer menus:

Button	Usage
	Bring the MATLAB desktop to the front.
	Display the Simulink Library Browser.

If you have Simulink Verification and Validation installed, you can use additional toolbar buttons relating to requirements links.

Adding Objects

You can use the Model Explorer to add many kinds of objects to a model, chart, or workspace. The types of objects that you can add depend on what node you select in the **Model Hierarchy** pane. Use toolbar buttons or the **Add** menu to add objects. The **Add** menu lists the kinds of objects you can add.



Customizing the Model Explorer Interface

You can customize the Model Explorer interface in several ways. This section describes how to show or hide the main toolbar and how to control the font size.

Other ways you can customize the Model Explorer interface include:

- “Marking Nonexistent Properties” on page 8-42
- “Showing and Hiding the Search Bar” on page 8-59
- “Showing and Hiding the Dialog Pane” on page 8-64

Showing and Hiding the Main Toolbar

To show or hide the main toolbar, in the Model Explorer select **View > Toolbars > Main Toolbar**.

Controlling the Font Size

You can change the font size in the Model Explorer panes:

- To increase the font size, press the **Ctrl + Plus Sign** (+).

  Alternatively, from the Model Explorer **View** menu, select **Increase Font Size**.

- To decrease the font size, press the **Ctrl + Minus Sign** (-).

  Alternatively, from the Model Explorer **View** menu, select **Decrease Font Size**.

Note The changes remain in effect for the Model Explorer and in the Simulink dialog boxes across Simulink sessions.

Basic Steps for Using the Model Explorer

Use the Model Explorer to perform a wide range of activities relating to viewing and changing model and chart elements. You can perform activities in any order, using panes in the order you choose. Your actions in one pane often affect other panes.

For example, if you want to edit properties of objects in a model, you might use a general workflow such as:

1. Open a model.
2. Open the Model Explorer.
3. Select the model in the **Model Hierarchy** pane.
4. Control what model information the **Contents** pane displays, and how it displays that information, by using a combination of:
   - The **View > Column View** option to control which property columns to display
   - The **View > Row Filter** option to control which types of objects to display
   - Techniques to directly manipulate column headings
5. Identify model elements with specific values, using the search bar.

6 Edit the values for model elements, in either the **Contents** pane or the **Dialog** pane.

Focusing on Specific Elements of a Model or Chart

As you explore a model or chart, you might want to narrow the contents that you see in the Model Explorer to particular elements of a model or chart. You can use several different techniques. The following table summarizes techniques for controlling what content the Model Explorer displays and how the contents appear.

Technique	When to Use	Documentation
Use the Row Filter option	To focus on, or hide, a specific kind of a model object, such as signals	"Using the Row Filter Option" on page 8-44
Search	To find objects that might not be currently displayed	"The Model Explorer: Search Bar" on page 8-58
Filter contents	To focus on specific objects in the **Contents** pane, based on a search string	"Filtering Contents" on page 8-46

Once you have the general set of data that you are interested in, you can use the following techniques to organize the display of contents.

Technique	When to Use	Documentation
Sort	To quickly organize data for a property in ascending or descending order	"Sorting Column Contents" on page 8-34
Group by property column	To logically group data based on values for a property	"How to Group by a Property Column" on page 8-37

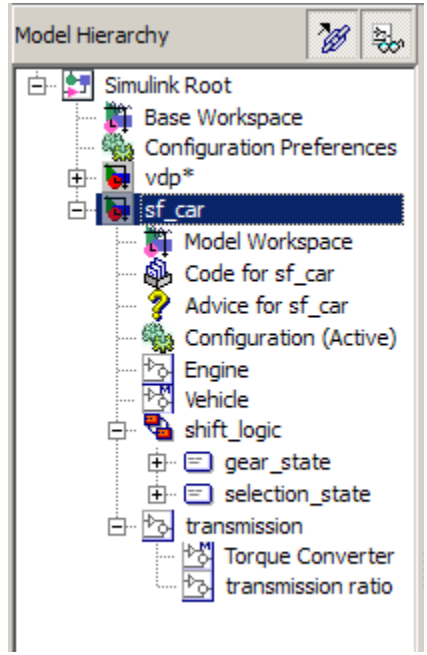
Technique	When to Use	Documentation
Use column views	To display a named subset of property columns to apply to different kinds of nodes in the **Model Hierarchy** pane	"The Model Explorer: Controlling Contents Using Views" on page 8-24
Add, delete, or rearrange property table columns	To customize property columns	"The Model Explorer: Organizing How Data Displays" on page 8-34

The Model Explorer: Model Hierarchy Pane

In this section...

What You Can Do with the Model Hierarchy Pane

The **Model Hierarchy** pane displays a tree-structured view of the Simulink model and Stateflow chart hierarchy. Use the **Model Hierarchy** pane to navigate to the part of the model and chart hierarchy that you want to explore.



Simulink Root

The first node in the hierarchy represents the Simulink root. Expand the root node to display nodes representing the MATLAB workspace, Simulink models, and Stateflow charts that are in the current session.

Base Workspace

This node represents the MATLAB workspace. The MATLAB workspace is the base workspace for Simulink models and Stateflow charts. Variables defined in this workspace are visible to all open models and charts.

For information about exporting and importing workspace variables, see “Exporting Workspace Variables” on page 8-54 and “Importing Workspace Variables” on page 8-56.

Configuration Preferences

To display a Configuration Preferences node in the expanded Simulink Root node, enable the **View > Show Configuration Preferences** option. Selecting this node displays the preferred configuration for new models (see "Setting Up Configuration Sets" on page 9-2). You can change the preferred configuration by editing the displayed settings and using the **Model Configuration Preferences** dialog box to save the settings (see "Model Configuration Preferences Dialog Box" on page 9-12).

Model Nodes

Expanding a model or chart node in the **Model Hierarchy** pane displays nodes representing the following elements, as applicable for the models and charts you have open.

Node	Description
Model workspace	For information about how to use the Model Explorer to work with model workspace variables, see the following sections: • "Finding Variables That Are Used by a Model or Block" on page 8-50 • "Finding Blocks That Use a Specific Variable" on page 8-53 • "Exporting Workspace Variables" on page 8-54 • "Importing Workspace Variables" on page 8-56 • "Using Model Workspaces" on page 3-67
Configuration sets	For information about adding, deleting, saving, and moving configuration sets, see "Setting Up Configuration Sets" on page 9-2.
Top-level subsystems	Expand a node representing a subsystem to display underlying subsystems, if any.

Node	Description
Model blocks	Expand to model blocks to show contents of referenced models (see “Expanding Model References” on page 8-14).
Stateflow charts	• Expand a node representing a Stateflow chart to display the top-level states of the chart. • Expand a node representing a state to display its substates.

Displaying Linked Library Subsystems

By default, the Model Explorer does not display the contents of linked library subsystems in the **Model Hierarchy** pane. To display the contents of linked library subsystems, use one of these approaches:

- At the top of the **Model Hierarchy** pane, click the **Show/Hide Library Links** button () .
- From the **View** menu, select **Show Library Links**.

Library-linked subsystems are visible in the **Contents** pane, regardless of how you configure the **Model Hierarchy** pane.

Note Search does not find elements in linked library or masked subsystems that are not displayed in the **Model Hierarchy** pane.

Displaying Masked Subsystems

By default, the Model Explorer does not display the contents of masked subsystems in the **Model Hierarchy** pane. To display the contents of masked subsystems, use one of these approaches:

- At the top of the **Model Hierarchy** pane, click the **Show/Hide Masked Subsystems** button () .
- From the **View** menu, select **Show Masked Subsystems**.

Masked subsystems are visible in the **Contents** pane, regardless of how you configure the **Model Hierarchy** pane.

Linked Library and Masked Subsystems

For subsystems that are both library-linked and masked, how you set the linked library subsystems and masked subsystems options affects which subsystems appear in the **Model Hierarchy** pane, as described in the following table.

Settings	Subsystems Displayed in the Model Hierarchy Pane
Show Library Links **Hide Masked Subsystems**	Only library-linked, unmasked subsystems
Hide Library Links **Show Masked Subsystems**	Only masked subsystems that are not library-linked subsystems
Show Library Links **Show Masked Subsystems**	All library-linked or masked subsystems

Displaying Node Contents

Select the object in the **Model Hierarchy** pane whose contents you want to display in the **Contents** pane.

Navigating to the Block Diagram

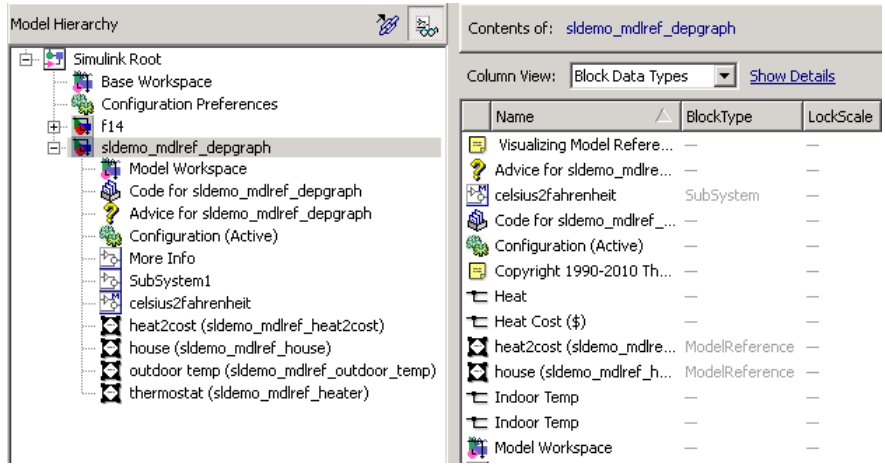
To open a graphical object (for example, a model, subsystem, or chart) in an editor window, right-click the object in the **Model Hierarchy** pane. From the context menu, select **Open**.

Working with Configuration Sets

See “Setting Up Configuration Sets” on page 9-2 for information about using the **Model Hierarchy** pane to perform tasks such as adding, deleting, saving, and moving configuration sets.

Expanding Model References

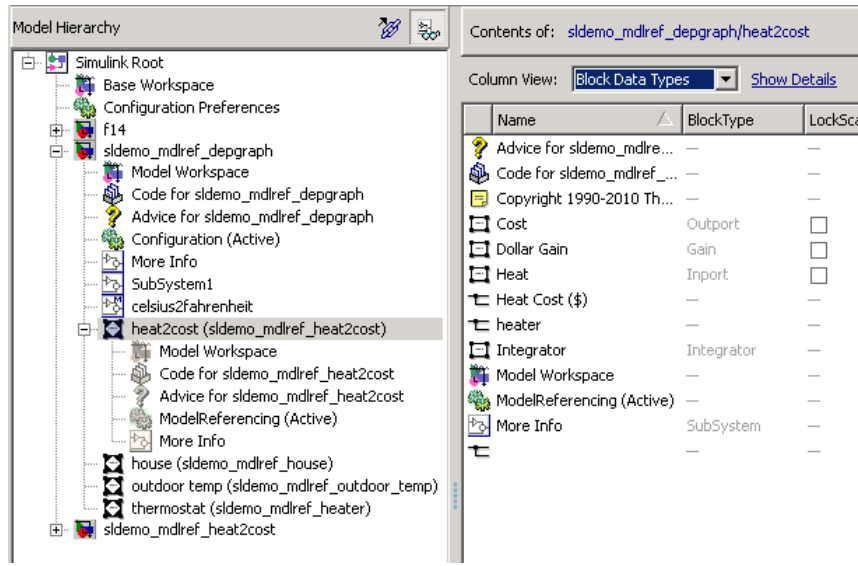
To browse a model that includes Model blocks, you can expand the **Model Hierarchy** pane nodes of the Model blocks. For example, the `sldemo_mdlref_depgraph` demo model includes Model blocks that reference other models. If you open the `sldemo_mdlref_depgraph` model and expand that model node in the **Model Hierarchy** pane, you see that the model contains several Model blocks, including `heat2cost`.



To browse a model referenced by a Model block:

1. Right-click the referenced model node in the **Model Hierarchy** pane.
2. From the context menu, choose **Open Model**.
   - The referenced model opens.
   - The **Model Hierarchy** pane indicates that you can expand the Model block node.
   - The **Model Hierarchy** pane displays a separate expandable node for the referenced model (read-only).
   - The **Contents** pane displays objects corresponding to the Model block node (read-only).

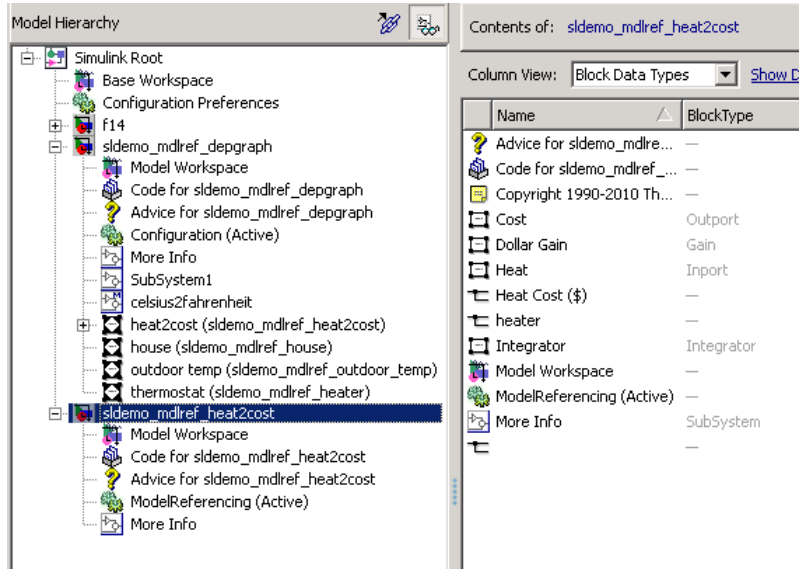
For example, if you right-click the `heat2cost` Model block node and select the **Open Model** option, the **Contents** pane displays the objects corresponding to the `heat2cost` Model block. You can expand the `heat2cost` node.



You can browse the contents of the referenced model, but you cannot edit the model objects that are underneath the Model block.

Editing the Referenced Model

To edit the referenced model, expand the referenced model node in the **Model Hierarchy** pane. For example, expand the `sldemo_mdlref_heat2cost` node:



You can now edit the properties of object in the referenced model.

For information about referenced models, see Chapter 5, “Referencing a Model”.

Cutting, Copying, and Pasting Objects

To cut, copy, and paste workspace objects from one workspace into another workspace:

1. In the **Contents** pane, right-click on the workspace object you want to cut or copy.
2. From the context menu, select **Cut** or **Copy**.
   - You can also cut a workspace object by selecting in the **Contents** pane **Edit > Cut** or by clicking the **Cut** button ( ).
   - You can also copy a workspace object by selecting **Edit > Copy** or by clicking the **Copy** button ( ).

3 If you want to paste the workspace object that you cut or copied, in the **Model Hierarchy** pane, right-click the workspace into which you want to paste the object, and select **Paste**.

   - You can also paste the object by selecting **Edit > Paste** or by clicking the **Paste** button ().

You can also perform cut, copy, and paste operations by selecting an object and performing drag and drop operations.

The Model Explorer: Contents Pane

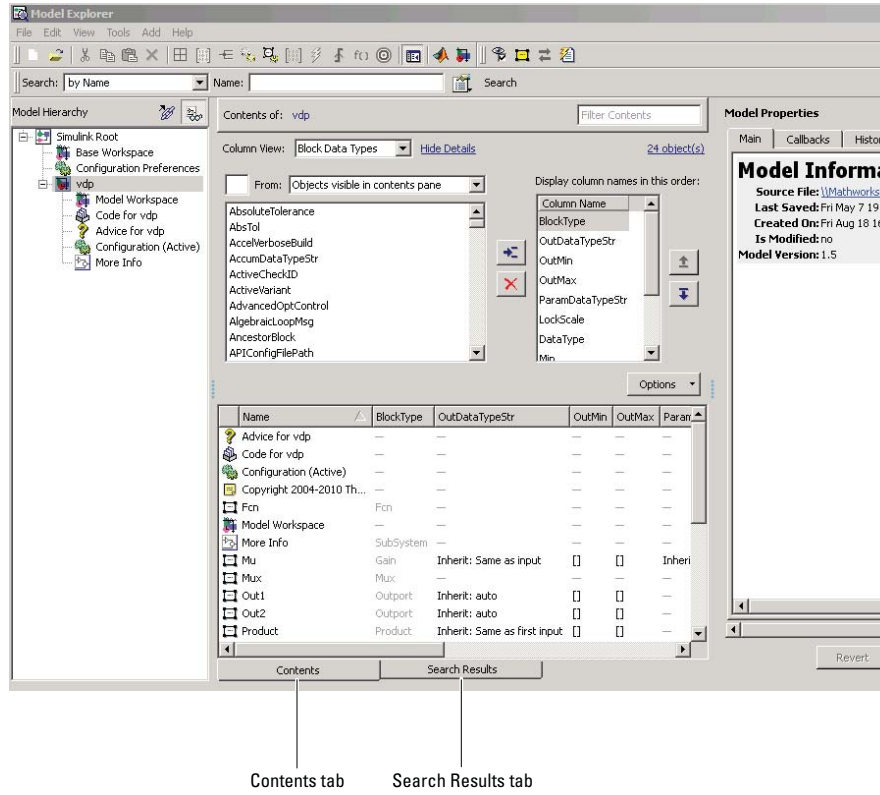
In this section...

Contents Pane Tabs

The **Contents** pane displays one of two tables containing information about models and charts, depending on the tab that you select:

- The **Contents** tab displays an object property table for the node that you select in the **Model Hierarchy** pane.
- The **Search Results** tab displays the search results table (see "The Model Explorer: Search Bar" on page 8-58).

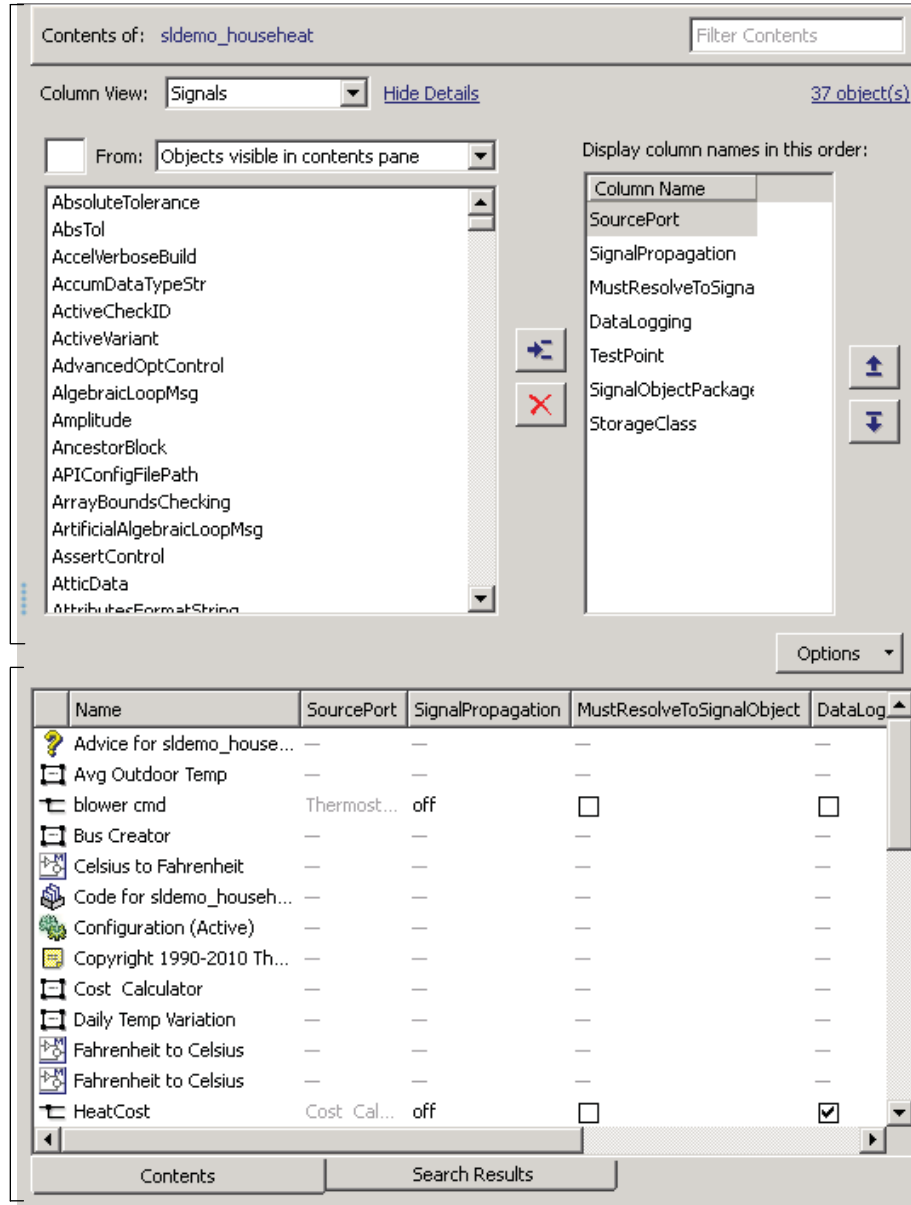
Optionally, you can also open a column view details section in the **Contents** pane. The following graphic shows the **Contents** pane with the column view details section opened.



To open the column view details section, click **Show Details**, at the top of the **Contents** pane.

Column View Details section

Object Property Table section



The **Column view details** section provides an interface for customizing the column view (hidden by default).

The **Object property table** section displays a table of model and chart object data (open by default).

Data Displayed in the Contents Pane

In the object property table section of the **Contents** tab and in the **Search Results** tab:

- Table columns correspond to object properties (for example, `Name` and `BlockType`).
- Table rows correspond to objects (for example, blocks, and states).

The objects and properties displayed in the **Contents** pane depend on:

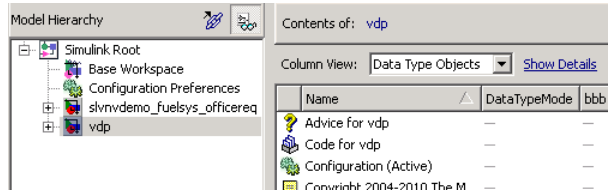
- The column view that you select in the **Contents** pane
- The node that you select in the **Model Hierarchy** pane
- The kind of object (for example, subsystem, chart, or configuration set) that you select in the **Model Hierarchy** pane
- The **View > Row Filter** options that you select

For more information about controlling which objects and properties to display in the **Contents** pane, see:

- "The Model Explorer: Controlling Contents Using Views" on page 8-24
- "The Model Explorer: Organizing How Data Displays" on page 8-34
- "The Model Explorer: Using the Row Filter Option and Filtering Contents" on page 8-44

Link to the Currently Selected Node

The **Contents of** link at the top left side of the **Contents** pane links to the currently selected node in the **Model Hierarchy** pane. In this example, **Contents of** links to the `vdp` model, which is the currently selected node.



Working with the Contents Pane

The following table summarizes the key tasks to control what is displayed in the **Contents**.

Task	Documentation
Control which kinds of objects to display.	"Using the Row Filter Option" on page 8-44
Search within the selected set of objects.	"The Model Explorer: Search Bar" on page 8-58
Specify a set of properties to display based on the kind of node.	"The Model Explorer: Controlling Contents Using Views" on page 8-24
Group data based on unique values in a property column.	"Grouping by a Property" on page 8-35
Manage views (for example, save and export a view).	"Managing Views" on page 8-28
Add, remove, or rearrange columns.	"The Model Explorer: Organizing How Data Displays" on page 8-34
Edit object property values.	"Editing Object Properties" on page 8-22

Editing Object Properties

To open a properties dialog box for an object in the **Model Hierarchy** pane, right-click the object, and from the context menu, select **Properties**. Alternatively, click an object and from the **Edit** menu, select **Properties**.

You can change modifiable properties in the **Contents** pane (for example, a block name) by editing the displayed value. To edit a value, first select the

row that contains the value, and then click the value. An edit control replaces the value (for example, an edit field for text values or a list for a range of values). Use the edit control to change the value of the selected property.

To assign the same property value to multiple objects in the **Contents** pane, select the objects and then change one of the selected objects to have the new property value. An edit control replaces the value with `<edit>`, indicating that you are doing batch editing. The Model Explorer assigns the new property value to the other selected objects, as well.

You can also change property values using the **Dialog** pane. See "The Model Explorer: Dialog Pane" on page 8-64.

The Model Explorer: Controlling Contents Using Views

In this section...

Using Views

What Is a Column View?

A view in the Model Explorer is a named set of properties.

The Model Explorer uses views to specify sets of property columns to display in the **Contents** pane.

For each kind of node in the **Model Hierarchy** pane, certain properties are most relevant for the objects displayed in the **Contents** pane. For example, for a Simulink model node, such as a model or subsystem, some properties that are useful to display include:

- `BlockType` (block type)
- `OutDataTypeStr` (output data type)
- `OutMin` (minimum value for the block output)

Generally, a column view does not contain the total set of properties for all the objects in a node. Specifying a subset of properties to display can streamline the task of exploring and editing model and chart object properties and increase the density of the data displayed in the **Contents** pane.

What You Can Capture in a View

You can use a view to capture the following characteristics of the model information to show in the Model Explorer:

- Properties that you want to display in the **Contents** pane (see "Customizing Views" on page 8-27)

- Layout of the **Contents** pane (for example, grouping by property, the order of property columns, and sorting), as described in "The Model Explorer: Organizing How Data Displays" on page 8-34.

Use Standard Views or Customized Views

You can use views in the following ways:

- Use the standard views shipped with the Model Explorer
- Customize the standard views
- Create your own views

Automatically Applied Views

The first time you open the Model Explorer, the software automatically applies one of the standard views to the node you select in the **Model Hierarchy** pane. The Model Explorer applies a view based on the kind of node you select.

The Model Explorer assigns one of four categories of nodes in the **Model Hierarchy** pane. The Model Explorer initially associates a default view with each node category. The four node categories are:

Node Category	Kinds of Hierarchy Nodes Included	Initial Associated View
Simulink	Models, subsystems, and root level models	`Block Data Types`
Workspace	Base and model workspace objects	`Data Objects`
Stateflow	Stateflow charts and states	`Stateflow`
Other	Objects that do not fit into one of the first three categories; for example, configuration sets	`Default`

The **Column View** field at the top of the **Contents** pane displays the view that the Model Explorer is currently using.

If you select a view. In the **Contents** pane, from the **Column View** list, you can select a different view. If you select a different view, then the Model Explorer associates that view with the category of the current node. For example, suppose the selected node in the **Model Hierarchy** pane is a Simulink model, and the current view is `Data Objects`. If you change the view to `Signals`, then when you select another Simulink model node, the Model Explorer uses the `Signals` view. See "Selecting a View Manually" on page 8-26.

Selecting a View Manually

By default, the Model Explorer automatically applies a view, based on the category of node that you select and the last view used for that node. You can manually select a view from the **Column View** list that better meets your current task.

You can shift from the default mode of having the Model Explorer automatically apply views to a mode in which you must manually select a view to change views.

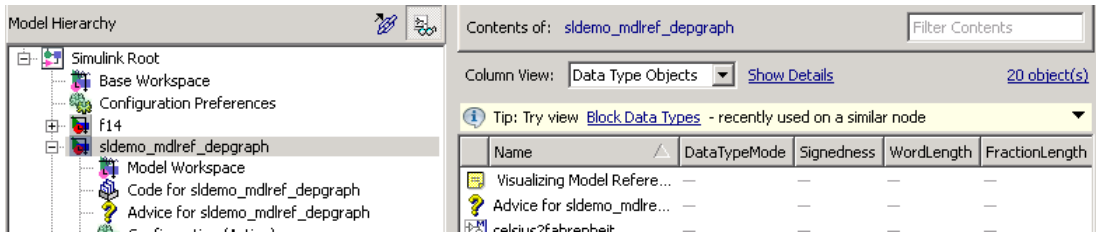
To enable the manual view selection mode:

1. Select **View > Column View > Manage Views**.

   The View Manager dialog box opens.

2. In the View Manager dialog box, click the **Options** button and clear **Change View Automatically**.

In the manual view selection mode, if you switch to a different kind of node in the **Model Hierarchy** pane that has a different view associated with it, the **Contents** pane displays a yellow informational bar suggesting a view to use.



Tip interface. The tip interface appears immediately above the object property table.

The tip does not appear if you use automatic view selection.

To hide the currently displayed tip, from the menu button on the right-hand side of the tip bar, select **Hide This Tip**.

The tip interface displays a link for changing the current view to a suggested view. To choose the suggested view displayed in the tip bar, click the link.

Initially, the suggested view is the default view associated with a node. If you associate a different view with a node category, then the tip suggests the most recently selected view when you select similar nodes.

To change from manual specification of views to automatic specification, from the tip interface, select the down arrow and then the **Change View Automatically** menu item.

Customizing Views

If a standard view does not meet your needs, you can either modify the view or create a new view.

You can customize the object property table represented by the current view in several ways, as described in these sections:

- “Adding Property Columns” on page 8-39
- “Hiding or Removing Property Columns” on page 8-41
- “Changing the Order of Property Columns” on page 8-38

How the Model Explorer Saves Your Customizations

As you modify the object property table, you change the current view definition.

The Model Explorer saves the following changes to the object property table as part of the column view definition:

- Grouping by property
- Sorting in a column
- Changing the order of property columns
- Adding a property column
- Hiding and removing property columns

When you change from one view to another view, the Model Explorer saves any customizations that you have made to the previous view.

For example, suppose you use the `Block Data Types` view and you remove the `LockScale` property column. If you then switch to use the `Data Objects` view, and later use the `Block Data Types` view again, the `Block Data Types` view no longer includes the `LockScale` column that you deleted.

At the end of a Simulink session, the Model Explorer saves the view customizations that you made during that session. When you reopen the Model Explorer, Simulink uses the customized view, reflecting any changes that you made to the view in the previous session.

Managing Views

If a standard view does not meet your needs, you can either modify the view or create a new view. See “Customizing Views” on page 8-27.

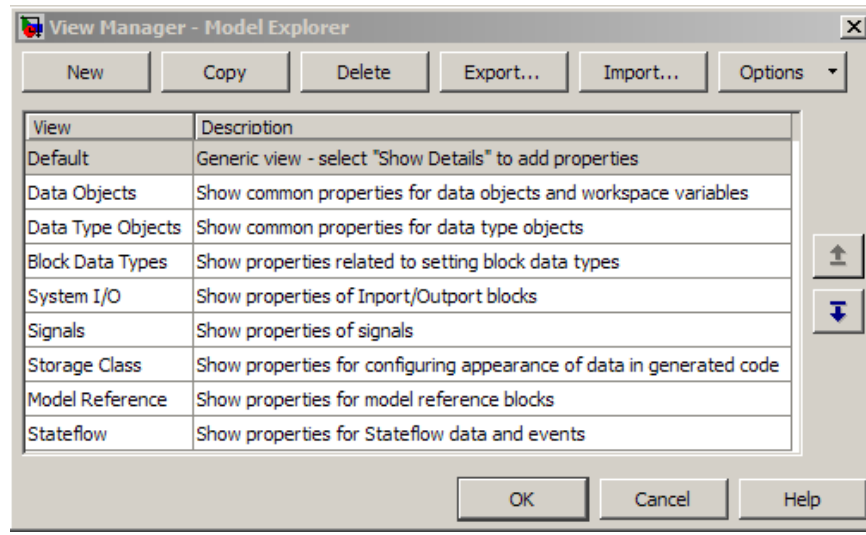
You can manage views (for example, create a new view or export a view) using the View Manager dialog box.

Opening the View Manager Dialog Box

To open the View Manager dialog box, select the **Manage Views** option from either:

- The **View > Column View** menu
- The options listed when you click the **Options** button in the column view details section

The View Manager dialog box displays a list of defined views and provides tools for you to manage views.



You can manage views in several ways, including:

- “Creating a New View” on page 8-30
- “Deleting Views” on page 8-31
- “Reordering Views” on page 8-31
- “Exporting Views” on page 8-31
- “Importing Views” on page 8-32
- “Resetting Views to Factory Settings” on page 8-32

Creating a New View

To create a new view that has a new name, you can use one of these approaches:

- Copy an existing view, rename it, and customize the view.
- Create a completely new view.

After you create a new view, you can customize the view as described in "Customizing Views" on page 8-27.

Copying and renaming an existing view. You can build a new view by copying an existing view, renaming it, and optionally customizing the renamed view. In the View Manager dialog box:

1. Select the view that you want to use as the starting point for your new view.
2. Click the **Copy** button.

   A new row appears at the bottom of the View Manager table of views. The new row contains the name of the view you copied, followed by a number in parentheses. For example, if you copy the `Stateflow` view, the initial name of the copied view is `Stateflow (1)`.

Creating a completely new view. To create a completely view, in the View Manager dialog box, click the **New** button. A new view row appears at the bottom of the View Manager dialog box list of views.

Naming and describing a new view. Once you create a view, you can name the view and provide a description of the view:

1. Double-click `New View` in the left column of the table of views and replace the text with a name for the view.
2. Double-click `Description` in the table and replace the text with a description of the view.
3. Click **OK**.

Deleting Views

To delete a view from the **Column View** list of views:

1. In the View Manager dialog box, select one or more views that you want to remove from the list.
2. Click the **Delete** button or the **Delete** key.
3. Click **OK**.

Deleting a view using the View Manager dialog box permanently deletes that view from the Model Explorer interface.

If you think you or someone else might want to use a view again, consider exporting the view before you delete it (see "Exporting Views" on page 8-31).

Reordering Views

To change the position of a view in the **Column View** list, in the View Manager dialog box:

1. Select one or more views that you wish to move up or down one row in the table of views.
2. Click the up or down arrow buttons to the right of the table of views. Repeat this step until the view appears where you want it to be in the table.
3. Click **OK**.

Exporting Views

To export views that you or others can then import, in the View Manager dialog box:

1. In the View Manager dialog box, select one or more views that you want to export.
2. Click the **Export** button.

   An Export Views dialog box opens, with check marks next to the views that you selected.

3 Click **OK**.

   An Export to File Name dialog box opens.

4 Navigate to the folder to which you want to export the view.

   By default, the Model Explorer exports views to the MATLAB current folder.

5 Specify the file name for the exported view.

   The file format is `.mat`.

6 Click **OK**.

Importing Views

To import view files from another location for use by the Model Explorer:

1 In the View Manager dialog box, click the **Import** button.

   The Select `.mat` File to Import dialog box opens.

2 Navigate to the folder from which you want to import the view.

3 Select the MAT-file containing the view that you want to import and then click **Open**.

   A confirmation dialog box opens. Click **OK** to import the view.

The imported view appears at the bottom of the **Column View** list of views.

The Model Explorer automatically renames the view if a name conflict occurs.

Resetting Views to Factory Settings

You can reset (restore) the original definition of a specific standard view (that is, a view shipped with the Model Explorer) if that view is the current view. To do so, click the **Options** button in the column view details section and select **Reset This View to Factory Settings**.

To reset the factory settings for *all* standard views in one step, in the View Manager dialog box, click the **Options** button and select **Reset All Views to Factory Settings**.

Note When you reset all views, the Model Explorer removes all the custom views you have created. Before you reset views to factory settings, export any views that you will want to use in the future.

The Model Explorer: Organizing How Data Displays

In this section...

Layout Options

You can control how the object property table and **Search Results** pane organize the layout of property information by:

- Sorting column contents
- Grouping by a property
- Changing the order of property columns
- Adding a property column
- Hiding and removing property columns

Sorting Column Contents

To order the contents in ascending order for a column, click the heading of the property column that you want to use to order the objects in the table. A triangle pointing up appears in the column heading. For the property column that determines the current order, to change the order from ascending to descending, or from descending to ascending, click the heading of that column again.

For example, if properties are in ascending order, based on the `Name` property (the default), click the heading of the `Name` column to display objects by name, in descending order.

By default, the **Contents** pane displays its contents in ascending order, based on the name of the object. Objects that have no values in any property columns appear at the end of the object property table.

Note When you group by property, the Model Explorer applies sorting of column contents within each group.

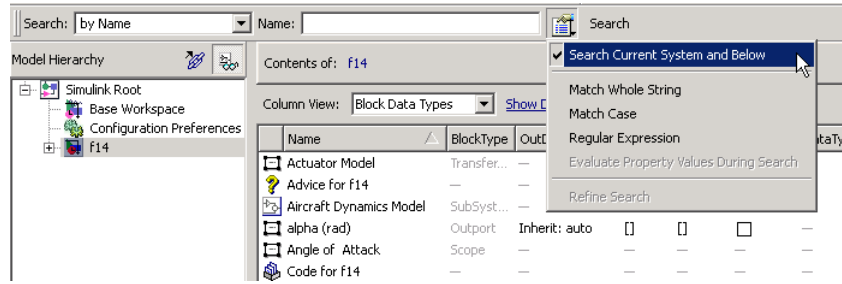
Grouping by a Property

Organizing Contents by Property Values

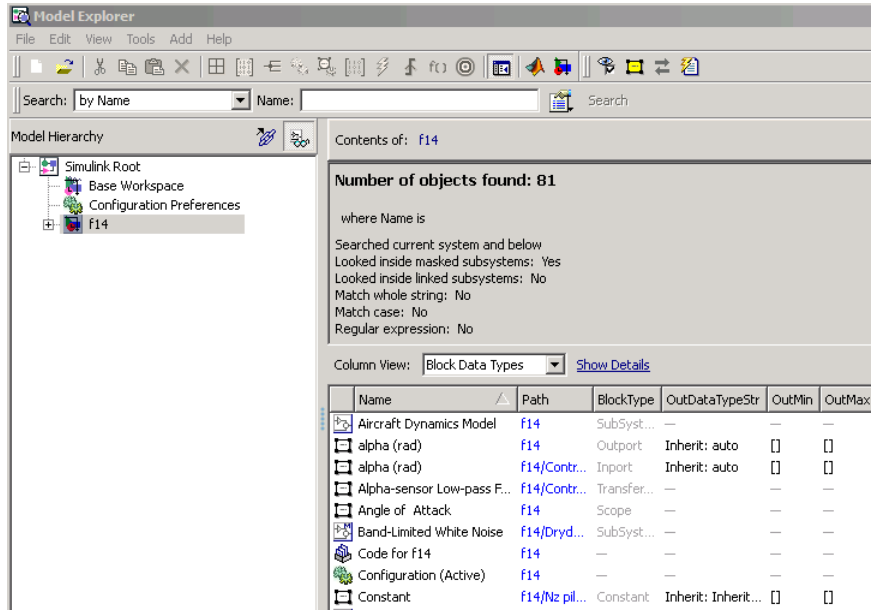
When you are exploring a model, you might want to focus on all objects with the same property value. One technique you can use in Model Explorer to achieve this goal is to group data by a property column.

An example, suppose that you want to organize contents based on the path name. Because path names can be long, grouping by the `Path` property makes it easy to see the whole path, without opening the `Path` property column so wide that you can see only a few other property columns.

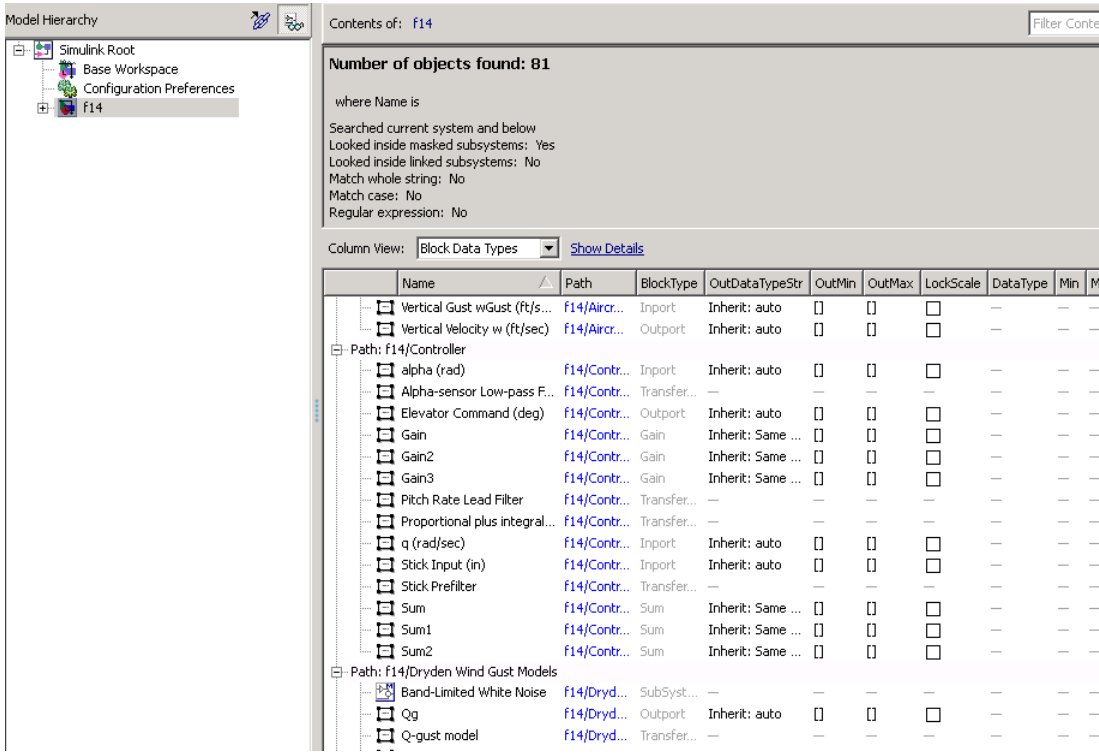
For example, suppose that you want to see all of the blocks in the model. For example, you could perform the following search on the f14 model:



The search results obscure the whole path name for lower-level nodes:



By grouping on the `Path` property column, you can see the whole path for lower-level nodes:



You can also collapse groups to focus on specific portions of a model.

How to Group by a Property Column

To group by a property:

1. In the object property table, right-click the column heading of the property by which you want to group contents.
2. From the context menu, select the **Group By This Column** menu item.

Sorting with Grouped Data

When you group by property, the Model Explorer applies sorting of column contents within each group.

Expanding and Collapsing Grouped Data

By default, Model Explorer displays groups in expanded form. That is, all the objects in each group are visible. You can collapse and expand groups.

- To collapse the contents of a group, click the minus sign icon for that group.
- To expand a group, click the plus sign.
- To collapse or expand all the groups, right-click anywhere in the object property table and select either the **Collapse All Groups** menu item (**Shift+C**) or **Expand All Groups** menu item (**Shift+E**).

Persistence of Grouped Data Settings

If you group by a property, that grouping is saved as part of the view definition.

When you select a different node in the **Model Hierarchy** pane, the contents for the new node are grouped by that same property. However, all groups are expanded, even if you had collapsed all groups before switching nodes.

Grouping Search Results

You can use grouping to organize the **Search Results** pane. The grouping that you apply to the **Search Results** pane also applies to the object property table, if that property is in the table. If the search results include a property that is not in the object property table, and you group on that property, then the Model Explorer removes the grouping setting that was in effect in the object property table.

Changing the Order of Property Columns

Name Column Is Always the First Column

The first column of every object property table is the `Name` property column. You cannot hide, remove, or change the location of the `Name` column.

How to Change the Order of Property Columns

To change the order of property columns in the object property table, use one of these approaches:

- In the object property table, select a column heading and drag it to a new location in the object property table.

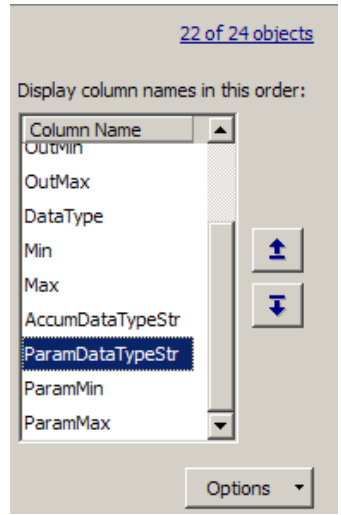
  This approach avoids opening the column view details section and makes it easier to move a column a short distance to the right or left in the table.

- In the column view details section, select one or more property columns and move them up or down in the list, using the arrow buttons to the right of the list.

  This approach allows you to move several property columns in one step, but it moves the selected columns right or left by only one column at a time.

  To move a property column by using the view details interface:

  1 In the **Display column names in this order** list on the right side of the column view details section, select one or more property columns that you want to move.

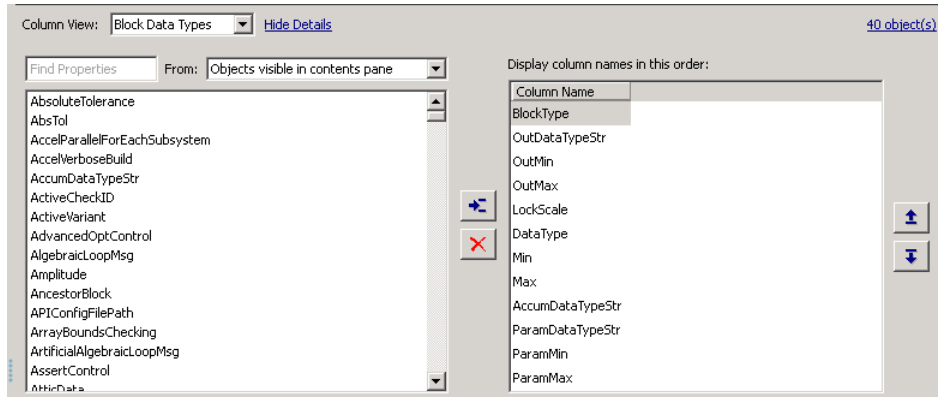


  2 Click the **Move column left in view** button () or the **Move column right in view** button ().

Adding Property Columns

To add property columns to a view:

1 If you do not have the column view details section of the **Contents** pane already open, then at the top of the **Contents** pane, select **Show Details**.



2 In the list of properties on left side of the column view details section, select one or more properties that you want to add.

- The list displays property names in alphabetical order. You can use the **Find Properties** search box in the column view details section to search for properties that contain the text string that you enter. You can specify the scope of the search with the **From** list to the right of the search box.

3 In the list of column names on the right side, select the property column that you want to be to the left of the property columns you insert.

4 Click the **Display property as column in view** button ()

Adding a Path Property Column

The Model Explorer provides a shortcut for adding a `Path` property column to a view. To add a `Path` property column:

1 Right-click the column heading in the object property table to the right of which you want to insert a `Path` column.

2 From the context menu, select **Insert Path**.

Hiding or Removing Property Columns

You can choose between two approaches to hide (remove) a property column from the object property table. Hiding and removing a column both have the same result. You can:

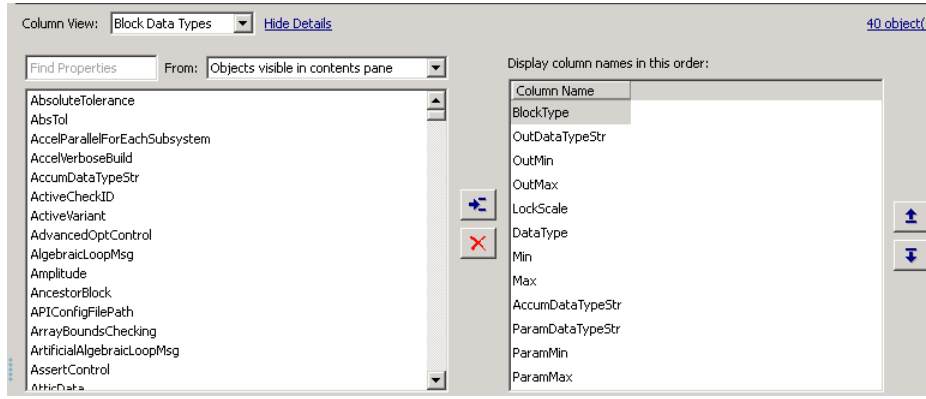
- Hide a column using the context menu for a column heading. This approach avoids needing to open the column view details section.
- Remove a column using the column view details interface. This approach allows you to delete several properties in one step.

Hiding a Column Using the Column Heading Context Menu

1. Right-click the column heading of the column that you want to remove.
2. From the context menu, select **Hide**.

Removing a Column Using the Column View Details Interface

1. If you do not have the column view details section of the **Contents** pane already open, then at the top of the **Contents** pane, select **Show Details**.



2. In the column view details section of the **Contents** pane, in the **Display column names in this order** list, select one or more properties that you want to remove.

3 Click the **Remove column from view** button () or the **Delete** key.

Inserting Recently Hidden or Removed Columns

The Model Explorer maintains a list of columns you hide or remove for each view during a Simulink session.

To add a recently hidden or removed column back into a view:

1 Right-click the column heading of the column to the right of which you want to insert a recently hidden column.

2 From the context menu, select **Insert Recently Hidden Columns**.

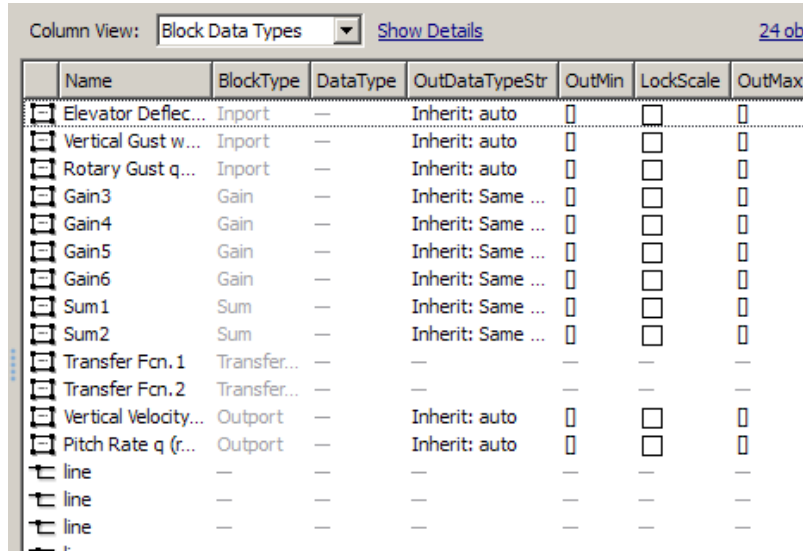
3 Select the column that you want to insert.

See "Hiding or Removing Property Columns" on page 8-41.

Marking Nonexistent Properties

Usually, some of the properties that the **Contents** pane displays do not apply to all the displayed objects (in other words, some objects do not have values set). By default, the Model Explorer displays a dash (–) to mark properties that do not have a value.

If you want the Model Explorer to display a blank (instead of the default dash) in property cells that have no values, clear the **View > Show Nonexistent Properties as "–"** option. The **Contents** pane looks similar to the following graphic:


Column View:
Block Data Types
Show Details
24 obje
Name
BlockType
DataType
OutDataTypeStr
OutMin
LockScale
OutMax
Elevator Deflec...
Inport
Inherit: auto
Vertical Gust w...
Inport
Inherit: auto
Rotary Gust q...
Inport
Inherit: auto
Gain3
Gain
Inherit: Same ...
Gain4
Gain
Inherit: Same ...
Gain5
Gain
Inherit: Same ...
Gain6
Gain
Inherit: Same ...
Sum1
Sum
Inherit: Same ...
Sum2
Sum
Inherit: Same ...
Transfer Fcn.1
Transfer...
Transfer Fcn.2
Transfer...
Vertical Velocity...
Outport
Inherit: auto
Pitch Rate q (r...
Outport
Inherit: auto
line
line
line

The Model Explorer: Using the Row Filter Option and Filtering Contents

In this section...

Controlling the Set of Objects to Display

This section describes two techniques that you can use to control the set of objects that appear in the **Contents** pane:

- Using the Row Filter option
- Filtering contents

For a summary of other techniques to help focus on a set of specific model or chart elements, see "Focusing on Specific Elements of a Model or Chart" on page 8-7.

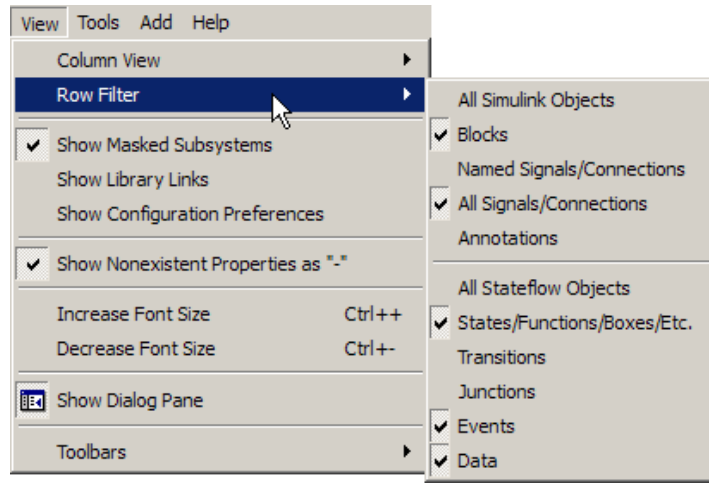
Using the Row Filter Option

You can filter the kinds of objects that the **Contents** pane displays:

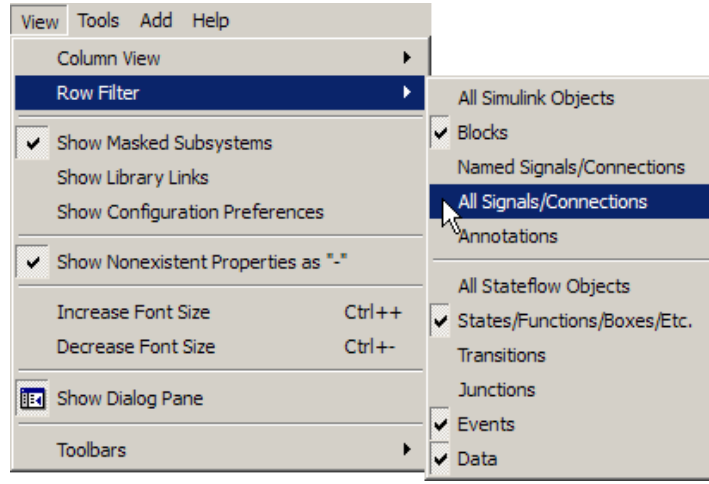
1. In the Model Explorer, select **View > Row Filter**.

   By default, the **Contents** pane displays these kinds of objects for the selected node:

   - Blocks
   - Signals and connections
   - Stateflow states, functions, and boxes
   - Stateflow events
   - Stateflow data

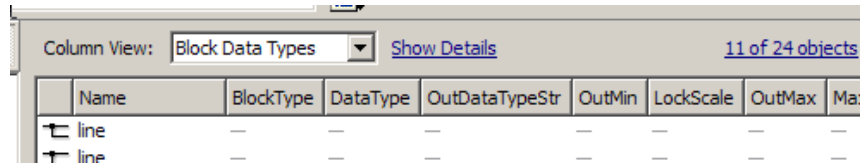


2 Clear the kinds of objects that you do not want to display in the **Contents** pane, or enable any cleared options to display additional kinds of objects. For example, clear the **All Signals/Connections** to prevent the display of signal and connection objects in the **Contents** pane.



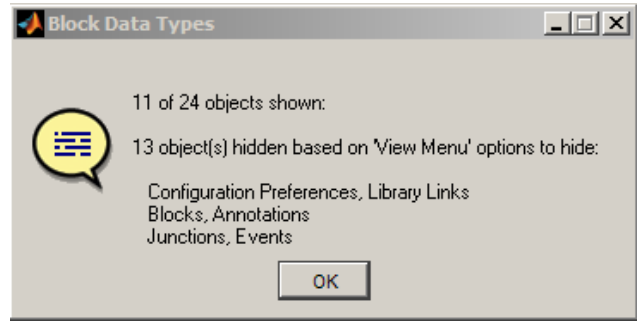
Object Count

The top-right portion of the **Contents** pane includes an object counter, indicating how many objects the **Contents** pane is displaying.



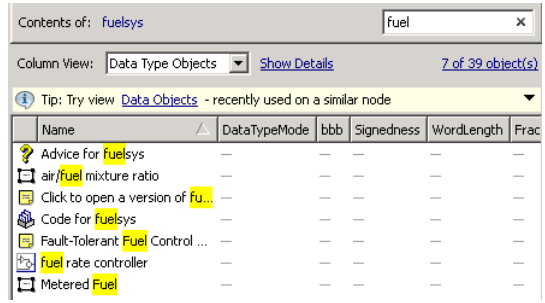
When you use the **Row Filter** option to filter objects, the object count indicator reflects that the **Contents** pane displays a subset of all the model and chart objects.

To view an explanation of the current object count, click the object count link (for example, `11 of 24 objects`). That link displays a pop-up information box:



Filtering Contents

To refine the display of objects that are currently displayed in the **Contents** pane, you can use the **Filter Contents** text box at the top of the **Contents** pane to specify search strings for filtering a subset of objects.



Using the **Filter Contents** text box can help you to find specific objects within the set of objects, based on a particular object name, property value, or property that is of interest to you. For example, if you enter the text string `fuel` in the **Filter Contents** edit box, the Model Explorer displays results similar to those shown above. The results highlight the text string that you specified.

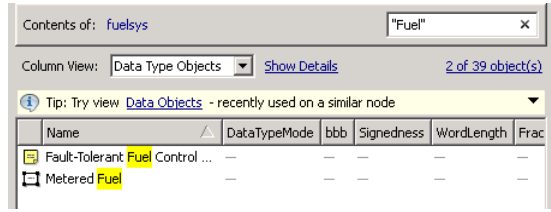
Specifying Filter Text Strings

As you enter text in the **Filter Contents** text box, the Model Explorer performs a dynamic search, displaying results that reflect the text as you enter it.

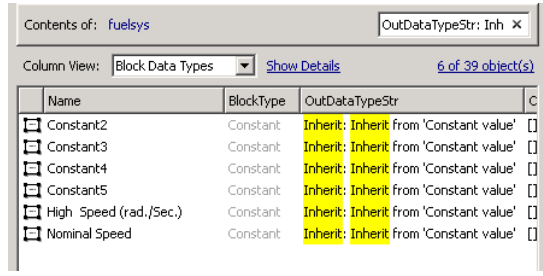
The text strings you enter must be in the format consistent with the guidelines described in the following sections.

Case Sensitivity. By default, the Model Explorer ignores case as it performs the filtering.

To specify that you want the Model Explorer to respect case sensitivity for a text string that you enter, put that text string in quotation marks. For example, if you want to restrict the filtering to display only objects that include the text `Fuel` (with a capital `F`), enter `"Fuel"` (with quotation marks).



Specifying Property Values. To restrict the filtering to apply to values for a specific property, specify the property name followed by a colon (:) and then the value. For example, to filter the contents to display only objects whose `OutDataTypeStr` property has a value that includes `Inherit`, enter `OutDataTypeStr: Inherit` (alternatively, you could put the whole string in quotation marks to enforce case sensitivity):



Wildcards and MATLAB Expressions Not Supported. The Model Explorer does not recognize wildcard characters, such as an asterisk (*), as having any special meaning. For example, if you enter `fuel*` in the **Filter Contents** text box, you get no results, even if several objects contain the text string `fuel`.

Also, if you specify a MATLAB expression, in the **Filter Contents** text box, the Model Explorer interprets that string as literal text, not as a MATLAB expression.

Clearing the Filtered Contents

To redisplay the object property table as it appeared before you filtered the contents, click the **X** in the **Filter Contents** text box.

Filtering Removes Grouping

If you have set up grouping on a column, then when you filtering contents, the Model Explorer does not retain that grouping.

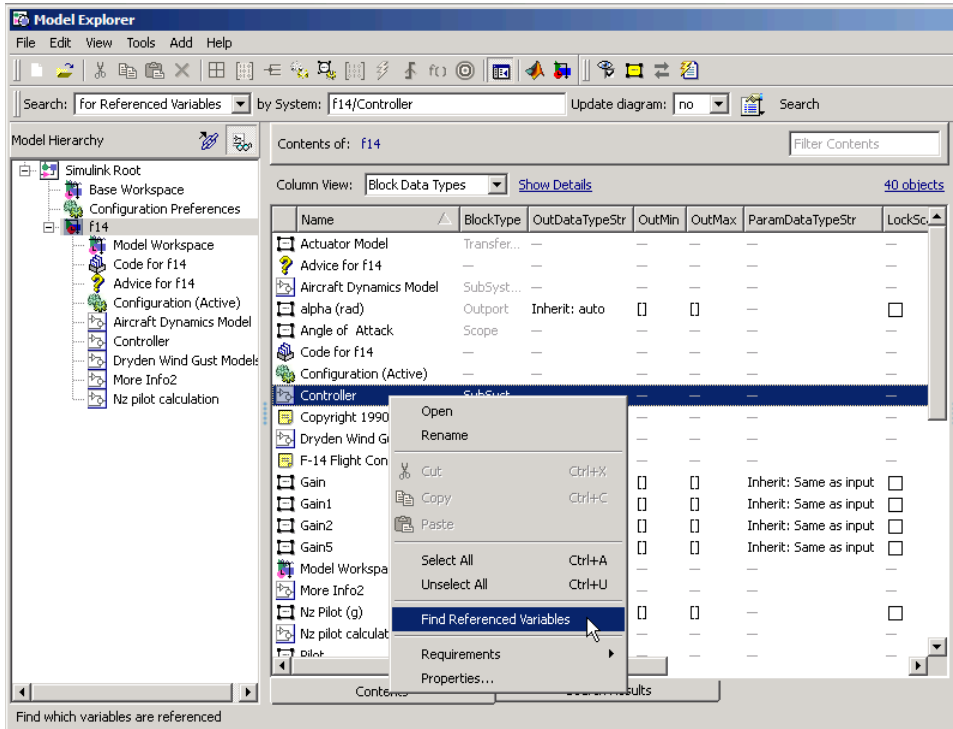
The Model Explorer: Working with Workspace Variables

In this section...

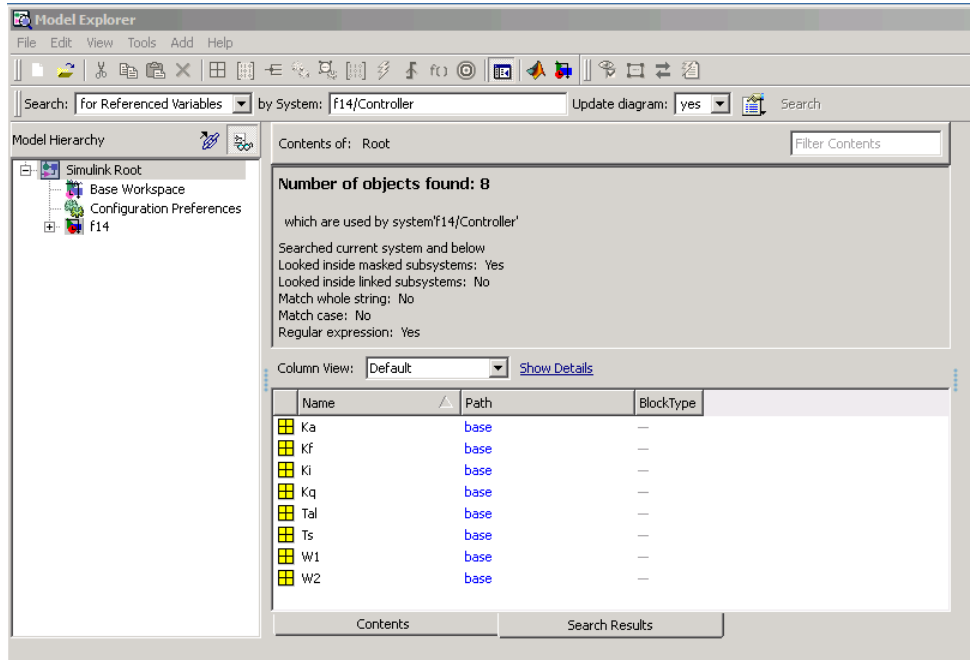
Finding Variables That Are Used by a Model or Block

In the Model Explorer, you can get a list of variables that a model or block uses. The following approach is one way to get that list of variables:

1. In the **Contents** pane, right-click the block for which you want to find the variables that it uses.
2. Select the **Find Referenced Variables** menu item.



Model Explorer returns results similar to this:



For performance, Model Explorer uses cached information from the last compiled version of the model. If you want to recompile the model, either do so manually or, in the Model Explorer, set the **Update diagram** field to `yes` and repeat the search.

You can also use the following approaches to find variables that a model or block uses:

- In the Model Explorer, in the search bar, use the `for Referenced Variables` search type option.
- In the Model Editor, right-click a block, subsystem, or in the canvas and select the **Find Referenced Variables** menu item. Clicking the canvas returns results for the whole model.

The `Simulink.findVars` function provides additional options for returning information about workspace variables that is not available from the Model Explorer or Model Editor.

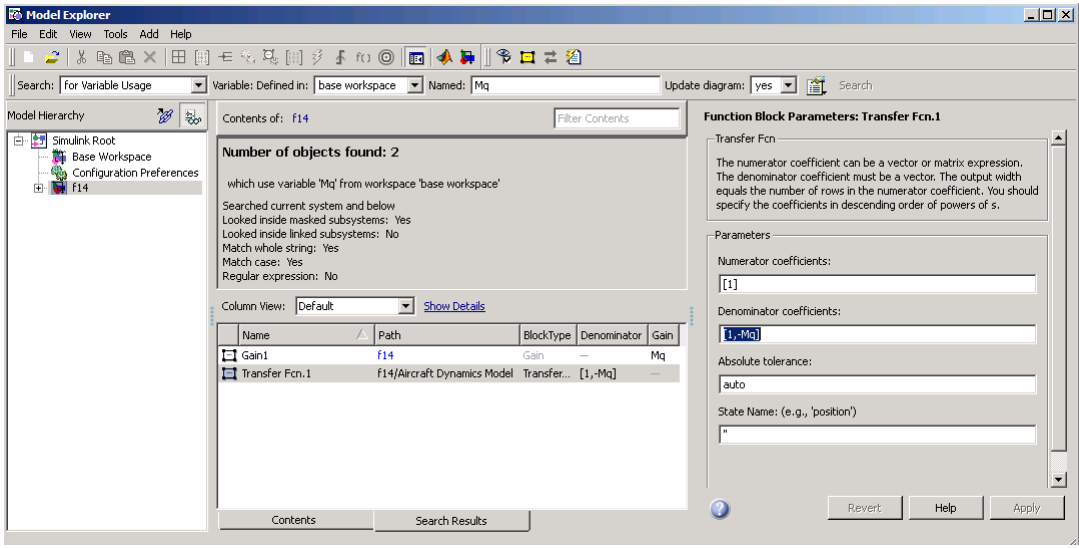
Using the Set of Returned Variables

For a variable in the set of returned variables, you can find the blocks that use that variable (for details, see “Finding Blocks That Use a Specific Variable” on page 8-53). Also, you can export variables from the returned set of variables. For details, see “Exporting Workspace Variables” on page 8-54.

Finding Blocks That Use a Specific Variable

You can use the Model Explorer to get a list of blocks that use a specific workspace variable. One way to get that list of blocks is to right-click a variable in the **Contents** pane and select the **Find Where Used** menu item. For example:

1. Open the `f14` model.
2. Open the Model Explorer.
3. In the **Model Hierarchy** pane, select the `Base Workspace` node.
4. In the **Contents** pane, right-click the `Mq` variable and select the **Find Where Used** menu item.
5. In the Hierarchy dialog box that appears, select `f14`. The Model Explorer displays output similar to this:



The property columns whose values include `Mq` represent the block parameters that use the `Mq` variable. If those property columns are not already in the view, then the Model Explorer adds them to the end of the search results display.

You can also find blocks that use a specific variable, by using one of these approaches:

- In the search bar, select the `for Variable Usage` search type option.
- In the **Search Results** pane, right-click a variable and select the **Find Where Used** menu item.

Exporting Workspace Variables

You can export (save) a set of variables listed in the Model Explorer, exporting either individual variables or all the variables in the base or model workspace.

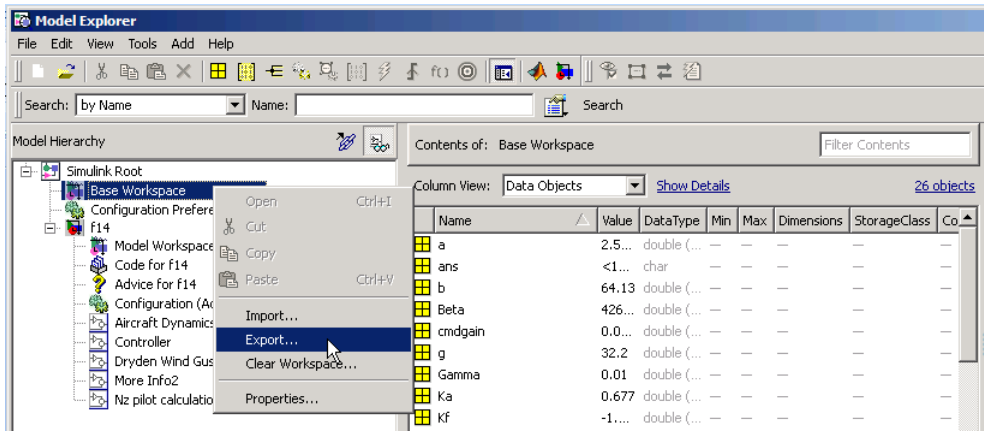
One possible workflow is to export the set of variables returned with the **Find Referenced Variables** option or the `Simulink.findVars` function. For details, see “Finding Variables That Are Used by a Model or Block” on page 8-50.

Note All the variables that you export must be from the same workspace.

To export all the variables in a workspace in the Model Explorer to a MATLAB code file or MAT-file:

1. Select the variables that you want to export.

   a. To select all the variables in a workspace, right-click the workspace node (for example, `Base Workspace`) and select the **Export** menu item. For example:



   b. To select individual variables, in the **Contents** pane, select the variables that you want to export. Right-click one of the highlighted variables and select the **Export Selected** menu item.

   If the **Contents** pane has data grouped by a property, selecting the top line in a group does not select all the variables in that group. For details about grouped data, see"Grouping by a Property" on page 8-35.

2. Specify whether to save the variables in a MATLAB code file or a MAT-file.

   The MATLAB code file format is easier to read, is editable, and supports version control. The MAT-file format is binary, which has performance advantages.

If you specify a MATLAB code file format, the Model Explorer may create an associated MAT-file, reflecting the name of the MATLAB code file, but with an extension of `.mat` instead of `.m`.

3. Specify a name and location for the file.

4. If the file already exists, Model Explorer displays a dialog box asking you to choose one of these options:

   - `Overwrite entire file`
     - Replaces all variables in the target file with the selected variables, which are stored in alphabetical order.
   - `Update variables that exist in file and append new variables to file`
     - Updates existing variables in place and appends new variables.
   - `Only update variables that exist in file`
     - Updates existing variables, but does not add any new variables, which eliminates potentially extraneous variables.

Importing Workspace Variables

You can import (load) a set of variables from a file into the base workspace or into a model workspace using the Model Explorer. When you import variables into a workspace, the Model Explorer overwrites existing variables and adds any new variables.

To import variables into a workspace:

1. In the **Model Hierarchy** pane, right-click the workspace into which you want to import variables.

2. Select the **Import** menu item.

3. In the Import from File dialog box, select a MATLAB code file or MAT-file for the variables that you want to import.

Note If you import a MATLAB code file, then Simulink also imports the associated MAT-file.

The Model Explorer: Search Bar

In this section...

Searching in the Model Explorer

Use the Model Explorer search bar to search for specific objects from the node you select in the **Model Hierarchy** pane.

The Model Explorer displays search results in the **Search Results** tab of the **Contents** pane.

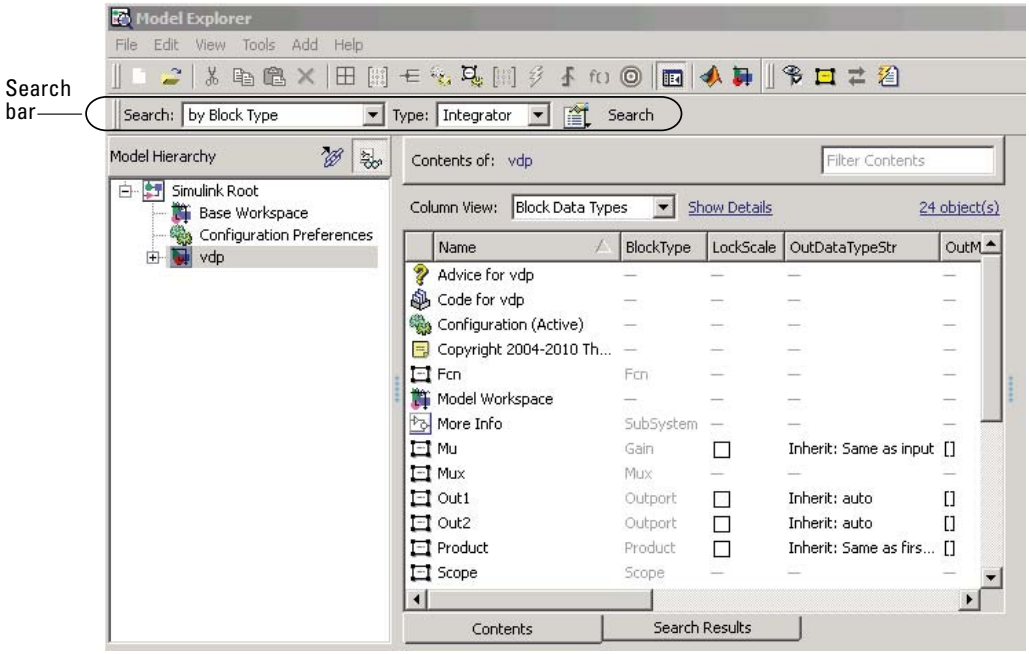
The search results appear in a table that is similar to the object property table in the **Contents** tab. The search results table uses the current column view (the object property table) definition as a starting point, and adds relevant properties that are not already included in the current view. Any additional property columns added to the **Search Results** pane do not affect the view definition.

If you modify the property columns in the search results table that also appear in the property table view, the changes you make affect both tables. For example, if you hide `OutMax` column in the search results table, and the `OutMax` column was also in the object property view table, then the `OutMax` column is hidden in both tables. However, if in the search results table you reorder where the `Complexity` column appears, if the view does not include the `Complexity` property, then that change to the search results table does not affect the view.

You can edit property values in the search results table.

The Search Bar

The search bar appears at the top of the Model Explorer window.

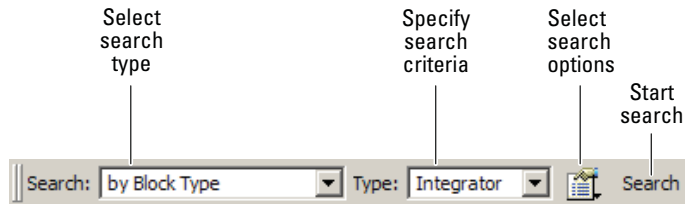


Showing and Hiding the Search Bar

By default, the search bar is visible. To show or hide the search bar, select or clear the **View > Toolbars > Search Bar** option.

Search Bar Controls

The search bar includes the following controls:



Search Type

Use the **Search Type** control to specify the type of objects or properties to include in the search.

Search Type Option	Description
`by Name`	Searches a model or chart for all objects that have the specified string in the name of the object. See "Search Strings" on page 8-62.
`by Property Name`	Searches for objects that have a specified property. Specify the target property name from a list of properties that objects in the search domain can have.
`by Property Value`	Searches for objects with a property value that matches the value you specify. Specify the name of the property, the value to be matched, and the type of match (for example, equals, less than, or greater than). See "Search Strings" on page 8-62.
`by Block Type`	Searches for blocks of a specified block type. Select the target block type from the list of types contained in the currently selected model.
`by Stateflow Type`	Searches for Stateflow objects of a specified type.
`for Variable Usage`	Searches for variables that blocks use. Select the base workspace or a model workspace (model name) and, optionally, the name of a variable. See "Search Strings" on page 8-62.

Search Type Option	Description
`for Referenced Variables`	Searches for variables that a model or block uses. Specify the name of the model or block in the `by System` field. The model or block must be in the **Model Hierarchy** pane.
`for Library Links`	Searches for library links in the current model.
`by Class`	Searches for Simulink objects of a specified class.
`for Fixed Point Capable`	Searches a model for all blocks that support fixed-point computations.
`for Model References`	Searches a model for references to other models.
`by Dialog Prompt`	Searches a model for all objects whose dialogs contain the prompt you specify. See "Search Strings" on page 8-62.
`by String`	Searches a model for all objects in which the string you specify occurs. See "Search Strings" on page 8-62.

Search Options

Use the **Search Options** control to specify the scope and how to apply search strings.

Search Option	Description
`Search Current System and Below`	Search the current system and the subsystems that it includes directly or indirectly.
`Match Whole String`	Do not allow partial string matches (for example, do not allow `sub` to match `substring`).

Search Option	Description
`Match Case`	Considers case when matching strings (for example, `Gain` does not match `gain`).
`Regular Expression`	Considers a string to be matched as a regular expression.
`Evaluate Property Values During Search`	Applies only for searches by property value. If enabled, the option causes the Model Explorer to evaluate the value of each property as a MATLAB expression and compare the result to the search value. If this option is disabled (the default), the Model Explorer compares the unevaluated property value to the search value.
`Refine Search`	Initiates a secondary search that provides additional search criteria to refine the initial search results. The second search operation searches for objects that meet both the original and the new search criteria (see "Refining a Search" on page 8-63).

Search Strings

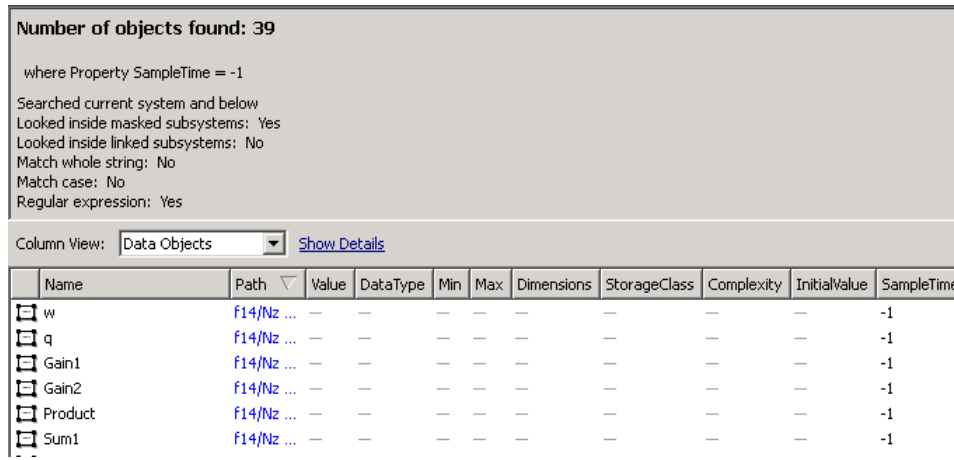
By default, search strings are case-insensitive and are treated as regular expressions.

By default, the search allows partial string matches. You cannot use wildcard characters in search strings. For example, if you enter `*1` as a name search string, you get no search results unless there is an item whose name starts with the two characters `*1`. If there is an `out1` item, the search results do not include that item.

Search Button

Click the **Search** button to start the search specified by the current settings of the search bar on the object selected in the **Model Hierarchy** pane. The Model Explorer displays the results of the search in the **Search Results** pane.

The top of the **Search Results** pane displays a summary of the results, including the scope of the search and the search criteria that you specified.



You can edit the results displayed in the **Search Results** pane. For example, to change all objects found by a search to have the same property value, select the objects in the **Search Results** pane and change the property value of one of the objects.

Refining a Search

To refine the previous search, in the search bar, click the **Select Search Options** button () and select **Refine Search**. A **Refine** button replaces the **Search** button on the search bar. Use the search bar to define new search criteria and then click the **Refine** button. The Model Explorer searches for objects that match both the previous search criteria and the new criteria.

The Model Explorer: Dialog Pane

In this section...

What You Can Do with the Dialog Pane

You can use the **Dialog** pane to view and change properties of objects that you select in the **Model Hierarchy** pane or in the **Contents** pane.

Showing and Hiding the Dialog Pane

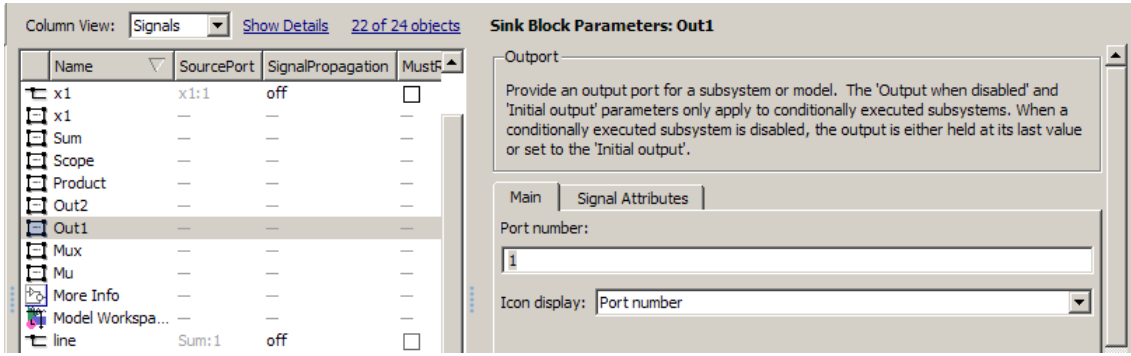
By default, the **Dialog** pane appears in the Model Explorer, to the right of the **Contents** pane. To show or hide the **Dialog** pane, use one of these approaches:

- From the **View** menu, select **Show Dialog Pane**.
- From the main toolbar, click the **Dialog View** button ().

Editing Properties in the Dialog Pane

To edit property values using the **Dialog** pane:

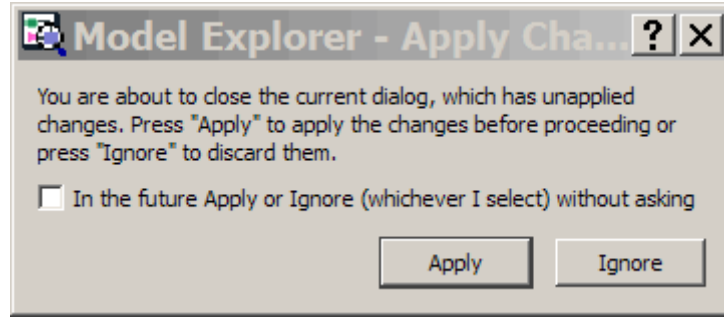
1. In the **Contents** pane, select an object (such as a block or signal). The **Dialog** pane displays the properties of the object you selected.



2 Change a property (for example, the port number of an Outport block) in the **Dialog** pane.

3 Click **Apply** to accept the change, or click **Revert** to return to the original value.

By default, clicking outside a dialog box with unapplied changes causes the Apply Changes dialog box to appear:



Click **Apply** to accept the changes or **Ignore** to revert to the original settings.

To prevent display of the **Apply Changes** dialog box:

1 In the dialog box, click the **In the future Apply or Ignore (whichever I select) without asking** check box.

2 If you want Simulink to apply changes without warning you, press **Apply**.
If you want Simulink to ignore changes without warning you, press **Ignore**.

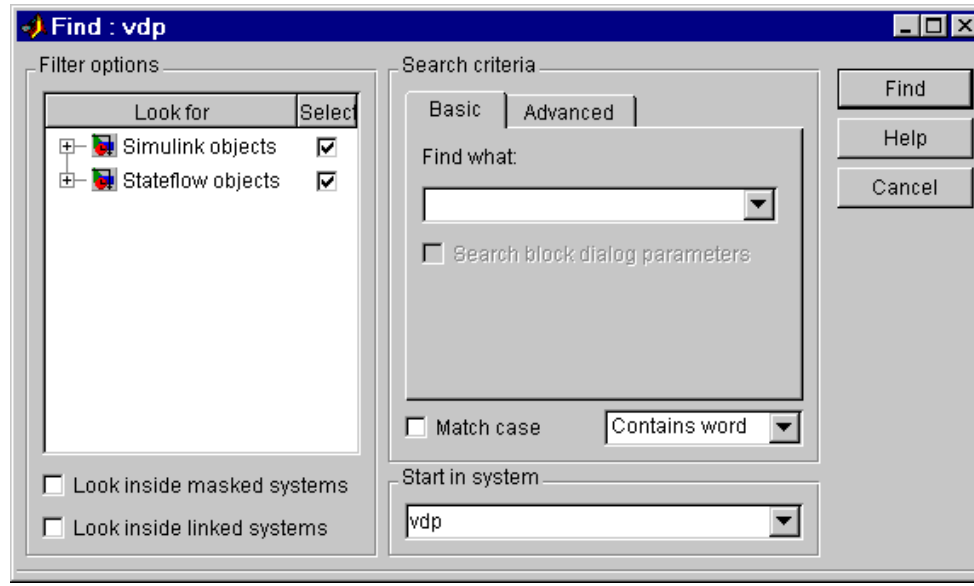
To restore display of the **Apply Changes** dialog box, from the **Tools** menu, select **Prompt if dialog has unapplied changes**.

The Finder

In this section...

About the Finder

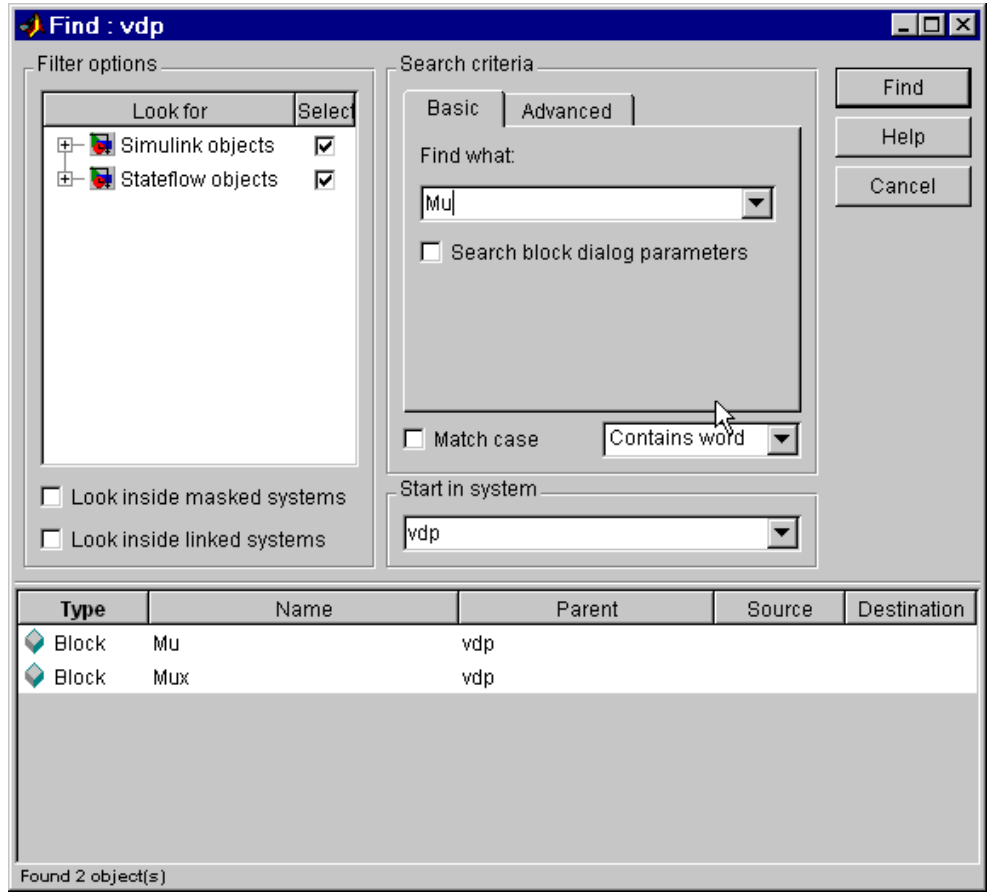
The Finder locates blocks, signals, states, or other objects in a model. To display the Finder, select **Find** from the Simulink Model Editor's **Edit** menu. The **Find** dialog box appears.



Use the **Filter options** (see "Filter Options" on page 8-69) and **Search criteria** (see "Search Criteria" on page 8-70) panels to specify the characteristics of the object you want to find. Next, if you have more than one system or subsystem open, select the system or subsystem where you want the search to begin from the **Start in system** list. Finally, click the

Find button. Simulink searches the selected system for objects that meet the criteria you have specified.

Any objects that satisfy the criteria appear in the results panel at the bottom of the dialog box.

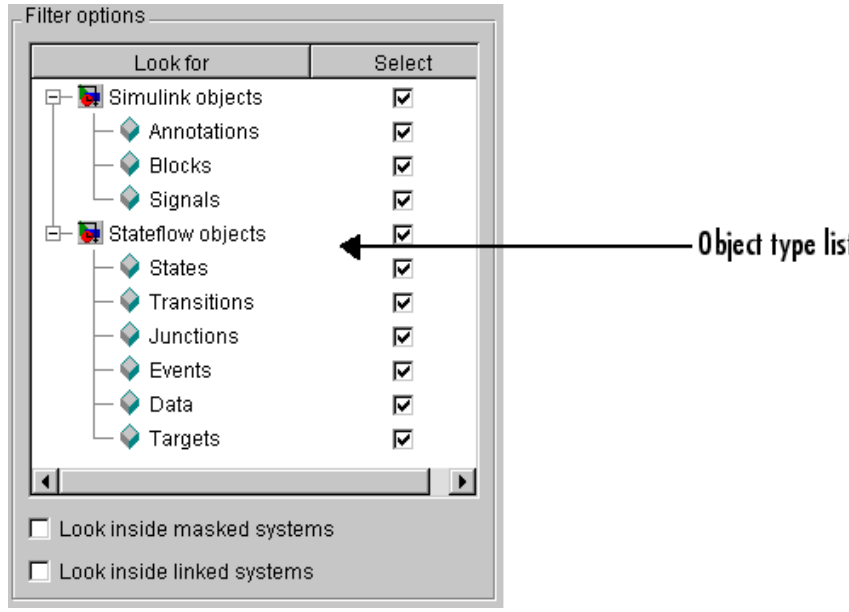


You can display an object by double-clicking its entry in the search results list. Simulink opens the system or subsystem that contains the object (if necessary) and highlights and selects the object. To sort the results list, click any of the buttons at the top of each column. For example, to sort the results by object type, click the **Type** button. Clicking a button once sorts the list in

ascending order, clicking it twice sorts it in descending order. To display an object's parameters or properties, select the object in the list. Then click the right mouse button and select **Parameter** or **Properties** from the resulting context menu.

Filter Options

The **Filter options** panel allows you to specify the kinds of objects to look for and where to search for them.



Object type list

The object type list lists the types of objects that Simulink can find. By clearing a type, you can exclude it from the Finder's search.

Look inside masked subsystem

Selecting this option causes Simulink to look for objects inside masked subsystems.

Look inside linked systems

Selecting this option causes Simulink to look for objects inside subsystems linked to libraries.

Search Criteria

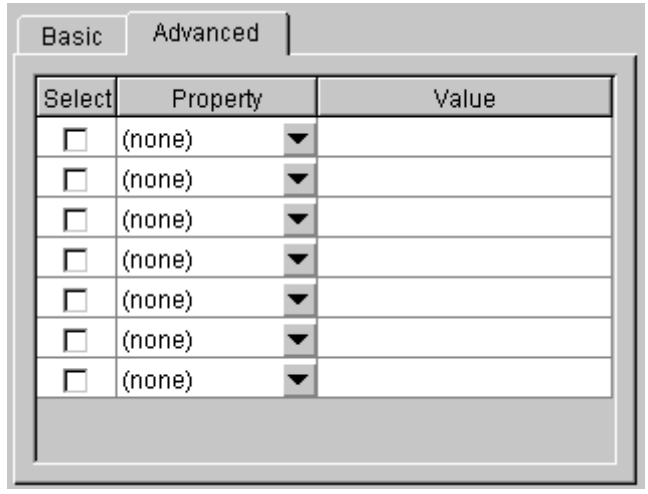
The **Search criteria** panel allows you to specify the criteria that objects must meet to satisfy your search request.

Basic

The **Basic** panel allows you to search for an object whose name and, optionally, dialog parameters match a specified text string. Enter the search text in the panel's **Find what** field. To display previous search text, select the dropdown list button next to the **Find what** field. To reenter text, click it in the list. Select **Search block dialog parameters** if you want dialog parameters to be included in the search.

Advanced

The **Advanced** panel allows you to specify a set of as many as seven properties that an object must have to satisfy your search request.



To specify a property, enter its name in one of the cells in the **Property** column of the **Advanced** pane or select the property from the cell's property list. To display the list, select the down arrow button next to the cell. Next enter the value of the property in the **Value** column next to the property name. When you enter a property name, the Finder checks the check box next to the property name in the **Select** column. This indicates that the property is to be included in the search. If you want to exclude the property, clear the check box.

Match case

Select this option if you want Simulink to consider case when matching search text against the value of an object property.

Other match options

Next to the **Match case** option is a list that specifies other match options that you can select.

- `Match whole word`

  Specifies a match if the property value and the search text are identical except possibly for case.

- `Contains word`

  Specifies a match if a property value includes the search text.

- `Regular expression`

  Specifies that the search text should be treated as a regular expression when matched against property values. The following characters have special meanings when they appear in a regular expression.

Character	Meaning
`^`	Matches start of string.
`$`	Matches end of string.
`.`	Matches any character.

Character	Meaning
`\`	Escape character. Causes the next character to have its ordinary meaning. For example, the regular expression `\..` matches `.a` and `.2` and any other two-character string that begins with a period.
`*`	Matches zero or more instances of the preceding character. For example, `ba*` matches `b`, `ba`, `baa`, etc.
`+`	Matches one or more instances of the preceding character. For example, `ba+` matches `ba`, `baa`, etc.
`[]`	Indicates a set of characters that can match the current character. A hyphen can be used to indicate a range of characters. For example, `[a-zA-Z0-9_]+` matches `foo_bar1` but not `foo$bar`. A `^` indicates a match when the current character is not one of the following characters. For example, `[^0-9]` matches any character that is not a digit.
`\w`	Matches a word character (same as `[a-z_A-Z0-9]`).
`\W`	Matches a nonword character (same as `[^a-z_A-Z0-9]`).
`\d`	Matches a digit (same as `[0-9]`).
`\D`	Matches a nondigit (same as `[^0-9]`).
`\s`	Matches white space (same as `[ \t\r\n\f]`).
`\S`	Matches nonwhite space (same as `[^ \t\r\n\f]`).
`\<WORD\>`	Matches `WORD` where `WORD` is any string of word characters surrounded by white space.

The Model Browser

In this section...

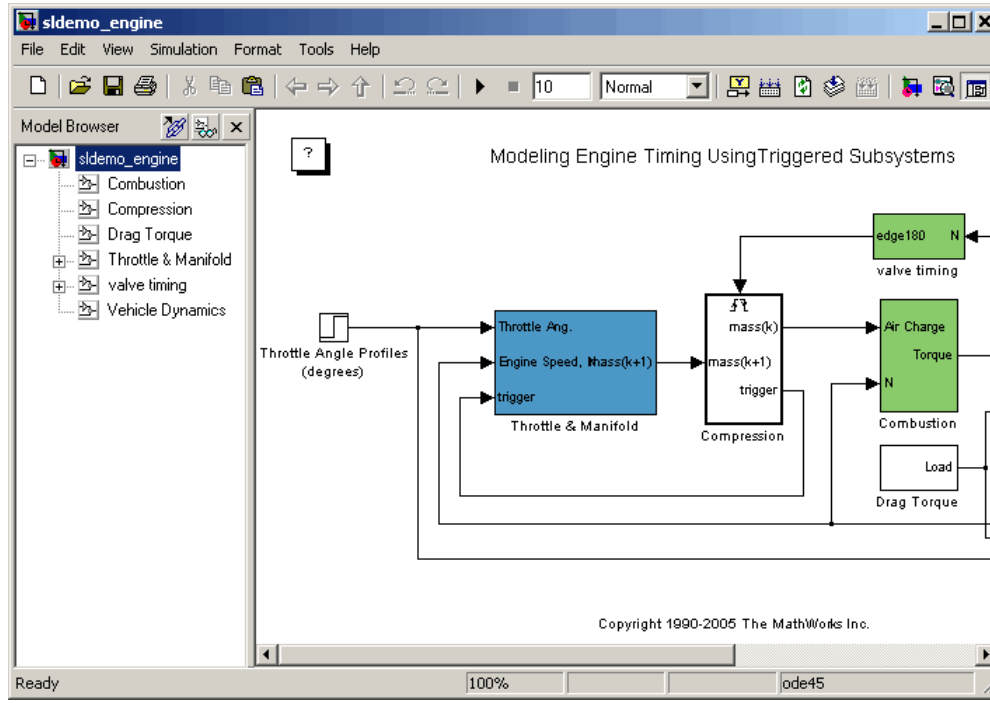
About the Model Browser

The Model Browser enables you to

- Navigate a model hierarchically
- Open systems in a model
- Determine the blocks contained in a model

Note The browser is available only on Microsoft Windows platforms.

To display the Model Browser, select **Model Browser Options > Model Browser** from the Simulink **View** menu.



The model window splits into two panes. The left pane displays the browser, a tree-structured view of the block diagram displayed in the right pane.

Note The **Browser initially visible** preference causes Simulink to open models by default in the Model Browser. To set this preference, select **Preferences** from the Simulink **File** menu.

The top entry in the tree view corresponds to your model. A button next to the model name allows you to expand or contract the tree view. The expanded view shows the model's subsystems. A button next to a subsystem indicates that the subsystem itself contains subsystems. You can use the button to list the subsystem's children. To view the block diagram of the model or any subsystem displayed in the tree view, select the subsystem. You can use either the mouse or the keyboard to navigate quickly to any subsystem in the tree view.

Navigating with the Mouse

Click any subsystem visible in the tree view to select it. Click the + button next to any subsystem to list the subsystems that it contains. Click the button again to contract the entry.

Navigating with the Keyboard

Use the up/down arrows to move the current selection up or down the tree view. Use the left/right arrow or +/- keys on your numeric keypad to expand an entry that contains subsystems.

Showing Library Links

The Model Browser can include or omit library links from the tree view of a model. Use the **Preferences** dialog box to specify whether to display library links by default. To toggle display of library links, select **Show Library Links** from the **Model Browser Options** submenu of the **View** menu.

Showing Masked Subsystems

The Model Browser can include or omit masked subsystems from the tree view. If the tree view includes masked subsystems, selecting a masked subsystem in the tree view displays its block diagram in the diagram view. Use the **Preferences** dialog box to specify whether to display masked subsystems by default. To toggle display of masked subsystems, select **Show Masked Subsystems** from the **Model Browser Options** submenu of the **View** menu.

Model Dependencies

In this section...

What Are Model Dependencies?

Each Simulink model requires a set of files to run successfully. These files can include referenced models, data files, S-functions, and other files without which the model cannot run. These required files are called *model dependencies*.

The Simulink Manifest Tools allow you to analyze a model to determine its model dependencies. After you identify these dependencies, you can:

- View the files required by your model in a "manifest" file.
- Package the model with its required files into a ZIP file to send to another Simulink user.
- Compare older and newer manifests for the same model.
- Save a specific version of the model and its required files in a revision control system.

You can also view the libraries and models referenced by your model in a graphical format using the Model Dependency Viewer. See "Using the Model Dependency Viewer" on page 8-101.

Generating Manifests

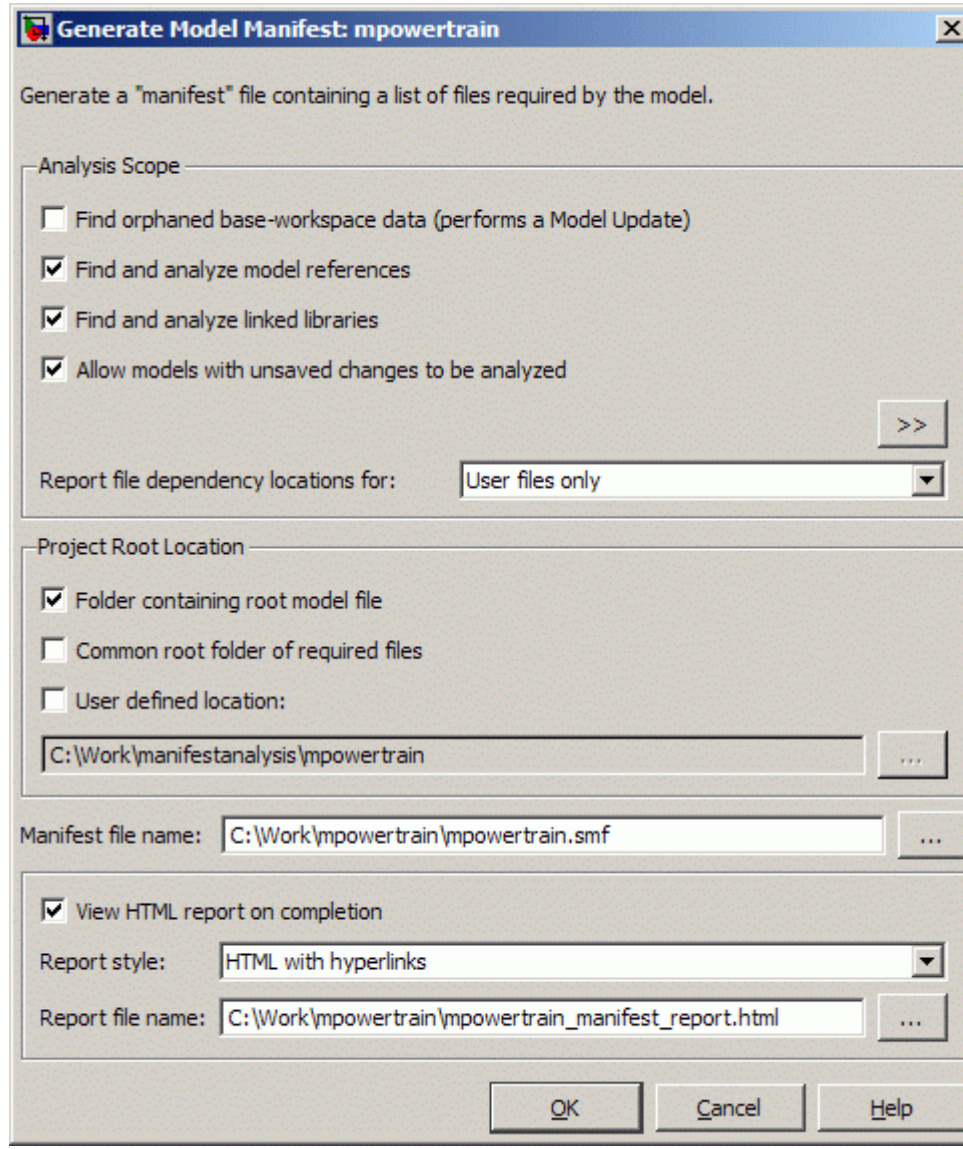
Generating a manifest performs the dependency analysis and saves the list of model dependencies to a manifest file. You must generate the manifest before using any of the other Simulink Manifest Tools.

Note The model dependencies identified in a manifest depend upon the *Analysis Scope* you specify. For example, performing an analysis without selecting **Find Library Links** may not find all the Simulink Blocksets that your model requires, since these are often included in a model as library links. See "Manifest Analysis Scope Options" on page 8-80.

To generate a manifest:

1 Select **Tools > Model Dependencies > Generate Manifest**.

The Generate Model Manifest dialog box appears.



2 Click **OK** to generate a manifest and report using the default settings.

Alternatively you can first change the following settings:

- Select the **Analysis scope** check boxes to specify the type of dependencies you want to detect (see "Manifest Analysis Scope Options" on page 8-80).
- Control whether to report file dependency locations by selecting **Report file dependency locations for**:
  - `User files only` (default) — only report locations where dependencies are upon user files. Use this option if you want to understand the interdependencies of your own code and do not care about the locations of dependencies on MathWorks® products. This option speeds up report creation and streamlines the report.
  - `All files` — report all locations where dependencies are introduced, including all dependencies on MathWorks products. This is the slowest option and the most verbose report. Use this option if you need to trace all dependencies to understand why a particular file or toolbox is required by a model. If you need to analyze many references, it can be helpful to sort the results by clicking the report column headers.
  - `None` — do not report any dependency locations. This is the fastest option and the most streamlined report. Use this option if you want to discover and package required files and do not require all the information about file references.
- If desired, change the **Project Root Location**. Select one of the check box options: **Folder containing root model file** (the default), **Common root folder of required files**, or **User-defined location** — for this option, enter a path in the edit box, or browse to a location.
- If desired, edit the **Manifest file name** and location in which to save the file.
- Use the check box **View HTML report on completion** to specify if you want to generate a report when you generate the manifest. You can edit the **Report file name** or leave the default, *`mymodelname`*`_manifest_report.html`. You can set the **Report style** to `Plain HTML` or `HTML with Hyperlinks`.

When you click **OK** Simulink generates a manifest file containing a list of the model dependencies. If you selected **View HTML report on completion**, the Model Manifest Report appears after Simulink generates the manifest. See "Using the Model Manifest Report" on page 8-96 for an example.

The manifest is an XML file with the extension `.smf` located (by default) in the same folder as the model itself.

Manifest Analysis Scope Options

The Simulink Manifest Tools allow you to specify the scope of analysis when generating the manifest. The dependencies identified by the analysis depend upon the scope you specify.

The following table describes the Analysis Scope options.

Check Box Option	Description
Find orphaned base workspace data (performs a Model Update)	Searches for base workspace variables the model requires, that are not defined in any file in this Manifest. If Model Update fails you see an error message. Either clear this analysis option to generate a manifest without a Model Update, or try a manual Model Update to find out more about the problem. For example your model may require variables that are not present in the workspace (e.g., if a block parameter defines a variable that you forgot to load manually).
Find and analyze model references	Searches for Model blocks in the model, and identifies any referenced models as dependencies.
Find and analyze linked libraries	Searches for links to library blocks in the model, and identifies any library links as dependencies.
Allow models with unsaved changes to be analyzed	Select this check box only if you want to allow analysis of unsaved changes.
Click the >> button on the right to show the following advanced analysis options.	

Check Box Option	Description
Find S-functions	Searches for S-Function blocks in the model, and identifies S-function files (MATLAB code and C) as dependencies. See the source code item in "Special Cases" on page 8-93.
Analyze model and block callbacks (including "MATLAB Fcn" blocks)	Searches for file dependencies introduced by the code in MATLAB Fcn blocks, block callbacks, and model callbacks. For more detail on how callbacks are analyzed, see "Code Analysis" on page 8-92.
Find files required for code generation	Searches for file dependencies introduced by Real-Time Workshop custom code, and Real-Time Workshop Embedded Coder templates. If you do not have a code generation product, this check is off by default, and produces a warning if you select it. This includes analysis of all configuration sets (not just the Active set) and *STF*`_make_rtw_hook` functions, and locates system target files and Target Function Library definition files (.m or .mat). See also "Required Toolboxes" on page 8-97, and the source code item in "Special Cases" on page 8-93.
Find data files (e.g. in "From File" blocks)	Searches for explicitly referenced data files, such as those in From File blocks, and identifies those files as dependencies. See "Special Cases" on page 8-93.
Analyze Stateflow charts	Searches for file dependencies introduced through the use of syntax such as `ml.mymean(myvariable)` in models that use Stateflow.

Check Box Option	Description
Analyze code in Embedded MATLAB blocks	Searches for Embedded MATLAB Function blocks in the model, and identifies any file dependencies (outside toolboxes) introduced in the code. Toolbox dependencies introduced by an Embedded MATLAB® Function block are not detected.
Find requirements documents	Searches for requirements documents linked using the Requirements Management Interface. Note that requirements links created with Telelogic® DOORS® software are not included in manifests. For more information, see "Requirements Linking and Traceability" in the Simulink Verification and Validation documentation.This option is disabled if you do not have a Simulink Verification and Validation license, and Simulink ignores any requirements links in your model.
Analyze files in "user toolboxes"	Searches for file dependencies introduced by files in user-defined toolboxes. See "Special Cases" on page 8-93.
Analyze MATLAB files	Searches for file dependencies introduced by MATLAB files called from the model. For example, if this option is selected and you have a callback to `mycallback.m`, then the referenced file `mycallback.m` is also analyzed for further dependencies. See "Code Analysis" on page 8-92.
Store MATLAB code analysis warnings in manifest	Saves any warnings in the manifest.

See also "Scope of Dependency Analysis" on page 8-91 for more information.

Command-Line Dependency Analysis

Check File Dependencies

To programmatically check for file dependencies, use the method `dependencies.fileDependencyAnalysis` as follows.

```
[files, missing, depfile, manifestfile] =
dependencies.fileDependencyAnalysis('modelname',
'manifestfile')
```

This returns the following:

- *`files`* — a cell array of strings containing the full-paths of all existing files referenced by the model *`modelname`*.
- *`missing`* — a cell array of strings containing the names all files that are referenced by the model *`modelname`*, but cannot be found.
- *`depfile`* — the full path of the file containing information about any user-defined files associated with the model *`modelname`*.
- *`manifestfile`* — (optional input) specify the name of the manifest file to create. Note that the suffix `.smf` is always added to the user-specified name.

  If you specify the optional input, *`manifestfile`*, then the command creates a manifest file with the specified name and path *`manifestfile`*. *`manifestfile`* can be a full-path or just a file name (in which case the file is created in the current folder).

If you try this analysis on a demo model, it returns an empty list of required files because the standard MathWorks installation includes all the files required for the demo models.

Check Toolbox Dependencies

To check which toolboxes are required, enter:

```
[names,dirs] =
dependencies.toolboxDependencyAnalysis(files_in)
```

files_in must be a cell array of strings containing `.m` or `.mdl` files on the MATLAB path. Simulink model names (without `.mdl` extension) are also allowed

This returns the following:

- *`names`* — a cell-array of toolbox names required by the files in *files_in*.
- *`dirs`* — a cell-array of the toolbox folders.

Note The method `toolboxDependencyAnalysis` looks for toolbox dependencies of the files in `files_in` but does *not* analyze any subsequent dependencies.

If you want to find all detectable toolbox dependencies of your model *and* the files it depends on:

1. Call `fileDependencyAnalysis` on your model.

   For example:

   ```
   [files, missing, depfile, manifestfile] = dependencies.fileDependencyAnalysis('mymodel')
   ```

   ```
   files =
       'C:\Work\manifest\foo.m'
       'C:\Work\manifest\mymodel.mdl'
   missing =
        []
   depfile =
        []
   manifestfile =
        []
   ```

2. Call `toolboxDependencyAnalysis` on the `files` output of step 1.

   For example:

```
tbxes = dependencies.toolboxDependencyAnalysis(files)

tbxes =
[1x24 char]    'MATLAB'    'Real-Time Workshop'    'Simulink'
```

To view long product names examine the `tbxes` cell array as follows:

```
tbxes{:}

ans =
Image Processing Toolbox

ans =
MATLAB

ans =
Real-Time Workshop

ans =

Simulink
```

For command line dependency analysis, the analysis uses the default settings for analysis scope to determine required toolboxes. For example, if you have code generation products, then the check **Find files required for code generation** is on by default and Real-Time Workshop is always reported as required. See "Required Toolboxes" on page 8-97 for more examples of how your installed products and analysis scope settings can affect reported toolbox requirements.

Editing Manifests

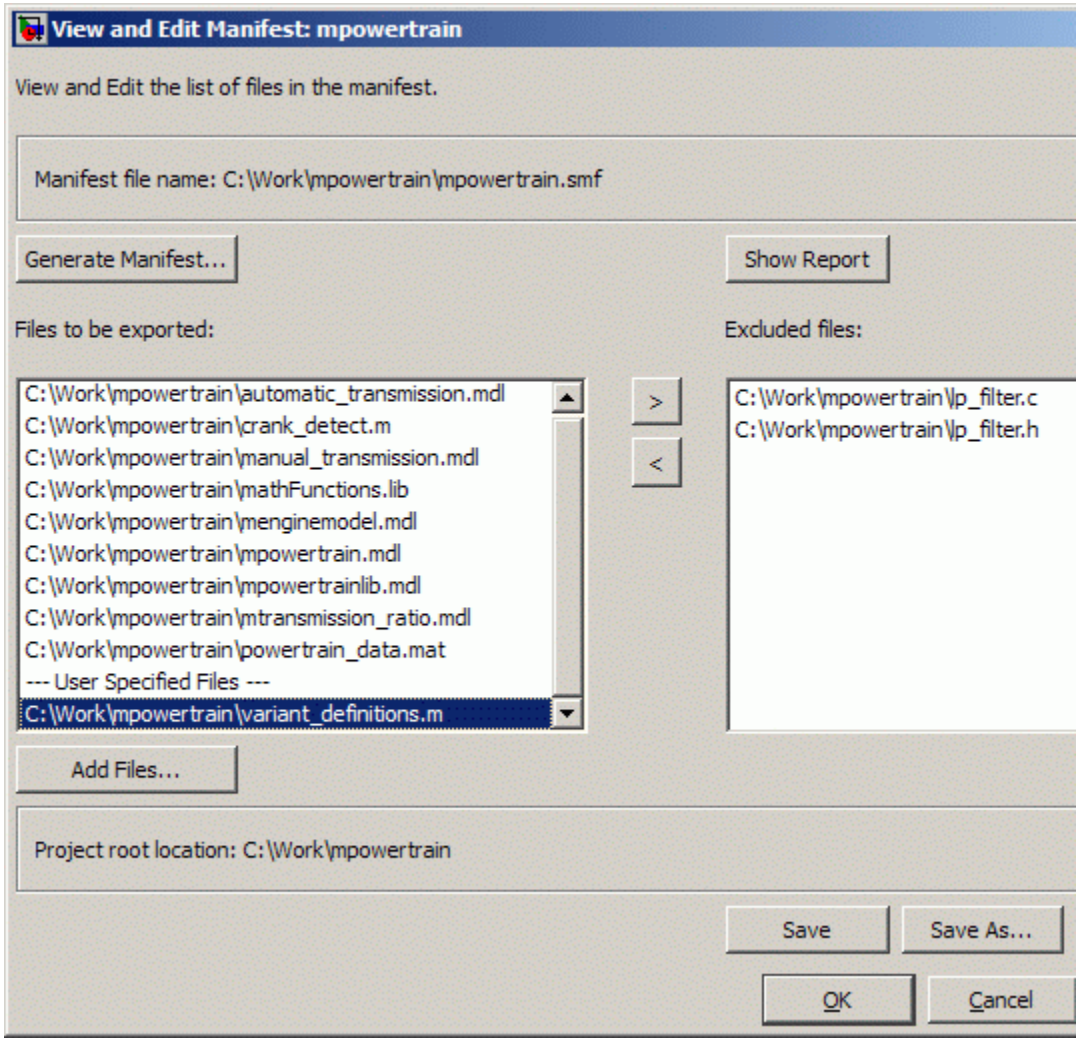
After you generate a manifest, you can view the list of files identified as dependencies, and manually add or delete files from the list.

To edit the list of required files in a manifest:

1 Select **Tools > Model Dependencies > View/Edit Manifest Contents**.

Alternatively, if you are viewing a manifest report you can click **Edit** in the top **Actions** box, or you can click **View and Edit Manifest** in the Export Manifest dialog box.

The View and Edit Manifest dialog box appears, showing the latest manifest for the current model.



Note You can open a different manifest by clicking the Browse for manifest file button  . If you have not generated a manifest, select **Generate Manifest** to open the Generate Model Manifest dialog box (see "Generating Manifests" on page 8-77).

2 Examine the **Files to be exported** list on the left side of the dialog box. This list shows the files identified as dependencies.

3 To add a file to the manifest:

   a Click **Add Files**.

   The Add Files to Manifest dialog box opens.

   b Select the file you want to add, then click **Open**.

   The selected file is added to the **Files to be exported** list.

4 To remove a file from the manifest:

   a Select the file you want to remove from the **Files to be exported** list.

   b Click the Exclude selected files button  .

   The selected file is moved to the **Excluded files** list.

   Note If you add a file to the manifest and then exclude it, that file is removed from the dialog (it is not added to the **Excluded files** list). Only files detected by the Simulink Manifest Tools are included in the Excluded files list.

5 If desired, change the **Project Root Location**.

6 Click **Save** to save your changes to the manifest file.

Simulink saves the manifest (`.smf`) file, and creates a user dependencies (`.smd`) file that stores the names of any files you manually added or

excluded. Simulink uses the `.smd` file to remember your changes the next time you generate a manifest. The user dependencies (`.smd`) file has the same name and folder as the model. By default, the user dependencies (`.smd`) file is also included in the manifest.

Note If the user dependencies (`.smd`) file is read-only, a warning is displayed when you save the manifest.

---

7 To view the Model Manifest Report for the updated manifest, click **Show Report**.

An updated Model Manifest Report appears, listing the required files and toolboxes, and details of references to other files. See "Using the Model Manifest Report" on page 8-96 for an example.

8 When you are finished editing the manifest, click **OK**.

Comparing Manifests

You can compare two manifests to see how the list of model dependencies differs between two models, or between two versions of the same model. You can also compare a manifest with a folder or a ZIP file.

To compare manifests:

1 From the Current Folder browser, right-click a manifest file and select **Compare Against > Choose**.

Alternatively, from your model, select **Tools > Model Dependencies > Compare Manifests**.

The dialog box Select Files or Folders for Comparison appears.

2 In the dialog box Select Files or Folders for Comparison, select files to compare, and the comparison type.

a Use the drop-down lists or browse to select manifest files to compare.

b Select the **Comparison type**. For two manifests you can select:

- `Simulink manifest comparison` — Select for a manifest file list comparison reporting new, removed and changed files. The report contains links to open files and compare files that differ. You can use a similar file `List comparison` for comparing a manifest to a folder or a ZIP file.
- `Simulink manifest comparison (printable)` — Select for a printable Model Manifest Differences Report without links. The report provides details about each manifest file, and lists the differences between the files.

3 View the report in the Comparison Tool comparing the file names, dates, and sizes stored in the manifests.

Be aware the details stored in the manifest may differ from the files on disk. If you click a "compare" link in the report, you see warnings if there are problems such as size mismatches, or if the tool cannot find those files on disk.

For more information on the Comparison Tool, see "Comparing Files and Folders" in the MATLAB Desktop Tools and Development Environment documentation.

Exporting Files in a Manifest

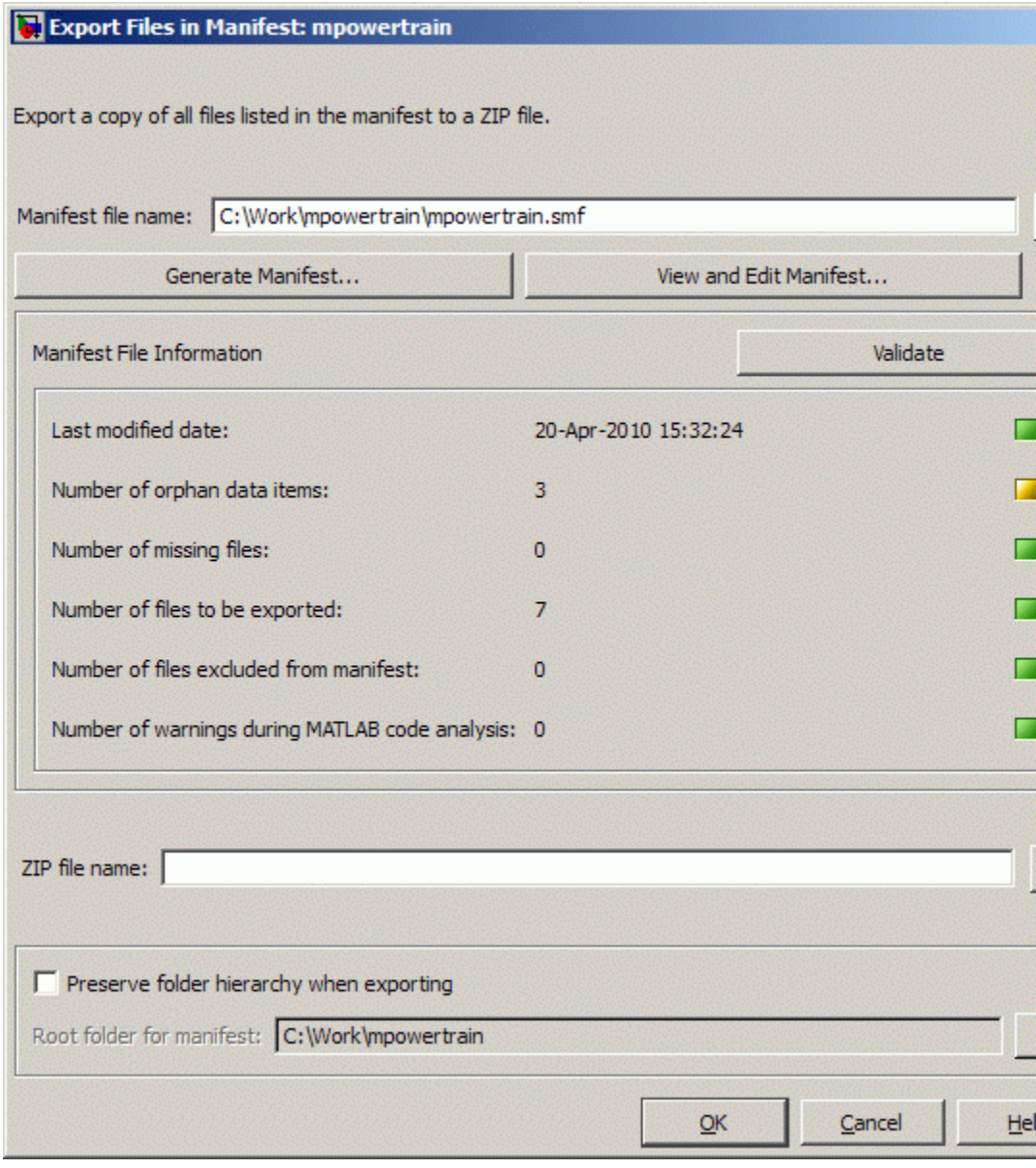
You can export copies of the files listed in the manifest to a ZIP file. Exporting the files allows you to package the model with its required files into a single ZIP file, so you can easily send it to another user or save it in a revision control system.

To export your model with its required files:

1 Select **Tools > Model Dependencies > Export Files in Manifest**.

Alternatively, if you are viewing a manifest report you can click **Export** in the top **Actions** box.

The Export Files in Manifest dialog box appears, showing the latest manifest for the current model.


Export Files in Manifest: mpowertrain
Export a copy of all files listed in the manifest to a ZIP file.
Manifest file name:
C:\Work\mpowertrain\mpowertrain.smf
Generate Manifest...
View and Edit Manifest...
Manifest File Information
Validate
Last modified date:
20-Apr-2010 15:32:24
Number of orphan data items:
3
Number of missing files:
0
Number of files to be exported:
7
Number of files excluded from manifest:
0
Number of warnings during MATLAB code analysis:
0
ZIP file name:
Preserve folder hierarchy when exporting
Root folder for manifest:
C:\Work\mpowertrain
OK
Cancel

Note You can export a different manifest by clicking the Browse for manifest file button  . If you have not generated a manifest, select **Generate Manifest** to open the Generate Model Manifest dialog box (see "Generating Manifests" on page 8-77).

2. If you want to view or edit the manifest before exporting it, click **View and Edit Manifest** to view or change the list of required files. See "Editing Manifests" on page 8-85. When you close the View and Edit Manifest dialog box, you return to the Export Files in Manifest dialog box.

3. Click **Validate** to check the manifest. Validation reports information about possible problems such as missing files, warnings, and orphaned base workspace data.

4. Enter the ZIP file name to which you want to export the model.

5. Select **Preserve folder hierarchy when exporting** if you want to keep folder structure for your exported model and files. Then, select the root folder to use for this structure (usually the same as the **Project Root Location** on the Generate Manifest dialog box).

Note You must select **Preserve folder hierarchy** if you are exporting a model that uses an `.m` file inside a MATLAB class (to maintain the folder structure of the class), or if the model refers to files in other folders (to ensure the exported files maintain the same relative paths).

6. Click **OK**.

   The model and its file dependencies are exported to the specified ZIP file.

Scope of Dependency Analysis

The Simulink Manifest Tools identify required files and list them in an XML file called a *manifest*. When Simulink generates a manifest file, it performs a static analysis on your model, which means that the model does not need

to be capable of performing an "update diagram" operation (see "Updating a Block Diagram" on page 1-27). The only exception to this is when you select the analysis option **Find orphaned base workspace data (performs a Model Update)**.

You can specify the type of dependencies you want to detect when you generate the manifest. See "Manifest Analysis Scope Options" on page 8-80.

For more information on what the tool analyzes, refer to the following sections:

- "Analysis Limitations" on page 8-92
- "Code Analysis" on page 8-92
- "Special Cases" on page 8-93

Analysis Limitations

The analysis might not find all files required by your model (for examples, see "Code Analysis" on page 8-92).

The analysis might not report certain blocksets or toolboxes required by a model. You should be aware of this limitation when sending a model to another user. Blocksets that do not introduce dependence on any files (such as Simulink® Fixed Point™) cannot be detected.

To include dependencies that the analysis cannot detect, you can add additional file dependencies to a manifest file using the View/Edit Manifest Contents option (see "Editing Manifests" on page 8-85).

Code Analysis

When the Simulink Manifest Tools encounter MATLAB code, for example in a model or block callback, or in a `.m` file S-function, they attempt to identify the files it references. If those files contain MATLAB code, *and* the analysis scope option **Analyze MATLAB files** is selected, the referenced files are also analyzed. This function is similar to `depfun` but with some enhancements:

- Files that are in MathWorks toolboxes are not analyzed.
- Strings passed into calls to `eval`, `evalc`, and `evalin` are analyzed.

- File names passed to `load`, `fopen`, `xlsread`, `importdata`, `dlmread`, `wk1read`, and `imread` are identified.

File names passed to `load`, etc., are identified only if they are literal strings. For example:

```
load('mydatafile')
load mydatafile
```

The following example, and anything more complicated, is not identified as a file dependency:

```
str = 'mydatafile';
load(str);
```

Similarly, arguments to `eval`, etc., are analyzed only if they are literal strings.

The Simulink Manifest Tools look inside MAT-files to find the names of variables to be loaded. This enables them to distinguish reliably between variable names and function names in block callbacks.

If a model depends upon a file for which both `.m` and `.p` files exist, then the manifest reports both, and, if the **Analyze MATLAB files** option is selected, the `.m` file is analyzed.

Special Cases

The following list contains additional information about specific cases:

- If your model references a user-defined MATLAB class created using the Data Class Designer, for example called *`MyPackage.MyClass`*, all files inside the folder *`MyPackage`* and its subfolders are added to the manifest.

  Warning **The analysis adds all files in the class, which includes any source control files such as `.svn` or `.cvs`. You may want to edit the manifest to remove these files.**

- A user-defined toolbox must have a properly configured `Contents.m` file. The Simulink Manifest Tools search user-defined toolboxes as follows:

  - If you have a `Contents.m` file in folder `X`, any file inside a subfolder of `X` is considered part of your toolbox.
  - If you have a `Contents.m` file in folder `X/X`, any file inside all subfolders of the "outer" folder `X` will be considered part of your toolbox.

    For more information on the format of a `Contents.m` file, see `ver`.

- If your S-functions require TLC files, these are detected.
- If you have Simscape™, your Simscape components are analyzed. See also "Required Toolboxes" on page 8-97 for other effects of your installed products on manifests.
- If you create a UI using GUIDE and add this to a model callback, then the dependency analysis detects the `.m` and `.fig` file dependencies.
- If you have a dependence on source code, such as `.c`, `.h` files, these files are not analyzed at all to find any files that they depend upon. For example, subsequent `#include` calls inside `.h` files are not detected. To make such files detectable, you can add them as dependent files to the "header file" section of the Custom Code pane of the Real-Time Workshop section of the Configuration Parameters dialog box (or specify them with `rtwmakecfg`). Alternatively, to include dependencies that the analysis cannot detect, you can add additional file dependencies to a manifest file using the View/Edit Manifest Contents option (see "Editing Manifests" on page 8-85).
- Various blocksets and toolboxes can introduce a dependence on a file through their additional source blocks. If the analysis scope option **Find data files (e.g. in "From File" blocks)** is selected, the analysis detects file dependencies introduced by the following blocks:

Product	Blocks
Signal Processing Blockset™	From Wave File (Obsolete) block (Microsoft Windows operating system only) From Multimedia File block (Windows only)
Video and Image Processing Blockset™	Image From File block Read Binary File block
Simulink® 3D Animation™	VR Sink block

The option **Find data files** also detects dependencies introduced by setting a "Model Workspace" for a model to either `MAT-File` or `MATLAB Code`.

Best Practices for Dependency Analysis

The starting point for dependency analysis is the model itself. Make sure that the model refers to any data files it needs, even if you would normally load these manually. For example, add code to the model's `PreLoadFcn` to load them automatically, e.g.,

```
load mydatafile
load('my_other_data_file.mat')
```

This way, the Simulink Manifest Tools can add them to the manifest. For more detail on callback analysis, see the notes on code analysis (see "Code Analysis" on page 8-92).

More generally, ensure that the model creates or loads any variables it uses, either in model callbacks or in scripts called from model callbacks. This reduces the possibility of the Simulink Manifest Tools confusing variable names with function names when analyzing block callbacks.

If you plan to export the manifest after creating it, ensure that the model does not refer to any files by their absolute paths, for example:

```
load C:\mymodel\mydata\mydatafile.mat
```

Absolute paths can become invalid when you export the model to another machine. If referring to files in other folders, do it by relative path, for example:

```
load mydata\mydatafile.mat
```

Select **Preserve folder hierarchy** when exporting, so that the exported files are in the same locations relative to each other. Also, choose a root folder so that all the files listed in the manifest are inside it. Otherwise, any files outside the root are copied into a new folder called `external` underneath the root, and relative paths to those files become invalid.

If you are exporting a model that uses a `.m` file inside a MATLAB class (in a folder called `@myclass`, for example), you must select the **Preserve folder**

hierarchy check box when exporting, to maintain the folder structure of the class.

Always test exported ZIP files by extracting the contents to a new location on your computer and testing the model. Be aware that in some cases required files may be on your path but not in the ZIP file, if your path contains references to folders other than MathWorks toolboxes.

Using the Model Manifest Report

Report Sections

If you selected **View HTML report on completion** in the Generate Model Manifest dialog box, the Model Manifest Report appears after Simulink generates the manifest. The report shows:

- Analysis date
- **Actions** panel — Provides links to conveniently regenerate, edit or compare the manifest, and export the files in the manifest to a ZIP file.
- **Model Reference and Library Link Hierarchy** — Links you can click to open models.
- **Files used by this model** — Required files, with paths relative to the `projectroot`.

  You can sort the results by clicking the report column headers.
- **Toolboxes required by this model**. For details see "Required Toolboxes" on page 8-97.
- **References in this model** — This section provides details of references to other files so you can identify where dependencies arise. You control the scope of this section with the **Report file dependency locations** options on the Generate Manifest dialog box. You can choose to include references to user files only, all files or no files. See "Generating Manifests" on page

8-77. Use this section of the report to trace dependencies to understand why a particular file or toolbox is required by a model. If you need to analyze many references, it can be helpful to sort the results by clicking the report column headers.

- **Folders referenced by this model**
- **Orphaned base workspace variables** — If you selected the analysis option **Find orphaned base workspace data**, this section reports any base workspace variables the model requires that are not defined in a file in this manifest.
- **Warnings generated while analyzing MATLAB code** — You can opt out of this section by clearing the **Store MATLAB code analysis warnings in manifest** analysis option.
- **Dependency analysis settings** — Records the details of the analysis scope options.

See the examples shown in "Example Model Manifest Report" on page 8-98.

Required Toolboxes

In the report, the "Toolboxes required by this model" section lists all products required by the model *that the analysis can detect*. Be aware that the analysis might not report certain blocksets or toolboxes required by a model, e.g., blocksets that do not introduce dependence on any files (such as Simulink Fixed Point) cannot be detected.

The results reported can be affected by your analysis scope settings and your installed products. For example:

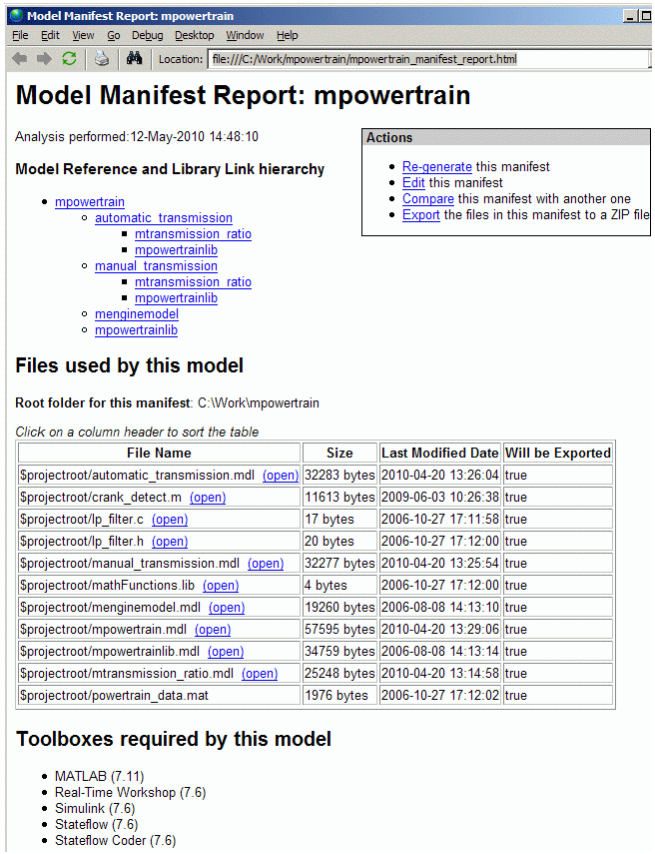
- If you have code generation products and select the scope option "**Find files required for code generation**", then:
  - Real-Time Workshop software is always reported as required.
  - If you also have an `.ert` system target file selected then Real-Time Workshop Embedded Coder software is always reported as required.
  - If your model uses Stateflow software, then Stateflow® Coder™ is always reported as required.

- If you clear the **Find library links** option, then the analysis cannot find a dependence on, for example, *`someBlockSet`*`.mdl`, and so no dependence is reported upon the block set.
- If you clear the **Analyze MATLAB files** option, then the analysis cannot find a dependence upon `fuzzy.m`, and so no dependence is reported upon the Fuzzy Logic Toolbox™.

Example Model Manifest Report

You should always check the **Dependency analysis settings** section in the Model Manifest Report to see the scope of analysis settings used to generate it.

Following are portions of a sample report.



Model Manifest Report: mpowertrain

File Edit View Go Debug Desktop Window Help

Location: file:///C:/Work/mpowertrain/mpowertrain_manifest_report.html

Model Manifest Report: mpowertrain

Analysis performed:12-May-2010 14:48:10

Actions

- Re-generate this manifest
- Edit this manifest
- Compare this manifest with another one
- Export the files in this manifest to a ZIP file

Model Reference and Library Link hierarchy

- mpowertrain
  - automatic_transmission
    - mtransmission_ratio
    - mpowertrainlib
  - manual_transmission
    - mtransmission_ratio
    - mpowertrainlib
  - menginemodel
  - mpowertrainlib

Files used by this model

Root folder for this manifest: C:\Work\mpowertrain

Click on a column header to sort the table

File Name	Size	Last Modified Date	Will be Exported
$projectroot/automatic_transmission.mdl (open)	32283 bytes	2010-04-20 13:26:04	true
$projectroot/crank_detect.m (open)	11613 bytes	2009-06-03 10:26:38	true
$projectroot/lp_filter.c (open)	17 bytes	2006-10-27 17:11:58	true
$projectroot/lp_filter.h (open)	20 bytes	2006-10-27 17:12:00	true
$projectroot/manual_transmission.mdl (open)	32277 bytes	2010-04-20 13:25:54	true
$projectroot/mathFunctions.lib (open)	4 bytes	2006-10-27 17:12:00	true
$projectroot/menginemodel.mdl (open)	19260 bytes	2006-08-08 14:13:10	true
$projectroot/mpowertrain.mdl (open)	57595 bytes	2010-04-20 13:29:06	true
$projectroot/mpowertrainlib.mdl (open)	34759 bytes	2006-08-08 14:13:14	true
$projectroot/mtransmission_ratio.mdl (open)	25248 bytes	2010-04-20 13:14:58	true
$projectroot/powertrain_data.mat	1976 bytes	2006-10-27 17:12:02	true

Toolboxes required by this model

- MATLAB (7.11)
- Real-Time Workshop (7.6)
- Simulink (7.6)
- Stateflow (7.6)
- Stateflow Coder (7.6)

References in this model

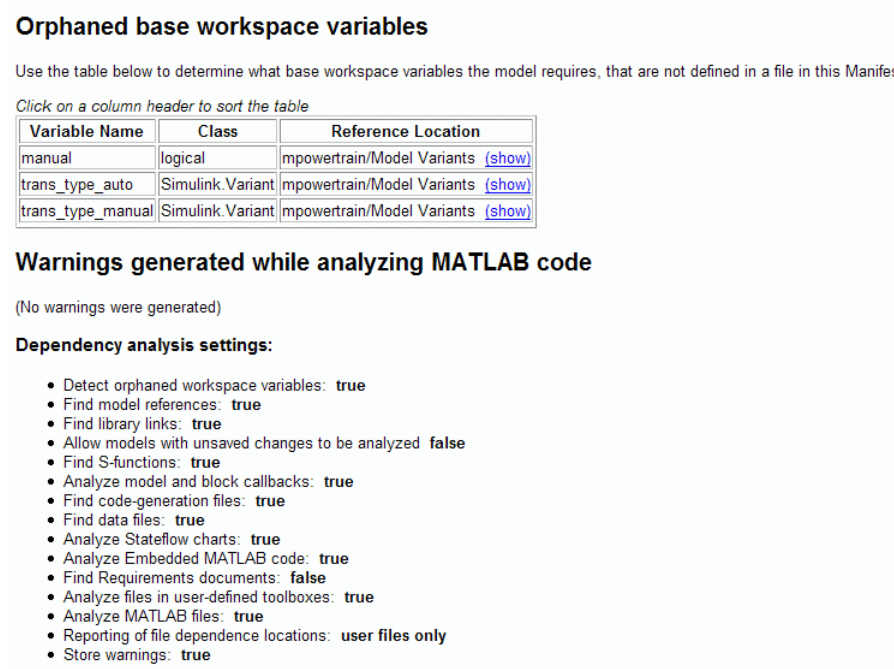
Use the table below to determine where in a model a dependence upon a particular file or toolbox originates.

Click on a column header to sort the table

Reference Type	Reference Location	File Name	Toolbox
ModelReference	mpowertrain/Model Variants (show)	$projectroot/automatic_transmission.mdl (open)	(not in a toolbox)
ModelReference	mpowertrain/Model Variants (show)	$projectroot/manual_transmission.mdl (open)	(not in a toolbox)
ModelReference	mpowertrain/engine model (show)	$projectroot/menginemodel.mdl (open)	(not in a toolbox)
LibraryLink	mpowertrain/Library Shift Logic (show)	$projectroot/mpowertrainlib.mdl (open)	(not in a toolbox)
ModelCallback,PreLoadFcn	mpowertrain (show)	$projectroot/powertrain_data.mat	(not in a toolbox)
RealTimeWorkshop,Configuration,CustomCode	automatic_transmission (show)	$projectroot/lp_filter.c (open)	(not in a toolbox)
RealTimeWorkshop,Configuration,CustomCode	automatic_transmission (show)	$projectroot/lp_filter.h (open)	(not in a toolbox)
RealTimeWorkshop,Configuration,CustomCode	automatic_transmission (show)	$projectroot/mathFunctions.lib (open)	(not in a toolbox)
LibraryLink	automatic_transmission/Grouped Unit Delay (show)	$projectroot/mpowertrainlib.mdl (open)	(not in a toolbox)
LibraryLink	automatic_transmission/Torque Converter/Torque Conversion (show)	$projectroot/mpowertrainlib.mdl (open)	(not in a toolbox)
ModelReference	automatic_transmission/transmission ratio (show)	$projectroot/mtransmission_ratio.mdl (open)	(not in a toolbox)
MSFunction	mtransmission_ratio/CrankSpeedSmoothing (show)	$projectroot/crank_detect.m (open)	(not in a toolbox)
RealTimeWorkshop,Configuration,CustomCode	manual_transmission (show)	$projectroot/lp_filter.c (open)	(not in a toolbox)
RealTimeWorkshop,Configuration,CustomCode	manual_transmission (show)	$projectroot/lp_filter.h (open)	(not in a toolbox)
RealTimeWorkshop,Configuration,CustomCode	manual_transmission (show)	$projectroot/mathFunctions.lib (open)	(not in a toolbox)
LibraryLink	manual_transmission/Grouped Unit Delay (show)	$projectroot/mpowertrainlib.mdl (open)	(not in a toolbox)
LibraryLink	manual_transmission/Torque Converter/Torque Conversion (show)	$projectroot/mpowertrainlib.mdl (open)	(not in a toolbox)
ModelReference	manual_transmission/transmission ratio (show)	$projectroot/mtransmission_ratio.mdl (open)	(not in a toolbox)

Folders referenced by this model

(This model does not refer to any folders)



Orphaned base workspace variables

Use the table below to determine what base workspace variables the model requires, that are not defined in a file in this Manifest

Click on a column header to sort the table

Variable Name	Class	Reference Location
manual	logical	mpowertrain/Model Variants (show)
trans_type_auto	Simulink.Variant	mpowertrain/Model Variants (show)
trans_type_manual	Simulink.Variant	mpowertrain/Model Variants (show)

Warnings generated while analyzing MATLAB code

(No warnings were generated)

Dependency analysis settings:

- Detect orphaned workspace variables: **true**
- Find model references: **true**
- Find library links: **true**
- Allow models with unsaved changes to be analyzed **false**
- Find S-functions: **true**
- Analyze model and block callbacks: **true**
- Find code-generation files: **true**
- Find data files: **true**
- Analyze Stateflow charts: **true**
- Analyze Embedded MATLAB code: **true**
- Find Requirements documents: **false**
- Analyze files in user-defined toolboxes: **true**
- Analyze MATLAB files: **true**
- Reporting of file dependence locations: **user files only**
- Store warnings: **true**

Using the Model Dependency Viewer

The Model Dependency Viewer displays a dependency view of a model. The dependency view is a graph of all the models and libraries referenced directly or indirectly by the model. You can use the dependency view to quickly find and open referenced libraries and models.

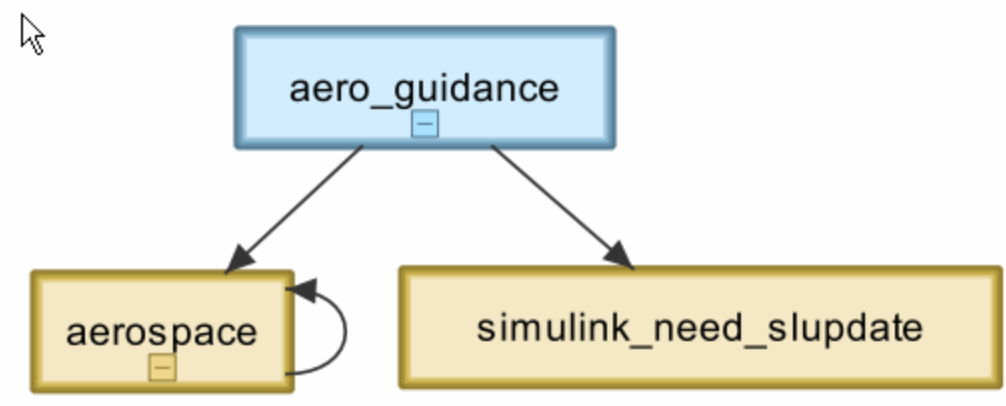
See the following topics for information on using the viewer:

- "About Model Dependency Views" on page 8-102
- "Opening the Model Dependency Viewer" on page 8-106
- "Manipulating a Dependency View" on page 8-107
- "Browsing Dependencies" on page 8-112
- "Saving a Dependency View" on page 8-112
- "Printing a Dependency View" on page 8-113

About Model Dependency Views

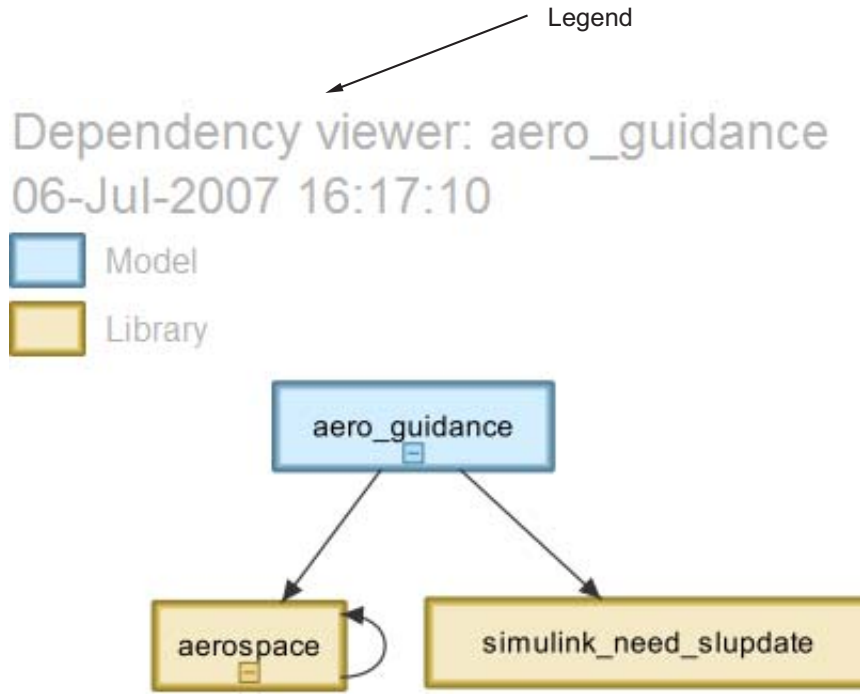
The Model Dependency Viewer allows you to choose between the following types of dependency views of a model reference hierarchy.

File Dependency View. A *file dependency* view shows the model and library files referenced by a top model. A referenced model or library file appears only once in the view even if it is referenced more than once in the model hierarchy displayed in the view. A file dependency view consists of a set of blocks connected by arrows. Blue blocks represent model files; brown boxes, libraries. Arrows represent dependencies. For example, the arrows in the following view indicate that the `aero_guidance` model references two libraries: `aerospace` and `simulink_need_slupdate`.

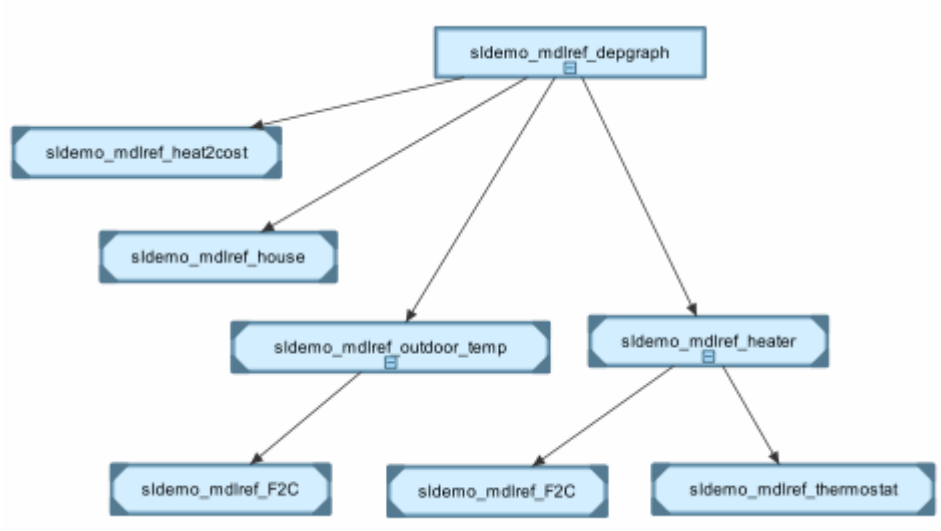


An arrow that points to the library from which it emerges indicates that the library references itself, i.e., blocks in the library reference other blocks in that same library. For example, the preceding view indicates that the `aerospace` library references itself.

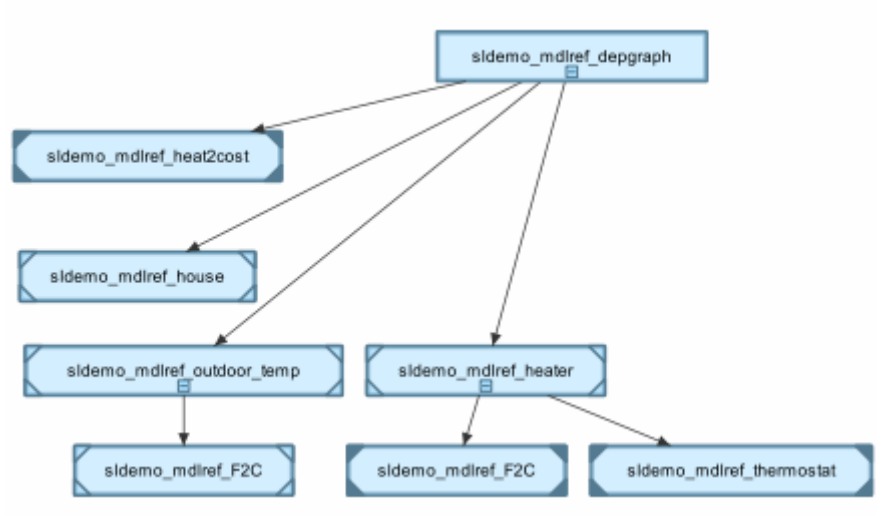
A file dependency view optionally includes a legend that identifies the model in the view and the date and time the view was created.



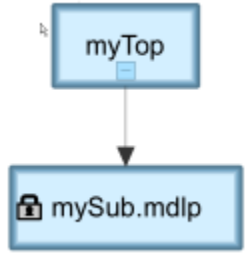
Referenced Model Instances View. A *referenced model instances* view shows every reference to a model in a model reference hierarchy (see Chapter 5, "Referencing a Model") rooted at the top model targeted by the view. If a model hierarchy references the same model more than once, the referenced model appears multiple times in the instance view, once for each reference. For example, the following view indicates that the model reference hierarchy rooted at `sldemo_mdlref_depgraph` contains two references to the model `sldemo_mdlref_F2C`.



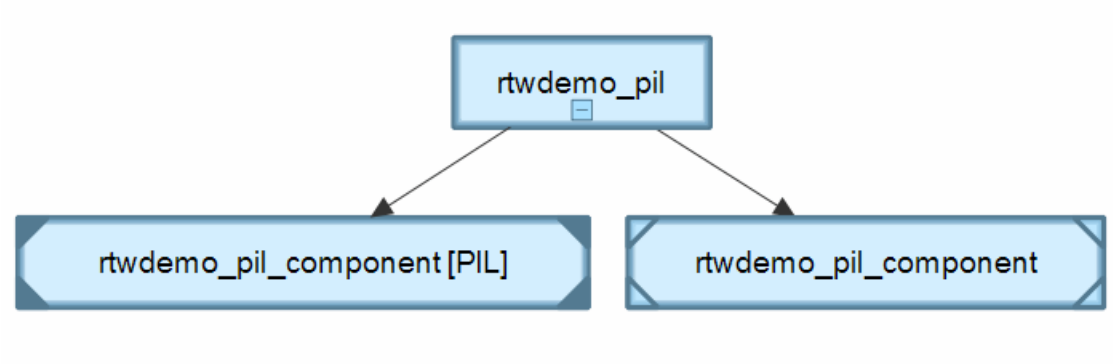
In an instance view, boxes represent a top model and model references. Boxes representing accelerated-mode instances (see “Referenced Model Simulation Modes” on page 5-12) have filled triangles in their corners; boxes representing normal-mode instances, have unfilled triangles in their corners. For example, the following diagram indicates that one of the references to `sldemo_mdlref_F2C` operates in normal mode; the other, in accelerated mode.



Boxes representing protected referenced models models have a lock icon, and the model name has the `.mdlp` extension. Protected referenced model boxes have no expand(+)/collapse(–) button.



Processor-in-the-Loop Mode Indicator. An instance view appends PIL to the names of models that run in Processor-in-the-Loop mode (see "Specifying the Simulation Mode" on page 5-14). For example, the following dependency instance view indicates that the model named `rtwdemo_pil_component` runs in processor-in-the-loop mode.



Warning Icon. An instance view displays warning icons on instance boxes to indicate that a reference is configured to run in Normal mode actually runs in Accelerated mode because it is directly or indirectly referenced by another model reference that runs in Accelerated mode.

The warning icon is a yellow triangle  .

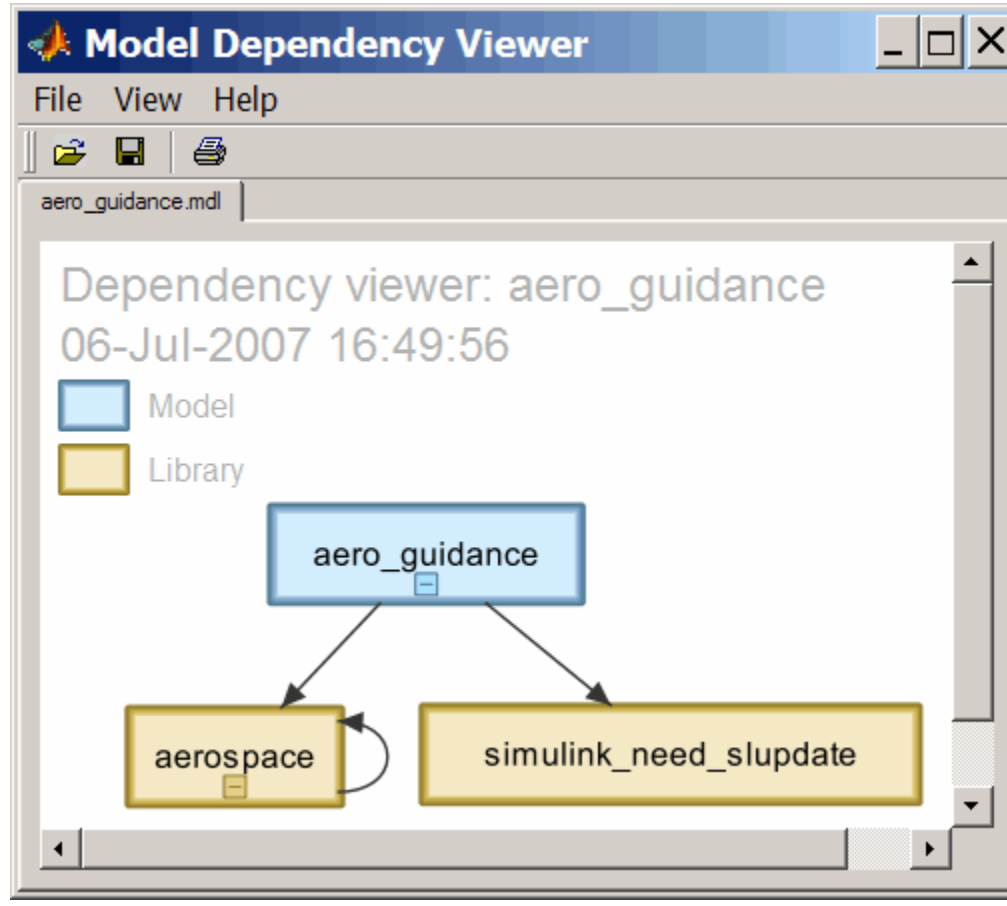
Opening the Model Dependency Viewer

The Model Dependency Viewer displays a graph of all the models and libraries referenced directly or indirectly by the model. You can use the dependency viewer to quickly find and open referenced libraries and models.

To display a dependency view for a model:

1. Open the model.
2. Select **Tools > Model Dependencies > Model Dependency Viewer**, then select the type of view you want to see:
   - **.mdl File Dependencies Including Libraries**
   - **.mdl File Dependencies Excluding Libraries**
   - **Referenced Model Instances**

   The Model Dependency Viewer appears, displaying a dependency view of the model.



Manipulating a Dependency View

The Model Dependency Viewer allows you to manipulate dependency views in various ways. See the following topics for more information:

- “Changing Dependency View Type” on page 8-108
- “Excluding Block Libraries from a File Dependency View” on page 8-108
- “Including Simulink Blocksets in a File Dependency View” on page 8-108
- “Changing View Orientation” on page 8-108

Changing Dependency View Type. You can change the type of dependency view displayed in the viewer.

To change the type of dependency view:

- Select **View > Dependency Type > .mdl File Dependencies** (see "File Dependency View" on page 8-102)

  or

- Select **View > Dependency Type > Referenced Model Instances** (see "Referenced Model Instances View" on page 8-103).

Excluding Block Libraries from a File Dependency View. By default a file dependency view includes libraries on which a model depends.

To exclude block libraries:

- Deselect **View > Include Libraries**.

Including Simulink Blocksets in a File Dependency View. By default, a file dependency view omits MathWorks block libraries when **View > Include Libraries** is selected.

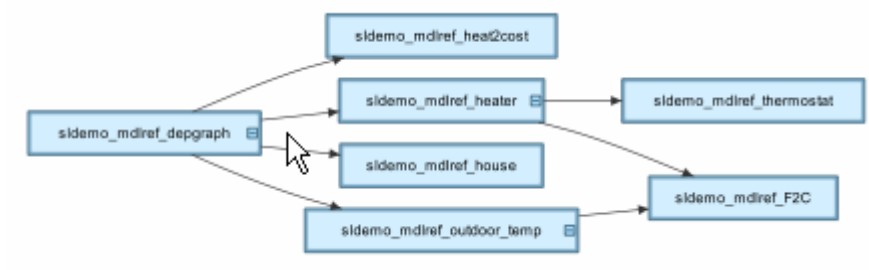
To include libraries supplied by MathWorks:

- Select **View > Show MathWorks Dependencies**.

Changing View Orientation. By default the orientation of the dependency graph displayed in the viewer is vertical.

To change the orientation to horizontal:

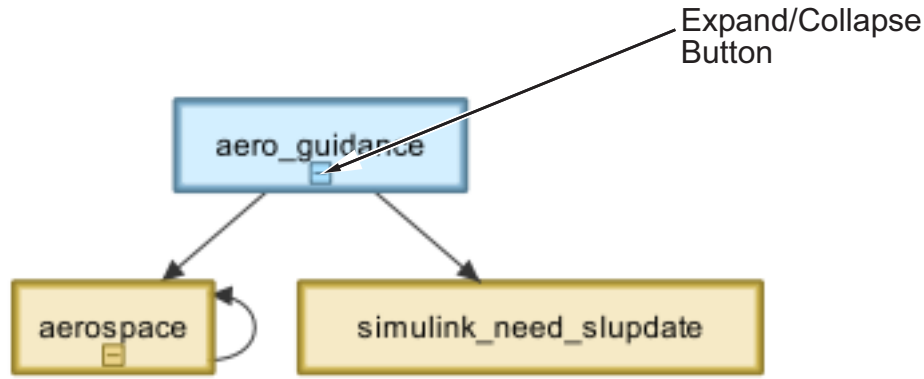
- Select **View > Orientation > Horizontal**.



Expanding or Collapsing Views. You can expand or collapse each model or library in the dependency view to display or hide the dependencies for that model or library.

To expand or collapse views:

- Click the expand(+)/collapse(-) button on the box representing the model or library to expand or collapse that view.



Zooming a Dependency View. You can enlarge or reduce the size of the dependency graph displayed in the viewer.

To zoom a dependency view in or out, do either of the following:

- Press and hold down the **spacebar** key and then press the **+** or **-** key on the keyboard.
- Move the scroll wheel on your mouse forward or backward.

To fit the view to the viewer window:

- Press and release the **spacebar** key.

Moving a Dependency View. You can move a dependency view to another location in the viewer window.

To move the dependency view:

1. Move the cursor over the view.
2. Press your keyboard's space bar and your mouse's left button simultaneously.
3. Move the cursor to drag the view to another location.

Rearranging a Dependency View. You can rearrange a dependency view by moving the blocks representing models and libraries. This can make a complex view easier to read.

To move a block to another location:

1. Select the block you want to move by clicking it.
2. Drag and drop the block in the new location.

Displaying and Hiding a Dependency View's Legend. The dependency view can display a legend that identifies the model in the view and the date and time the view was created.

To display or hide a dependency view's legend:

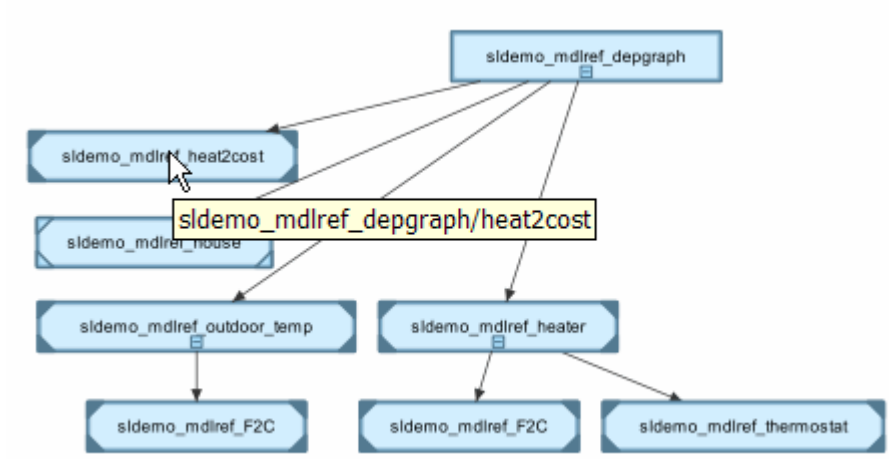
- Select **View > Show Legend** from the viewer's menu bar.

Displaying Full Paths of Referenced Model Instances. In an instance view (see “Referenced Model Instances View” on page 8-103) , you can display the full path of a model reference in a tooltip or in the box representing the reference.

To display the full path in a tooltip:

- Move the cursor over the box representing the reference in the view.

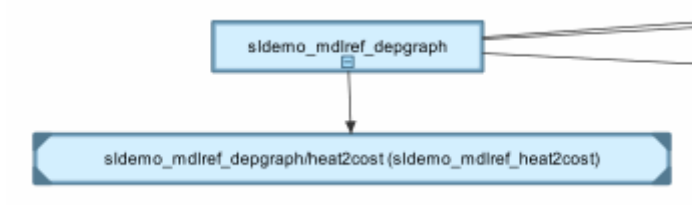
  A tooltip appears, displaying the path displays the full path of the Model block corresponding to the instance.



To display full paths in the boxes representing the instances:

- Select **View > Show Full Path**.

  Each box in the instance view now displays the path of the Model block corresponding to the instance. The name of the referenced model appears in parentheses as illustrated in the following figure.



Refreshing a Dependency View. After changing a model displayed in a dependency view or any of its dependencies, you must update the view to reflect any dependency changes.

To update the view:

- Select **View > Refresh** from the dependency viewer's menu bar.

Browsing Dependencies

You can use a dependency view to browse a model's dependencies:

- To open a model or library displayed in the view, double-click its block.
- To display the Model block corresponding to an instance in an instance view, right-click the instance and select **Highlight Block** from the menu that appears.
- To open all models displayed in the view, select **File > Open All Models** from the viewer's menu bar.
- To save all models displayed in the view, select **File > Save All Models**.
- To close all models displayed in the view, select **File > Close All Models**.

Saving a Dependency View

You can save a dependency view for later viewing.

To save the current view:

- Select **File > Save As** from the viewer's menu bar, then enter a name for the view.

To reopen the view:

- Select **File > Open** from any viewer's menu bar, then select the view you want to open.

Printing a Dependency View

To print a dependency view:

- Select **File > Print** from the dependency viewer's menu bar.

Viewing Linked Requirements in Models and Blocks

In this section...

Overview of Requirements Features in Simulink

If your Simulink model has links to requirements in external documents, you can review these links. To identify which model objects satisfy certain design requirements, use the requirements features available in Simulink software.

- Highlighting objects in your model that have links to external requirements
- Viewing information about a requirements link
- Navigating from a model object to its associated requirement
- Filtering requirements highlighting based on specified keywords

Having a Simulink Verification and Validation license enables you to perform the following additional tasks, using he Requirements Management Interface (RMI):

- Adding new requirements
- Changing existing requirements
- Deleting existing requirements
- Applying user tags to requirements
- Creating reports about requirements links in your model
- Checking the validity of the links between the model objects and the requirements documents

Highlighting Requirements in a Model

You can highlight a model to identify which objects in the model have links to requirements in external documents. Both the Model Editor and the Model Explorer provide this capability.

In addition, you can filter highlighted objects based on specified user tags associated with a requirement.

- "Highlighting a Model Using the Model Editor" on page 8-115
- "Highlighting a Model Using the Model Explorer" on page 8-117

Note If your model contains a Model block whose referenced model contains requirements, those requirements are not highlighted. You can view this information only in requirements reports. To generate requirements information for referenced models and then see highlighted snapshots of those requirements, follow the steps in "Reporting on Requirements in Model Blocks".

Highlighting a Model Using the Model Editor

If you are working in the Model Editor and want to see which model objects in the `slvnvdemo_fuelsys_officereq` model have requirements, follow these steps:

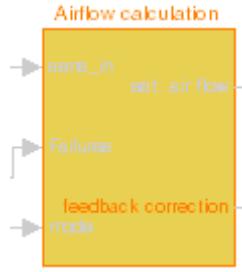
1. Open the demo model:

   ```
   slvnvdemo_fuelsys_officereq
   ```

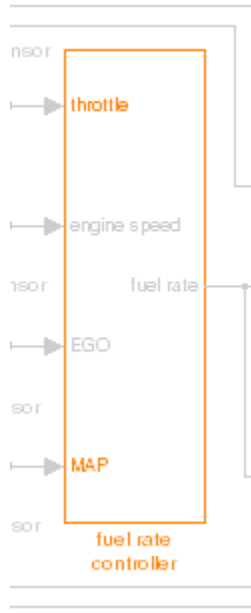
2. Select **Tools > Requirements > Highlight model**.

   Two types of highlighting indicate model objects with requirements:

   - Yellow fill indicates objects that have requirements links for the object itself.



- Orange outline indicates objects, such as subsystems, whose child objects have requirements links.



Objects that do not have requirements appear dimmed.

3 To remove the highlighting from the model, select **Tools > Requirements > Unhighlight model**. Alternatively, you can right-click anywhere in the model, and select **Remove Highlighting**.

While a model is highlighted, you can still manage the model and its contents as you do normally.

Highlighting a Model Using the Model Explorer

If you are working in the Model Explorer and want to see which model objects have requirements, follow these steps:

1 Open the demo model:

```
slvnvdemo_fuelsys_officereq
```

2 Select **View > Model Explorer**.

3 To highlight the model objects with requirements, click the **Highlight items with requirements on model** icon ( ).

The Model Editor window opens, and all objects in the model with requirements are highlighted.

Viewing Information About a Requirements Link

Using Simulink, you can view detailed information about a requirements link, such as identifying the location and type of document that contains the requirement.

Note You can only modify the requirements information if you have a Simulink Verification and Validation license.

For example, to view information about the requirements link from the MAP Sensor block in the `slvnvdemo_fuelsys_officereq` demo model, follow these steps:

1. Open the demo model:

   ```
   slvnvdemo_fuelsys_officereq
   ```

2. Right-click the MAP sensor block, and select **Requirements > Edit/Add Links**.

   The Requirements dialog box opens and displays the following information about the requirements link:

   - The description of the link (which is the actual text of the requirement).
   - The Microsoft® Excel® workbook named `slvnvdemo_FuelSys_TestScenarios.xlsx`, which contains the linked requirement.
   - The requirements text, which appears in the named cell `Simulink_requirement_item_2` in the workbook.
   - The user tag `test`, which is associated with this requirement.

Navigating to Requirements from a Model

Navigating from the Model Object

You can navigate directly from a model object to that object's associated requirement. When you take these steps, the external requirements document opens in the appropriate application, with the requirements text highlighted:

1. Open the demo model:

   ```
   slvnvdemo_fuelsys_officereq
   ```

2. Open the fuel rate controller subsystem.

3. To open the linked requirement, right-click the Airflow calculation subsystem and select **Requirements > 1. "Mass airflow estimation"**.

The Microsoft Word document, `slvnvdemo_FuelSys_DesignDescription.docx`, opens, with the section **2.1 Mass airflow estimation** selected.

Navigating from a System Requirements Block

Sometimes you want to see all the requirements links at a given level of the model hierarchy. In such cases, you can insert a System Requirements block to collect all requirements links in the model or subsystem. The System Requirements block does not list requirements links for any blocks for that model or subsystem.

For example, you can insert the System Requirements block at the top level of the `slvnvdemo_fuelsys_officereq` model, and navigate to the requirements using the links inside the block:

1. Open the demo model:

   ```
   slvnvdemo_fuelsys_officereq
   ```

2. Select **Tools > Requirements > Highlight model**.

3. In the `slvnvdemo_fuelsys_officereq` model, open the fuel rate controller subsystem.

   The Airflow calculation subsystem has a requirements link.

4. Open the Airflow calculation subsystem.

5. Select **View > Library Browser**

6. On the **Libraries** pane, click the **Simulink Verification and Validation** library.

   This library contains only one block—the System Requirements block.

7. Drag a System Requirements block into the Airflow calculation subsystem.

   The RMI software collects and displays any requirements links for that subsystem.

8. Double-click **1. "Mass airflow subsystem"**.

The Microsoft Word document, `slvnvdemo_FuelSys_DesignDescription.docx`, opens, with the section **2.1 Mass airflow estimation** selected.

Filtering Requirements in a Model

Filtering Requirements Highlighting by User Tag

Some requirements links in your model can have one or more associated user tags. *User tags* are keywords that you create to categorize a requirement, for example, `design` or `test`.

For example, in the `slvnvdemo_fuelsys_officereq` model, the requirements link from the MAP sensor block has the user tag `test`.

To highlight only all the blocks that have a requirement with the user tag `test`:

1. Open the demo model:

   ```
   slvnvdemo_fuelsys_officereq
   ```

2. In the Model Editor, select **Tools > Requirements > Settings**.

   The Requirements Settings dialog box opens. If you do not have a Simulink Verification and Validation license, the **Filters** tab is the only option available.

   By default, your model has no requirements filtering enabled.

3. Select **Filter links by user tags when highlighting and reporting requirements**.

4. In the **Include links with any of these tags** text box, delete `design`, and enter `test`.

5. Press **Enter**.

6 Highlight the `slvnvdemo_fuelsys_officereq` model for requirements. Select **Tools > Requirements > Highlight model**.

   In the top-level model, only the MAP sensor block and the Test inputs block are highlighted.

7 To disable the filtering by user tag, select **Tools > Requirements > Settings**, and clear **Filter links by user tags when highlighting and reporting requirements**.

   The model highlighting updates immediately.

Filtering Options for Highlighting Requirements

On the **Filters** tab, you select options that designate which objects with requirements are highlighted. The following table describes these settings, which apply to all requirements in your model for the duration of your MATLAB session.

Option	Description
Filter links by user tags when highlighting and reporting requirements	Enables filtering for highlighting and reporting, based on specified user tags.
Include links with any of these tags	Highlights all objects whose requirements match at least one of the specified user tags. The tag names must match exactly. Separate multiple user tags with commas or spaces.
Exclude links with any of these tags	Excludes from the highlighting all objects whose requirements match at least one of the specified user tags. The tag names must match exactly. Separate multiple user tags with commas or spaces.

Option	Description
Apply same filters in context menus	Disables navigation links in context menus for all objects whose requirements do not match at least one of the specified user tags.
Under **Link type filters**, **Disable DOORS surrogate item links in context menus**	Disables links to IBM® Rational® DOORS® surrogate items from the context menus when you right-click a model object. This option does not depend on current user tag filters.

9

Managing Configuration Sets

Setting Up Configuration Sets

In this section...

About Configuration Sets

A *configuration set* is a named set of values for the parameters of a model, such as solver type and simulation start or stop time. Every new model is created with a default configuration set, called Configuration, that initially specifies default values for the model parameters. You can subsequently create and modify additional configuration sets and associate them with the model. The sets associated with a model can specify different values for any or all configuration parameters.

This section describes techniques for defining and using configuration sets that are stored in individual models. These configuration sets are available only to the model that contains them. The next section, "Referencing

Configuration Sets" on page 9-14, describes techniques for storing configuration sets in the base workspace, independently of any model. They can be shared by any number of models.

Configuration Set Components

A configuration set comprises groups of related parameters called components. Every configuration set includes the following components:

- Solver
- Data Import/Export
- Optimization
- Diagnostics
- Hardware Implementation
- Model Referencing
- Simulation Target

Some MathWorks products that work with Simulink, such as Real-Time Workshop, define additional components. If such a product is installed on your system, the configuration set also contains the components that the product defines.

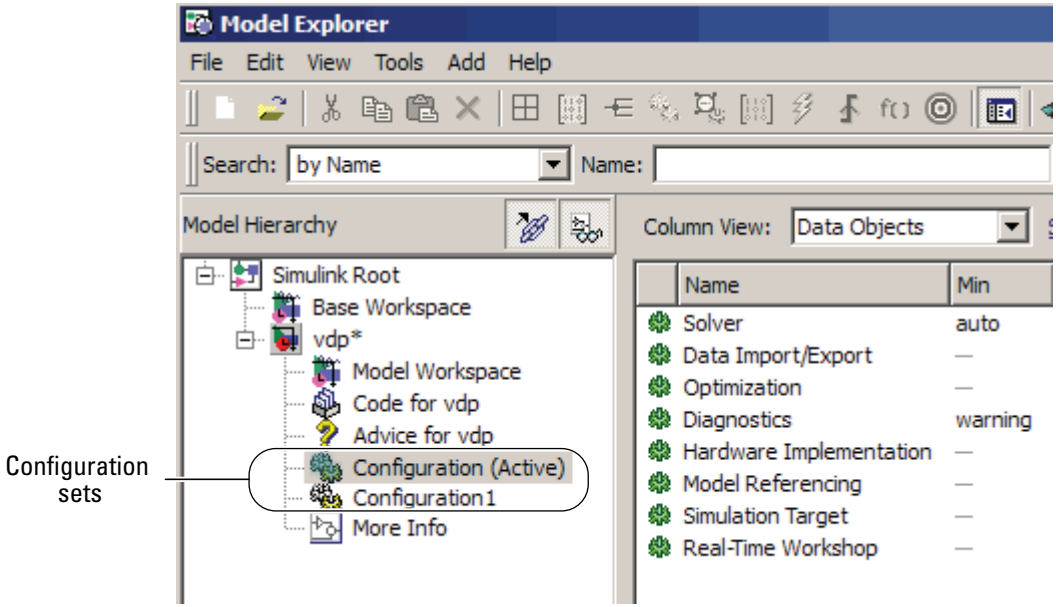
The Active Set

Only one of the configuration sets associated with a model is active at any given time. The active set determines the current values of the model parameters. Changing the value of a parameter in the Model Explorer changes its value in the associated configuration set. You can change the active or inactive set at any time (except when executing the model). In this way, you can quickly reconfigure a model for different purposes, for example, testing and production, or apply standard configuration settings to new models.

Displaying Configuration Sets

To display the configuration sets associated with a model, open the Model Explorer (see "The Model Explorer: Overview" on page 8-2). The configuration

sets associated with the model appear as gear-shaped nodes in the **Model Hierarchy** pane.



The **Contents** pane in the Model Explorer displays the components of the selected configuration set. The **Dialog** pane displays a dialog box for setting the parameters of the selected group (see "Configuration Parameters Dialog Box").

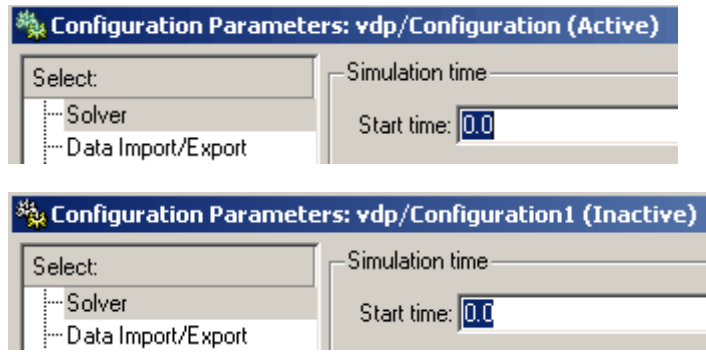
Activating a Configuration Set

To activate a configuration set, right-click the configuration set's node to display the context menu, then select **Activate** from the context menu.

Opening Configuration Sets

In the Model Explorer, to open the Configuration Parameters dialog box for a configuration set, right-click the configuration set's node to display the context menu, then select **Open**. You can open the Configuration Parameters dialog box for any configuration set, whether or not it is active. You might want to open a configuration set to inspect or edit the parameter settings.

The title bar of the dialog box indicates whether the configuration set is active or inactive.



Note Every configuration set has its own Configuration Parameters dialog box. As you change the state of a configuration set, the title bar of the dialog box changes to reflect the state.

Copying, Deleting, and Moving Configuration Sets

You can use edit commands on the Model Explorer **Edit** or context menus or object drag-and-drop operations to delete, copy, and move configuration sets among models displayed in the **Model Hierarchy** pane.

For example, to copy a configuration set, using edit commands:

1. Select the model with a configuration set that you want to copy in the **Model Hierarchy** pane.
2. Select the configuration set that you want to copy in the **Contents** pane.
3. Select **Copy** from the Model Explorer **Edit** menu or the configuration set's context menu.
4. Select the model in which you want to create the copy.

Note You can create a copy in the same model as the original.

5 Select **Paste** from the Model Explorer **Edit** menu or from the model's context menu.

To copy the configuration set, using object drag-and-drop, hold the right mouse button down and drag the configuration set's node to the node of the model in which you want to create the copy. To move a configuration set from one model to another, using drag-and-drop, hold the left mouse button down and drag the configuration set's node to the node of the destination model.

Note You cannot move or delete an active configuration set from a model.

Copying Configuration Set Components

To copy a configuration set component from one configuration set to another:

1 Select the component in the Model Explorer **Contents** pane.

2 Select **Copy** from the Model Explorer **Edit** menu or the component's context menu.

3 Select the configuration set into which you want to copy the component.

4 Select **Paste** from the Model Explorer **Edit** menu or the component's context menu.

Note The copy replaces the component of the same name in the destination configuration set. For example, if you copy the Solver component of configuration set A and paste it into configuration set B, the copy replaces the existing Solver component in B.

Creating Configuration Sets

To create a new configuration set, select **Configuration Set** from the Model Explorer **Add** menu or click the **Add Configuration** button  in the Model Explorer toolbar. You can also create a new configuration set by copying an existing configuration set.

Saving Configuration Sets

You can save the settings of configuration sets as MATLAB functions or scripts. Using the MATLAB function or script, you can share and archive model configuration sets. You can also compare the settings in different configuration sets by comparing the MATLAB functions or scripts of the configuration sets.

You can use the following methods to save configuration sets:

- "Saving a Configuration Set from the Model Explorer" on page 9-7
- "Saving the Active Configuration Set from the Command Line" on page 9-8
- "Saving a Configuration Set from the Command Line" on page 9-8

Saving a Configuration Set from the Model Explorer

To save an active or inactive configuration set from the Model Explorer:

1. Open the model.
2. Open the Model Explorer.
3. Save the configuration set:
   a. In the **Model Hierarchy** pane:
      - Right-click the model node and select **Export Active Configuration Set**.
      - Right-click a configuration set and select **Export**.
      - Select the model. In the **Contents** pane, right-click a configuration set and select **Export**.

b In the Export Configuration Set to File dialog box, specify the name of the file and the file type. If you specify a `.m` extension, the file contains a function that creates a configuration set object. If you specify a `.mat` extension, the file contains a configuration set object.

Note Do not specify the name of the file to be the same as a model name. If the file and model have the same name, the software cannot determine which file contains the configuration set object when loading the file.

---

c Click **Save**. The Simulink software saves the configuration set.

Saving the Active Configuration Set from the Command Line

To save the active configuration set from the command line:

1. Open the model.
2. Use the `Simulink.BlockDiagram.saveActiveConfigSet` function to save the active configuration set.

Saving a Configuration Set from the Command Line

To save an active or inactive configuration set as a MATLAB function or script:

1. Use the `getActiveConfigSet` or `getConfigSet` function to get a handle to the configuration set.
2. Use the `saveAs` method of the `Simulink.Configset` class to save the configuration set as a function or script.

Loading Saved Configuration Sets

You can load configuration sets that you previously saved as MATLAB functions or scripts.

You can use the following methods to load configuration sets:

- "Loading a Configuration Set from the Model Explorer" on page 9-9

Loading a Configuration Set from the Model Explorer

To load a configuration set from the Model Explorer:

1. Open the model.
2. Open the Model Explorer.
3. In the **Model Hierarchy** pane, right-click the model and select **Import Configuration Set**.
4. In the Import Configuration Set From File dialog box, select the `.m` file that contains the function to create the configuration set object, or the `.mat` file that contains the configuration set object.
5. Click **Open**. The Simulink software loads the configuration set.

Note If you load a configuration set object that contains an invalid custom target, the software sets the **"System target file"** parameter to `ert.tlc`.

---

6. Optionally, activate the configuration set. For more information, see "Activating a Configuration Set" on page 9-4.

Loading and Activating a Configuration Set from the Command Line

To load a configuration set from the command line and make it the active configuration set:

1. Open the model.
2. Use the `Simulink.BlockDiagram.loadActiveConfigSet` function to load the configuration set and make it active.

Note If you load a configuration set with the same name as the:

- Active configuration set, the software overwrites the active configuration set.
- Inactive configuration set that is associated with the model, the software detaches the inactive configuration from the model.

Loading a Configuration Set from the Command Line

To load a configuration set from a MATLAB function or script:

1. Use the `getActiveConfigSet` or `getConfigSet` function to get a handle to the configuration set that you want to update.
2. Call the MATLAB function or execute the MATLAB script to load the saved configuration set.
3. Optionally, use the `attachConfigSet` function to attach the configuration set to the model. To avoid configuration set naming conflicts, set *`allowRename`* to `true`.
4. Optionally, activate the configuration set. For more information, see "Activating a Configuration Set" on page 9-4.

Setting Values in Configuration Sets

To set the value of a parameter in a configuration set, select the configuration set in the Model Explorer and then edit the value of the parameter on the corresponding dialog box in the **Dialog** pane.

Configuration Set API

An application program interface (API) lets you create and manipulate configuration sets from the command line or in a script. The API includes the `Simulink.ConfigSet` data object class and the following functions:

- `attachConfigSet`
- `attachConfigSetCopy`

- `detachConfigSet`
- `getConfigSet`
- `getConfigSets`
- `setActiveConfigSet`
- `getActiveConfigSet`
- `openDialog`
- `closeDialog`
- `Simulink.BlockDiagram.saveActiveConfigSet`
- `Simulink.BlockDiagram.loadActiveConfigSet`

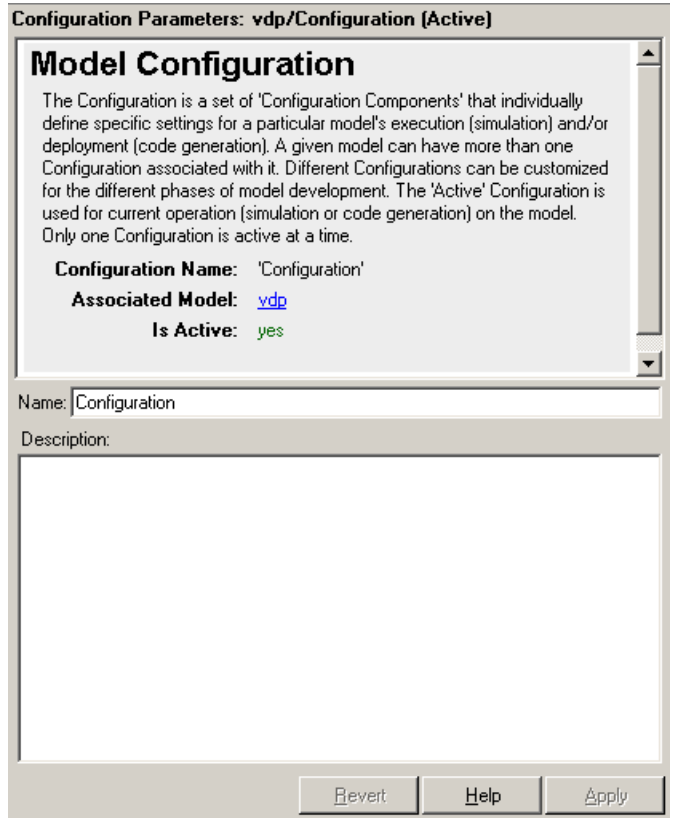
These functions, along with the methods and properties of `Simulink.ConfigSet` class, allow you to create a script to:

- Create and modify configuration sets.
- Attach configuration sets to a model.
- Set the active configuration set for a model.
- Open and close configuration sets.
- Detach configuration sets from a model.
- Save configuration sets.
- Load configuration sets.

For examples using the above functions and the `Simulink.ConfigSet` class, see the function and class reference pages.

Model Configuration Dialog Box

The Model Configuration dialog box appears in the Model Explorer **Dialog** pane when you select any model configuration.



You can edit the name and description of your configuration. See “Model Configuration Pane”.

Model Configuration Preferences Dialog Box

The Model Configuration Preferences dialog box appears in the Model Explorer **Dialog** pane when you view the default model configuration.

1. Enable **View > Show Configuration Preferences** in the Model Explorer menu.
2. Select **Configuration Preferences** under the **Simulink Root** node in the Model Explorer **Model Hierarchy** pane.

You can also edit the configuration defaults in the Simulink Preferences window. See “Model Configuration Pane”.

Referencing Configuration Sets

In this section...

Overview of Configuration References

By default, a configuration set resides within a single model, so that only that model can use it. Alternatively, you can store a configuration set independently, so that you can use it with any models. A configuration set that exists outside any model is a *freestanding configuration set*. Each model that uses a freestanding configuration set defines a *configuration reference* that points to the configuration set. The result is the same as if the referenced configuration set resides within the model.

Reasons to Use Configuration References

You can use configuration references and freestanding configuration sets to:

- **Assign the same configuration set to any number of models**

  Each model that uses a given configuration set contains a configuration reference that points to a MATLAB variable. The value of that variable is a freestanding configuration set. All the models share that configuration set, and changing the value of any parameter in the set changes it for every model that uses the set. Use this feature to reconfigure many submodels quickly and ensure consistent configuration of parent models and referenced models.

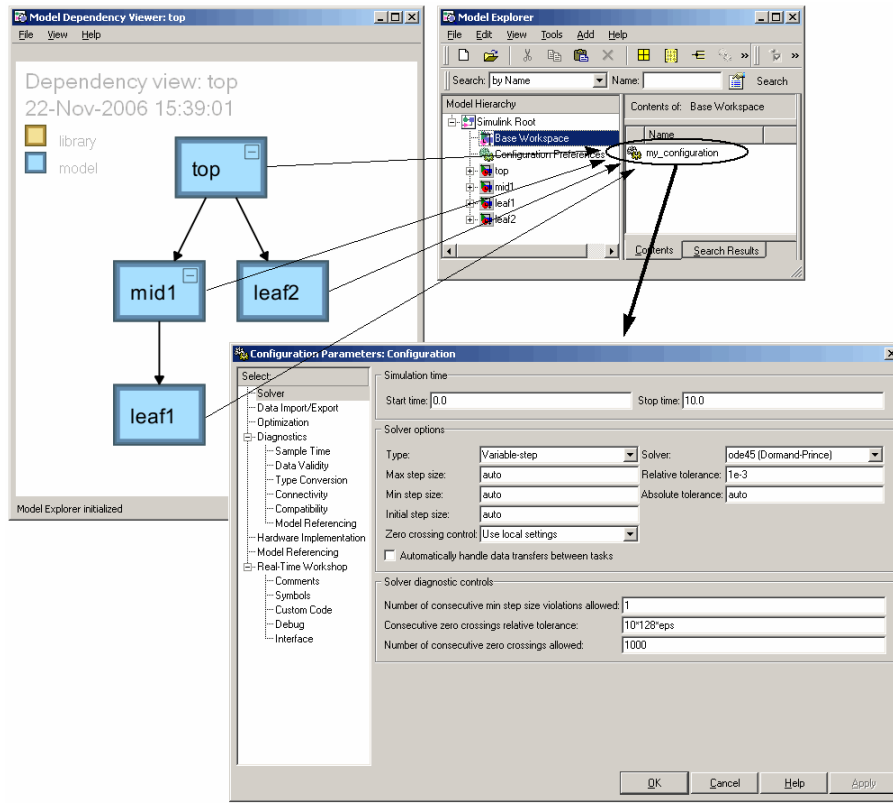
- **Replace the configuration sets of any number of models without changing the model files**

  When multiple models use configuration references to access a freestanding configuration set, assigning a different set to the MATLAB variable assigns that set to all models. Use this feature to maintain a library of configuration sets and assign them to any number of models in a single operation.

- **Use different configuration sets for a referenced model used in different contexts without changing the model file**

  A submodel that uses different configuration sets in different contexts contains a configuration reference that specifies the submodel configuration set as a variable. When you call an instance of the submodel, Simulink software assigns that variable a freestanding configuration set for the current context.

The next figure shows one way to use configuration references. Each model that appears in the Model Dependency Viewer specifies the configuration reference `my_reference` as its active configuration set, and `my_reference` points to the freestanding configuration set `Configuration`. The parameter values in `Configuration` therefore apply to all four models, and any parameter change in `Configuration` applies to all four models.



Basic Steps for Using a Configuration Reference

To use a configuration reference to link a freestanding configuration set to a model, follow these steps.

Step	Task	Reference
1	Create or obtain a configuration set and store it in the base workspace as the value of a MATLAB variable.	"Creating a Freestanding Configuration Set" on page 9-17
2	Create a configuration reference that specifies the relevant MATLAB variable.	"Creating and Attaching a Configuration Reference" on page 9-19

Step	Task	Reference
3	Attach the configuration reference to a model.	"Creating and Attaching a Configuration Reference" on page 9-19
4	Activate the configuration reference.	"Activating a Configuration Reference" on page 9-26
5	Access, set, and change configuration set parameters and the MATLAB variable as needed.	• "Getting Values from a Referenced Configuration Set" on page 9-27 • "Changing Values in a Referenced Configuration Set" on page 9-27 • "Replacing a Referenced Configuration Set" on page 9-29

Comparison of Configuration References and Configuration Sets

A configuration reference is an object of type `Simulink.ConfigSetRef`, and a configuration set is an object of type `Simulink.ConfigSet`. The two classes are similar in many ways. Wherever the same operation is applicable to both, the relevant functions and methods overload to work with either class. For example, you can `attach` or `activate` a configuration set or a configuration reference using the same GUI operations and API syntax.

You cannot nest configuration references, because only one level of indirection is available. You can obtain configuration parameter values by operating on a configuration reference as if it were the configuration set that it references. See "Getting Values from a Referenced Configuration Set" on page 9-27 for details. General information about configuration sets appears in "Setting Up Configuration Sets" on page 9-2.

Creating a Freestanding Configuration Set

All freestanding configuration sets reside in the base workspace as the values of MATLAB variables. Although you can store a configuration set in a model

and point to it with a base workspace variable, such a configuration set is not freestanding. Trying to use it in a configuration reference causes an error. You can store a freestanding configuration set in the base workspace in these ways:

- Create and populate a new configuration set.
- Copy a configuration set that resides within a model.
- Load a configuration set from a MAT-file.

You can store any number of configuration sets in the base workspace by assigning each set to a different variable. Use any technique to manipulate a freestanding configuration set and its parameter values that you use with a configuration set stored directly in a model.

Creating and Populating a New Configuration Set

You can create a configuration set in the base workspace using any of the techniques described in "Creating Configuration Sets" on page 9-7 or as follows:

```
cset = Simulink.ConfigSet
```

where *cset* is a new or existing base workspace variable. The new configuration set initially has default parameter values, copied from the default configuration set.

Copying a Configuration Set Stored in a Model

You can copy an existing configuration set to the base workspace using drag and drop operations described in "Copying, Deleting, and Moving Configuration Sets" on page 9-5, and assign the set to a MATLAB variable. For example:

```
cset = copy (getActiveConfigSet(mdl))
cset = copy (getConfigSet(mdl, ConfigSetName))
```

where *mdl* is any open model, and *ConfigSetName* is the name of any configuration set attached to the model. The first example obtains the currently active configuration set. The second example obtains a configuration set by specifying the name under which it appears in the Model Explorer.

Be sure to copy any configuration set obtained from an existing model, as shown in the examples. Otherwise, *`cset`* refers to the existing configuration set stored in the model, rather than a new freestanding configuration set in the base workspace. In this case, any use of a configuration reference that links to *`cset`* causes an error.

Reading a Configuration Set from a MAT-File

To use a freestanding configuration set across multiple MATLAB sessions, you can save it to a MAT-file. To create the MAT-file, you first copy the configuration set to a base workspace variable, as previously described, then save the variable to the MAT-file:

```
save (workfolder/ConfigSetName.mat, cset)
```

where *`workfolder`* is a working folder, *`ConfigSetName`*`.mat` is the MAT-file name, and *`cset`* is a base workspace variable whose value is the configuration set to save. When you later reopen your model, you can reload the configuration set into the variable:

```
load (workfolder/ConfigSetName.mat)
```

To execute code that reads configuration sets from MAT-files, use one of these techniques:

- The preload function of a top model
- The MATLAB startup script
- Interactive entry of `load` statements

Any technique that executes the necessary code works.

Creating and Attaching a Configuration Reference

After you store a configuration set in the base workspace, you can link to that set from a configuration reference and attach it to a model. The model then has the same configuration parameters that it does as if the referenced configuration set resides directly in the model. You can attach any number of configuration references to a model. Each reference must have a unique name.

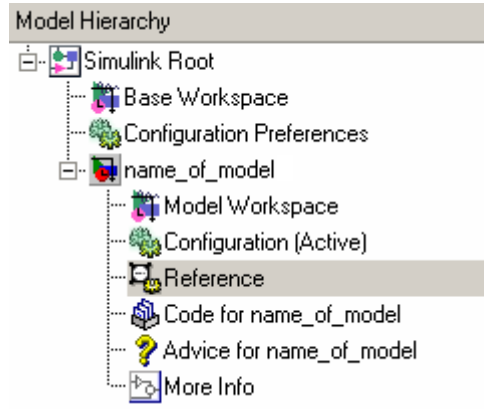
GUI Techniques

To create a configuration reference using the GUI:

1. In the Model Explorer, select the model to which to attach the configuration reference.

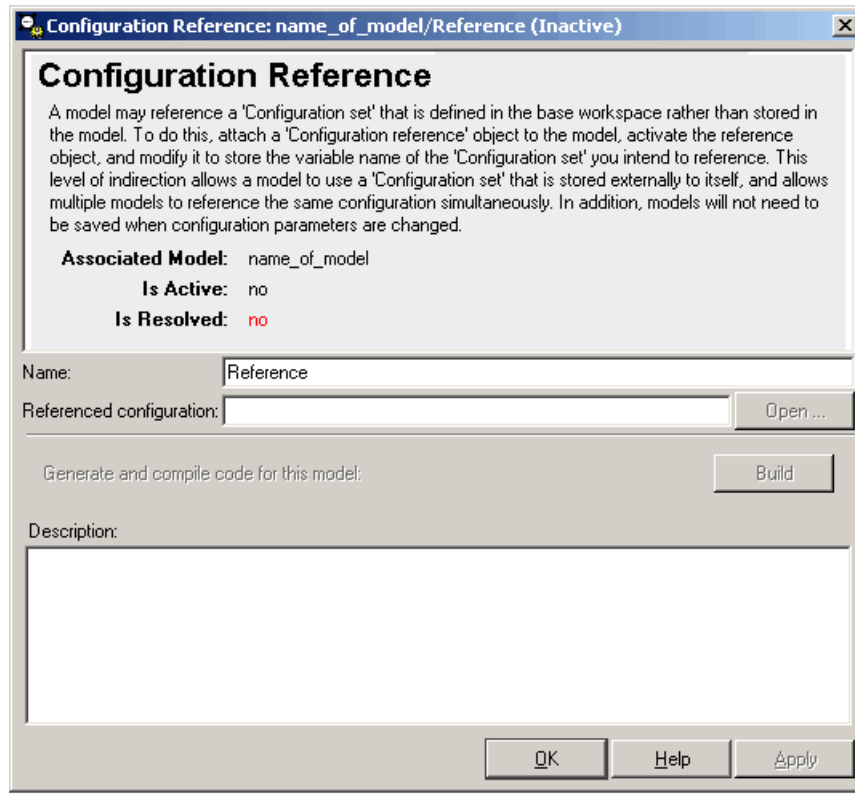
2. Click the **Add Reference** tool  or select **Add > Configuration Reference**.

   A new configuration reference attaches to the selected model. The default name of the new reference is `Reference`, with a digit appended if necessary to prevent name conflict. The name of the configuration reference appears in the Model Hierarchy pane under the Model Workspace icon, below the names of any configuration sets.



3. Select the new configuration reference in the Model Hierarchy pane, or right-click the configuration reference and select **Open** from the context menu.

   The Configuration Reference dialog box appears in the Dialog pane or a separate window.



4 Change the default **Name** if desired. This name exists for human readability and does not affect the configuration reference functionally.

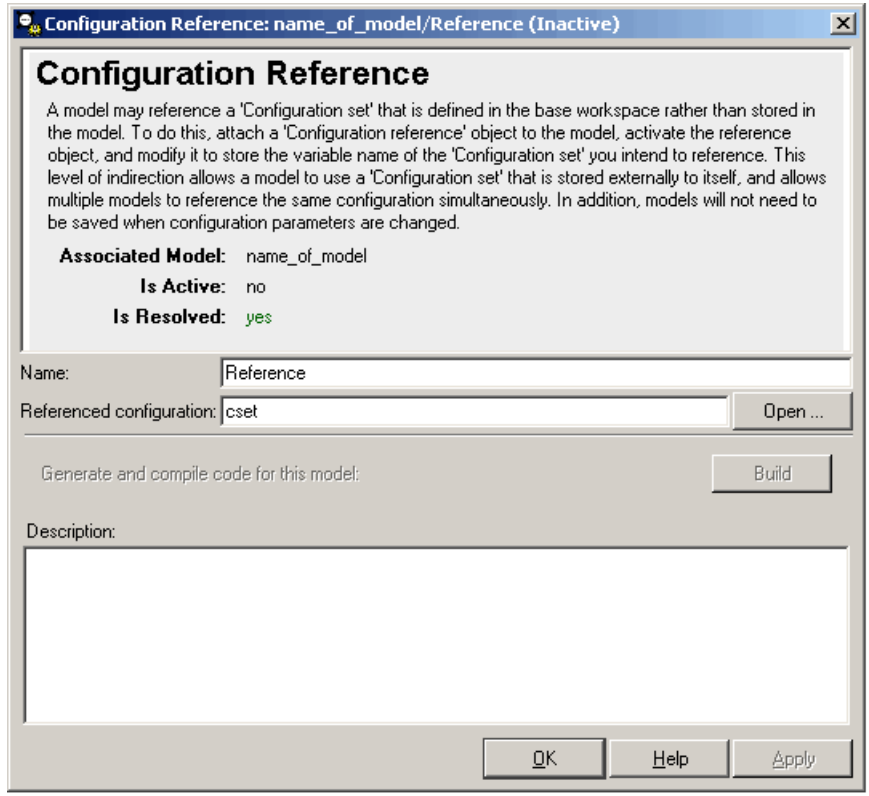
5 Specify the **Referenced configuration** set to be the base workspace variable whose value is the freestanding configuration set that you want to reference.

Tip Do not specify the name of a configuration reference. If you nest a configuration reference, an error occurs.

---

6 Click **OK** or **Apply**.

The **Is Resolved** field in the dialog box changes to `yes`.



If you do not specify a valid **Referenced configuration**, a warning appears. Using a configuration reference with an invalid **Referenced configuration** generates an error. The API equivalent of **Referenced configuration** is `WSVarName`. You can later use the GUI or API to correct the specification or provide a configuration set that has the correct name. See "Unresolved Configuration References" on page 9-26 for more information.

API Techniques

To create and populate a configuration reference using the API:

1 Create the reference:

```
cref = Simulink.ConfigSetRef
```

2 Change the default name if desired:

```
cref.Name = 'ConfigSetRefName'
```

3 Specify the referenced configuration set:

```
cref.WSVarName = 'cset'
```

Tip Do not specify the name of a configuration reference. If you nest a configuration reference, an error occurs.

---

4 Attach the reference to a model:

```
attachConfigSet(mdl, cref, true)
```

The third argument is optional and authorizes renaming to avoid a name conflict.

Using a configuration reference with an invalid `WSVarName` generates an error. The GUI equivalent of `WSVarName` is **Referenced configuration**. You can later use the API or GUI to correct the reference or provide a configuration set that has the correct name. See "Unresolved Configuration References" on page 9-26 for more information.

Obtaining a Configuration Reference Handle

Most functions and methods that operate on a configuration reference take a handle to the reference. If you create a configuration reference programmatically, with a statement like

```
cref = Simulink.ConfigSetRef
```

the variable `cref` contains a handle to the reference. If you do not already have a handle, you can obtain one by executing:

```
cref = getConfigSet(mdl, 'ConfigSetRefName')
```

where *ConfigSetRefName* is the name of the configuration reference as it appears in the Model Explorer, for example, `Reference`. You specify this name by setting the **Name** field in the Configuration Reference dialog box or executing

```
cref.Name = 'ConfigSetRefName'
```

The technique for obtaining a configuration reference handle is the same you use to obtain a configuration set handle. Wherever the same operation applies to both configuration sets and configuration references, applicable functions and methods overloadto perform correctly with either class.

Attaching a Configuration Reference to Other Models

After you create a configuration reference and attach it to a model, you can attach copies of the reference to any other models. To create and attach a copy of a configuration reference, you can use any technique you use to copy and attach a configuration set. See "Copying, Deleting, and Moving Configuration Sets" on page 9-5 and "Configuration Set API" on page 9-10.

Models do not share configuration reference objects. Each model has its own copy of any configuration reference attached to it, just as each has its own copy of any attached configuration set. Configuration references in different models establish configuration set sharing by specifying the same base workspace variable, which links different models to the same freestanding configuration set.

If you use the GUI, attaching an existing configuration reference to another model automatically attaches a copy, as distinct from a handle to the original. If necessary to prevent name conflict, the GUI adds or increments a digit at the end of the name of the copied reference. If you use the API, be sure to copy the configuration reference explicitly before attaching it, with statements like:

```
cref = copy (getConfigSet(mdl, ConfigSetRefName))
attachConfigSet (mdl, cref,  true)
```

If you omit the `copy` operation, *cref* becomes a handle to the original configuration reference, rather than a copy of the reference. Any attempt to use *cref* causes an error. If you omit the argument `true` to `attachConfigSet`, the operation fails if a name conflict exists.

The following example shows code for obtaining a freestanding configuration set and attaching references to it to two models. After the code executes, one of the models contains an internal configuration set and a configuration reference that points to a freestanding copy of that set. If the internal copy is extra, you can remove it with `detachConfigSet`, as shown in the last line of the example.

```
% Get copy of original config set as
% a variable in the base workspace
open_system('mdl1')
% Get handle to local cset
cset = getConfigSet('mdl1', 'Configuration')
% Create freestanding copy; original remains in model
cset1 = copy(cset)
% In the original model, create a configuration
% reference to the cset copy
cref1 = Simulink.ConfigSetRef
cref1.WSVarName = 'cset1'
% Rename if name conflict occurs
attachConfigSet('mdl1', cref1, true)

% In a second model, create a configuration
% reference to the same cset
open_system('mdl2')
% Rename if name conflict occurs
attachConfigSetCopy('mdl2', cref1, true)
% Delete original cset from first model
detachConfigSet('mdl1', 'Configuration')
```

Changing a Configuration Reference

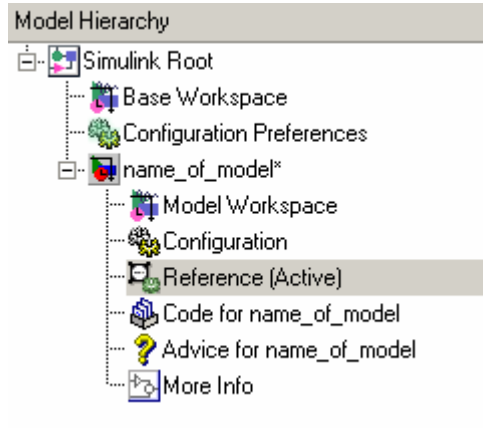
You can change an existing configuration reference by reopening its Configuration Reference dialog box and changing the **Name** or **Referenced configuration**. Similarly, you can use the API on an existing configuration reference to change the `Name` or `WSVarName`. If you refer to a configuration set that does not yet exist, no error occurs, but the configuration reference is unusable. The configuration reference becomes usable as soon as the configuration set exists.

Activating a Configuration Reference

After you create a configuration reference and attach it to a model, activate it using any technique that activates a configuration set in the model:

- From the GUI, select **Activate** from the context menu of the configuration reference.
- From the API, execute `setActiveConfigSet`, specifying the configuration reference as the second argument.

When a configuration reference is active, the **Is Active** field of the Configuration Reference dialog box is `yes`. Also, the Model Explorer shows the name of the reference with the suffix `(Active)`.



The freestanding configuration set of the active reference now provides the configuration parameters for the model that contains the reference.

Unresolved Configuration References

When a configuration reference does not specify a valid configuration set, the **Is Resolved** field of the Configuration Reference dialog box has the value `no`. If you activate an unresolved configuration reference, no warning or error occurs. However, an unresolved configuration reference that is Active provides no configuration parameter values to the model. Therefore:

- Fields that display values known only by accessing a configuration parameter, like Stop Time in the model window, are blank.
- Trying to build the model, simulate it, generate code for it, or otherwise require it to access configuration parameter values, causes an error.

"Creating and Attaching a Configuration Reference" on page 9-19 describes techniques for resolving configuration references.

Getting Values from a Referenced Configuration Set

You can use `get_param` on a configuration reference to obtain parameter values from the linked configuration set, as if the reference object were the configuration set itself. Simulink software retrieves the referenced configuration set and performs the indicated `get_param` on it.

For example, if configuration reference *`cref`* links to configuration set *`cset`*, the following operations give identical results:

```
get_param (cset, 'StopTime')
get_param (cref, 'StopTime')
```

Changing Values in a Referenced Configuration Set

You cannot change a configuration set in any way, such as changing configuration parameter values, by operating on a configuration reference. With `cref` and `cset` as before, if you execute:

```
set_param (cset, 'StopTime', '300')
set_param (cref, 'StopTime', '300')          % ILLEGAL
```

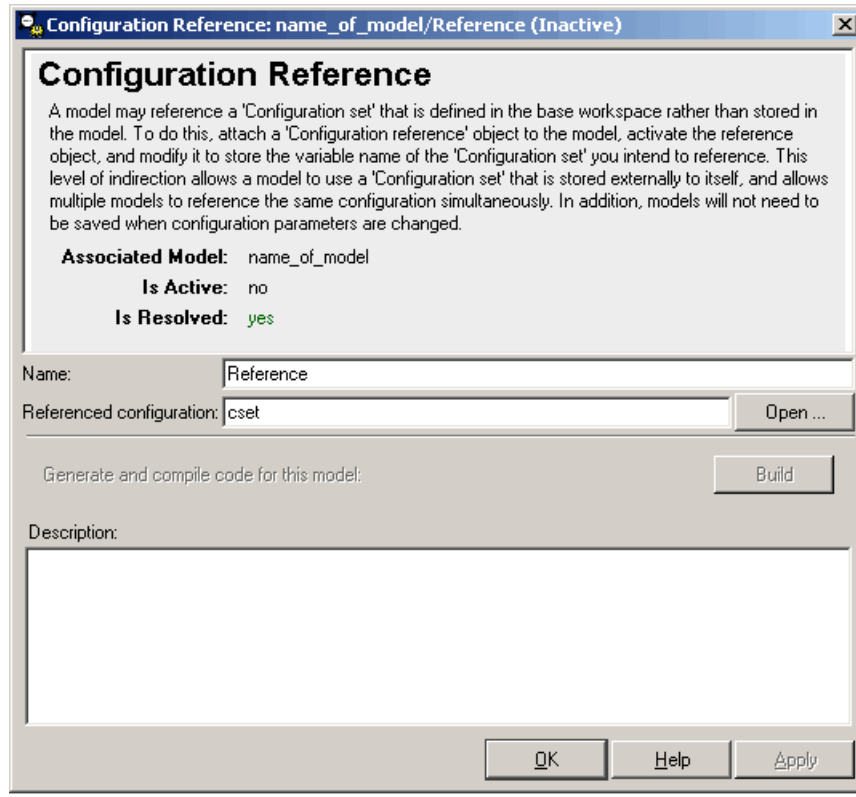
the first operation succeeds, but the second causes an error. Instead, you must obtain the configuration set itself and change it directly, using the GUI or the API.

GUI Techniques

To obtain a referenced configuration set using the GUI:

1. Select the configuration reference in the Model Hierarchy pane, or right-click the configuration reference and select **Open** from the context menu.

The Configuration Reference dialog box appears in the Dialog pane or a separate window.



2 Click **Open** to the right of the **Referenced configuration** field.

The Configuration Parameters dialog box opens on the configuration set specified by **Referenced configuration**. You can now change and apply or save parameter values as you would for any configuration set.

API Techniques

To obtain a referenced configuration set using the API:

1 Obtain a handle to the configuration reference, as described in “Obtaining a Configuration Reference Handle” on page 9-23.

2 Obtain the configuration set *cset* from the configuration reference *cref*:

```
cset = cref.getRefConfigSet
```

You can now use `set_param` on *cset* to change parameter values. For example:

```
set_param (cset, 'StopTime', '300')
```

Tip If you want to change parameter values through the GUI, execute:

```
cset.openDialog
```

The Configuration Parameters dialog box opens on the specified configuration set.

Replacing a Referenced Configuration Set

You can replace the base workspace variable and configuration set that a configuration reference uses. However, the pointer from the configuration reference to the configuration set becomes stale. To avoid this situation, execute:

```
cref.refresh
```

where *cref* is the configuration reference. If you do not execute `refresh`, the configuration reference continues to use the previous instance of the base workspace variable and its configuration set. This example illustrates the problem.

```
% Create a new configuration set
cset1 = Simulink.ConfigSet;
% Set a non-default stop time
set_param (cset1, 'StopTime', '500')
% Create a new config reference
cref1 = Simulink.ConfigSetRef;
% Resolve the config ref to the set
cref1.WsVarName = 'cset1';
% Attach the config ref to an untitled model
attachConfigSet('untitled', cref1, true)
```

```
% Set the active configuration set to the reference
setActiveConfigSet('untitled','Reference')
% Replace config set in the base workspace
cset1 = Simulink.ConfigSet;
% Call to refresh is commented out!
% cref1.refresh;
% Set a different stop time
set_param (cset1, 'StopTime', '75')
```

If you simulate the model, the simulation stops at 500, not 75. Calling `cref1.refresh` as shown prevents the problem.

Building Models and Generating Code

The Real-Time Workshop pane of the Configuration Parameters dialog box contains a **Build** button. Its availability depends on whether the configuration set displayed by the dialog box resides in a model or is a freestanding configuration set.

- When the pane displays a configuration set stored in a model, the **Build** button is available. You can use it to generate and compile code for the model.
- When the pane displays a freestanding configuration set, the **Build** button is unavailable. The configuration set does not know which (if any) models link to it.

To provide the same capabilities whether a configuration set resides in a model or is freestanding, the Configuration Reference dialog box contains a **Build** button. This button has the same effect as its equivalent in the Configuration Parameters dialog box and operates on the model that contains the configuration reference.

Configuration Reference Limitations

- You cannot nest configuration references. Only one level of indirection is available, so a configuration reference cannot link to another configuration reference. Each reference must specify a freestanding configuration set.

- If you replace the base workspace variable and configuration set that configuration references use, execute `refresh` for each reference that uses the replaced variable and set. See "Replacing a Referenced Configuration Set" on page 9-29.
- If you activate a configuration reference when using a custom target, the `ActivateCallback` function does not trigger to notify the corresponding freestanding configuration set. Likewise, if a freestanding configuration set switches from one target to another, the `ActivateCallback` function does not trigger to notify the new target. This behavior applies, even if an active configuration reference points to that target. For more information about `ActivateCallback` functions, see "rtwgensettings Structure" in the Real-Time Workshop documentation.

Configuration References for Models with Older Simulation Target Settings

Suppose that you have a nonlibrary model that contains one of these blocks:

- Embedded MATLAB Function block
- Stateflow chart
- Truth Table block
- Attribute Function block

In R2008a and earlier, this type of nonlibrary model does not store simulation target (or `sfun`) settings in the configuration parameters. Instead, the model stores the settings outside any configuration set.

When you load this older type of model, the simulation target settings migrate to parameters in the active configuration set.

- If the active configuration set resides internally with the model, the migration happens automatically.
- If the model uses an active configuration reference to point to a configuration set in the base workspace, the migration process is different.

The following sections describe the two types of migration for nonlibrary models that use an active configuration reference.

Default Migration Process That Disables the Configuration Reference

Because multiple models can share a configuration set in the base workspace, loading a nonlibrary model cannot automatically change any parameter values in that configuration set. By default, these actions occur during loading of a model to ensure that simulation results are the same, no matter which version you use:

1. A copy of the configuration set in the base workspace attaches to the model.
2. The simulation target settings migrate to the corresponding parameters in this new configuration set.
3. The new configuration set becomes active.
4. The old configuration reference becomes inactive.

A warning message appears in the MATLAB Command Window to describe those actions. Although this process ensures consistent simulation results for the model, it disables the configuration reference that links to the configuration set in the base workspace.

Optional Migration Process That Restores the Configuration Reference

If you want your models to retain an active configuration reference, use the `updatecsref` utility. This utility can compare the simulation target settings among all specified nonlibrary models with the parameters of the configuration set in the base workspace.

- If all settings are consistent with parameters in the shared configuration set, the utility does not perform any updates on the shared set.
- If all settings are not consistent, the utility provides a list of differences in the Command Window.

  The utility copies simulation target settings to the shared configuration set only if you approve the changes.

Suppose that you have models created in R2008a that contain:

- Stateflow charts
- Identical, non-default simulation target settings
- Active configuration references that point to the same configuration set in the base workspace

To run the `updatecsref` utility on these models, follow these steps:

1. At the command prompt, type:

   ```
   updatecsref('modelfile1', 'modelfile2', ..., 'modelfileN')
   ```

2. For each model, the utility looks for the active configuration reference that points to a configuration set in the base workspace. Sample messages include:

   ```
   Analyzing 'active_csref_8a_v1'
   Found the following valid configuration reference(s) in model 'active_csref_8a_v1'
   [1] Configuration reference 'Ref' points to the base workspace configuration set
   object 'cset'
   It will be used as the active configuration set.  Do you want to continue? (Y/n)

   Analyzing 'active_csref_8a_v2'
   Found the following valid configuration reference(s) in model 'active_csref_8a_v2'
   [1] Configuration reference 'Ref' points to the base workspace configuration set
   object 'cset'
   It will be used as the active configuration set.  Do you want to continue? (Y/n)
   ```

   If you approve this shared configuration set, choose **Y**. Otherwise, choose **n** to stop the migration process.

3. All differences between the simulation target settings and the shared configuration set appear. Sample messages include:

   ```
   Parameter 'SFSimEcho' of 'cset' will be changed from 'on' to 'off'
   Parameter 'SFSimOverflowDetection' of 'cset' will be changed from 'on' to 'off'
   Do you want to proceed and change base workspace object 'cset'? (Y/n)
   ```

If you agree with all changes to the configuration set in the base workspace, choose **Y**. Otherwise, choose **n** to stop the migration process.

Note If any simulation target settings between nonlibrary models are inconsistent, these messages appear in the Command Window:

- A list of the differences
- A request to update your models to ensure consistent settings

In this case, the utility exits automatically. After you update your models as requested, you can start over from step 1.

---

4 The utility displays messages about updates to your nonlibrary models and the shared configuration set.

Your models continue to use an active configuration reference to point to the configuration set in the base workspace.

Note For more information about using the `updatecsref` utility, type `help updatecsref` at the command prompt.

10

Modeling Best Practices

General Considerations when Building Simulink Models

In this section...

Avoiding Invalid Loops

You can connect the output of a block directly or indirectly (i.e., via other blocks) to its input, thereby, creating a loop. Loops can be very useful. For example, you can use loops to solve differential equations diagrammatically (see "Modeling a Continuous System" on page 10-8) or model feedback control systems. However, it is also possible to create loops that cannot be simulated. Common types of invalid loops include:

- Loops that create invalid function-call connections or an attempt to modify the input/output arguments of a function call (see "Function-Call Subsystems" on page 6-23 for a description of function-call subsystems)
- Self-triggering subsystems and loops containing non-latched triggered subsystems (see "Triggered Subsystems" on page 6-14 in the Using Simulink documentation for a description of triggered subsystems and `Inport` in the Simulink reference documentation for a description of latched input)
- Loops containing action subsystems

The Subsystem Examples block library in the Ports & Subsystems library contains models that illustrates examples of valid and invalid loops involving triggered and function-call subsystems. Examples of invalid loops include the following models:

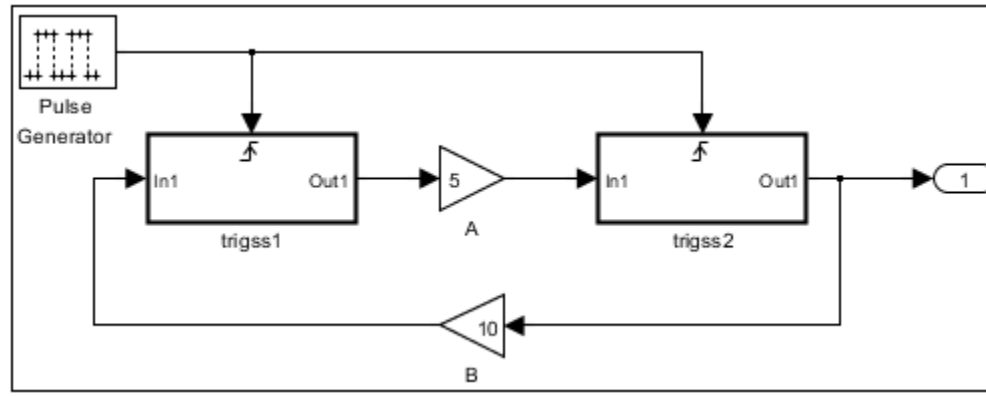
- `simulink/Ports&Subsystems/sl_subsys_semantics/Triggered subsystem/sl_subsys_trigerr1` (`sl_subsys_trigerr1`)
- `simulink/Ports&Subsystems/sl_subsys_semantics/Triggered subsystem/sl_subsys_trigerr2` (`sl_subsys_trigerr2`)

- `simulink/Ports&Subsystems/sl_subsys_semantics/Function-call systems/sl_subsys_fncallerr3` (`sl_subsys_fncallerr3`)

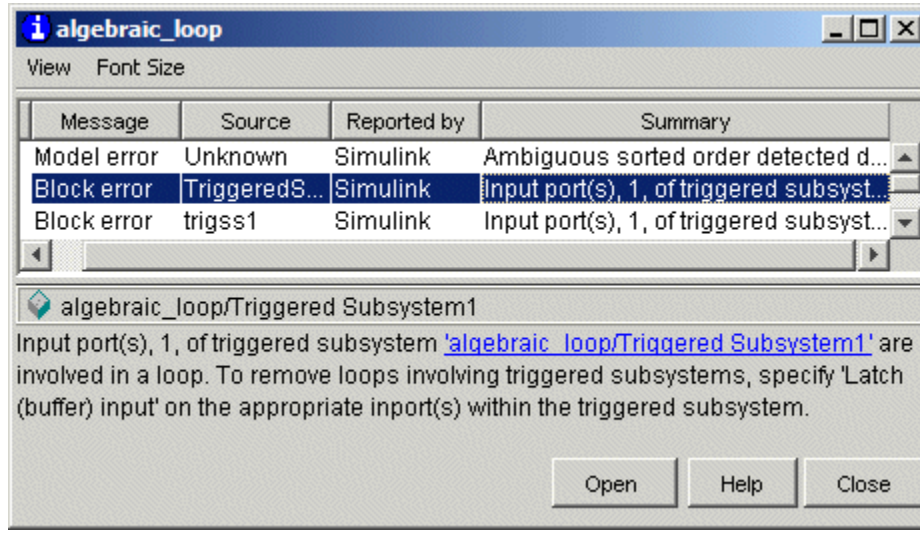
You might find it useful to study these examples to avoid creating invalid loops in your own models.

Detecting Invalid Loops

To detect whether your model contains invalid loops, select **Update Diagram** from the model's **Edit** menu. If the model contains invalid loops, the invalid loops are highlighted. This is illustrated in the following model ,



and displays an error message in the Simulation Diagnostics Viewer.



Shadowed Files

If there are two Model files with the same name (e.g. `mylibrary.mdl`) on the MATLAB path, the one higher on the path is loaded, and the one lower on the path is said to be "shadowed".

The rules Simulink software uses to find Model files are similar to those used by MATLAB software. See "How the Search Path Determines Which Function to Use" in the MATLAB documentation. However, there is an important difference between how Simulink block diagrams and MATLAB functions are handled: a loaded block diagram takes precedence over any unloaded ones, regardless of its position on the MATLAB path. This is done for performance reasons, as part of the Simulink software's incremental loading methodology.

The precedence of a loaded block diagram over any others can have important implications, particularly since a block diagram can be loaded without the corresponding Simulink window being visible.

Making Sure the Correct Block Diagram Is Loaded

When using libraries and referenced models, a block diagram may be loaded without showing its window. If the MATLAB path or the current MATLAB

folder changes while block diagrams are in memory, these block diagrams may interfere with the use of other files of the same name. For example, after a change of folder, a loaded but invisible library may be used instead of the one the user expects.

To see an example:

1. Enter `sldemo_hydcyl4` to open the Simulink demo model `sldemo_hydcyl4`.
2. Use the find_system command to see which block diagrams are in memory:

   ```
   find_system('type','block_diagram')

   ans =

       'hydlib'
       'sldemo_hydcyl4'
   ```

   Note that a Simulink library, `hydlib`, has been loaded, but is currently invisible.
3. Now close `sldemo_hydcyl4`. Run the `find_system` command again, and you will see that the library is still loaded.

If you change to another folder which contains a different library called `hydlib`, and try to run a model in that folder, the library in that folder would not be loaded because the block diagram of the same name in memory takes precedence. This can lead to problems including:

- Simulation errors
- "Bad Link" icons on blocks which are library links
- Wrong results

To prevent these conditions, it is necessary to close the library explicitly as follows:

```
close_system('hydlib')
```

Then, when the Simulink software next needs to use a block in a library called `hydlib` it will use the file called `hydlib.mdl` which is highest on the MATLAB path at the time. Alternatively, to make the library visible, enter:

```
open_system('hydlib')
```

Detecting and Fixing Problems

When updating a block diagram, the Simulink software checks the position of its file on the MATLAB path and will issue a warning if it detects that another file of the same name exists and is higher on the MATLAB path. The warning reads:

```
The file containing block diagram 'mylibrary' is shadowed
by a file of the same name higher on the MATLAB path.
```

This may indicate that the wrong file called `mylibrary.mdl` is being used. To see which file called `mylibrary.mdl` is loaded into memory, enter:

```
 which mylibrary

C:\work\Model1\mylibrary.mdl
```

To see all the files called `mylibrary` which are on the MATLAB path, including MATLAB scripts, enter:

```
which -all mylibrary

C:\work\Model1\mylibrary.mdl
C:\work\Model2\mylibrary.mdl  % Shadowed
```

To close the block diagram called `mylibrary` and let the Simulink software load the file which is highest on the MATLAB path, enter:

```
close_system('mylibrary')
```

Model Building Tips

Here are some model-building hints you might find useful:

- Memory issues

In general, more memory will increase performance.

- Using hierarchy

  More complex models often benefit from adding the hierarchy of subsystems to the model. Grouping blocks simplifies the top level of the model and can make it easier to read and understand the model. For more information, see "Creating Subsystems" on page 3-37. The Model Browser provides useful information about complex models (see "The Model Browser" on page 8-73).

- Cleaning up models

  Well organized and documented models are easier to read and understand. Signal labels and model annotations can help describe what is happening in a model. For more information, see "Naming Signals" on page 29-3 and "Annotating Diagrams" on page 3-26.

- Modeling strategies

  If several of your models tend to use the same blocks, you might find it easier to save these blocks in a model. Then, when you build new models, just open this model and copy the commonly used blocks from it. You can create a block library by placing a collection of blocks into a system and saving the system. You can then access the system by typing its name in the MATLAB Command Window.

  Generally, when building a model, design it first on paper, then build it using the computer. Then, when you start putting the blocks together into a model, add the blocks to the model window before adding the lines that connect them. This way, you can reduce how often you need to open block libraries.

Modeling a Continuous System

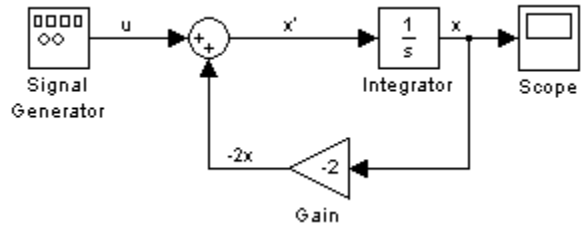
To model the differential equation

$$x' = -2x(t)+u(t),$$

where $u(t)$ is a square wave with an amplitude of 1 and a frequency of 1 rad/sec, use an integrator block and a gain block. The Integrator block integrates its input x' to produce x. Other blocks needed in this model include a Gain block and a Sum block. To generate a square wave, use a Signal Generator block and select the Square Wave form but change the default units to radians/sec. Again, view the output using a Scope block. Gather the blocks and define the gain.

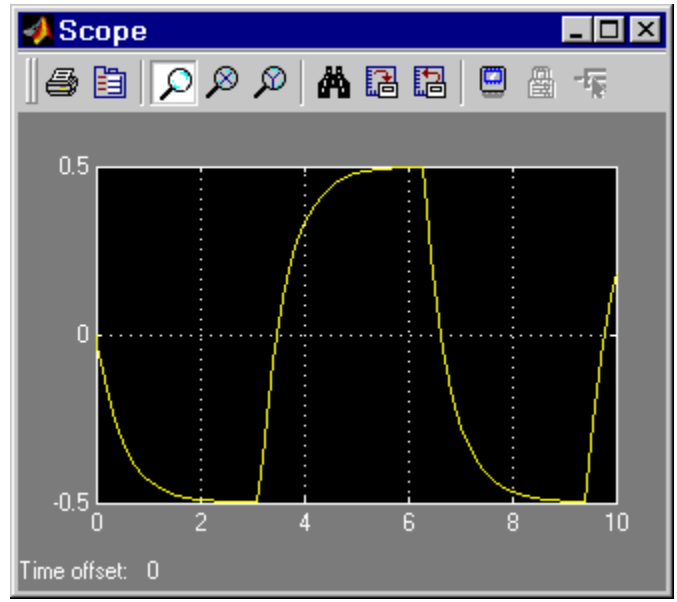
In this model, to reverse the direction of the Gain block, select the block, then use the **Flip Block** command from the **Format** menu. To create the branch line from the output of the Integrator block to the Gain block, hold down the **Ctrl** key while drawing the line. For more information, see "Drawing a Branch Line" on page 3-19.

Now you can connect all the blocks.



An important concept in this model is the loop that includes the Sum block, the Integrator block, and the Gain block. In this equation, x is the output of the Integrator block. It is also the input to the blocks that compute x', on which it is based. This relationship is implemented using a loop.

The Scope displays x at each time step. For a simulation lasting 10 seconds, the output looks like this:



The equation you modeled in this example can also be expressed as a transfer function. The model uses the Transfer Fcn block, which accepts u as input and outputs x. So, the block implements x/u. If you substitute sx for x' in the above equation, you get

$$sx = -2x + u.$$

Solving for x gives

$$x = u/(s + 2)$$

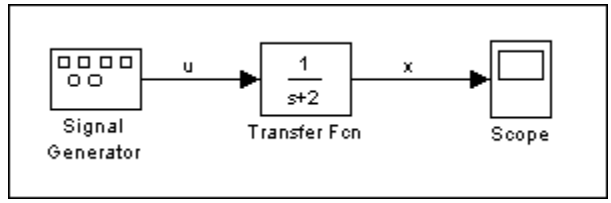
or,

$$x/u = 1/(s + 2).$$

The Transfer Fcn block uses parameters to specify the numerator and denominator coefficients. In this case, the numerator is 1 and the denominator

is `s+2`. Specify both terms as vectors of coefficients of successively decreasing powers of `s`.

In this case the numerator is `[1]` (or just `1`) and the denominator is `[1 2]`.



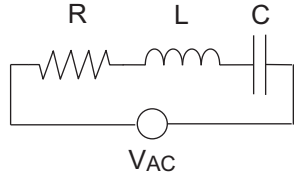
The results of this simulation are identical to those of the previous model.

Best-Form Mathematical Models

In this section...

Series RLC Example

You can often formulate the mathematical system you are modeling in several ways. Choosing the best-form mathematical model allows the simulation to execute faster and more accurately. For example, consider a simple series RLC circuit.



According to Kirchoff's voltage law, the voltage drop across this circuit is equal to the sum of the voltage drop across each element of the circuit.

$$V_{AC} = V_R + V_L + V_C$$

Using Ohm's law to solve for the voltage across each element of the circuit, the equation for this circuit can be written as

$$V_{AC} = Ri + L\frac{di}{dt} + \frac{1}{C}\int_{-\infty}^{t} i(t)dt$$

You can model this system in Simulink by solving for either the resistor voltage or inductor voltage. Which you choose to solve for affects the structure of the model and its performance.

Solving Series RLC Using Resistor Voltage

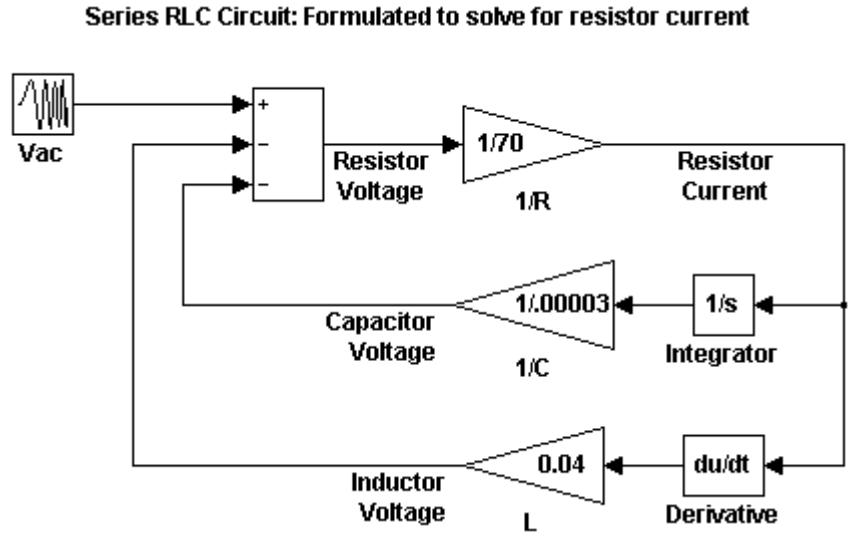
Solving the RLC circuit for the resistor voltage yields

$$V_R = Ri$$

$$Ri = V_{AC} - L\frac{di}{dt} - \frac{1}{C}\int_{-\infty}^{t} i(t)dt$$

Circuit Model

The following diagram shows this equation modeled in Simulink where R is `70`, C is `0.00003`, and L is `0.04`. The resistor voltage is the sum of the voltage source, the capacitor voltage, and the inductor voltage. You need the current in the circuit to calculate the capacitor and inductor voltages. To calculate the current, multiply the resistor voltage by a gain of $1/R$. Calculate the capacitor voltage by integrating the current and multiplying by a gain of $1/C$. Calculate the inductor voltage by taking the derivative of the current and multiplying by a gain of L.



This formulation contains a Derivative block associated with the inductor. Whenever possible, you should avoid mathematical formulations that require Derivative blocks as they introduce discontinuities into your system. Numerical integration is used to solve the model dynamics though time.

These integration solvers take small steps through time to satisfy an accuracy constraint on the solution. If the discontinuity introduced by the Derivative block is too large, it is not possible for the solver to step across it.

In addition, in this model the Derivative, Sum, and two Gain blocks create an algebraic loop. Algebraic loops slow down the model's execution and can produce less accurate simulation results. See "Algebraic Loops" on page 2-39 for more information.

Solving Series RLC Using Inductor Voltage

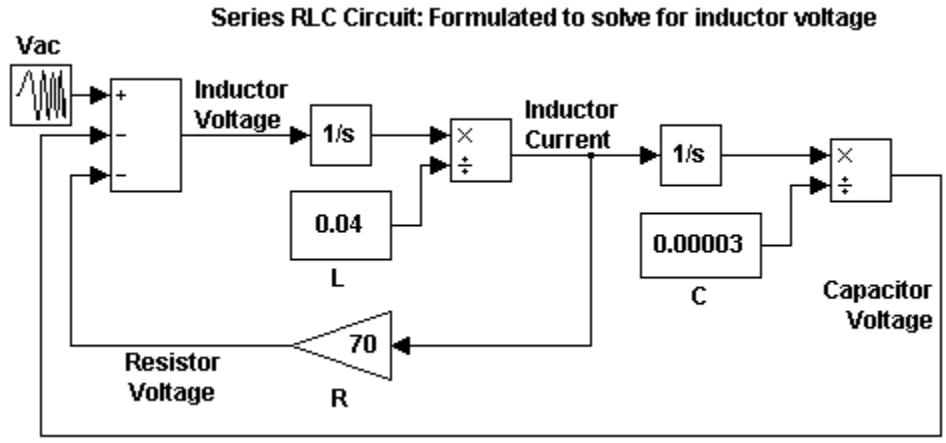
To avoid using a Derivative block, formulate the equation to solve for the inductor voltage.

$$V_L = L\frac{di}{dt}$$

$$L\frac{di}{dt} = V_{AC} - Ri - \frac{1}{C}\int_{-\infty}^{t} i(t)dt$$

Circuit Model

The following diagram shows this equation modeled in Simulink. The inductor voltage is the sum of the voltage source, the resistor voltage, and the capacitor voltage. You need the current in the circuit to calculate the resistor and capacitor voltages. To calculate the current, integrate the inductor voltage and divide by *L*. Calculate the capacitor voltage by integrating the current and dividing by *C*. Calculate the resistor voltage by multiplying the current by a gain of *R*.



This model contains only integrator blocks and no algebraic loops. As a result, the model simulates faster and more accurately.

Example: Converting Celsius to Fahrenheit

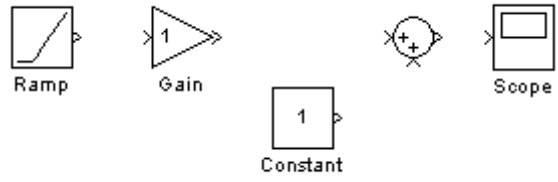
To model the equation that converts Celsius temperature to Fahrenheit

$$T_F = 9/5(T_C) + 32$$

First, consider the blocks needed to build the model:

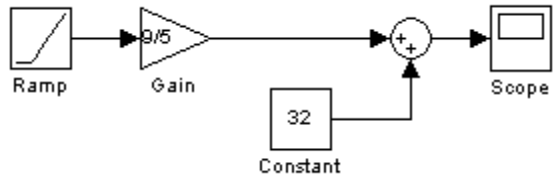
- A Ramp block to input the temperature signal, from the Sources library
- A Constant block to define a constant of 32, also from the Sources library
- A Gain block to multiply the input signal by 9/5, from the Math Operations library
- A Sum block to add the two quantities, also from the Math Operations library
- A Scope block to display the output, from the Sinks library

Next, gather the blocks into your model window.



Assign parameter values to the Gain and Constant blocks by opening (double-clicking) each block and entering the appropriate value. Then, click the **OK** button to apply the value and close the dialog box.

Now, connect the blocks.



The Ramp block inputs Celsius temperature. Open that block and change the **Initial output** parameter to 0. The Gain block multiplies that temperature by the constant 9/5. The Sum block adds the value 32 to the result and outputs the Fahrenheit temperature.

Open the Scope block to view the output. Now, choose **Start** from the **Simulation** menu to run the simulation. The simulation runs for 10 seconds.

Simulating Dynamic Systems

11

Running Simulations

Simulation Basics

You can simulate a model at any time simply by clicking the **Start** button on the Model Editor displaying the model (see "Starting a Simulation" on page 11-3). However, before starting the simulation, you might want to specify various simulation options, such as the simulation's start and stop time and the type of solver used to solve the model at each simulation time step. Specifying simulation options is called "configuring the model". With the Simulink software you can create multiple model configurations, called configuration sets, modify existing configuration sets, and switch configuration sets with a click of a mouse button (see "Setting Up Configuration Sets" on page 9-2 for information on creating and selecting configuration sets).

Once you have defined or selected a model configuration set that meets your needs, you can start the simulation. The simulation runs from the specified start time to the specified stop time. While the simulation is running, you can interact with the simulation in various ways, stop or pause the simulation (see "Pausing or Stopping a Simulation" on page 11-5), and launch simulations of other models. If an error occurs during a simulation, Simulink halts the simulation and the Simulation Diagnostics Viewer pops up that helps you to determine the cause of the error.

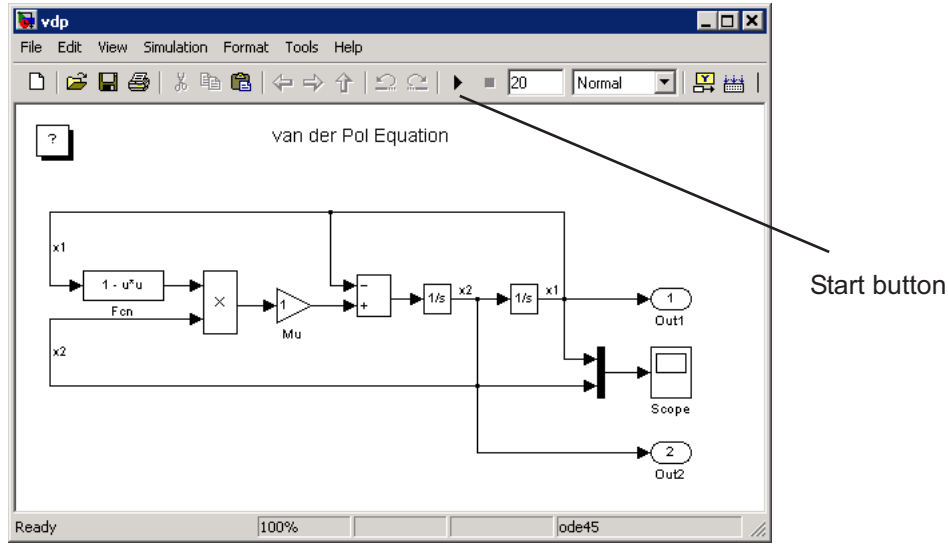
Controlling Execution of a Simulation

In this section...

Starting a Simulation

This sections explains how to run a simulation interactively. See Chapter 12, "Running a Simulation Programmatically" for information on running a simulation from a program, an S-function, or the MATLAB command line.

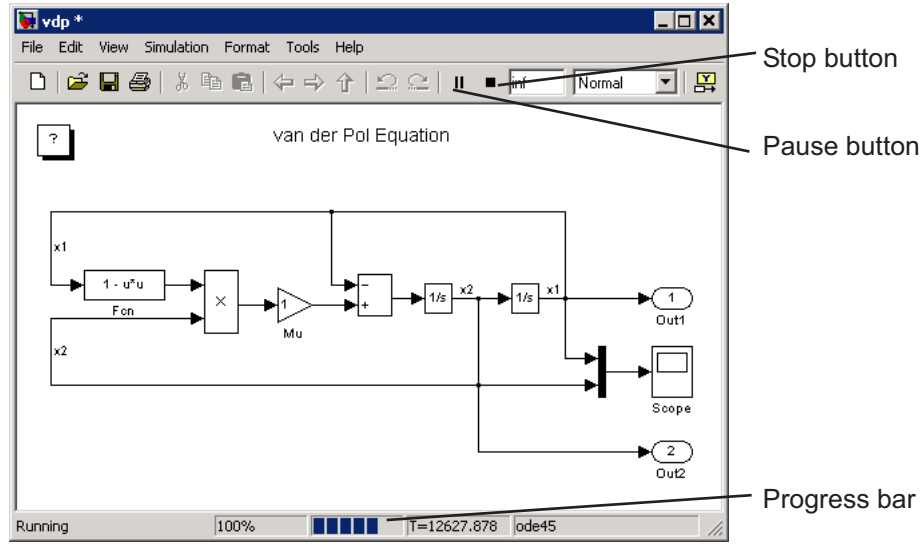
To start the execution of a model, from the **Simulation** menu of the Model Editor, select **Start** or click the **Start** button on the model toolbar.



Note A common mistake is to start a simulation while the Simulink block library is the active window. Make sure that your model window is the active window before starting a simulation.

The model execution begins at the start time that you specify on the Configuration Parameters dialog box. Execution continues until an error occurs, until you pause or terminate the simulation, or until the simulation reaches the stop time as specified on the Configuration Parameters dialog box (see "Configuration Parameters Dialog Box").

While the simulation is running, a progress bar at the bottom of the model window shows how far the simulation has progressed. A **Stop** command replaces the **Start** command on the **Simulation** menu. A **Pause** command appears on the menu and replaces the **Start** button on the model toolbar.



Your computer beeps to signal the completion of the simulation.

Pausing or Stopping a Simulation

Select the **Pause** command or button to pause the simulation. Once Simulink completes the execution of the current time step, it suspends the simulation. When you select **Pause**, the menu item and the button change to **Continue**. (The button has the same appearance as the **Start** button). You can resume a suspended simulation at the next time step by choosing **Continue**.

To terminate execution of the model, select the **Stop** button or the `Stop` Simulation menu item. Simulink completes the execution of the current time step and then terminates the simulation. Subsequently selecting the **Start** menu item or button restarts the simulation at the first time step specified on the Configuration Parameters dialog box.

If the model includes any blocks that write output to a file or to the workspace, or if you select output options on the Configuration Parameters dialog box, the Simulink software writes the data when the simulation is terminated or suspended.

Using Blocks to Stop or Pause a Simulation

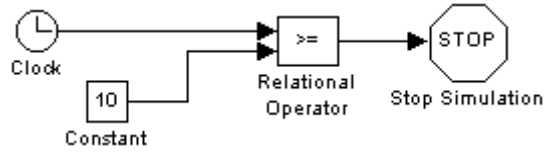
Using Stop Blocks

You can use the Stop Simulation block to terminate a simulation when the input to the block is nonzero. To use the Stop Simulation block:

1. Drag a copy of the Stop Simulation block from the Sinks library and drop it into your model.

2. Connect the Stop Simulation block to a signal whose value becomes nonzero at the specified stop time.

For example, this model stops the simulation when the input signal reaches 10.



If the block input is a vector, any nonzero element causes the simulation to terminate.

Creating Pause Blocks

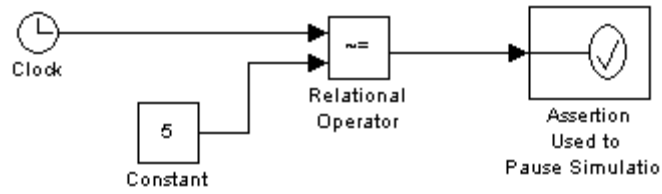
You can use an Assertion block to pause the simulation when the input signal to the block is zero. To create a pause block:

1. Drag a copy of the Assertion block from the Model Verification library and drop it into your model.
2. Connect the Assertion block to a signal whose value becomes zero at the desired pause time.
3. Open the Block Parameters dialog box of the Assertion block .
   - Enter the following commands into the **Simulation callback when assertion fails** field:

     ```
     set_param(bdroot,'SimulationCommand','pause'),
     disp(sprintf('\nSimulation paused.'))
     ```

   - Uncheck the **Stop simulation when assertion fails** option.
4. Click **OK** to apply the changes and close this dialog box.

The following model uses a similiarly configured Assertion block, in conjunction with the Relational Operator block, to pause the simulation when the simulation time reaches 5.



When the simulation pauses, the Assertion block displays the following message at the MATLAB command line.

```
Simulation paused
Warning: Assertion detected in 'assertion_as_pause/
   Assertion Used to Pause Simulation' at time 5.000000
```

You can resume the suspended simulation by choosing **Continue** from the **Simulation** menu on the model editor, or by selecting the **Continue** button in the toolbar.

Note The Assertion block uses the `set_param` command to pause the simulation. See Chapter 12, "Running a Simulation Programmatically" for more information on using the `set_param` command to control the execution of a Simulink model.

Specifying a Simulation Start and Stop Time

By default, simulations start at 0.0 s and end at 10.0 s.

Note In the Simulink software, time and all related parameters (such as sample times) are implicitly in seconds. If you choose to use a different time unit, you must scale all parameters accordingly.

The **Solver** configuration pane allows you to specify other start and stop times for the currently selected simulation configuration. See "Solver Pane" for more information. On computers running the Microsoft Windows operating system, you can also specify the simulation stop time in the `Simulation` menu.

Note Simulation time and actual clock time are not the same. For example, if running a simulation for 10 s usually does not take 10 s as measured on a clock. The amount of time it actually takes to run a simulation depends on many factors including the complexity of the model, the step sizes, and the computer speed.

Choosing a Solver

In this section...

What Is a Solver?

A solver is a component of the Simulink software. The Simulink product provides an extensive library of solvers, each of which determines the time of the next simulation step and applies a numerical method to solve the set of ordinary differential equations that represent the model. In the process of solving this initial value problem, the solver also satisfies the accuracy requirements that you specify. To help you choose the solver best suited for your application, "Choosing a Solver Type" on page 11-10 provides background on the different types of solvers while "Choosing a Fixed-Step Solver" on page 11-13 and "Choosing a Variable-Step Solver" on page 11-17 provide guidance on choosing a specific fixed-step or variable-step solver, respectively.

The following table summarizes the types of solvers in the Simulink library and provides links to specific categories. All of these solvers can work with the algebraic loop solver.

		Discrete	Continuous	Variable-Order
Fixed-Step	Explicit	Not Applicable	"Explicit Fixed-Step Continuous Solvers" on page 11-14	Not Applicable
	Implicit	Not Applicable	"Implicit Fixed-Step Continuous Solvers" on page 11-16	Not Applicable

		Discrete	Continuous	Variable-Order
Variable-Step	Explicit	"Choosing a Variable-Step Solver" on page 11-17	"Explicit Continuous Variable-Step Solvers" on page 11-18	"Variable-Order Solvers" on page 11-13
	Implicit		"Implicit Continuous Variable-Step Solvers" on page 11-19	"Variable-Order Solvers" on page 11-13

Note

1. The fixed-step discrete solvers do not solve for discrete states; each block calculates its discrete states independent of the solver. For more information, see "Discrete versus Continuous Solvers" on page 11-12
2. Every solver in the Simulink library can perform on models that contain algebraic loops.

For information on tailoring the selected solver to your model, see "Improving Simulation Accuracy" on page 15-10.

Choosing a Solver Type

The Simulink library of solvers is divided into two major types in the "Solver Pane": fixed-step and variable-step. You can further divide the solvers within each of these categories as: discrete or continuous, explicit or implicit, one-step or multistep, and single-order or variable-order.

Fixed-Step versus Variable-Step Solvers

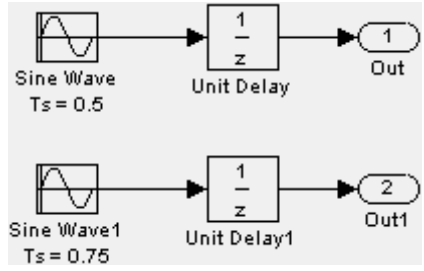
Both fixed-step and variable-step solvers compute the next simulation time as the sum of the current simulation time and a quantity known as the *step size*. With a fixed-step solver, the step size remains constant throughout the simulation. In contrast, with a variable-step solver, the step size can vary from step to step, depending on the model dynamics. In particular, a variable-step solver increases or reduces the step size to meet the error

tolerances that you specify. The **Type** control on the Simulink **Solver** configuration pane allows you to select either of these two types of solvers.

The choice between the two types depends on how you plan to deploy your model and the model dynamics. If you plan to generate code from your model and run the code on a real-time computer system, choose a fixed-step solver to simulate the model because you cannot map the variable-step size to the real-time clock.

If you do not plan to deploy your model as generated code, the choice between a variable-step and a fixed-step solver depends on the dynamics of your model. A variable-step solver might shorten the simulation time of your model significantly. A variable-step solver allows this savings because, for a given level of accuracy, the solver can dynamically adjust the step size as necessary and thus reduce the number of steps. Whereas the fixed-step solver must use a single step size throughout the simulation based upon the accuracy requirements. To satisfy these requirements throughout the simulation, the fixed-step solver might require a very small step.

The following model shows how a variable-step solver can shorten simulation time for a multirate discrete model.



This model generates outputs at two different rates: every 0.5 s and every 0.75 s. To capture both outputs, the fixed-step solver must take a time step every 0.25 s (the *fundamental sample time* for the model).

```
[0.0 0.25 0.5 0.75 1.0 1.25 1.5 ...]
```

By contrast, the variable-step solver needs to take a step only when the model generates an output.

```
[0.0 0.5 0.75 1.0 1.5 ...]
```

This scheme significantly reduces the number of time steps required to simulate the model.

If you wish to achieve evenly spaced steps, you must use the format 0.4*[0.0: 100.0] rather than [0.0:0.4:40].

Discrete versus Continuous Solvers

When you set the **Type** control of the **Solver** configuration pane to `fixed-step` or to `variable-step`, the adjacent **Solver** control allows you to choose a specific solver. Both sets of solvers comprise two types: discrete and continuous. Discrete and continuous solvers rely on the model blocks to compute the values of any discrete states. Blocks that define discrete states are responsible for computing the values of those states at each time step. However, unlike discrete solvers, continuous solvers use numerical integration to compute the continuous states that the blocks define . Therefore, when choosing a solver, you must first determine whether you need to use a discrete solver or a continuous solver.

If your model has no continuous states, then Simulink switches to either the fixed-step discrete solver or the variable-step discrete solver. If instead your model has continuous states, you must choose a continuous solver from the remaining solver choices based on the dynamics of your model. Otherwise, an error occurs.

Explicit versus Implicit Solvers

While you can apply either an implicit or explicit continuous solver, the implicit solvers are designed specifically for solving stiff problems whereas explicit solvers are used to solve nonstiff problems. A generally accepted definition of a stiff system is a system that has extremely different time scales. Compared to the explicit solvers, the implicit solvers provide greater stability for oscillatory behavior, but they are also computationally more expensive; they generate the Jacobian matrix and solve the set of algebraic equations at every time step using a Newton-like method. To reduce this extra cost, the implicit solvers offer a `Solver Jacobian method` parameter that allows you to improve the simulation performance of implicit solvers. See “Choosing a Jacobian Method for an Implicit Solver” on page 11-23 for more information.

One-Step versus Multistep Solvers

The Simulink solver library provides both *one-step* and *multistep* solvers. The one-step solvers estimate $y(t_n)$ using the solution at the immediately preceding time point, $y(t_{n-1})$, and the values of the derivative at a number of points between t_n and t_{n-1}. These points are *minor steps*.

The multistep solvers use the results at several preceding time steps to compute the current solution. Simulink provides one explicit multistep solver, `ode113`, and one implicit multistep solver, `ode15s`. Both are variable-step solvers.

Variable-Order Solvers

Two variable-order solvers, `ode15s` and `ode113`, are part of the solver library. These solvers use multiple orders to solve the system of equations. Specifically, the implicit, variable-step `ode15s` solver uses first-order through fifth-order equations while the explicit, variable-step `ode113` solver uses first-order through thirteenth-order. For `ode15s`, you can limit the highest order applied via the `Maximum Order` parameter. For more information, see "Maximum Order" on page 11-20.

Choosing a Fixed-Step Solver

About the Fixed-Step Discrete Solver

The fixed-step discrete solver computes the time of the next simulation step by adding a fixed step size to the current time. The accuracy and the length of time of the resulting simulation depends on the size of the steps taken by the simulation: the smaller the step size, the more accurate the results are but the longer the simulation takes. You can allow the Simulink software to choose the size of the step (the default) or you can choose the step size yourself. If you choose the default setting of `auto`, and if the model has discrete sample times, then Simulink sets the step size to the fundamental sample time of the model. Otherwise, if no discrete rates exist, Simulink sets the size to the result of dividing the difference between the simulation start and stop times by 50.

Note If you try to use the fixed-step discrete solver to update or simulate a model that has continuous states, an error message appears. Thus, selecting a fixed-step solver and then updating or simulating a model is a quick way to determine whether the model has continuous states.

About Fixed-Step Continuous Solvers

The fixed-step continuous solvers, like the fixed-step discrete solver, compute the next simulation time by adding a fixed-size time step to the current time. For each of these steps, the continuous solvers use numerical integration to compute the values of the continuous states for the model. These values are calculated using the continuous states at the previous time step and the state derivatives at intermediate points (minor steps) between the current and the previous time step. The fixed-step continuous solvers can, therefore, handle models that contain both continuous and discrete states.

Note In theory, a fixed-step continuous solver can handle models that contain no continuous states. However, that would impose an unnecessary computational burden on the simulation. Consequently, Simulink uses the fixed-step discrete solver for a model that contains no states or only discrete states, even if you specify a fixed-step continuous solver for the model.

Two types of fixed-step continuous solvers that Simulink provides are: explicit and implicit. (See "Explicit versus Implicit Solvers" on page 11-12 for more information). The difference between these two types lies in the speed and the stability. An implicit solver requires more computation per step than an explicit solver but is more stable. Therefore, the implicit fixed-step solver that Simulink provides is more adept at solving a stiff system than the fixed-step explicit solvers.

Explicit Fixed-Step Continuous Solvers. Explicit solvers compute the value of a state at the next time step as an explicit function of the current values of both the state and the state derivative. Expressed mathematically for a fixed-step explicit solver:

$$x(n+1) = x(n) + h * Dx(n)$$

where x is the state, Dx is a solver-dependent function that estimates the state derivative, h is the step size, and n indicates the current time step.

Simulink provides a set of explicit fixed-step continuous solvers. The solvers differ in the specific numerical integration technique that they use to compute the state derivatives of the model. The following table lists each solver and the integration technique it uses.

Solver	Integration Technique	Order of Accuracy
`ode1`	Euler's Method	First
`ode2`	Heun's Method	Second
`ode3`	Bogacki-Shampine Formula	Third
`ode4`	Fourth-Order Runge-Kutta (RK4) Formula	Fourth
`ode5`	Dormand-Prince (RK5) Formula	Fifth
`ode8`	Dormand-Prince RK8(7) Formula	Eighth

The table lists the solvers in order of the computational complexity of the integration methods they use, from the least complex (`ode1`) to the most complex (`ode8`).

None of these solvers has an error control mechanism. Therefore, the accuracy and the duration of a simulation depends directly on the size of the steps taken by the solver. As you decrease the step size, the results become more accurate, but the simulation takes longer. Also, for any given step size, the more computationally complex the solver is, the more accurate are the simulation results.

If you specify a fixed-step solver type for a model, then by default, Simulink selects the `ode3` solver, which can handle both continuous and discrete states with moderate computational effort. As with the discrete solver, if the model has discrete rates (sample times), then Simulink sets the step size to the fundamental sample time of the model by default. If the model has no discrete rates, Simulink automatically uses the result of dividing the simulation total duration by 50. Consequently, the solver takes a step at each simulation

time at which Simulink must update the discrete states of the model at its specified sample rates. However, it does not guarantee that the default solver accurately computes the continuous states of a model. Therefore, you might need to choose another solver, a different fixed step size, or both to achieve acceptable accuracy and an acceptable simulation time.

Implicit Fixed-Step Continuous Solvers. An implicit fixed-step solver computes the state at the next time step as an implicit function of the state at the current time step and the state derivative at the next time step. In other words:

$$x(n+1) - x(n) - h * Dx(n+1) = 0$$

Simulink provides one implicit fixed-step solver : `ode14x`. This solver uses a combination of Newton's method and extrapolation from the current value to compute the value of a state at the next time step. You can specify the number of Newton's method iterations and the extrapolation order that the solver uses to compute the next value of a model state (see "Fixed-step size (fundamental sample time)"). The more iterations and the higher the extrapolation order that you select, the greater the accuracy you obtain. However, you simultaneously create a greater computational burden per step size.

Process for Choosing a Fixed-Step Continuous Solver

Any of the fixed-step continuous solvers in the Simulink product can simulate a model to any desired level of accuracy, given a small enough step size. Unfortunately, it generally is not possible, or at least not practical, to decide *a priori* which combination of solver and step size will yield acceptable results for the continuous states in the shortest time. Determining the best solver for a particular model generally requires experimentation.

Following is the most efficient way to choose the best fixed-step solver for your model experimentally.

1. Choose error tolerances. For more information, see "Specifying Variable-Step Solver Error Tolerances" on page 11-22.

2. Use one of the variable-step solvers to simulate your model to the level of accuracy that you desire. Start with `ode45`. If your model runs slowly, your problem might be stiff and need an implicit solver. The results of this

step give a good approximation of the correct simulation results and the appropriate fixed step size.

3. Use `ode1` to simulate your model at the default step size for your model. Compare the simulation results for `ode1` with the simulation for the variable-step solver. If the results are the same for the specified level of accuracy, you have found the best fixed-step solver for your model, namely `ode1`. You can draw this conclusion because `ode1` is the simplest of the fixed-step solvers and hence yields the shortest simulation time for the current step size.

4. If `ode1` does not give satisfactory results, repeat the preceding steps with each of the other fixed-step solvers until you find the one that gives accurate results with the least computational effort. The most efficient way to perform this task is to use a binary search technique:

   a. Try `ode3`.

   b. If `ode3` gives accurate results, try `ode2`. If `ode2` gives accurate results, it is the best solver for your model; otherwise, `ode3` is the best.

   c. If `ode3` does not give accurate results, try `ode5`. If `ode5` gives accurate results, try `ode4`. If `ode4` gives accurate results, select it as the solver for your model; otherwise, select `ode5`.

   d. If `ode5` does not give accurate results, reduce the simulation step size and repeat the preceding process. Continue in this way until you find a solver that solves your model accurately with the least computational effort.

Choosing a Variable-Step Solver

When you set the **Type** control of the **Solver** configuration pane to `Variable-step`, the **Solver** control allows you to choose one of the variable-step solvers. As with fixed-step solvers, the set of variable-step solvers comprises a discrete solver and a subset of continuous solvers. However, unlike the fixed-step solvers, the step size varies dynamically based on the local error.

The choice between the two types of variable-step solvers depends on whether the blocks in your model define states and, if so, the type of states that they

define. If your model defines no states or defines only discrete states, select the discrete solver. In fact, if a model has no states or only discrete states, Simulink uses the discrete solver to simulate the model even if you specify a continuous solver. If the model has continuous states, the continuous solvers use numerical integration to compute the values of the continuous states at the next time step.

About Variable-Step Continuous Solvers

The variable-step solvers in the Simulink product dynamically vary the step size during the simulation. Each of these solvers increases or reduces the step size using its local error control to achieve the tolerances that you specify. Computing the step size at each time step adds to the computational overhead but can reduce the total number of steps, and the simulation time required to maintain a specified level of accuracy.

You can further categorize the variable-step continuous solvers as: one-step or multistep, single-order or variable-order, and explicit or implicit. (See "Choosing a Solver Type" on page 11-10 for more information.)

Explicit Continuous Variable-Step Solvers

The explicit variable-step solvers are designed for nonstiff problems. Simulink provides three such solvers: `ode45`, `ode23`, and `ode113`.

ODE Solver	One-Step Method	Multistep Method	Order of Accuracy	Method
`ode45`	X		Medium	Runge-Kutta, Dormand-Prince (4,5) pair
`ode23`	X		Low	Runge-Kutta (2,3) pair of Bogacki & Shampine
`ode113`		X	Variable, Low to High	PECE Implementation of Adams-Bashforth-Moutlon

ODE Solver	Tips on When to Use
ode45	In general, the `ode45` solver is the best to apply as a first try for most problems. For this reason, `ode45` is the default solver for models with continuous states. This Runge-Kutta (4,5) solver is a fifth-order method that performs a fourth-order estimate of the error. This solver also uses a fourth-order "free" interpolant, which allows for event location and smoother plots. The `ode45` is more accurate and faster than `ode23`. If the `ode45` is slow computationally, your problem may be stiff and thus in need of an implicit solver.
ode23	The `ode23` can be more efficient than the `ode45` solver at crude error tolerances and in the presence of mild stiffness. This solver provides accurate solutions for "free" by applying a cubic Hermite interpolation to the values and slopes computed at the ends of a step.
ode113	For problems with stringent error tolerances or for computationally intensive problems, the Adams-Bashforth-Moulton PECE solver can be more efficient than `ode45`.

Implicit Continuous Variable-Step Solvers

If your problem is stiff, try using one of the implicit variable-step solvers: `ode15s`, `ode23s`, `ode23t`, or `ode23tb`.

ODE Solver	One-Step Method	Multistep Method	Order of Accuracy	Solver Reset Method	Max. Order	Method
`ode15s`		X	Variable, Low to Medium	X	X	Numerical Differentiation Formulas (NDFs)
`ode23s`	X		Low			Second-order, modified Rosenbrock formula

ODE Solver	One-Step Method	Multistep Method	Order of Accuracy	Solver Reset Method	Max. Order	Method
`ode23t`	X		Low	X		Trapezoidal rule using a "free" interpolant
`ode23tb`	X		Low	X		TR-BDF2

Solver Reset Method. For three of the stiff solvers—`ode15s`, `ode23t`, and `ode23tb`—a drop-down menu for the `Solver reset method` appears on the **Solver** Configuration pane. This parameter controls how the solver treats a reset caused, for example, by a zero-crossing detection. The options allowed are `Fast` and `Robust`. The former setting specifies that the solver does not recompute the Jacobian for a solver reset, whereas the latter setting specifies that the solver does. Consequently, the `Fast` setting is faster computationally but might use a small step size for certain cases. To test for such cases, run the simulation with each setting and compare the results. If there is no difference, you can safely use the `Fast` setting and save time. If the results differ significantly, try reducing the step size for the fast simulation.

Maximum Order. For the `ode15s` solver, you can choose the maximum order of the numerical differentiation formulas (NDFs) that the solver applies. Since the `ode15s` uses first- through fifth-order formulas, the `Maximum order` parameter allows you to choose 1 through 5. For a stiff problem, you may want to start with order 2.

Tips for Choosing a Variable-Step Implicit Solver. The following table provides tips relating to the application of variable-step implicit solvers. For a demonstration comparing the behavior of these solvers, see sldemo_solvers.

ODE Solver	Tips on When to Use
ode15s	`ode15s` is a variable-order solver based on the numerical differentiation formulas (NDFs). NDFs are related to, but are more efficient than the backward differentiation formulas (BDFs), which are also known as Gear's method. The `ode15s` solver numerically generates the Jacobian matrices. If you suspect that a problem is stiff, or if `ode45` failed or was highly inefficient, try `ode15s`. As a rule, start by limiting the maximum order of the NDFs to 2.
ode23s	`ode23s` is based on a modified Rosenbrock formula of order 2. Because it is a one-step solver, it can be more efficient than `ode15s` at crude tolerances. Like `ode15s`, `ode23s` numerically generates the Jacobian matrix for you. However, it can solve certain kinds of stiff problems for which `ode15s` is not effective.
ode23t	The `ode23t` solver is an implementation of the trapezoidal rule using a "free" interpolant. Use this solver if your model is only moderately stiff and you need a solution without numerical damping. (Energy is not dissipated when you model oscillatory motion.)
ode23tb	`ode23tb` is an implementation of TR-BDF2, an implicit Runge-Kutta formula with two stages. The first stage is a trapezoidal rule step while the second stage uses a backward differentiation formula of order 2. By construction, the method uses the same iteration matrix in evaluating both stages. Like `ode23s`, this solver can be more efficient than `ode15s` at crude tolerances.

Note For a *stiff* problem, solutions can change on a time scale that is very small as compared to the interval of integration, while the solution of interest changes on a much longer time scale. Methods that are not designed for stiff problems are ineffective on intervals where the solution changes slowly because these methods use time steps small enough to resolve the fastest possible change. For more information, see Shampine, L. F., *Numerical Solution of Ordinary Differential Equations*, Chapman & Hall, 1994.

Support for Zero-Crossing Detection

Both the variable-step discrete and continuous solvers use zero-crossing detection (see "Zero-Crossing Detection" on page 2-23) to handle continuous signals.

Specifying Variable-Step Solver Error Tolerances

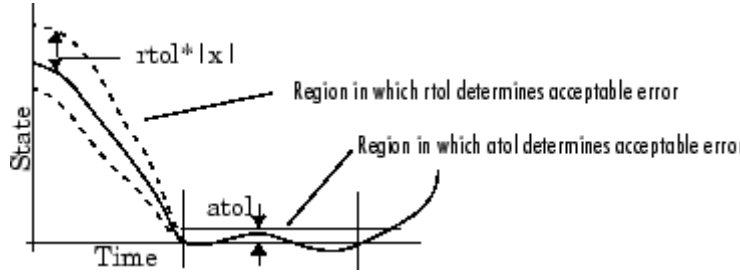
The solvers use standard local error control techniques to monitor the error at each time step. During each time step, the solvers compute the state values at the end of the step and determine the *local error*—the estimated error of these state values. They then compare the local error to the *acceptable error*, which is a function of both the relative tolerance (*rtol*) and the absolute tolerance (*atol*). If the local error is greater than the acceptable error for *any* state, the solver reduces the step size and tries again.

- The *Relative tolerance* measures the error relative to the size of each state. The relative tolerance represents a percentage of the state value. The default, 1e-3, means that the computed state is accurate to within 0.1%.
- *Absolute tolerance* is a threshold error value. This tolerance represents the acceptable error as the value of the measured state approaches zero.

The solvers require the error for the `i`th state, e_i, to satisfy:

$$e_i \le \max(rtol \times |x_i|, atol_i).$$

The following figure shows a plot of a state and the regions in which the relative tolerance and the absolute tolerance determine the acceptable error.



If you specify `auto` (the default), Simulink initially sets the absolute tolerance for each state to 1e-6. As the simulation progresses, the absolute tolerance for each state is reset to the maximum value that the state has assumed thus far, times the relative tolerance for that state. Thus, if a state changes from 0 to 1 and `reltol` is 1e-3, then by the end of the simulation, `abstol` is set to 1e-3 also. If a state goes from 0 to 1000, then `abstol` is set to 1.

If the computed setting is not suitable, you can determine an appropriate setting yourself. You might have to run a simulation more than once to determine an appropriate value for the absolute tolerance.

The Integrator, Second-Order Integrator Limited, Variable Time Delay, Transfer Fcn, State-Space, and Zero-Pole blocks allow you to specify absolute tolerance values for solving the model states that they compute or that determine their output. The absolute tolerance values that you specify for these blocks override the global settings in the Configuration Parameters dialog box. You might want to override the global setting in this way. For example, if the global setting does not provide sufficient error control for all of your model states because they vary widely in magnitude, then you might want to set the value yourself.

Choosing a Jacobian Method for an Implicit Solver

About the Solver Jacobian

For implicit solvers, Simulink must compute the *solver Jacobian*, which is a submatrix of the Jacobian matrix associated with the continuous representation of a Simulink model. In general, this continuous representation is of the form:

$$\dot{x} = f(x,t,u)$$
$$y = g(x,t,u).$$

The Jacobian, J, formed from this system of equations is:

$$J = \begin{pmatrix} \frac{\partial f}{\partial x} & \frac{\partial f}{\partial u} \\ \frac{\partial g}{\partial x} & \frac{\partial g}{\partial u} \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix}.$$

In turn, the solver Jacobian is the submatrix, J_x.

$$J_x = A = \frac{\partial f}{\partial x}.$$

Sparsity of Jacobian. For many physical systems, the solver Jacobian J_x is *sparse*, meaning that many of the elements of J_x are zero.

Consider the following system of equations:

$$\dot{x}_1 = f_1(x_1, x_3)$$
$$\dot{x}_2 = f_2(x_2)$$
$$\dot{x}_3 = f_3(x_2).$$

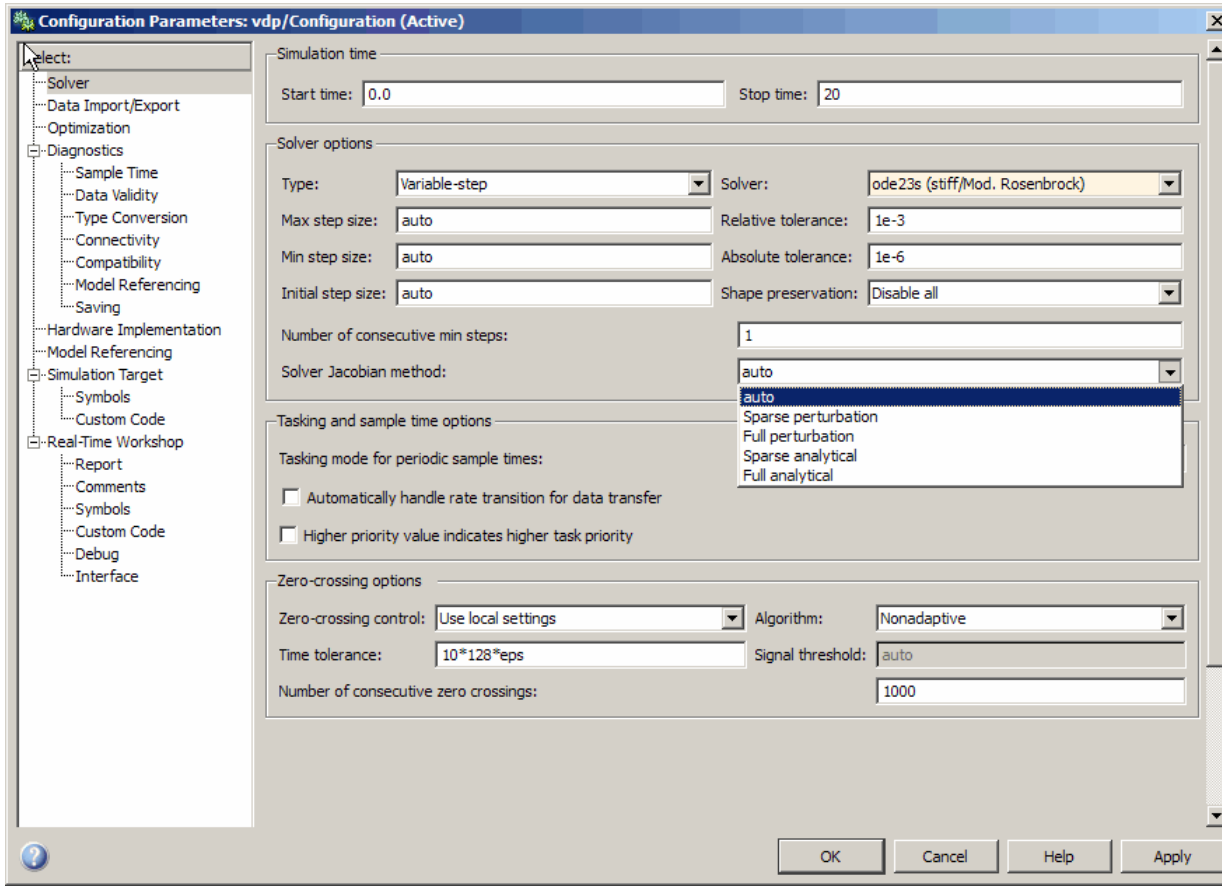
From this system, you can derive a sparsity pattern that reflects the structure of the equations. The pattern, a Boolean matrix, has a 1 for each x_i that appears explicitly on the right-hand side of an equation. You thereby attain:

$$J_{x,pattern} = \begin{pmatrix} 1 & 0 & 1 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \end{pmatrix}$$

As discussed in "Full and Sparse Perturbation Methods" on page 11-28 and "Full and Sparse Analytical Methods " on page 11-30 respectively, the Sparse Perturbation Method and the Sparse Analytical Method may be able to take advantage of this sparsity pattern to reduce the number of computations necessary and thereby improve performance.

Solver Jacobian Methods

When you choose an implicit solver from the **Solver** pane of the Configuration Parameters dialog box, a parameter called `Solver Jacobian method` and a drop-down menu appear. This menu has five options for computing the solver Jacobian: **auto**, **Sparse perturbation**, **Full perturbation**, **Sparse analytical**, and **Full analytical**.



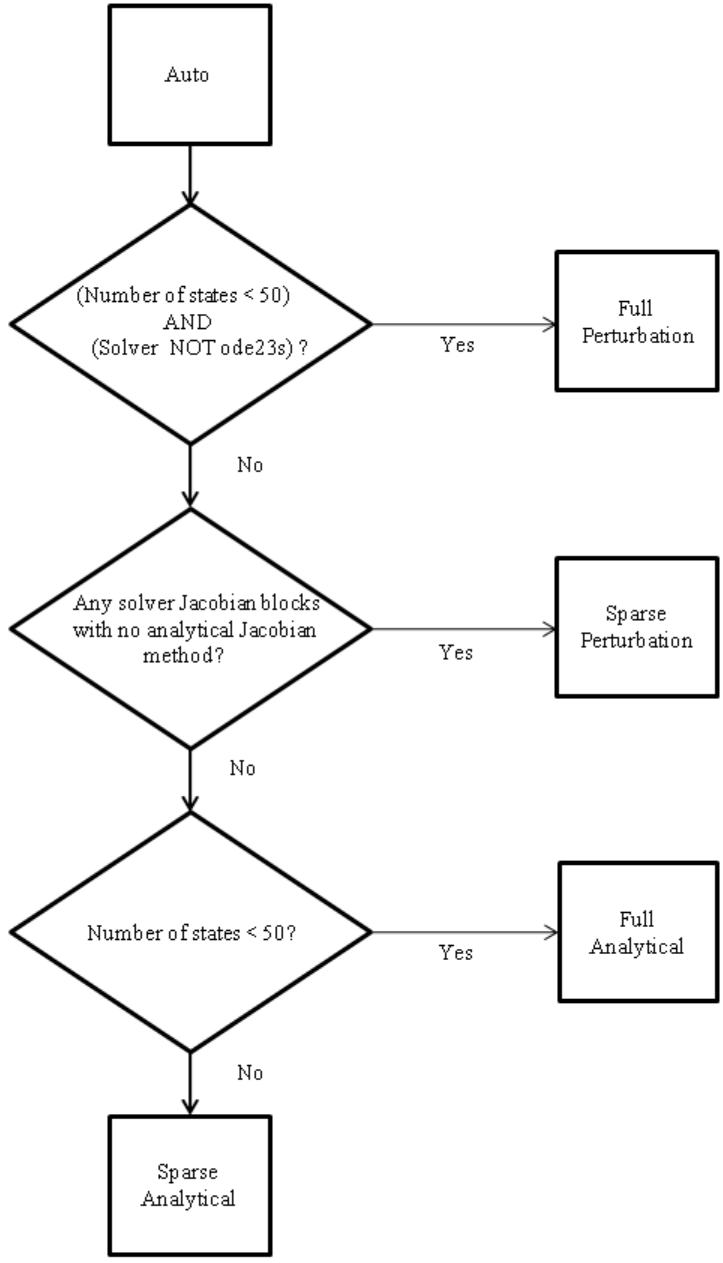
Note If you set **Automatic solver parameter selection** to `warning` or `error` in the Solver Diagnostics pane, and you choose a different solver method than Simulink, you might receive a warning or an error.

Limitations. The solver Jacobian methods have the following limitations associated with them.

- If you select an analytical Jacobian method, but one or more blocks in the model do not have an analytical Jacobian, then Simulink applies a perturbation method.
- If you select sparse perturbation and your model contains data store blocks, Simulink applies the full perturbation method.

Heuristic 'auto' Method

The default setting for the `Solver Jacobian method` is `auto`. Selecting this choice causes Simulink to perform a heuristic to determine which of the remaining four methods best suits your model. This algorithm is depicted in the following flowchart.


Auto
(Number of states < 50)
AND
(Solver NOT ode23s) ?
Yes
Full
Perturbation
No
Any solver Jacobian blocks
with no analytical Jacobian
method?
Yes
Sparse
Perturbation
No
Number of states < 50?
Yes
Full
Analytical
No
Sparse
Analytical

Because the sparse methods are beneficial for models having a large number of states, the heuristic chooses a sparse method if more than 50 states exist in your model. The logic also leads to a sparse method if you specify `ode23s` because, unlike other implicit solvers, `ode23s` generates a new Jacobian at every time step. A sparse analytical or a sparse perturbation method is, therefore, highly advantageous. The heuristic also ensures that the analytical methods are used only if every block in your model can generate an analytical Jacobian.

Full and Sparse Perturbation Methods

The full perturbation method was the standard numerical method that Simulink used to solve a system. For this method, Simulink solves the full set of perturbation equations and uses LAPACK for linear algebraic operations. This method is costly from a computational standpoint, but it remains the recommended method for establishing baseline results.

The sparse perturbation method attempts to improve the run-time performance by taking mathematical advantage of the sparse Jacobian pattern. Returning to the sample system of three equations and three states,

$$\dot{x}_1 = f_1(x_1, x_3)$$
$$\dot{x}_2 = f_2(x_2)$$
$$\dot{x}_3 = f_3(x_2).$$

The solver Jacobian is:

$$J_x = \begin{pmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} & \frac{\partial f_1}{\partial x_3} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} & \frac{\partial f_2}{\partial x_3} \\ \frac{\partial f_3}{\partial x_1} & \frac{\partial f_3}{\partial x_2} & \frac{\partial f_3}{\partial x_3} \end{pmatrix}$$

$$= \begin{pmatrix} \frac{f_1(x_1+\Delta x_1, x_2, x_3) - f_1}{\Delta x_1} & \frac{f_1(x_1, x_2+\Delta x_2, x_3) - f_1}{\Delta x_2} & \frac{f_1(x_1, x_2, x_3+\Delta x_3) - f_1}{\Delta x_3} \\ \frac{f_2(x_1+\Delta x_1, x_2, x_3) - f_2}{\Delta x_1} & \frac{f_2(x_1, x_2+\Delta x_2, x_3) - f_2}{\Delta x_2} & \frac{f_2(x_1, x_2, x_3+\Delta x_3) - f_2}{\Delta x_3} \\ \frac{f_3(x_1+\Delta x_1, x_2, x_3) - f_3}{\Delta x_1} & \frac{f_3(x_1, x_2+\Delta x_2, x_3) - f_3}{\Delta x_2} & \frac{f_3(x_1, x_2, x_3+\Delta x_3) - f_3}{\Delta x_3} \end{pmatrix}$$

It is, therefore, necessary to perturb each of the three states three times and to evaluate the derivative function three times. For a system with n states, this method perturbs the states n times.

By applying the sparsity pattern and perturbing states x_1 and x_2 together, this matrix reduces to:

$$J_x = \begin{pmatrix} \frac{f_1(x_1+\Delta x_1, x_2+\Delta x_2, x_3) - f_1}{\Delta x_1} & 0 & \frac{f_1(x_1, x_2, x_3+\Delta x_3) - f_1}{\Delta x_3} \\ 0 & \frac{f_2(x_1+\Delta x_1, x_2+\Delta x_2, x_3) - f_2}{\Delta x_2} & 0 \\ 0 & \frac{f_3(x_1+\Delta x_1, x_2+\Delta x_2, x_3) - f_3}{\Delta x_2} & 0 \end{pmatrix}$$

The solver can now solve columns 1 and 2 in one sweep. While the sparse perturbation method saves significant computation, it also adds overhead to compilation. It might even slow down the simulation if the system does not have a large number of continuous states. A tipping point exists for which you

obtain increased performance by applying this method. In general, systems having a large number of continuous states are usually sparse and benefit from the sparse method.

The sparse perturbation method, like the sparse analytical method, uses UMFPACK to perform linear algebraic operations. Also, the sparse perturbation method supports both RSim and Rapid Accelerator mode.

Full and Sparse Analytical Methods

The full and sparse analytical methods attempt to improve performance by calculating the Jacobian using analytical equations rather than the perturbation equations. The sparse analytical method, also uses the sparsity information to accelerate the linear algebraic operations required to solve the ordinary differential equations.

Sparsity Pattern

For details on how to access and interpret the sparsity pattern in MATLAB, see sldemo_metro.

Support for Code Generation

While the sparse perturbation method supports RSim, the sparse analytical method does not. Consequently, regardless of which sparse method you select, any generated code uses the sparse perturbation method.

Interacting with a Running Simulation

You can perform certain operations interactively while a simulation is running. You can do the following:

- Modify some configuration parameters, including the stop time and the maximum step size
- Click a line to see the signal carried on that line on a floating (unconnected) Scope or Display block
- Modify the parameters of a block, as long as you do not cause a change in the:
  - Number of states, inputs, or outputs
  - Sample time
  - Number of zero crossings
  - Vector length of any block parameters
  - Length of the internal block work vectors
  - Dimension of any signals
- Display block data tips on a computer running the Microsoft Windows operating system (see "Block Data Tips" on page 18-2).

You cannot make changes to the structure of the model, such as adding or deleting lines or blocks, during a simulation. To make these kinds of changes, stop the simulation, make the change, then start the simulation again to see the results of the change.

Saving and Restoring the Simulation State as the SimState

In this section...

Overview of the SimState

In real-world applications, you simulate a Simulink model repeatedly to analyze the behavior of a system for different input, boundary conditions, or operating conditions. In many applications, a start-up phase with significant dynamic behavior is common to multiple simulations. For example, the cold start take-off of a gas turbine engine occurs before each set of aircraft maneuvers. Ideally, you would simulate this start-up phase once, save the simulation state at the end of the start-up phase, and then use this simulation state or *SimState* as the initial state for each set of conditions or maneuvers.

The Simulink `SimState` feature allows you to save all run-time data necessary for restoring the simulation state of a model. A `SimState` includes both the logged and internal state of every block (e.g., continuous states, discrete states, work vectors, zero-crossing states) and the internal state of the Simulink engine (e.g., the data of the ODE solver).

You can save a `SimState`:

- At the final **Stop time**
- When you interrupt a simulation with the **Pause** or **Stop** button
- When you use a block (e.g., the Stop block) to stop a simulation

At a later time, you can restore the `SimState` and use it as the initial conditions for any number of simulations.

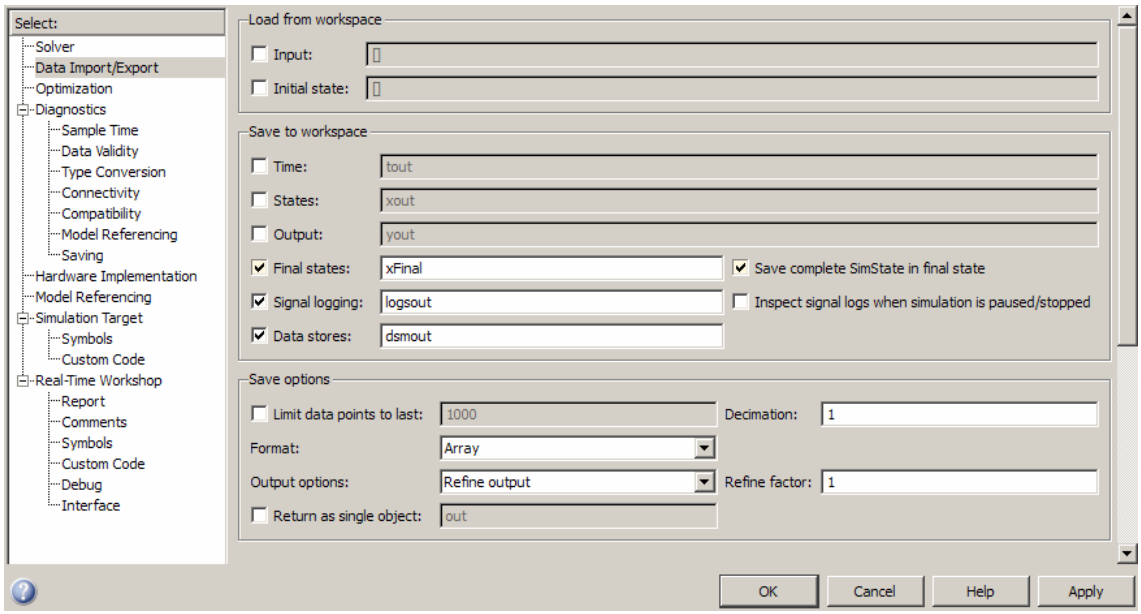
Note The **Final states** option of the **Data Import/Export** pane in Simulink saves only *logged* states—the continuous and discrete states of blocks—which are a subset of the complete simulation state of the model. Hence you cannot use the **Final states** to save and restore the complete simulation state as the initial state of a new simulation.

How to Save the SimState

Saving the SimState Interactively

To save the complete `SimState` at the beginning of the final step:

1. In the Simulink model window, select **Simulation > Configuration Parameters**.
2. Navigate to the **Data Import/Export** pane.
3. Select the **Final states** check box. The **Save complete SimState in final state** check box becomes active.
4. Select the **Save complete SimState in final state** check box.
5. In the adjacent field, enter a variable name for the `SimState`.
6. Simulate the model by selecting **Simulation > Start**.



Saving the SimState Programmatically

You can save the `SimState` at the beginning of the final step programmatically using the `sim` command in conjunction with the `set_param` command with the `SaveCompleteFinalSimState` parameter set to `on`:

```
set_param(mdl, 'SaveFinalState', 'on', 'FinalStateName',...
 [mdl 'SimState'],'SaveCompleteFinalSimState', 'on')
simOut = sim(mdl, 'StopTime', tstop)
set_param(mdl, 'SaveFinalState', 'off')
```

How to Restore the SimState

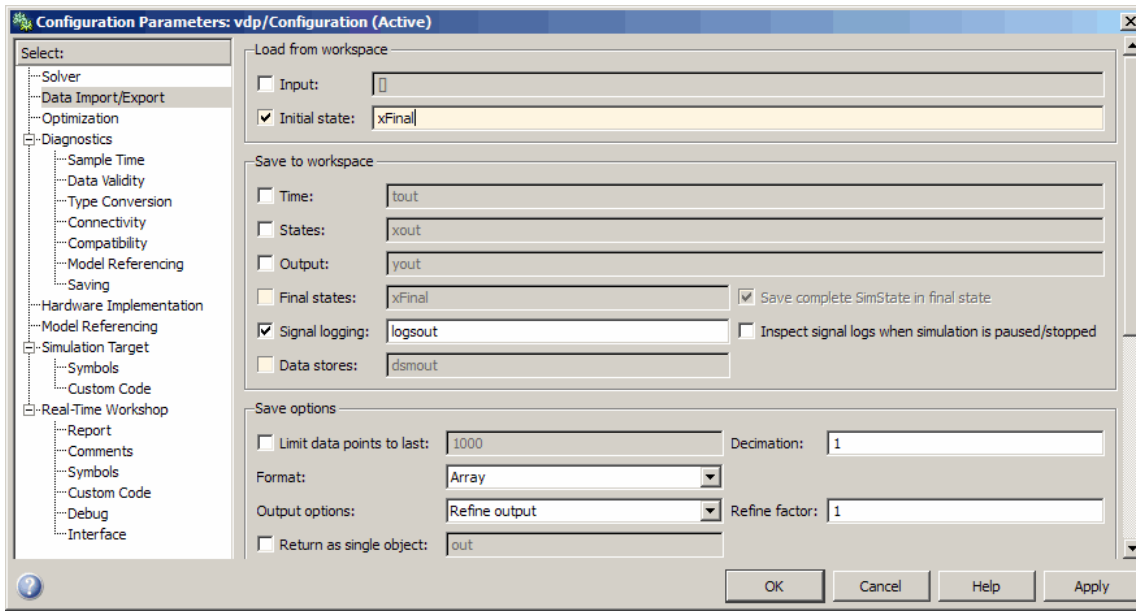
Restoring the SimState Interactively

You can restore the `SimState` interactively.

In the **Data Import/Export** pane:

1. Under **Load from workspace**, select the check box next to **Initial state**. The adjacent field becomes active.

2. Enter the name of the variable containing the `SimState` in the field.



In the **Solver** pane of the **Configuration Parameters** window:

1. Keep the **Start time** set to its original value.

2. Set the **Stop time** to the sum of the original simulation time plus the new additional simulation time.

3. Click **OK**.

The **Start time** must maintain its original value because it is a reference value for all time and time-dependent variables in both the original and the current simulations. For example, a block may save and restore the number of sample time hits that occurred since the beginning of simulation as the `SimState` . For clarity, consider a model that you ran from 0 s to 100 s and that you now wish to run from 100 s to 200 s. The **Start time** is 0 s for both

the original simulation (0 s to 100 s) and for the current simulation (100 s to 200 s). And 100 s is the initial time of the current simulation. Also, if the block had ten sample time hits during the original simulation, Simulink recognizes that the next sample time hit will be the eleventh relevant to 0 s (not 100 s).

Restoring the SimState Programmatically

Use the `set_param` command to specify the initial condition as the `SimState`.

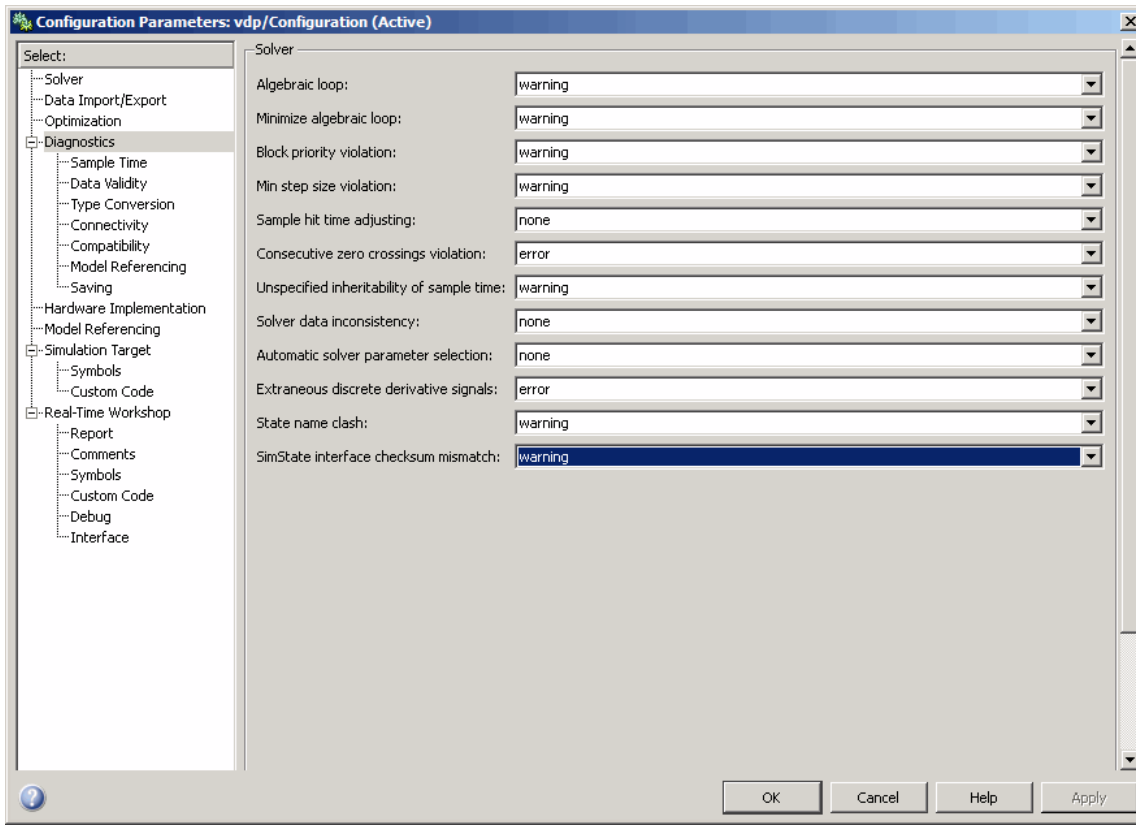
```
set_param(mdl, 'LoadInitialState', 'on', 'InitialState',...
[mdl 'SimState']);
simOut = sim(mdl, 'StopTime', tstop)
```

How to Change the States of a Block within the SimState

You can use the `loggedStates` to get or set the `SimState`. The `loggedStates` field has the same structure as xout.signals if *xout* is the state log that Simulink exports to the workspace.

Using the SimState Interface Checksum Diagnostic

The `SimState` interface checksum is primarily based upon the configuration settings of your model. A diagnostic, 'SimState interface checksum mismatch', resides on the Diagnostics pane of the Configuration Parameters dialog box. You can set this diagnostic to 'none', 'warning', or 'error" to receive a warning or an error if the interface checksum of the restored `SimState` does not match the current interface checksum of the model. Such mismatches may occur when you try to simulate using a solver that is different from the one that generated the saved `SimState`. Simulink permits such solver changes. For example, you can use a solver such as ode15s, to solve the initial stiff portion of a simulation, save the final `SimState`, and then continue the simulation with the restored `SimState` and using ode45. In other words, this diagnostic is purely to serve your own purposes for detecting solver changes.



Limitations of the SimState

Several limitations exist for the `SimState`:

- You can use only the Normal or the Accelerator mode of simulation.
- You cannot save the SimState in Normal mode and restore it in Accelerator mode, or vice versa.
- You can save the `SimState` only at the final stop time or at the execution time at which you pause or stop the simulation.
- By design, Simulink does not save user data, run-time parameters, or logs of the model.

- The `SimState` feature does not support code generation, including Model Reference in accelerated modes.
- You cannot make any structural changes to the model between the time at which you save the `SimState` and the time at which you restore the simulation using the `SimState`. For example, you cannot add or remove a block after saving the `SimState` without repeating the simulation and saving the new `SimState`.
- You cannot input the `SimState` to model functions.
- You cannot save the `SimState` in one version of Simulink and restore it to another version of Simulink.

Using SimState within S-Functions

Special APIs for C and Level-2 MATLAB S-functions are available, which enable the S-functions to work with the `SimState`. For information on how to implement these APIs within S-functions, see "S-Function Compliance with the `SimState`".

Diagnosing Simulation Errors

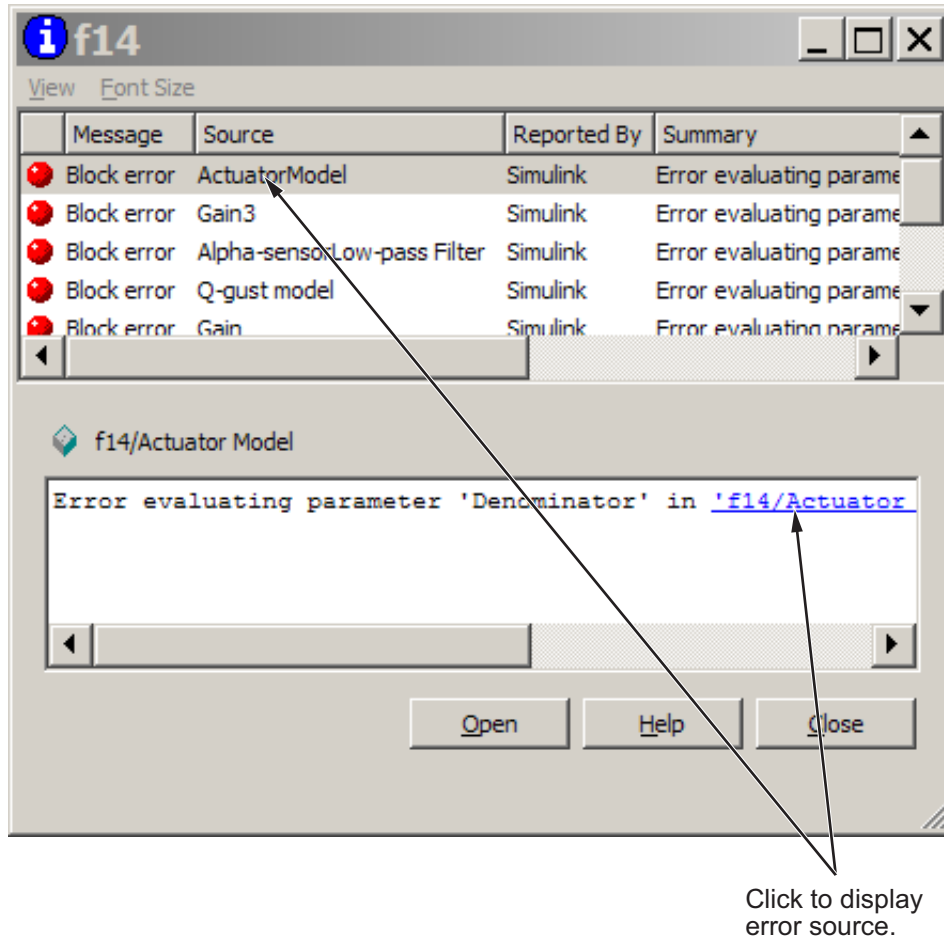
In this section...

Response to Run-Time Errors

If errors occur during a simulation, the Simulink software halts the simulation, opens the subsystems that caused the error (if necessary), and displays the errors in the Simulation Diagnostics Viewer. The following sections explain how to use the viewer to determine the cause of the errors, and how to create custom error messages.

Simulation Diagnostics Viewer

The viewer comprises an Error Summary pane and an Error Message pane.



Error Summary Pane

The upper pane lists the errors that caused the simulation to terminate. The pane displays the following information for each error.

Message. Message type (for example, block error, warning, or log)

Source. Name of the model element (for example, a block) that caused the error

Reported By. Component that reported the error (for example, the Simulink product, the Stateflow product, or the Real-Time Workshop product).

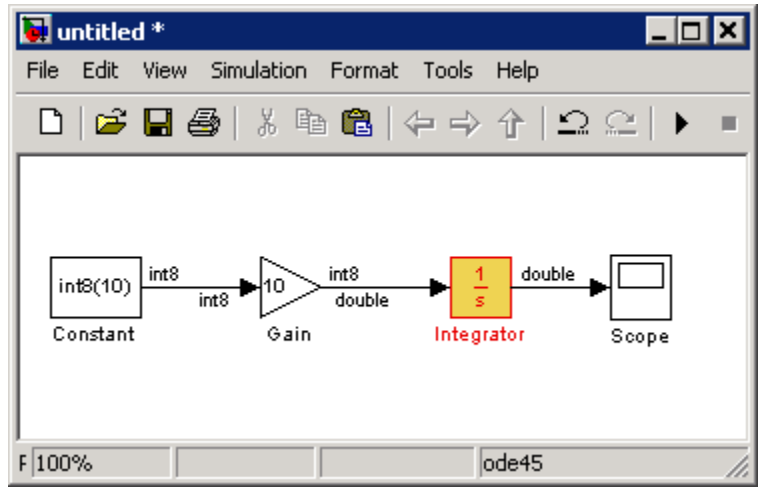
Summary. Error message, abbreviated to fit in the column

You can remove any of these columns of information to make room for other columns. To remove a column, select the **View** menu and uncheck the corresponding item.

Error Message Pane

The lower pane initially contains the contents of the first error message listed in the top pane. You can display the contents of other messages by clicking their entries in the upper pane.

In addition to displaying the viewer, the Simulink software opens (if necessary) the subsystem that contains the first error source and highlights the source.



You can display the sources of other errors by clicking: anywhere in the error message in the upper pane; the name of the error source in the error message (highlighted in blue); or the **Open** button on the viewer.

Changing Font Size

To change the size of the font used to display errors, select **Increase Font Size** or **Decrease Font Size** from the **Font Size** menu of the viewer.

Creating Custom Simulation Error Messages

The Simulation Diagnostics Viewer displays the output of any instance of the MATLAB error function executed during a simulation. Such instances include those invoked by block or model callbacks, or by S-functions that you create or that the MATLAB Fcn block executes.

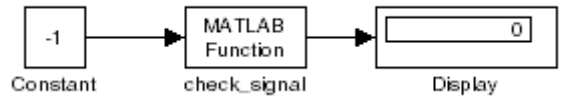
You can use the MATLAB error function in callbacks, S-functions or the MATLAB Fcn block to create custom error messages specific to your application. Following are the capabilities available to messages:

- Display the contents of a text string
- Include hyperlinks to an object
- Link to an HTML file

Displaying A Text String

To display the contents of a text string, pass the string enclosed by quotation marks to the error function.

The following example shows how you can make the user-created function `check_signal` display the string `Signal is negative`.

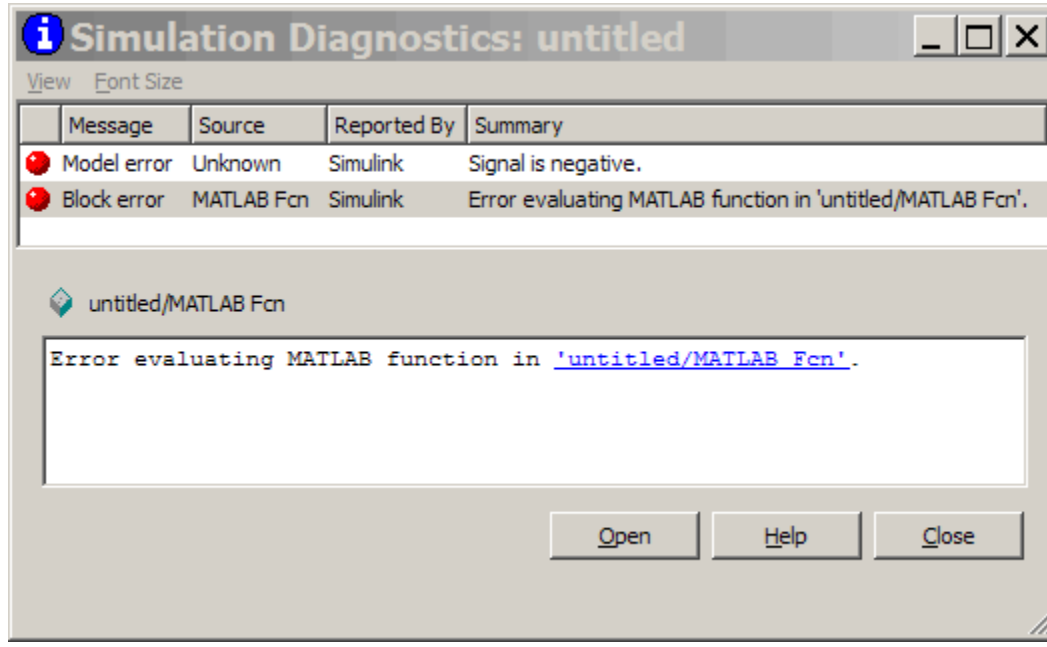


The MATLAB Fcn block invokes the following function:

```
function y=check_signal(x)
  if x<0
    error('Signal is negative');
  else
    y=x;
```

```
end
```

Executing this model displays the error message in the Simulation Diagnostics Viewer.



Creating Hyperlinks to Files, Directories, or Blocks

To include a hyperlink to a block, file, or folder in the error message, include the path to the item enclosed in quotation marks.

- `error ('Error evaluating parameter in block "mymodel/Mu"')`

  displays a text hyperlink to the block Mu in the model “mymodel”. Clicking the hyperlink displays the block in the model window.

- `error ('Error reading data from "c:/work/test.data"')`

  displays a text hyperlink to the file `test.data` in the error message. Clicking the link displays the file in your preferred MATLAB editor.

- `error ('Could not find data in folder "c:/work"')`

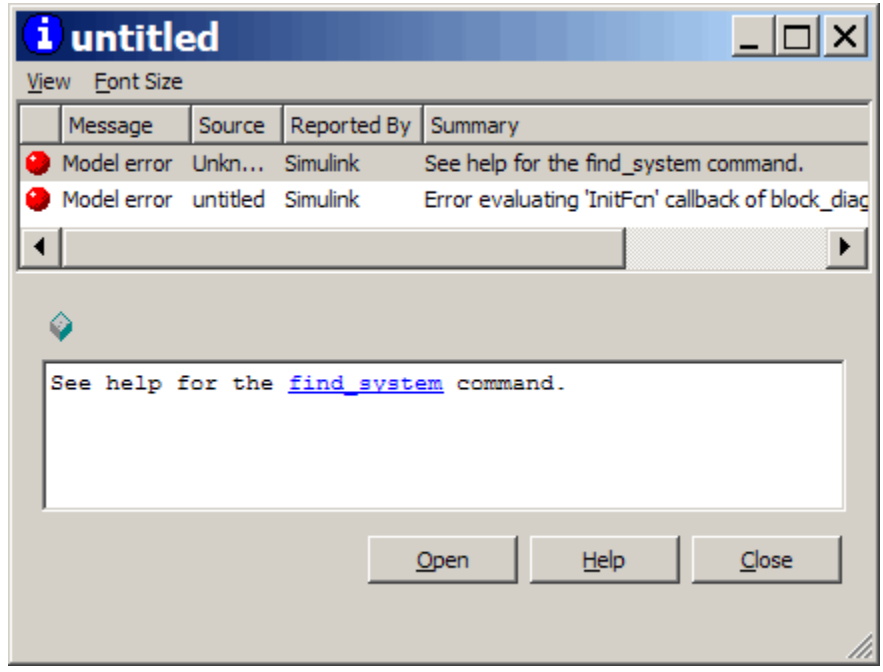
displays a text hyperlink to the `c:/work` folder. Clicking the link opens a system command window (shell) and sets its working folder to `c:/work`.

Creating Programmatic Hyperlinks

You can create a hyperlink that, when clicked, causes the evaluation of a MATLAB expression. For example, the following model `InitFcn` callback displays an error, when the model starts, with a hyperlink to help for the `find_system` command.

```
error('See help for the <a href="matlab:doc
find_system">find_system</a>
```

In this example, the Simulation Diagnostics Viewer displays a hyperlink labeled `find_system`. Clicking the link opens the documentation for the `find_system` command in the MATLAB Help browser.



12

Running a Simulation Programmatically

About Programmatic Simulation

Entering simulation commands in the MATLAB Command Window or from a MATLAB file enables you to run unattended simulations. You can perform Monte Carlo analysis by changing the parameters randomly and executing simulations in a loop. You can use either the `sim` command or the `set_param` command to run a simulation programmatically. To run simulations simultaneously, you can call `sim` from within a `parfor` loop under specific conditions.

Using the sim Command

In this section...

Single-Output Syntax for the sim Command

The general form of the command syntax for running a simulation is:

```
SimOut = sim('model', Parameters)
```

where *model* is the name of the block diagram and *Parameters* can be a list of parameter name-value pairs, a structure containing parameter settings, or a configuration set. The `sim` command returns, `SimOut`, a single Simulink.SimulationOutput object that contains all of the simulation outputs (logged time, states, and signals). This syntax is the "single-output format" of the `sim` command.

```
SimOut = sim('model', 'Param1', Value1, 'Param2', Value2...);
SimOut = sim('model', ParameterStruct);
SimOut = sim('model', ConfigSet);
```

During simulation, the specified parameters override the values in the block diagram configuration set.The original configuration values are restored at the end of simulation. If you wish to simulate the model without overriding any parameters, and you want the simulation results returned in the single-output format, then you must do one of the following:

- select **Return as single object** on the Data Import/Export pane of the Configuration Parameters dialog box
- specify the `ReturnWorkspaceOutputs` parameter value as 'on' in the `sim` command:

```
SimOut = sim('model', 'ReturnWorkspaceOutputs', 'on');
```

To log the model time, states, or outputs, use the Configuration Parameters Data Import/Export dialog box. To log signals, either use a block such as the To Workspace block or the Scope block, or use the **Signal and Scope Manager** to log results directly.

For complete details of the `sim` command syntax, see the `sim` reference page. For information about the configuration parameters, see "Configuration Parameters Dialog Box".

Examples of Implementing the sim Command

Following are examples that demonstrate the application of each of the three formats for specifying parameter values using the single-output format of the `sim` command.

Specifying Parameter Name-Value Pairs

In the following example, the `sim` syntax specifies the model name, `vdp`, followed by consecutive pairs of parameter name and parameter value. For example, the value of the `SimulationMode` parameter is `rapid`.

```
simOut = sim('vdp','SimulationMode','rapid','AbsTol','1e-5',...
             'SaveState','on','StateSaveName','xoutNew',...
             'SaveOutput','on','OutputSaveName','youtNew');
simOutVars = simOut.who;
yout = simOut.get('youtNew');
```

Specifying a Parameter Structure

The following example shows how to specify parameter name-value pairs as a structure to the `sim` command.

```
paramNameValStruct.SimulationMode = 'rapid';
paramNameValStruct.AbsTol         = '1e-5';
paramNameValStruct.SaveState      = 'on';
paramNameValStruct.StateSaveName  = 'xoutNew';
paramNameValStruct.SaveOutput     = 'on';
paramNameValStruct.OutputSaveName = 'youtNew';
simOut = sim('vdp',paramNameValStruct);
```

Specifying a Configuration Set

The following example shows how to create a configuration set and use it with the `sim` syntax.

```
mdl = 'vdp';
load_system(mdl)
simMode = get_param(mdl, 'SimulationMode');
set_param(mdl, 'SimulationMode', 'rapid')
cs = getActiveConfigSet(mdl);
mdl_cs = cs.copy;
set_param(mdl_cs,'AbsTol','1e-5',...
         'SaveState','on','StateSaveName','xoutNew',...
         'SaveOutput','on','OutputSaveName','youtNew')
simOut = sim(mdl, mdl_cs);
set_param(mdl, 'SimulationMode', simMode)
```

The block diagram parameter, `SimulationMode`, is not part of the configuration set, but is associated with the model. Therefore, the set_param command saves and restores the original simulation mode by passing the model rather than the configuration set.

Calling sim from within parfor

For information on how to run simultaneous simulations by calling `sim` from within `parfor`, see "Running Parallel Simulations" on page 12-9.

Backwards Compatible Syntax

The following syntax is now obsolete but will be maintained for backwards compatibility with Simulink Versions 7.3 or earlier releases.

```
[T,X,Y] =sim('model',Timespan, Options, UT)
[T,X,Y1,...,Yn] =sim('model',Timespan, Options, UT)
```

If only one right-hand side argument exists, then Simulink automatically saves the time, the state and the output to the specified left-hand side arguments. You can explicitly switch to the single-output format by changing the defaults.

If you do not specify any left-hand side arguments, then Simulink determines what data to log based on the workspace I/O settings of the Data Import/Export pane of the Configuration Parameters dialog box.

T	The time vector returned.
X	The state returned in matrix or structure format. The state matrix contains continuous states followed by discrete states.
Y	The output returned in matrix or structure format. For block diagram models, this variable contains all root-level blocks.
Y1,...,*Yn*	The outports, which can only be specified for diagram models. Here *n* must be the number of root-level blocks. Each outport will be returned in the *Y*1,...,*Yn* variables.
'*model*'	The name of a block diagram model.
Timespan	The timespan can be one of the following: TFinal, [TStart TFinal], or [TStart OutputTimes TFinal]. Output times are time points which will be returned in *T*, but in general *T* will include additional time points.
Options	Optional simulation parameters created in a structure by the `simset` command using name-value pairs.
UT	Optional external inputs including: • A MATLAB function, expressed as a string, that specifies the input $u = UT(t)$ at each simulation step. • A table of input values versus time for all input ports $UT = [T, U1,...,Un]$ where $T = [t1,...,tm]$. • A structure array containing data for all input ports. • A comma-separated list of tables. Each table corresponds to a specific input port, and must be an array, a structure, a Simulink.Timeseries object, or a Simulink.TsArray object.

Simulink only requires the first parameter. Simulink takes all defaults from the block diagram, including unspecified options. If you specify any optional arguments, your specified settings override the settings in the block diagram.

Specifying the right-hand side argument of `sim` as the empty matrix, [ ], causes Simulink to use the default for the argument.

To specify the single-output format for `sim('model', Timespan, Options, UT)`, set the 'ReturnWorkspaceOutputs' option of the options structure to 'on'.

See also `simset` and `simget`.

Using the set_param Command

You can use the `set_param` command to start, stop, pause, or continue a simulation, to update a block diagram, or to write all data logging variables to the base workspace. The format of the `set_param` command is:

```
set_param('sys', 'SimulationCommand', 'cmd')
```

where '*sys*' is the name of the system and '*cmd*' is `'start'`, `'stop'`, `'pause'`, `'continue'`, `'update'`, or `'WriteDataLogs'`. See Chapter 27, "Importing and Exporting Data" for information about data logging.

Similarly, you can use the `get_param` command to check the status of a simulation. The format of the `get_param` function call for this use is

```
get_param('sys', 'SimulationStatus')
```

The Simulink software returns `'stopped'`, `'initializing'`, `'running'`, `'paused'`, `'updating'`, `'terminating'`, or `'external'` (used with the Real-Time Workshop product).

Note If you use `matlab -nodisplay` to start a session, then you cannot use `set_param` to run your simulation session.

Running a Simulation from an S-Function

S-functions can use the `set_param` command to control simulation execution. A C MEX S-function can use the `mexCallMATLAB` macro to call the `set_param` command itself.

Running Parallel Simulations

In this section...

Overview of Calling sim from within parfor

The MATLAB `parfor` command allows you to run parallel Simulink simulations. Calling `sim` from within a `parfor` loop is often advantageous for performing multiple simulation runs of the same model for different inputs or for different parameter settings. For example, you may save significant simulation time performing parameter sweeps and Monte Carlo analyses by running them in parallel. Note that running parallel simulations using `parfor` does not currently support decomposing your model into smaller connected pieces and running the individual pieces simultaneously on multiple workers.

Normal, Accelerator, and Rapid Accelerator simulation modes are supported by `sim` in `parfor`. (See for details on selecting a simulation mode and "Designing Your Model for Effective Acceleration" on page 17-14 for optimizing simulation run times.) For other simulations modes, you need to address any workspace access issues and data concurrency issues in order to produce useful results. Specifically, the simulations need to create separately named output files and workspace variables; otherwise, each simulation will overwrite the same workspace variables and files, or possibly have collisions trying to write variables and files simultaneously.

For details about the `parfor` command, see `parfor`.

Note All simulation modes require a homogeneous file system. The workers and the callers must be on the same operating system and have the same type of file system (for example, NTFS or FAT).

sim in parfor with Rapid Accelerator Mode

Running Rapid Accelerator simulations in `parfor` combines speed with automatic distribution of a prebuilt executable to the `parfor` workers. As a result, this mode eliminates duplication of the update diagram phase.

To run parallel simulations in Rapid Accelerator simulation mode using the `sim` and `parfor` commands, you must:

- Configure the model to run in Rapid Accelerator simulation mode
- Ensure that the Rapid Accelerator target is already built and up to date
- Disable the Rapid Accelerator target up-to-date check by setting the `sim` command option `RapidAcceleratorUpToDateCheck` to '`off`'.

To satisfy the second condition, you can only change parameters between simulations that do not require a model rebuild. In other words, the structural checksum of the model must remain the same. Hence, you can change only tunable block diagram parameters and tunable run-time block parameters between simulations. For a discussion on tunable parameters that do not require a rebuild subsequent to their modifications, see "Determining If the Simulation Will Rebuild" on page 17-7.

As for the third condition, the following sample code demonstrates how to disable the up-to-date check using the `sim` command.

```
% Load the model and set parameters
mdl = 'vdp';
load_system(mdl)
set_param(mdl, 'SimulationMode', 'rapid')
% Build the Rapid Accelerator target
rtp = Simulink.BlockDiagram.buildRapidAcceleratorTarget(mdl);
% Run parallel simulations
parfor i=1:4
   simOut{i} = sim(mdl,...
```

```
                'RapidAcceleratorUpToDateCheck', 'off',...
                'SaveTime', 'on',...
                'StopTime', num2str(10*i));
end
```

In this example, the call to the `buildRapidAcceleratorTarget` function generates code once. Subsequent calls to `sim` with the `RapidAcceleratorUpToDateCheck` option `off` guarantees that code is not regenerated. Data concurrency issues are thus resolved.

For a detailed demonstration of this method of running parallel simulations, refer to the Rapid Accelerator Simulations Using PARFOR demo.

Workspace Access Issues

In order to run `sim` in `parfor`, you must first open a MATLAB pool of workers using the `matlabpool` command. The `parfor` command then runs the code within the `parfor` loop in these MATLAB worker sessions. The MATLAB workers, however, do not have access to the workspace of the MATLAB client session where the model and its associated workspace variables have been loaded. Hence, if you load a model and define its associated workspace variables outside of and before a `parfor` loop, then neither is the model loaded, nor are the workspace variables defined in the MATLAB worker sessions where the `parfor` iterations are executed. This is typically the case when you define model parameters or external inputs in the base workspace of the client session. These scenarios constitute workspace access issues.

Resolving Workspace Access Issues

When a Simulink model is loaded into memory in a MATLAB client session, it is only visible and accessible in that MATLAB session; it is not accessible in the memory of the MATLAB worker sessions. Similarly, the workspace variables associated with a model that are defined in a MATLAB client session (such as parameters and external inputs) are not automatically available in the worker sessions. You must therefore ensure that the model is loaded and that the workspace variables referenced in the model are defined in the MATLAB worker session by using the following two methods.

- In the `parfor` loop, use the `sim` command to load the model and to set parameters that change with each iteration. (Alternative: load the model

and then use the `g(s)et_param` command(s) to set the parameters in the `parfor` loop)

- In the `parfor` loop, use the MATLAB `evalin` and `assignin` commands to assign data values to variables.

Alternatively, you can simplify the management of workspace variables by defining them in the model workspace. These variables will then be automatically loaded when the model is loaded into the worker sessions. There are, however, limitations to this method. For example, you cannot have tunable parameters in a model workspace. For a detailed discussion on the model workspace, see "Using Model Workspaces" on page 3-67.

Specifying Parameter Values Using the sim Command

Use the `sim` command in the `parfor` loop to set parameters that change with each iteration.

```
% Run parallel simulations of a model that does not
% result in data concurrency issues
mdl = 'vdp';
paramName = 'StopTime';
paramValue = {'10', '20', '30', '40'};
parfor i=1:4
    simOut{i} = sim(mdl, ...
                    paramName, paramValue{i}, ...
                    'SaveTime', 'on');
end
```

An equivalent method is to load the model and then use the `set_param` command to set the `paramName` in the `parfor` loop.

Specifying Variable Values Using the assignin Command

You can pass the values of model or simulation variables to the MATLAB workers by using the `assignin` or the `evalin` command. The following example illustrates how to use this method to load variable values into the appropriate workspace of the MATLAB workers.

```
parfor i = 1:4
    assignin('base', 'extInp', externalInput{i})
```

```
    % 'extInp' is the name of the variable in the base
    % workspace which contains the External Input data
    simOut{i} = sim(mdl, 'ExternalInput', 'extInp');
end
```

For further details, see the Rapid Accelerator Simulations Using PARFOR demo.

Data Concurrency Issues

Data concurrency issues refer to scenarios for which software makes simultaneous attempts to access the same file for data input or output. In Simulink, they primarily occur as a result of the nonsequential nature of the `parfor` loop during simultaneous execution of Simulink models. The most common incidences arise when code is generated or updated for a simulation target of a Stateflow, Model or Embedded MATLAB block during parallel computing. The cause, in this case, is that Simulink tries to concurrently access target data from multiple worker sessions. Similarly, To File blocks may simultaneously attempt to log data to the same files during parallel simulations and thus cause I/O errors. Or a third-party blockset or user-written S-function may cause a data concurrency issue while simultaneously generating code or files.

A secondary cause of data concurrency is due to the unprotected access of network ports. This type of error occurs, for example, when a Simulink product provides blocks that communicate via TCP/IP with other applications during simulation. One such product is the EDA Simulator Link™ for use with the Mentor Graphics® ModelSim® HDL simulator.

Resolving Data Concurrency Issues

The core requirement of `parfor` is the independence of the different iterations of the `parfor` body. This restriction is not compatible with the core requirement of simulation via incremental code generation, for which the simulation target from a prior simulation is reused or updated for the current simulation. Hence during the parallel simulation of a model that involves code generation (such as Accelerator mode simulation), Simulink makes concurrent attempts to access (update) the simulation target . However, you

can avoid such data concurrency issues by creating a temporary folder within the `parfor` loop and then adding several lines of MATLAB code to the loop to perform the following steps:

1. Change the current folder to the temporary, writable folder.
2. In the temporary folder, load the model, set parameters and input vectors, and simulate the model.
3. Return to the original, current folder.
4. Remove the temporary folder and temporary path.

In this manner, you avoid concurrency issues by loading and simulating the model within a separate temporary folder. Following are examples that use this method to resolve common concurrency issues.

A Model with Stateflow, Embedded MATLAB, or Model Blocks

In this example, either the model (mdl) is configured to simulate in Accelerator mode or it contains a Stateflow®, an Embedded MATLAB™, or a Simulink Model block (for example, *sf_bounce*, *sldemo_autotrans*, or *sldemo_modelref_basic*). For these cases, Simulink generates code during the initialization phase of simulation. Simulating such a model in `parfor` would cause code to be generated to the same files, while the initialization phase is running on the worker sessions. As illustrated below, you can avoid such data concurrency issues by running each iteration of the `parfor` body in a different temporary folder.

```
parfor i=1:4
   cwd = pwd;
   addpath(cwd)
   tmpdir = tempname;
   mkdir(tmpdir)
   cd(tmpdir)
   load_system(mdl)
   % set the block parameters, e.g., filename of To File block
   set_param(someBlkInMdl, blkParamName, blkParamValue{i})
   % set the model parameters by passing them to the sim command
   out{i} = sim(mdl, mdlParamName, mdlParamValue{i});
   cd(cwd)
```

```
    rmdir(tmpdir,'s')
    rmpath(cwd)
end
```

Note that you can also avoid other concurrency issues due to file I/O errors by using a temporary folder for each iteration of the `parfor` body.

A Model with To File Blocks

If you simulate a model with To File blocks from inside of a `parfor` loop, the nonsequential nature of the loop may cause file I/O errors. To avoid such errors during parallel simulations, you can either use the temporary folder idea above or use the `sim` command in Rapid Accelerator mode with the option to append a suffix to the file names specified in the model To File blocks. By providing a unique suffix for each iteration of the `parfor` body, you can avoid the concurrency issue.

```
parfor i=1:4
   sim(mdl, ...
        'ConcurrencyResolvingToFileSuffix', num2str(i),...
        'SimulationMode', 'rapid');
end
```

Exception Associated with Autosave Feature

The one case that you cannot resolve by using a temporary folder involves the autosave feature. If you select this option for a model that calls `sim` from within `parfor`, your model may encounter data concurrency issues regardless of whether or not you load and simulate from a temporary folder. The simple solution is to turn off the autosave feature:

1. In the model window, select **File > Preferences**. A Simulink Preferences dialog opens.

2. In the Simulink Preferences pane under **Autosave Options**, clear the check mark from the **Save before simulating or updating the model** check box.

Error Handling in Simulink Using MSLException

Error Reporting in a Simulink Application

Simulink allows you to report an error by throwing an exception using the `MSLException` object , which is a subclass of the MATLAB `MException` class. As with the MATLAB `MException` object, you can use a `try-catch` block with a `MSLException` object construct to capture information about the error. The primary distinction between the `MSLException` and the `MException` objects is that the `MSLException` object has the additional property of handles. These handles allow you to identify the object associated with the error.

The MSLException Class

The `MSLException` class has five properties: `identifier`, `message`, `stack`, `cause`, and `handles`. The first four of these properties are identical to those of `MException`. For detailed information about them, see "Error Handling". The fifth property, `handles`, is a cell array with elements that are double array. These elements contain the handles to the Simulink objects (blocks or block diagrams) associated with the error.

Methods of the MSLException Class

The methods for the `MSLException` class are identical to those of the `MException` class. For details of these methods, see `MException`.

Capturing Information about the Error

The structure of the Simulink `try-catch` block for capturing an exception is:

```
try
  Perform one or more operations
catch E
  if isa(E, 'MSLException')
...
end
```

If an operation within the `try` statement causes an error, the `catch` statement catches the exception (*E*). Next, an `if isa` conditional statement tests to

determine if the exception is Simulink specific, i.e., an `MSLException`. In other words, an `MSLException` is a type of `MException`.

The following code demonstrates how to get the handles associated with an error.

```
errHndls = [];
try
    sim('ModelName', ParamStruct);
catch e
    if isa(e,'MSLException')
   errHndls = e.handles{1}
    end
end
```

You can see the results by examining *e*. They will be similar to the following output:

```
e =

  MSLException

  Properties:
       handles: {[7.0010]}
    identifier: 'Simulink:Parameters:BlkParamUndefined'
       message: [1x87 char]
         cause: {0x1 cell}
         stack: [0x1 struct]

  Methods, Superclasses
```

To identify the name of the block that threw the error, use the `getfullname` command. For the present example, enter the following command at the MATLAB command line:

```
getfullname(errHndls)
```

If a block named Mu threw an error from a model named *vdp*, MATLAB would respond to the `getfullname` command with:

```
ans =
```

vdp/Mu

13

Visualizing and Comparing Simulation Results

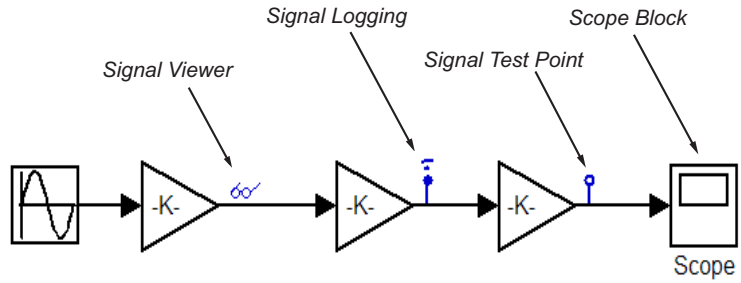
About Scope Blocks, Viewers, Signal Logging, and Test Points

In this section...

What Are Scope Blocks, Signal Viewers, Test Points and Data Logging?

Scope blocks, signal viewers, test points, and data logging provide ways for you to display and capture results from your simulations.

These icons represent the various data display and data capture devices:



- To learn how to quickly perform basic signal viewer tasks, see "Performing Common Viewer Tasks" on page 13-18.
- For detailed information on signal viewers, see "Introducing the Signal and Scope Manager" on page 29-38.
- To learn how to add and change signal viewers, see "Using the Signal and Scope Manager" on page 29-44.
- For more information on signal logging, see "Logging Signals" on page 27-3.

- For more information on Signal Test Points, see “Working with Test Points” on page 29-61.
- For more information on Scope Blocks, see “Sinks”.

How Scope Blocks and Signal Viewers Differ

You use Scope Blocks and signal viewers to display simulation results, but as shown in this table, their characteristics differ:

Characteristic	Signal Viewer	Scope Block
Interface	Attach to signal using Signal Selector or context menu See “The Signal Selector” on page 29-49 See “Scope Viewer Context Menu” on page 13-17	Drag from Library Browser
Scope of Control	All viewers centrally managed from Signal and Scope Manager See “Introducing the Signal and Scope Manager” on page 29-38	Each managed individually
Signals per axis	Multiple	One nonbus signal per axis or multiple signals fed through a mux or a bus
Axes per scope	Multiple “Displaying Multiple Axes” on page 13-20	Multiple
Data handling	Save data to a signal logging object	Save variable data to workspace as structures or arrays

Characteristic	Signal Viewer	Scope Block
Data logging	Log data to model-wide data object See Simulink.ModelDataLogs	None
Scrolling display data capability	Yes	No
Display	• Data markers • Legends • Color and line codes distinguish signals	Color and line codes distinguish signals
Graph Refresh Period	Adjustable	Fixed
Display of Minor Steps	The viewer does not display minor steps regardless of the value of the Refine parameter setting.	The scope displays minor steps if the Refine parameter is greater than 1. The value of the Refine parameter indicates the number of intermediate steps displayed.

Why Use Generators and Signal Viewers Instead of Source and Scope Blocks?

You should use signal generators and viewers instead of Source and Scope blocks when:

- You want to navigate to and attach generators or viewers deep within a model hierarchy.
- You want to centrally manage all generators and viewers present in your model.

- You want to use the display features provided by signal viewers that are not available in Scope blocks.
- You want to reduce clutter in your block diagram. Because signal viewers attach directly to signals, it is not necessary to route them to a Scope block. This results in fewer signal routes in your block diagram.
- You want to easily view data from referenced models. See "Working with Test Points" on page 29-61 for more information.

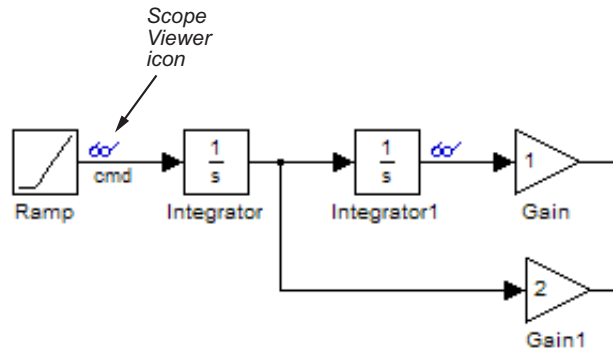
Methods for Attaching a Generator or Viewer

Generators and viewers attach to signals in your model in one of two ways:

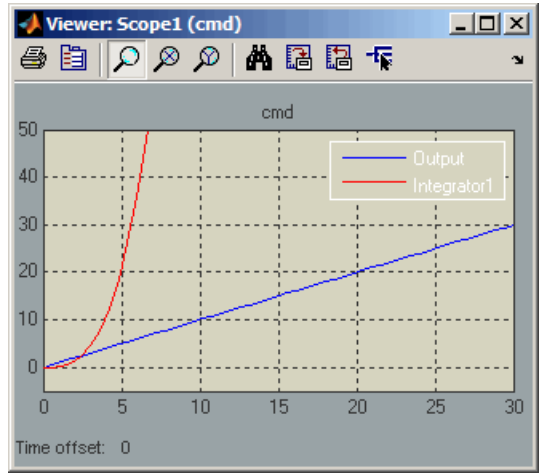
When...	Use...
You want to review all of the scopes and viewers, and the signals connected to them	Signal and Scope Manager
You want to quickly connect and disconnect a viewer or generator	Signal Context Menu

Displaying a Scope Viewer

Click the Scope Viewer icon to display a particular Scope Viewer:



Two plots are displayed in this viewer example. Each is identified with a unique color, and the graph has a legend.



- To learn how to add a legend and to zoom into regions in your graph, see “Performing Common Viewer Tasks” on page 13-18.
- To learn how a viewer can display multiple signals, see “Adding Multiple Signals to a Scope Viewer” on page 13-18.

- To learn about the Scope Viewer controls, see “Changing Viewer Characteristics” on page 13-12.
- To learn how to attach a Scope Viewer to a signal, see “Attaching a Scope Viewer” on page 13-18.

Tip You must first attach a viewer for the Scope Viewer icon to be visible.

Things to Know When Using Viewers

In this section...

About Viewers

- The Scope Viewer is not the same as the Scope block. For an explanation of the differences, see "How Scope Blocks and Signal Viewers Differ" on page 13-3.
- The Scope Viewer does not show the signal label on the axis.
- The Scope Viewer does not work with the Report Generator.
- The Scope Viewer does not display the simulation minor time step values.
- Not all of the Scope Viewer features are supported when you simulate your model in Rapid Accelerator mode. For more information, see "Using Scopes and Viewers with Rapid Accelerator Mode" on page 17-16.
- The **Help** button for the Scope Viewer is located in the Scope Viewer's Parameters dialog box. For more information, see "Scope Viewer Parameters Dialog Box" on page 13-13.

How the Viewer Determines Trace Color Coding and Line Styles

The Scope Viewer displays each signal as a separate, color-coded trace, in the following order:

1 Blue

2 Red

3 Magenta

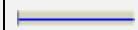
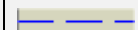
4 Cyan

5 Yellow

6 Green

The viewer cycles through the colors if the axis is displaying more than six signals.

If a signal contains multiple elements (such as a vector or matrix), the viewer distinguishes the elements with different line styles. If a signal has more than four elements, the viewer cycles through the line styles. The line styles retain the color of the signal.

Signal Element	Scope Viewer
1	
2	
3	
4	

How Scope Viewer Parameter Settings Can Affect Performance

In some cases, when a Scope Viewer needs to display a large number of data points, the simulation slows. When this happens, you can improve simulation performance by adjusting the settings of some of the viewer parameters. Try one or a combination of the following until you are satisfied with the simulation performance.

- Turn off scroll mode. See "**Scroll**" on page 13-14.
- Reduce the time range. See "**Time Range**" on page 13-14.

- Use decimation to reduce the number of data points. See "**Decimation**" on page 13-15.
- Increase the refresh period to decrease the refresh rate. See "**Refresh Period**" on page 13-16.
- Limit the number of data points that the viewer saves to the workspace. See "**Limit data points to last**" on page 13-15.

Changing Viewer Characteristics

In this section...

The Scope Viewer Toolbar

The Scope Viewer toolbar is attached to each Scope Viewer. It has the following controls:

Icon	Function
	Opens the Print dialog box so you can print the contents of a Scope Viewer window.
	Opens the Scope Parameters dialog for modifying display characteristics. For details, see "Scope Viewer Parameters Dialog Box" on page 13-13.
	Simultaneously zooms in on the *x* and *y* axes. The zoom feature is not active while the simulation is running. For more information, see "Zooming In On Graph Regions" on page 13-19.
	Use this button to zoom in on the *x* axis only. The zoom feature is not active while the simulation is running. For more information, see "Zooming In On Graph Regions" on page 13-19.
	Use this button to zoom in on the *y* axis only. The zoom feature is not active while the simulation is running. For more information, see "Zooming In On Graph Regions" on page 13-19.
	Automatically scales the axis to fully display all signals.

Icon	Function
	Stores the current axis settings so you can apply them to the next simulation.
	Restores the graph setting values saved by the most recent **Save axes settings** command.
	Activates the Signal Selector. For more information, see "The Signal Selector" on page 29-49.
	Docks and undocks the Scope Viewer. When you dock the Scope Viewer, it is placed within the MATLAB Command Window and automatically resized.

Scope Viewer Parameters Dialog Box

To open the Scope Parameters dialog box:

- On the scope toolbar, click 
- Point to the figure, right-click to display the content menu, and then select **Scope parameters**

There are three tabs on the dialog box:

- **General**, where you set the axis characteristics and the sampling decimation value (see "General Tab" on page 13-13).
- **History**, where you control the amount of stored and displayed data (see "History Tab" on page 13-15).
- **Performance**, where you control the scope refresh rate (see "Performance Tab" on page 13-16).

General Tab

With this tab you control the number of axes, the time range, and the appearance of your graph.

Number of axes. Set the number of axes in this data field. Each axis is displayed as a separate graph within a single Scope Viewer.

An example of this is shown in "Adding Multiple Signals to a Scope Viewer" on page 13-18.

Time Range. Change the *x*-axis limits by entering a number or `auto` in the **Time range** field.

Entering a number of seconds causes each screen to display the amount of data that corresponds to that number of seconds. Enter `auto` to set the *x*-axis to the duration of the simulation.

Note Do not enter variable names in these fields.

Tick labels. Specifies whether to label axes ticks. The options are:

Option	Effect
`all`	Places ticks on the outside of all axes
`inside`	Places tick labels inside all axes (available only on signal viewers)
`bottom axis only`	Places tick labels outside the bottom axes

Scroll. When you select this option, the scope continuously scrolls the displayed signals to the left to keep as much data in view as will fit on the screen at any one time.

In contrast, when this option is not selected, the scope draws a screen full of data from left to right until the screen is full, erases the screen, and draws the next screen full of data. This loop is repeated until the end of simulation time. The effects of this option are discernible only when drawing is slow, for example, when the model is very large or has a very small step size.

Note In some cases, the simulation slows when the simulation runs with the scroll option selected. See "How Scope Viewer Parameter Settings Can Affect Performance" on page 13-10.

Data markers. Displays a marker at each data point on the Scope Viewer screen.

Legends. Displays a legend on the scope that indicates the line style used to display each signal.

Decimation. Logs every Nth data point, where N is the number entered in the edit field.

For example, suppose that the input signal to your Scope block has a fixed sample time of 0.1 s. If you enter a value of 2, data points for this viewer will be recorded at times 0.0, 0.2, 0.4....

History Tab

With this tab you control the amount of data that the Scope Viewer stores, displays and stores to the workspace. The values that appear in these fields are the values that are used in the next simulation.

Limit data points to last. Limits the number of data points saved to the workspace. Select the **Limit data points to last** check box and enter a value in its data field.

The Scope relies on its data history for zooming and autoscaling operations. If the number of data points is limited to 1,000 and the simulation generates 2,000 data points, only the last 1,000 are available for regenerating the display.

Save to model signal logging object. At the end of the simulation, this option saves the data displayed on the Scope Viewer . The data is saved in the `Simulink.ModelDataLogs` object used to log data for the model (see "Logging Signals" on page 27-3 for more information).

For this option to take effect, you must also enable signal logging for the model as a whole. To do this, check the **Signal logging** option on the **Data Import/Export** pane of the model's **Configuration Parameters** dialog box.

Logging Name. Specifies the name under which to store the viewer's data in the model's `Simulink.ModelDataLogs` object. The name must be different from the log names specified by other signal viewers or for other signals, subsystems, or model references logged in the model's `Simulink.ModelDataLogs` object.

Performance Tab

Controls how frequently the Scope Viewer is refreshed. Reducing the refresh rate can speed up the simulation in some cases.

Note For information about additional Scope Viewer parameters that can affect performance, see "How Scope Viewer Parameter Settings Can Affect Performance" on page 13-10.

This tab contains the following controls.

Refresh Period. Select the units in which the refresh period is expressed. Options are either seconds or frames, where a frame is the width of the scope's screen in seconds. This is the value of the scope's **Time range** parameter.

Refresh Slider. Sets the refresh rate.

Drag the slider button to the right to increase the refresh period and hence decrease the refresh rate.

Freeze Button. Controls refresh.

Click the button to freeze (stop refreshing) or unfreeze the Scope Viewer.

Scope Viewer Context Menu

The Scope Viewer context menu is a convenient way to make simple changes to a Scope Viewer without navigating to the Scope Parameters dialog box.

Right-click within a Scope Viewer to display the context menu. It contains the following controls:

Control	Function
Legends	Adds a legend to your viewer.
Autoscale	Autoscales the viewer axis.
Signal selection	Displays the Signal Selector dialog. For information, see "The Signal Selector" on page 29-49.
Axes properties	Displays the Axis Properties dialog. You can manually set the minimum and maximum range for the *y* axis here.
Scope parameters	Displays the Scope parameters dialog. For information, see "Scope Viewer Parameters Dialog Box" on page 13-13.
Tick labels	Displays the Tick Labels dialog. From here you can turn on and off various tick options.

Performing Common Viewer Tasks

In this section...

Attaching a Scope Viewer

1. In your block diagram, right-click a signal and then from the context menu, select **Create & Connect Viewer**.
2. From the list that appears, select the type of scope you want to attach.

   An empty Scope Viewer will be displayed. You must run the simulation after the viewer has been attached for the information to be plotted.

Tip You can also attach signal viewers with the Signal and Scope Manager. To learn how to do this, see "Using the Signal and Scope Manager" on page 29-44

Adding Multiple Signals to a Scope Viewer

To add additional traces to an existing Scope Viewer:

1. In your block diagram, right-click a signal.
2. From the signal context menu, select **Connect to existing viewer**.

A list of Signal Viewers that have already been created is displayed.

3 From the list, select the scope to which the new signal will be added.

You can also add signals to Signal Viewers with the Signal and Scope Manager. To learn how to do this, see "Using the Signal and Scope Manager" on page 29-44.

Note The simulation must be run again for the new trace to be displayed in the viewer.

Adding a Legend

1 In a Viewer window, right-click.

2 From the context menu, select **Legends**.

The viewer draws a box and identifies each signal with the name of the signal. If a signal does not have a name, the legend uses the name of the originating block or subsystem.

3 Left-click and drag a legend box to move it to another location on the graph.

For information about the color and line styles in the Viewer window, see "How the Viewer Determines Trace Color Coding and Line Styles" on page 13-9.

Zooming In On Graph Regions

- To zoom in on a region (simultaneously zooming in on the *x* and *y* directions), select  from the Scope Viewer toolbar, and left-click within the graph. While holding down the mouse button, define the region of interest.

To zoom, click and hold the left mouse button, and drag the mouse to define the zoom region bounding box. Release the mouse button to effect the change.

- Select  and use the mouse to zoom only in the x direction.

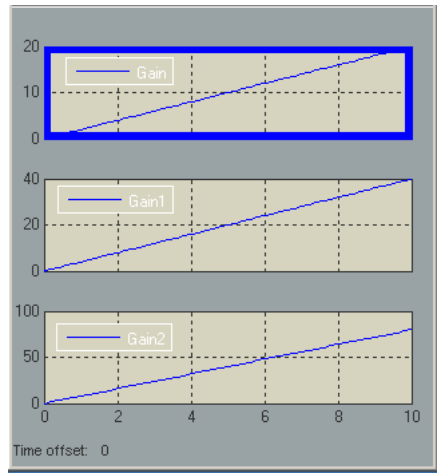
  Define the zoom region by positioning the pointer at one end of the region, pressing and holding down the left mouse button, then moving the pointer to the other end of the region. Release the mouse button to effect the change. To zoom, click and hold the left mouse button, and drag the mouse to define the zoom region bounding box. Release the mouse button to effect the change.

- Select  and use the mouse to zoom only the y direction.

Tip Use Autoscale () to restore the display if you mistakenly zoom in too much.

Displaying Multiple Axes

You can add multiple plots (called *axes*) to a Scope Viewer. Each axes can have different *y*-axis settings. This Scope Viewer has three axes, each displaying a separate signal with their own *y* axis settings.



To add axes to an existing Scope Viewer:

1. Open the Scope Viewer Signal Properties dialog.

   Access this dialog from the Scope Viewer toolbar or by right-clicking within a viewer.

   For information on the Scope Viewer toolbar, see "The Scope Viewer Toolbar" on page 13-12.

2. In the **Number of axes** field, enter the total number of axes for the graph.

3. Click OK to accept the change and dismiss the dialog.

4. In your block diagram, right-click on the signal to be added.

   The signal context menu appears.

5. Select **Connect to existing viewer**.

   A list of signal viewers is displayed.

6. From the list, select the scope to which the new signal will be added.

7. From the list of Axes, select the pane to which the signal will be plotted. The panes are numbered from top to bottom.

Repeat this step until signals for each of the axes have been assigned.

Note Run the simulation again to display the new traces.

How to Save Data to MATLAB Workspace

To save the data displayed on the viewer to the MATLAB workspace, perform the following steps:

1. Click on the  in the Viewer toolbar.
2. Click on the **History** tab.
3. Select **Save to model signal logging object (logsout)**.
4. Enter the logging variable name in the **Logging name** field.
5. Assign a name to the signal in the block diagram, for example, *x*1.
6. Run the simulation by selecting **Simulation > Start**.

You can now view the data in the MATLAB command window by entering the following commands:

```
logsout.unpack('all')
data = x1.Data
x1.time
```

where *x*1 is the name of the signal.

Saving the Viewer Data to a File

You can quickly save the viewer data to a file using the Time Series Tools.

1. Open the Time Series Tools using the MATLAB **Start** button by selecting **Start > MATLAB > Time Series Tools**. The *Time Series Tools* opens and the file tree contains your data on the lowest-level nodes under `logsout`.

2 Export the data to a file by following the directions in "Importing and Exporting Data".

Plotting the Viewer Data

You can plot the data interactively or programmatically.

- **Simulation Data Inspector**: plot the data as explained in "Inspecting and Comparing Logged Signal Data" on page 13-25.
- **Time Series Tools**: plot the data interactively using the *Time Series Tools* as explained in "Plotting Time Series".
- **Simplot**: plot the data from the command line using the `simplot` command (see `simplot`). The resulting figure looks identical to the viewer window and can be annotated using the Plot Editing Tools.

Performing Common Generator Tasks

In this section...

Attaching a Generator

1. Right-click the input to a block (such as a gain block), and from the signal context menu select **Create & Connect Signal Generator**.
2. From the list that appears, select the type of scope to be attached.

   The generator will appear in the block diagram as a small rectangle that lists the generator type you have chosen. Double-click this region to display a dialog from where you can change the generators properties.

You can also attach generators with the Signal and Scope Manager. To learn how to do this, see "Using the Signal and Scope Manager" on page 29-44.

Removing a Generator

To remove the generator from the block diagram:

1. Right-click a generator.
2. From the context menu, select **Disconnect Generator**.

Inspecting and Comparing Logged Signal Data

In this section...

Overview

The Simulation Data Inspector tool provides the capability to inspect and compare time series data at several stages of your workflow:

- Model design: Inspect and compare simulation data after making changes to the model diagram or its configuration.
- Testing your model: Compare simulation data with different input data
- Code generation: Compare simulation data and generated code output of your model

You can compare variable-step data, fixed-step solver data from Simulink and Real-Time Workshop, and fixed-step output with external data. When you import logged signal data into the Simulation Data Inspector tool, you can select all, or a subset, of your logged signals.

A typical workflow for inspecting and comparing signal data is:

1. Set up your model to log signal data, as in "Logging Signals" on page 27-3.
2. Open the Simulation Data Inspector tool, as described in "Opening the Simulation Data Inspector Tool" on page 13-38.

3. Simulate your model and import logged signal data, as described in "Importing Logged Signal Data into the Simulation Data Inspector Tool" on page 13-38 .

4. Inspect signals quickly to determine if the run satisfies requirements, as described in "Visual Inspection of Signal Data" on page 13-26.

5. If the run is unsatisfactory, delete it. Repeat steps 3 and 4 to collect the desired simulation runs for comparing data.

6. Optionally assign tolerances to signals and graphically inspect the applied tolerances. For more information on data differencing in the Simulation Data Inspector tool, see "How the Simulation Data Inspector Tool Compares Time Series Data" on page 13-37.

7. Compare individual signals in the same run, or from different runs, as described in "Comparison of Signal Data" on page 13-27.

8. Compare all of the imported signal data from multiple runs, as described in "Comparison of All Logged Signal Data From Multiple Simulations" on page 13-31.

9. Determine which signals have discrepancies within the specified tolerances. Plot and analyze the discrepancies of any two signals.

10. Save the imported signal data and comparison results, as described in "Exporting Results" on page 13-35.

Visual Inspection of Signal Data

In the Simulation Data Inspector tool, the **Inspect Signals** tab of the "Signal Browser Table" on page 13-45 provides many options for inspecting signals from one simulation run or multiple simulation runs.

1. Open the Simulation Data Inspector. See "Opening the Simulation Data Inspector Tool" on page 13-38.

2. To import data into the Simulation Data Inspector, see "Importing Logged Signal Data into the Simulation Data Inspector Tool" on page 13-38.

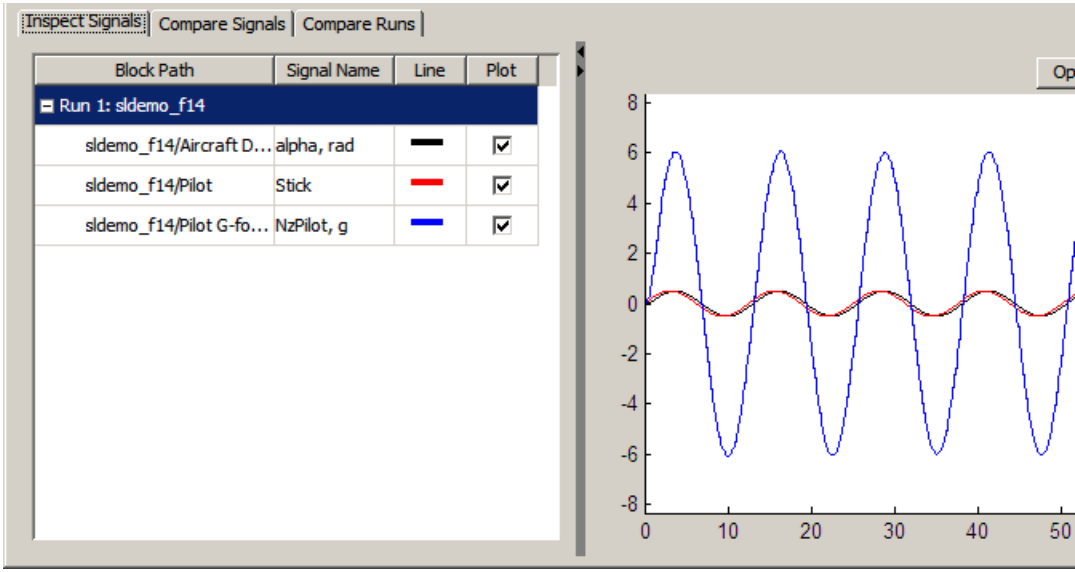
3. In the Signal Browser table, if the **Inspect Signals** tab is not already selected, select it. By default, the **Inspect Signals** view displays a row for

each signal, organized by simulation runs. You can expand or collapse any of the runs to view the logged signals in a run. For more information, see "Signal Browser Table" on page 13-45.

4 "Specify the Line Configuration" on page 13-50 for a signal.

5 Click the **Plot** column for a signal. The signal data is displayed in the **Signals** graph on the right pane of the Simulation Data Inspector tool.

6 To select multiple signals, highlight the signals by clicking a row, then select a check box in the **Plot** column.



For more information on manipulating the graph, see "Understanding the Simulation Data Inspector Interface" on page 13-35.

Comparison of Signal Data

In the Simulation Data Inspector tool, you can use the **Compare Signals** tab of the "Signal Browser Table" on page 13-45 for comparing two signals. To compare two signals:

1 Open the Simulation Data Inspector tool. See "Opening the Simulation Data Inspector Tool" on page 13-38.

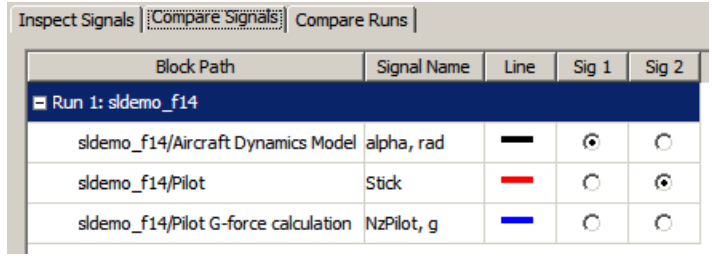
2 Import data into the Simulation Data Inspector tool. See "Importing Logged Signal Data into the Simulation Data Inspector Tool" on page 13-38.

3 If it is not already selected, select the **Compare Signals** tab of the Signal Browser table. By default, the **Compare Signals** view displays a row for each signal data, organized by simulation runs. For more information on modifying the Signal Browser table, see "Signal Browser Table" on page 13-45.

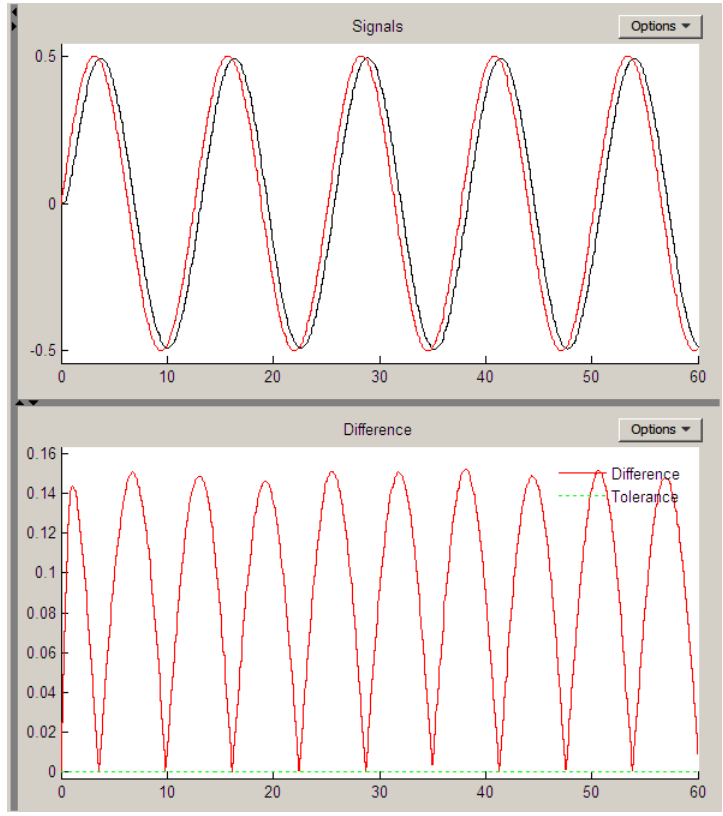
4 "Specify the Line Configuration" on page 13-50 for the signals that you are comparing.

5 In the **Sig 1** column, click one signal for plotting. In this column, you can select only one signal.

6 In the **Sig 2** column, click one signal for plotting. In this column, you can select only one signal.



The **Signals** graph displays the signal data and the **Difference** graph displays the difference and tolerance values.



For information on manipulating the graphs, see “Understanding the Simulation Data Inspector Interface” on page 13-35.

Comparison of One Signal From Multiple Simulations

In the Simulation Data Inspector tool, you can use the **Compare Signals** tab of the “Signal Browser Table” on page 13-45 to compare the same signal from two different simulation runs. To compare two data runs for a signal:

1. Open the Simulation Data Inspector tool. See “Opening the Simulation Data Inspector Tool” on page 13-38.

2 Import data for two simulation runs. For more information, see "Importing Logged Signal Data into the Simulation Data Inspector Tool" on page 13-38.

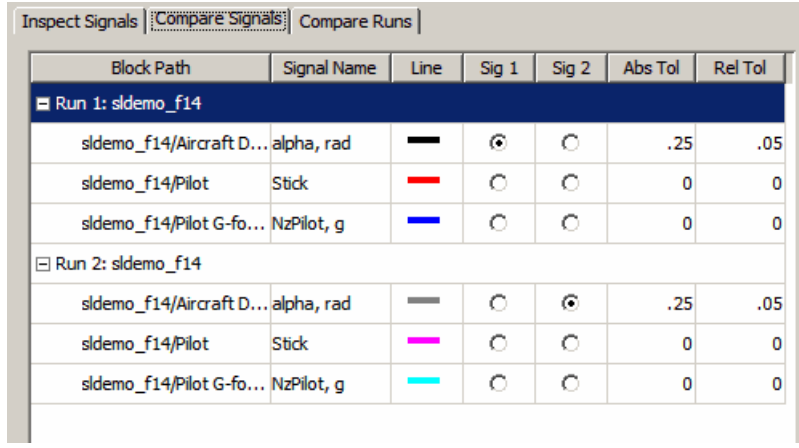
3 If the **Compare Signals** tab is not already selected, select it. By default, the **Compare Signals** view displays a row for each signal data, organized by simulation runs. For more information on modifying the Signal Browser table, see "Signal Browser Table" on page 13-45.

4 "Specify the Line Configuration" on page 13-50 for the signals that you are comparing.

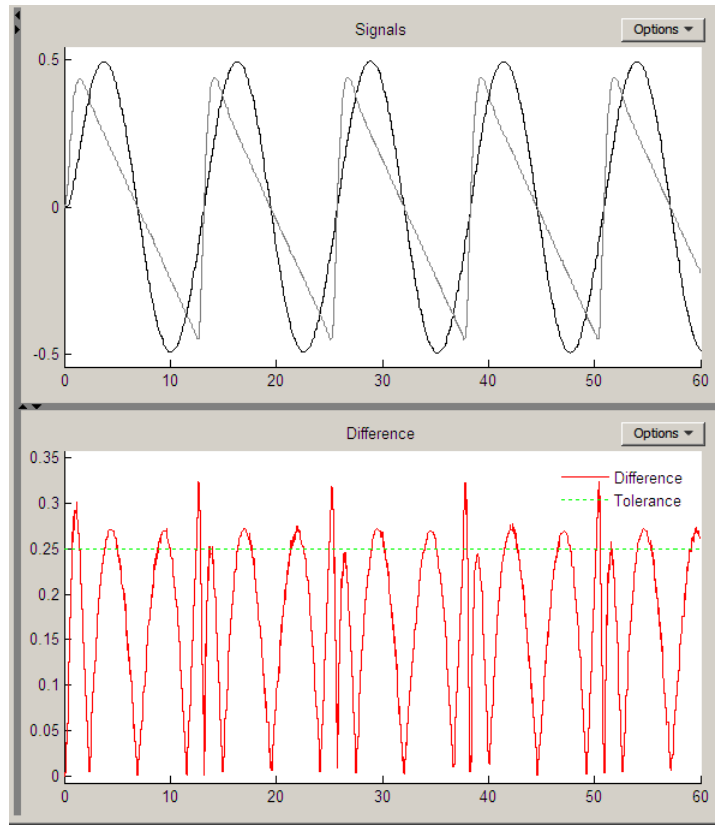
5 To change the relative tolerance and absolute tolerance, add the **Rel Tol** and **Abs Tol** columns to the Signal Browser table. Double-click the corresponding fields for a signal and type in a value.

6 In the **Sig 1** column, click one signal from the first simulation run for plotting. In this column, you can select only one signal.

7 In the **Sig 2** column, click a signal from another simulation run for plotting. In this column, you can select only one signal.



Once two signals are selected, the **Signals** graph displays the signal data and the **Difference** graph displays the difference and tolerance values.



For information on manipulating the graphs, see "Understanding the Simulation Data Inspector Interface" on page 13-35.

Comparison of All Logged Signal Data From Multiple Simulations

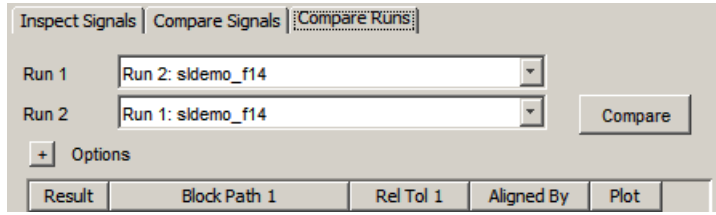
In the Simulation Data Inspector tool, you can use the **Compare Runs** tab of the "Signal Browser Table" on page 13-45 to compare all signal data from two different simulation runs. To compare two runs:

1. Open the Simulation Data Inspector tool. See "Opening the Simulation Data Inspector Tool" on page 13-38.

2 Import data from multiple simulation runs, for more information, see "Importing Logged Signal Data into the Simulation Data Inspector Tool" on page 13-38.

3 If the **Compare Runs** tab is not already selected, select it.

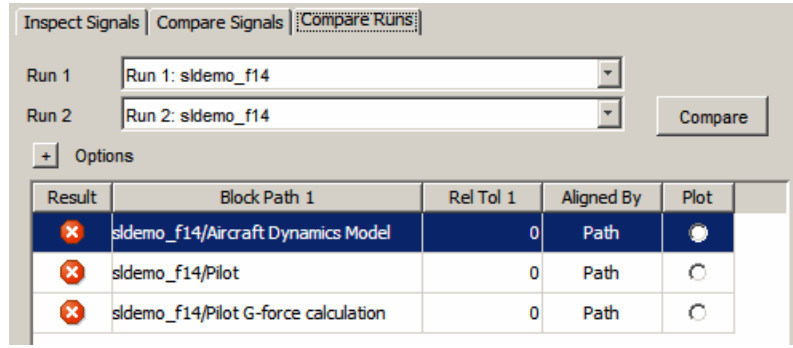
4 From the **Run 1** and **Run 2** drop-down lists, select two different runs.



Note The number in a column name indicates the run number. For example, **Abs Tol 1** refers to the absolute tolerance values for signals of the run specified for **Run 1**. **Abs Tol 2** refers to the absolute tolerance values for signals of the run specified for **Run 2**.

5 Select the **Options** button to specify the signal alignment. The Simulation Data Inspector attempts to match signals according to the **Align By** parameter. Keep the default values of **Align By**, `Path`, and **Then By**, `None`.

6 Click the **Compare** button. The Comparison Results table lists the comparison of two matched signals. If a signal from one run cannot be matched with a signal from the other run, the signal does not appear in the table.

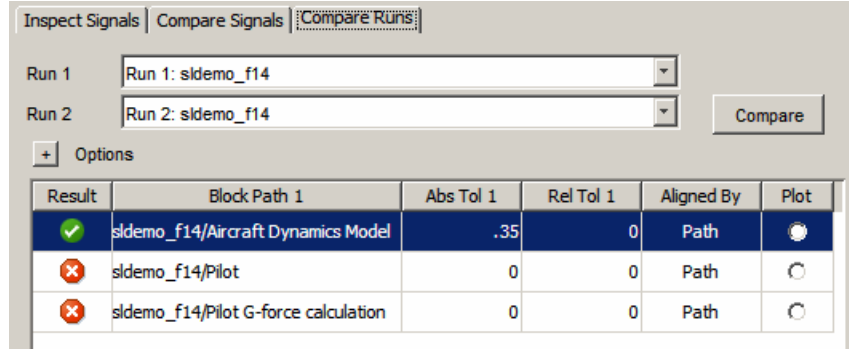


7 To change the relative tolerance and absolute tolerance, add the **Abs Tol 1** column to the Signal Browser table. Double-click the corresponding fields for a signal and type in a value.

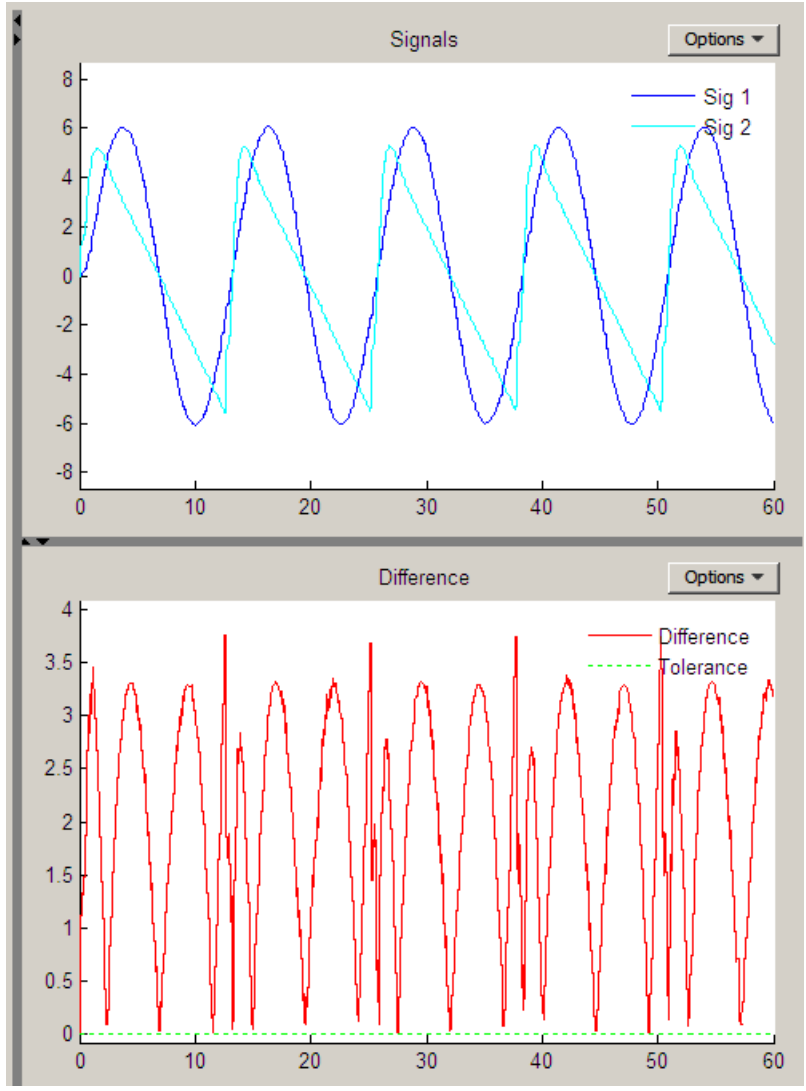
Note Tolerances specified in the other tab views do not carry over to the **Compare Runs** view.

---

8 To see a signal that is within the acceptable tolerance across two simulation runs, set the absolute tolerance in column **Abs Tol 1** to `.35`.



9 Select a signal to plot, for example, '`sldemo_f14/Pilot G-force calculation`'. The **Signals** graph displays the signal data for the two runs. The **Difference** graph displays the difference and tolerance values.



For information on manipulating the graph, see “Understanding the Simulation Data Inspector Interface” on page 13-35.

Exporting Results

The Simulation Data Inspector tool provides the capability to save data collected by the tool to a MAT-file that you can later reload. The format of the MAT-file is different from the format of a MAT-file created from the base workspace.

Save Data to a MAT-File

To save signal data in the Simulation Data Inspector tool to a MAT-File, do the following:

1. Click **Save** or select **File > Save**.
2. Type the name of the file.
3. Click **OK**. Your data is now saved in a MAT-file that you can load back into the Simulation Data Inspector.

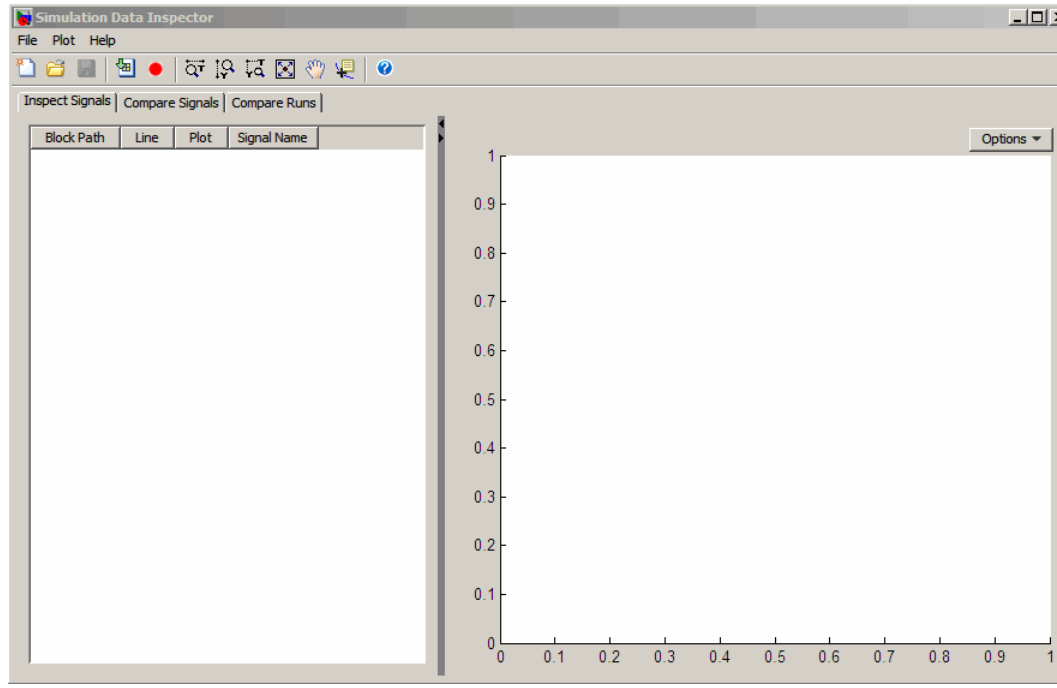
Understanding the Simulation Data Inspector Interface

Overview

Before using the Simulation Data Inspector tool, consider the requirements and the following information:

- "Requirements" on page 13-36
- "How the Simulation Data Inspector Tool Compares Time Series Data" on page 13-37
- "Limitations of the Simulation Data Inspector Tool" on page 13-54

To open the Simulation Data Inspector, see "Opening the Simulation Data Inspector Tool" on page 13-38.



The Simulation Data Inspector Window includes the following elements:

- "Menu Bar" on page 13-42
- "Tool Bar" on page 13-43
- "Signal Browser Table" on page 13-45 with three views: **Inspect Signals**, **Compare Signals**, and **Compare Runs**
- "Plot View" on page 13-52

To learn how to import data into the Simulation Data Inspector tool, see "Importing Logged Signal Data into the Simulation Data Inspector Tool" on page 13-38.

Requirements

The Simulation Data Inspector tool requires time series data in the following Simulink data export formats:

- `Structure with Time` format for Time (`tout`), States (`xout`), Output (`yout`), and Data stores (`dsout`)
- `Structure with Time` format for To Workspace, To File, and Scope blocks
- Logged signals Simulink.ModelDataLogs (`logsout`)
- `Timeseries` objects, Simulink.Timeseries

How the Simulation Data Inspector Tool Compares Time Series Data

To compare time series data, the Simulation Data Inspector:

1. Converts Simulink time series data to MATLAB time series data.
2. Aligns the time vectors using the default synchronization method `union`. To change the synchronization method for a signal, add the **Sync Method** column to the "Signal Browser Table" on page 13-45 and choose a method.
3. Aligns the data vectors using the default interpolation method, `zoh` (zero-order hold). To change the interpolation method for a signal, add the **Interp Method** column to the Signal Browser table and choose a method.
4. Differences the data.
5. Applies the specified tolerances for plotting the **Difference** . For more information, see "How Tolerances Are Applied" on page 13-37.

How Tolerances Are Applied. The default values for the relative tolerance and absolute tolerance for a signal is 0. If you specify tolerances, then the Simulation Data Inspector tool calculates the tolerances as follows:

```
tolerance = max(absoluteTolerance, relativeTolerance*abs(baselineData));
```

To change the relative tolerance and absolute tolerance, add the **Rel Tol** and **Abs Tol** columns to the Signal Browser table. Double-click the corresponding fields for a signal and type in a value.

Opening the Simulation Data Inspector Tool

To launch the Simulation Data Inspector tool, choose one of the following methods:

- **MATLAB command-line**: Enter

  ```
  Simulink.sdi.view
  ```

- **Model Diagram window**: Select **Tools > Inspect Signal Logs**
- **Configuration Parameters Dialog Box**: To configure your model to automatically launch the Simulation Data Inspector tool when a simulation is stopped or paused, see "Import Signal Data Automatically After Simulation" on page 13-38.

Importing Logged Signal Data into the Simulation Data Inspector Tool

Requirements. Before importing data into the Simulation Data Inspector tool, you must have one of the following:

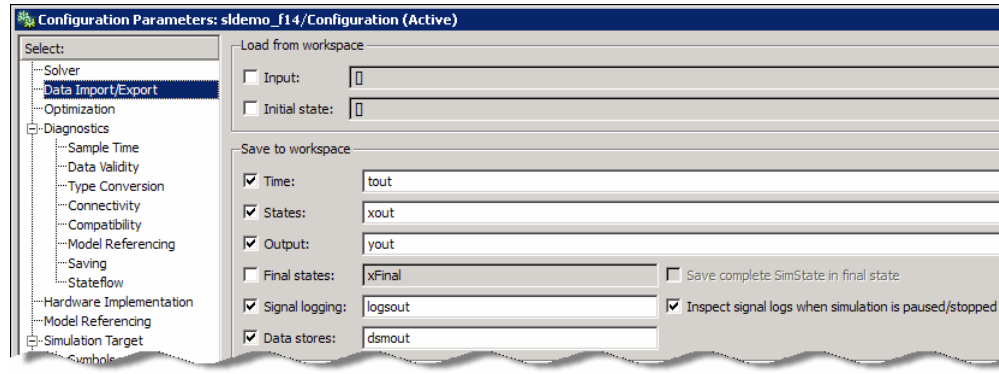
- Your model configured for logging signal data
- Logged signal data in the base workspace
- Logged signal data in a MAT-file

For information on how to log signal data, see "Logging Signals" on page 27-3.

Import Signal Data Automatically After Simulation. Use this technique when you want the Simulation Data Inspector tool to open and import simulation data every time you run or pause a simulation.

1. Select **Simulation > Configuration Parameters** to open the Configuration Parameters dialog box.
2. Select the **Data Import/Export** pane.
3. Select the **Signal logging** parameter.

4 Select the **Inspect signal logs when simulation is paused stopped** parameter.



Import Signal Data Interactively With Simulations. To set the Simulation Data Inspector to automatically import data after a simulation run:

1 Open the Simulation Data Inspector tool.

2 Click the **Record** button  .

3 In the model diagram window, simulate your model. When the simulation is done, the data automatically appears within a new run in the Simulation Data Inspector tool. To modify the run name, see “Renaming a Run” on page 13-49.

4 To import another simulation run, leave the **Record** button selected, and simulate your model again. When the simulation is done, the data appears as another as new run.

5 When you are done importing data for your simulations, click the **Record** button. When the record button is not pressed, data from any simulations are not imported into the tool.

Load Saved Data from a MAT-File. To load all signal data from a MAT-file, which was created from the Simulation Data Inspector:

1 On the Simulation Data Inspector Tool Bar, click the **Open** button

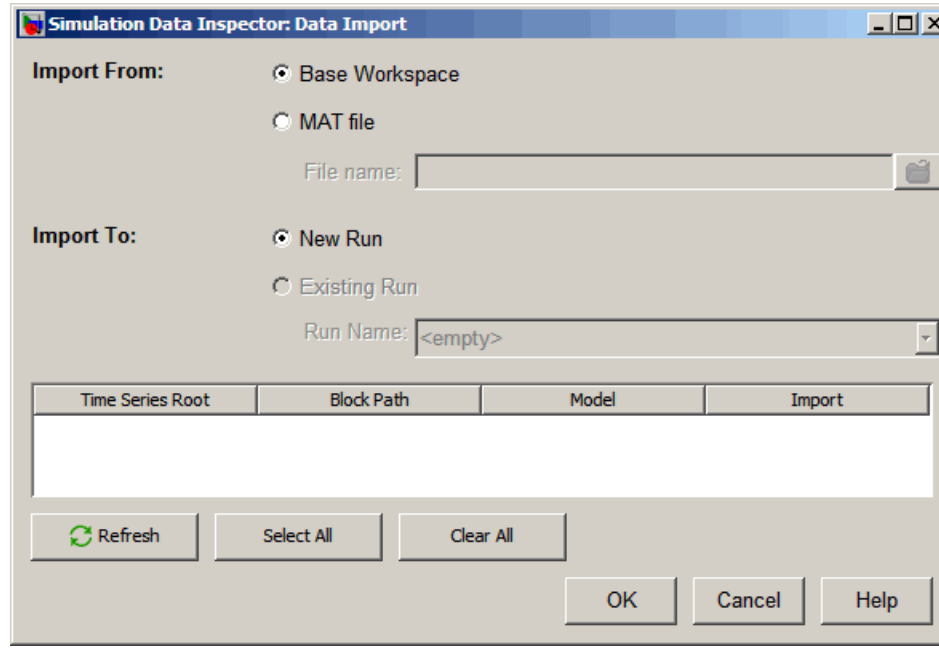
or select **File > Open**.

2 Select the name of the MAT-file.

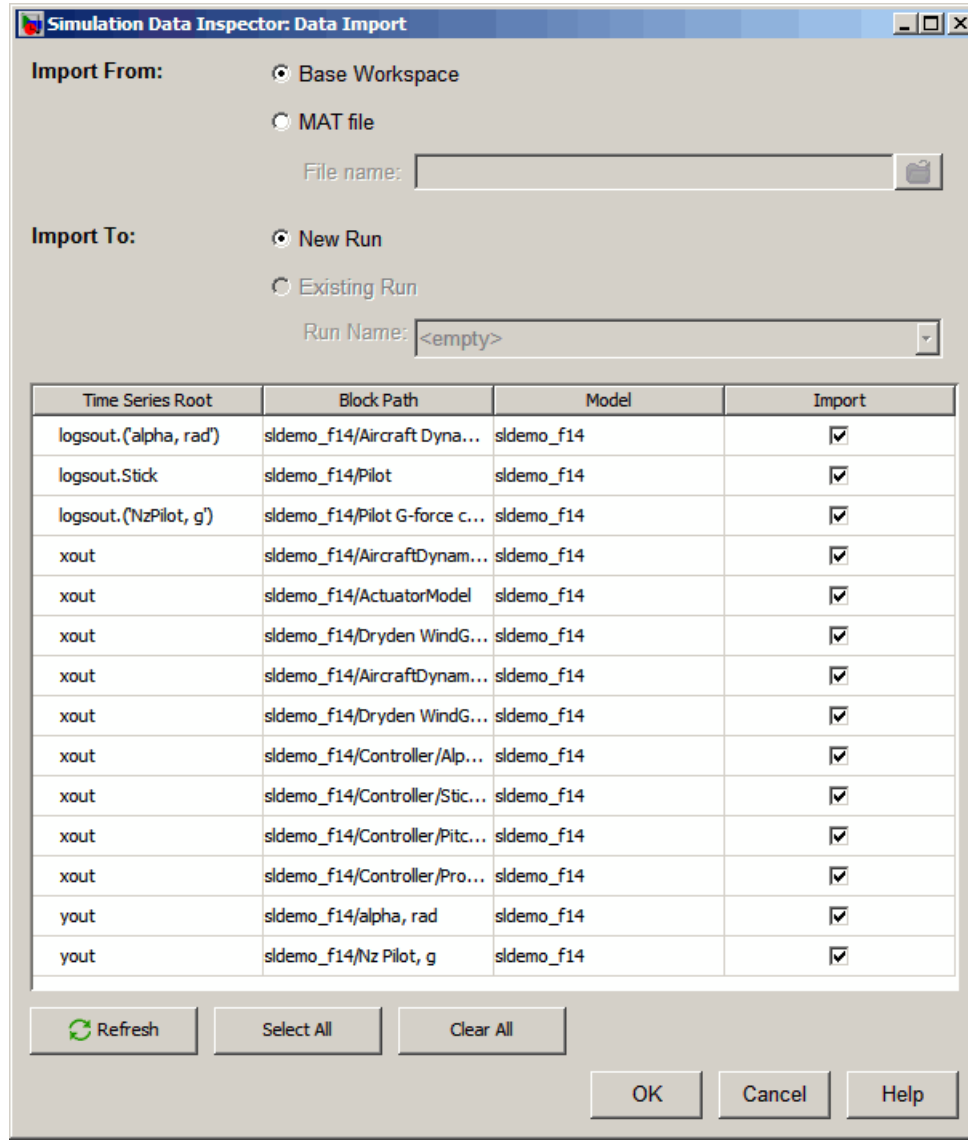
3 Click **OK**. Data stored in the MAT-file appears in the Simulation Data Inspector tool.

Import Signal Data from the Base Workspace. Using the Data Import tool, you can import data from the base workspace.

1 Open the Data Import tool by selecting the **Import Data** button  or selecting **File > Import Data**.



2 Select **Base Workspace**. Data from `logsout`, `xout`, and `yout` appear in the table.



3 Select the **Import** check box to import a signal and clear the **Import** check box for signals that you do not want. You can also use the **Select All** and **Clear All** buttons for mass selection or clearing of all signals.

4 Select **OK**. The selected signals appear in the Signal Browser table.

Import Signal Data from a MAT-File. With the Data Import tool, you can select a subset of signals from a MAT-file to import into the Simulation Data Inspector tool.

Note The MAT-file must be a file previously created from saving data from the Simulation Data Inspector tool.

Follow the steps to import a MAT-File, previously saved from the Simulation Data Inspector tool.

1 Open the Data Import tool by selecting the **Import Data** button  or selecting **File > Import Data**.

2 For **Import From**, select **MAT file**. The **File name** parameter is enabled.

3 The Data Import tool finds a MAT-file in the current directory. Alternatively, click the **Open folder** button to browse for your MAT-file. The data from the MAT-file will populate the data table.

4 Specify **Import To** by selecting **New Run** or **Existing Run**. If you select **Existing Run**, select a run from the **Run Name** list.

5 Select the **Import** check box to import signals. Clear the **Import** check box for signals that you do not want. You can also use the **Select All** and **Clear All** buttons for selection or clearing of all the signals.

6 Select **OK**.

Menu Bar

The menu bar contains the following commands:

- **File**: general file operations including:
  - **New**: clear data from the Signal Browser table
  - **Open**: open a MAT file previously saved in the Signal Browser table
  - **Save**: save data in the Signal Browser table to a MAT-file
  - **Save as**: specify a file name and save data in the Signal Browser table to a MAT-file.
  - **Import Data**: open the Data Import dialog box
  - **Record Simulation Output**: load data dynamically from a simulation run
  - **Exit**: close the Simulation Data Inspector tool
- **Plot**: Operations on the plot graph:
  - **Zoom in T**: enlarge an area along the time axis
  - **Zoom in Y**: enlarge an area along the data value axis
  - **Zoom in T and Y**: enlarge a section of the graph
  - **Zoom Out**: zoom out, incrementally, each time you click
  - **Pan**: move the graph in the figure up, down, left, or right
  - **Data Cursor**- add a data point to the plot

Tool Bar

The tool bar contains the following command buttons.

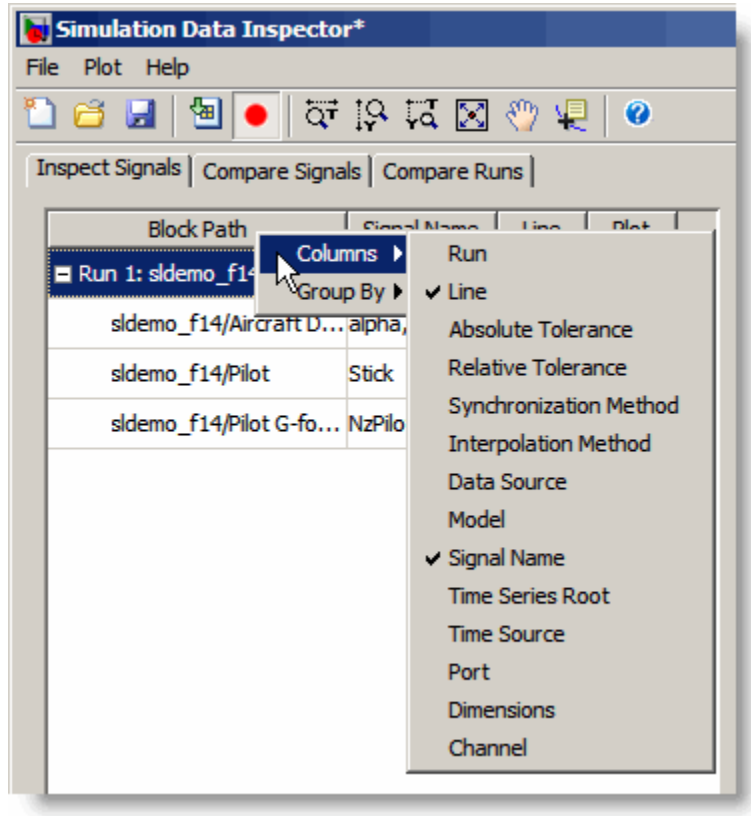
To...	Click...
Clear the Simulation Data Inspector of all data.	**New** 
Open a MAT file previously saved from the Simulation Data Inspector	**Open** 

To...	Click...
Save data in Simulation Data Inspector to a MAT-file.	**Save** 
Enable recording of data from a simulation. After you click the button, simulate your model and the logged data automatically populates the Simulation Data Inspector.	**Record** 
Zoom in along the time axis. After selecting the icon, on the graph, click and hold the left mouse button and drag the mouse to select an area to enlarge.	**Zoom in T** 
Zoom in along the data value axis. After selecting the icon, on the graph, click and hold the left mouse button and drag the mouse to select an area to enlarge.	**Zoom in T** 
Zoom in on a section of the graph along both axes. After selecting the icon, on the graph, click and hold the left mouse button, and drag the mouse to select an area to enlarge.	**Zoom in T and Y** 
Zoom out the graph. After selecting the icon, click the graph to incrementally zoom out.	**Zoom Out** 
Move the plot in the graph up, down, left, or right. After selecting the icon, on the graph, click and hold the left mouse button and move the mouse to the area of the graph that you want to view.	**Pan** 
Display the `T` and `Y` values of a data point in the plot. After selecting the icon, click a point on the line to view a data point.	**Data Cursor** 

Signal Browser Table

The Signal Browser table has three tabbed views: **Inspect Signals**, **Compare Signals**, and **Compare Runs**. You can modify the columns in the table to view the information that best supports your workflow. To customize the Signal Browser table, you can perform the following tasks:

Adding/Deleting a Column in the Signal Browser table. To add or remove a column, right-click the Signal Browser table title bar. Select `Columns` and click an option on the list. The column is displayed in the table.



Column Options for the Inspect Signals and Compare Signals View

Column Option	Value
Run	Name of a simulation run
Line	Line style
Absolute Tolerance	Positive number (user-specified)
Relative Tolerance	Positive number (user-specified)
Synchronization Method	Method to align time vector: **union**, **intersection**, **uniform** (user-specified)

Column Options for the Inspect Signals and Compare Signals View (Continued)

Column Option	Value
Interpolation Method	Method to align data: **zoh**, **linear** (user-specified)
Data Source	Name for the data (`logsout.Stick.Data`)
Model	Model name for the signal data
Signal	Signal name for the data (`Stick`)
Time Series Root	String signifying the name of the Simulink.Timeseries object (`logsout.Stick.Time`)
Time Source	String signifying the array containing the time data(`logsout.Stick.Time`)
Port	Index of the output port that emits the signal logged
Dimensions	Number of dimensions of the signal
Channel	Channel of matrix data

Column Options for Compare Runs View

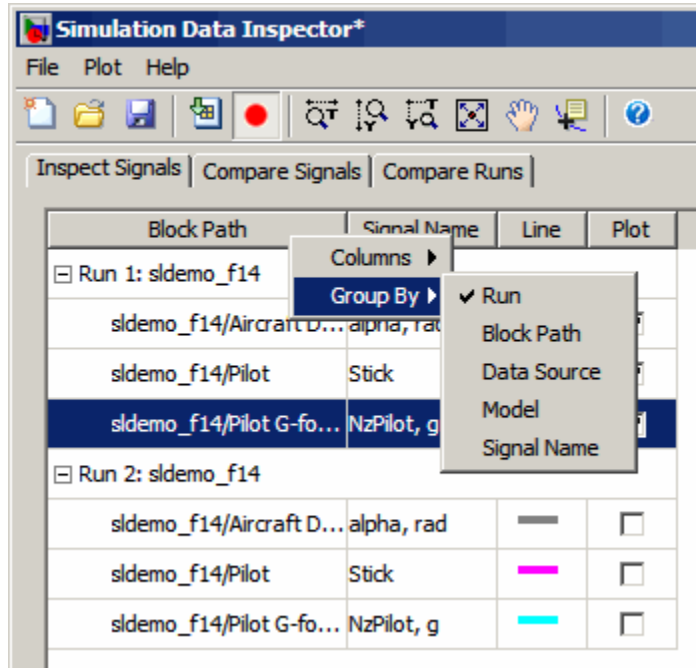
Column Option	Value
Result	Result of the comparison for the signal across the specified runs
Block Path	• **Run 1: Block Path** • **Run 2: Block Path**
Data Source	String identifying the data source • **Run 1: Data Source** • **Run 2: Data Source**

Column Options for Compare Runs View (Continued)

Column Option	Value
SID	"Simulink Identifier" • **Run 1: SID** • **Run 2: SID**
Absolute Tolerance	Positive number (user-specified)
Relative Tolerance	Positive number (user specified)
Synchronization Method	Method to align time vector: **union**, **intersection**, **uniform** (user-specified)
Interpolation Method	Method to align data: **zoh**, **linear** (user-specified)
Channel 1	Channel of matrix data

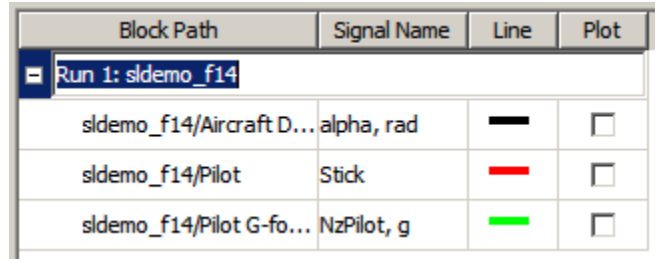
After selecting a column option, the new column is added to the table in the order that it appears in the options list.

Modifying Grouping in the Signal Browser Table. Right-click the Signal Browser table title bar. Select `Group By`. You can group the signal data in the table by selecting an option from the list.



Renaming a Run. To rename a run name:

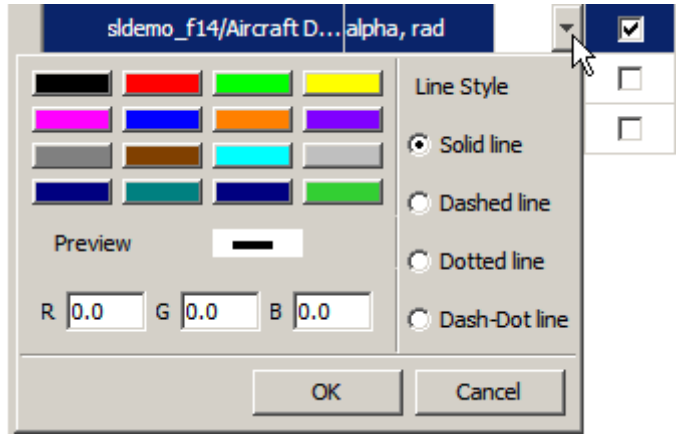
1. If the Signal Browser table is not grouped by run, right-click the table and in the menu select **Group By > Run**.
2. Double-click the Run row.



3. Type the new run name and press **Enter**.

Specify the Line Configuration.

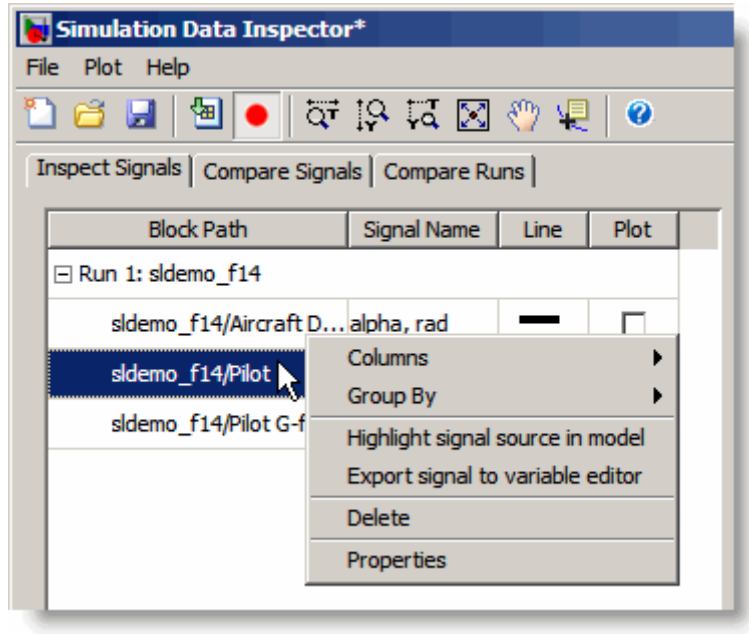
1 Click in the **Line** column of a signal and click the down arrow. The Line dialog box opens.



2 Specify the color and the **Line Style** for the signal.

3 Click **OK**.

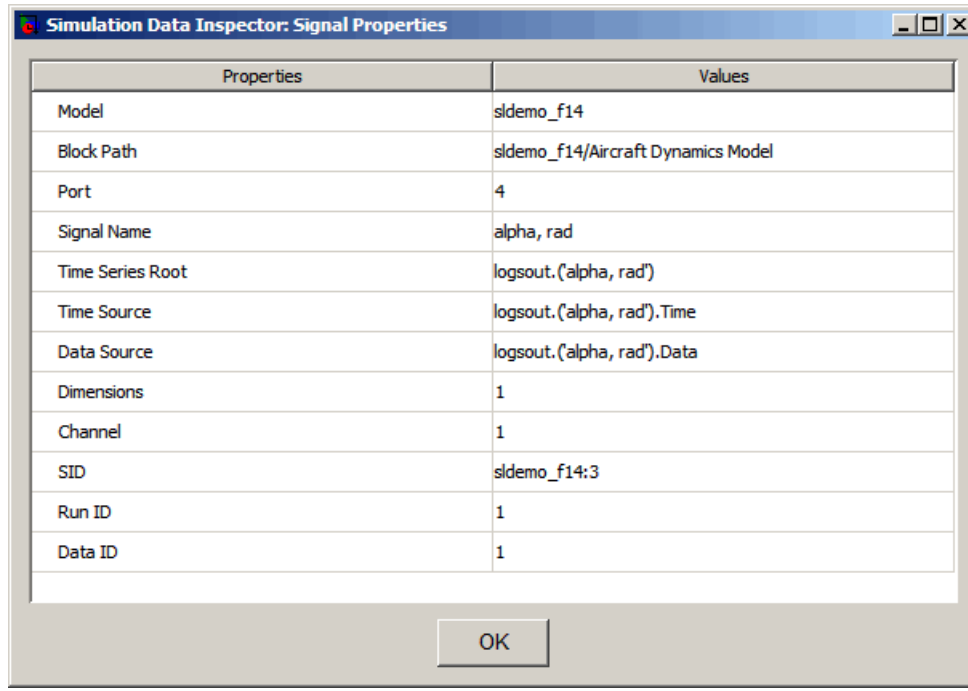
Selecting a Signal Option in the Signal Browser Table. In the Signal Browser table, right-click a signal for a menu list of options.



To...	Select...
Display the list of Column options. See Table Column Options for the Inspect Signals and Compare Signals View on page 13-46	**Columns**
Group signal data by the specified options: **Run**, **Block Path**, **Data Source**, **Model**, and **Signal Name**	**Group By**
Highlight the source of the selected signal in the model diagram	**Highlight signal source in model**
Open the Variable Editor and display the selected signal data	**Export signal to variable editor**

To...	Select...
Delete the highlighted signal in the Signal Browser table (this option does not appear in the **Compare Runs** view)	**Delete**
Display the signal properties of the selected signal	**Properties**

The Signal Properties dialog box displays the following signal information.

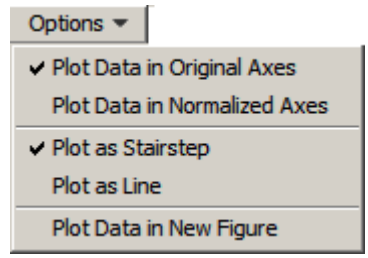


Plot View

The Plot view is on the right pane of the Simulation Data Inspector tool. The Plot view for the **Inspect Signals** view displays the **Signals** graph. The Plot view for the **Compare Signals** and **Compare Runs** views, displays the **Signals** graph and the **Difference** graph. Both graphs have an **Options** menu.

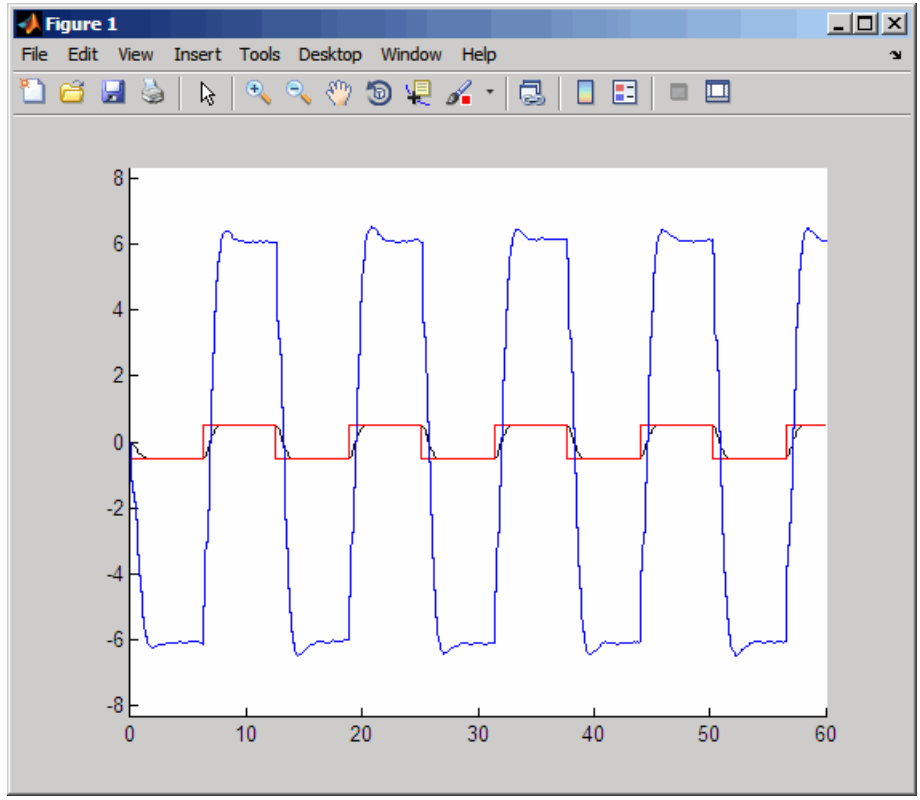
Modifying the Plot in the Simulation Data Inspector Tool. To modify the plot, you can:

- **Tool bar**: Select icons in the tool bar, to zoom into data, move the plot, or add a data point to the plot. For more information on these icons, see the "Tool Bar" on page 13-43 section.
- **Options menu**: Click the **Options** menu on the plot to select alternatives for plotting the data.



To...	The Simulation Data Inspector...
Plot Data in Original Axes	Plots the data according to the maximum and minimum values of the data points.(default)
Plot Data in Normalized Axes	Normalizes the data for each signal from -1 to 1 along the y-axis. If the data is already within that range, the data is displayed as a constant at 1.
Plot as Stairstep	Plots the data as a stairstep plot. (default)
Plot as Line	Interpolates the data points and produces a linear plot.
Plot Data in New Figure	Launches the graph in a MATLAB figure window.

- **New figure**: Click the **Options** menu on the plot and select **Plot Data in New Figure**. The plot opens in a new figure window.



For more information on plotting and customizing your data plots using the GUI tools, see the *MATLAB Graphics* documentation.

To view an example, see "Creating, Saving, and Printing a Figure in Simulation Data Inspector", in the *Simulink Getting Started Guide*.

Limitations of the Simulation Data Inspector Tool

The following Simulink data export formats are not supported:

- Structure (without time)
- Model-level outputs: both, states(`xout`) and output(`yout`), without time(`tout`)
- Array

The following Simulink data types are not supported:

- Complex data, `int64` and `unit64`
- Enumerated data types

14

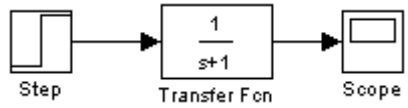
Analyzing Simulation Results

Viewing Output Trajectories

In this section...

Using the Scope Block

You can display output trajectories on a Scope block during simulation as illustrated by the following model.

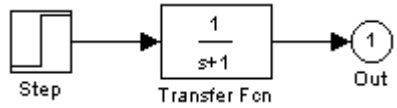


The display on the Scope shows the output trajectory. The Scope block enables you to zoom in on an area of interest or save the data to the workspace.

The XY Graph block enables you to plot one signal against another.

Using Return Variables

By returning time and output histories, you can use the plotting commands provided in the MATLAB software to display and annotate the output trajectories.



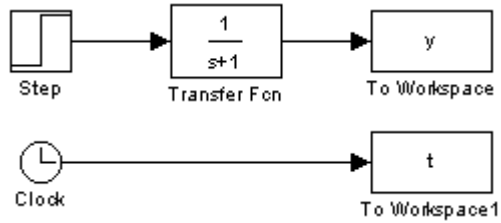
The block labeled Out is an Outport block from the Ports & Subsystems library. The output trajectory, `yout`, is returned by the integration solver. For more information, see "Data Import/Export Pane".

You can also run this simulation from the **Simulation** menu by specifying variables for the time, output, and states on the **Data Import/Export** pane of the **Configuration Parameters** dialog box. You can then plot these results using

```
plot(tout,yout)
```

Using the To Workspace Block

The To Workspace block can be used to return output trajectories to the workspace. The following model illustrates this use:

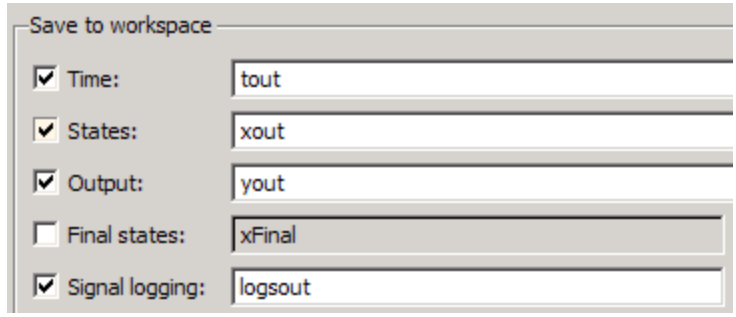


The variables `y` and `t` appear in the workspace when the simulation is complete. You store the time vector by feeding a Clock block into a To Workspace block. You can also acquire the time vector by entering a variable name for the time on the **Data Import/Export** pane of the **Configuration Parameters** dialog box, for menu-driven simulations, or by returning it using the `sim` command (see "Data Import/Export Pane" for more information).

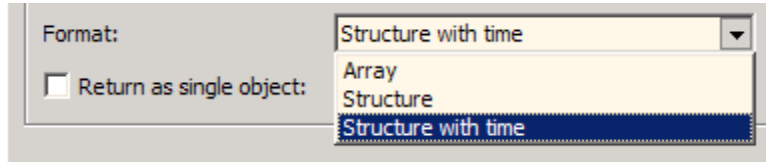
The To Workspace block can accept an array input, with each input element's trajectory stored in the resulting workspace variable.

Using the Simulation Data Inspector Tool

- By configuring your model to log signal data to the base workspace, you can view the output in the Simulation Data Inspector tool. On the **Data Import/Export** pane of the Configuration Parameters dialog box, select the following:



You must also specify the **Format** parameter as `Structure with time`:



For more information on the Simulation Data Inspector tool, see "Inspecting and Comparing Logged Signal Data" on page 13-25.

Linearizing Models

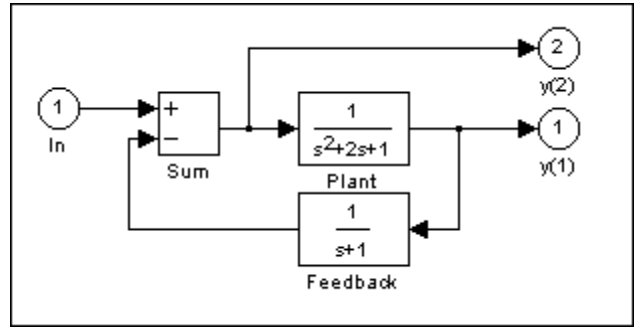
In this section...

About Linearizing Models

The Simulink product provides the `linmod`, `linmod2`, and `dlinmod` functions to extract linear models in the form of the state-space matrices *A*, *B*, *C*, and *D*. State-space matrices describe the linear input-output relationship as

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du,$$

where *x*, *u*, and *y* are state, input, and output vectors, respectively. For example, the following model is called `lmod`.



To extract the linear model of this system, enter this command.

```
[A,B,C,D] = linmod('lmod')

A =
    -2    -1    -1
     1     0     0
     0     1    -1
B =
     1
     0
     0
C =
     0     1     0
     0     0    -1
D =
     0
     1
```

Inputs and outputs must be defined using Inport and Outport blocks from the Ports & Subsystems library. Source and sink blocks do not act as inputs and outputs. Inport blocks can be used in conjunction with source blocks, using a Sum block. Once the data is in the state-space form or converted to an LTI object, you can apply functions in the Control System Toolbox product for further analysis:

- Conversion to an LTI object

  ```
  sys = ss(A,B,C,D);
  ```

- Bode phase and magnitude frequency plot

  ```
  bode(A,B,C,D) or bode(sys)
  ```

- Linearized time response

  ```
  step(A,B,C,D) or step(sys)
  impulse(A,B,C,D) or impulse(sys)
  lsim(A,B,C,D,u,t) or lsim(sys,u,t)
  ```

You can use other functions in the Control System Toolbox and the Robust Control Toolbox™ products for linear control system design.

When the model is nonlinear, an operating point can be chosen at which to extract the linearized model. Extra arguments to `linmod` specify the operating point.

```
[A,B,C,D] = linmod('sys', x, u)
```

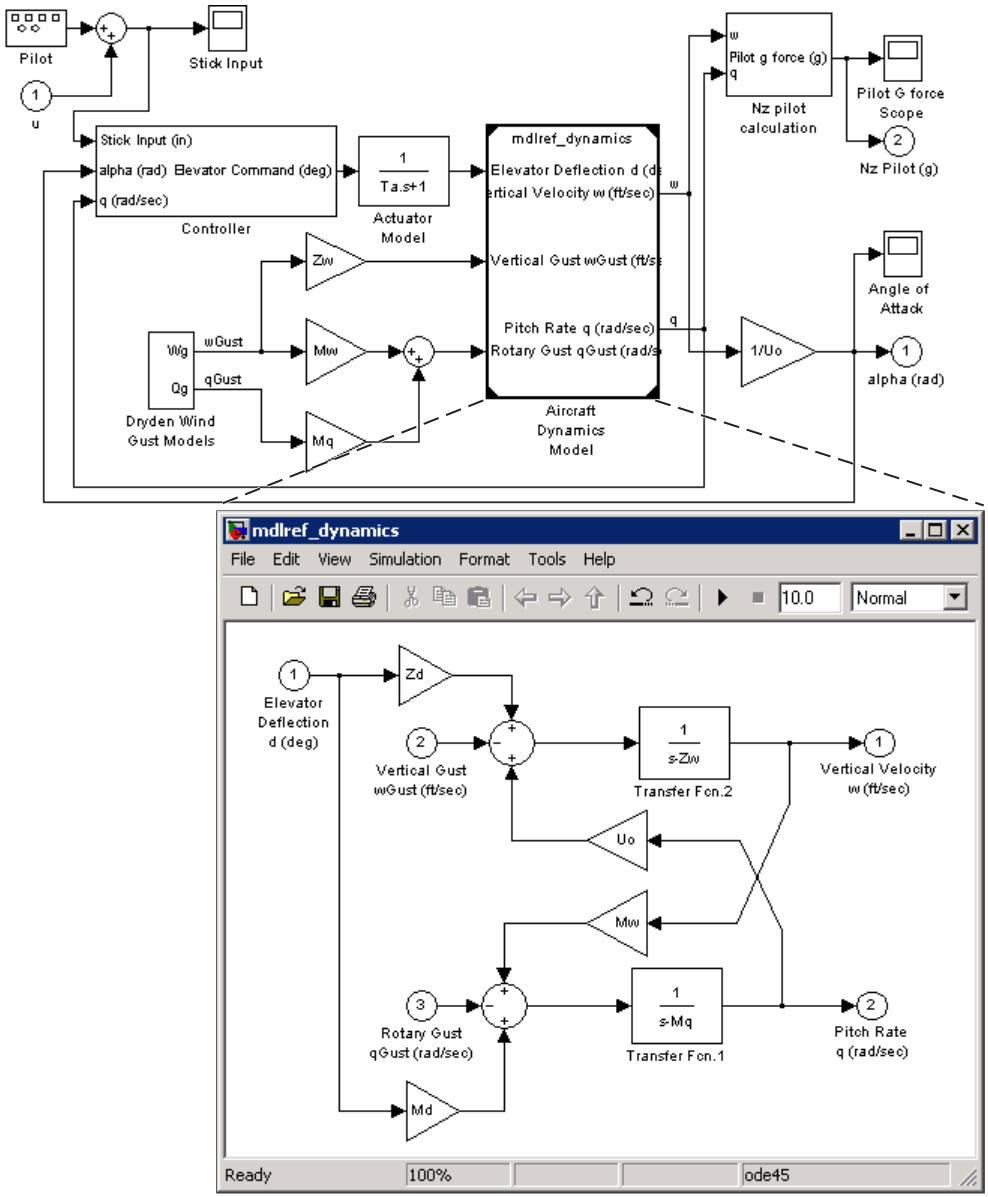
For discrete systems or mixed continuous and discrete systems, use the function `dlinmod` for linearization. This function has the same calling syntax as `linmod` except that the second right-hand argument must contain a sample time at which to perform the linearization.

Linearization with Referenced Models

You can use `linmod` to extract a linear model from a Simulink environment that contains Model blocks.

Note In Normal mode, the `linmod` command applies the block-by-block linearization algorithm on blocks inside the referenced model. If the Model block is in Accelerator mode, the `linmod` command uses numerical perturbation to linearize the referenced model. Due to limitations on linearizing multirate Model blocks in Accelerator mode, you should use Normal mode simulation for all models referenced by Model blocks when linearizing with referenced models. See the Control Design documentation for an explanation of the block-by-block linearization algorithm.

For example, consider the `f14` model `mdlref_f14.mdl`. The Aircraft Dynamics Model block refers to the model `mdlref_dynamics.mdl`.



To linearize the `mdlref_f14` model, call the `linmod` command on the top `mdlref_f14` model as follows.

```
[A,B,C,D] = linmod('mdlref_f14')
```

The resulting state-space model corresponds to the complete `f14` model, including the referenced model.

You can call `linmod` with a state and input operating point for models that contain Model blocks. When using operating points, the state vector `x` refers to the total state vector for the top model and any referenced models. You must enter the state vector using the structure format. To get the complete state vector, call

```
x = Simulink.BlockDiagram.getInitialState(topModelName)
```

Linearization Using the 'v5' Algorithm

Calling the `linmod` command with the `'v5'` argument invokes the perturbation algorithm created prior to MATLAB software version 5.3. This algorithm also allows you to specify the perturbation values used to perform the perturbation of all the states and inputs of the model.

```
[A,B,C,D]=linmod('sys',x,u,para,xpert,upert,'v5')
```

Using `linmod` with the `'v5'` option to linearize a model that contains Derivative or Transport Delay blocks can be troublesome. Before linearizing, replace these blocks with specially designed blocks that avoid the problems. These blocks are in the Simulink Extras library in the Linearization sublibrary.

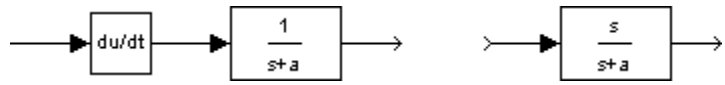
You access the Extras library by opening the Blocksets & Toolboxes icon:

- For the Derivative block, use the Switched derivative for linearization.
- For the Transport Delay block, use the Switched transport delay for linearization. (Using this block requires that you have the Control System Toolbox product.)

When using a Derivative block, you can also try to incorporate the derivative term in other blocks. For example, if you have a Derivative block in series with a Transfer Fcn block, it is better implemented (although this is not always possible) with a single Transfer Fcn block of the form

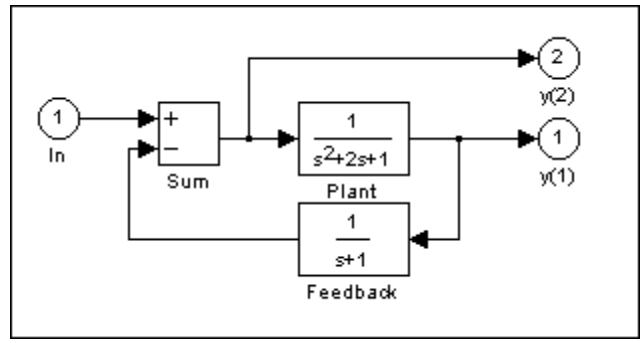
$$\frac{s}{s+a}.$$

In this example, the blocks on the left of this figure can be replaced by the block on the right.



Finding Steady-State Points

The Simulink `trim` function uses a model to determine steady-state points of a dynamic system that satisfy input, output, and state conditions that you specify. Consider, for example, this model, called `lmod`.



You can use the `trim` function to find the values of the input and the states that set both outputs to 1. First, make initial guesses for the state variables (`x`) and input values (`u`), then set the desired value for the output (`y`).

```
x = [0; 0; 0];
u = 0;
y = [1; 1];
```

Use index variables to indicate which variables are fixed and which can vary.

```
ix = [];      % Don't fix any of the states
iu = [];      % Don't fix the input
iy = [1;2];   % Fix both output 1 and output 2
```

Invoking `trim` returns the solution. Your results might differ because of roundoff error.

```
[x,u,y,dx] = trim('lmod',x,u,y,ix,iu,iy)

x =
   0.0000
   1.0000
   1.0000
u =
   2
y =
   1.0000
   1.0000
dx =
   1.0e-015 *
    -0.2220
    -0.0227
     0.3331
```

Note that there might be no solution to equilibrium point problems. If that is the case, `trim` returns a solution that minimizes the maximum deviation from the desired result after first trying to set the derivatives to zero. For a description of the `trim` syntax, see `trim` in the *Simulink Reference*.

15

Improving Simulation Performance and Accuracy

About Improving Performance and Accuracy

Simulation performance and accuracy can be affected by many things, including the model design and choice of configuration parameters.

The solvers handle most model simulations accurately and efficiently with their default parameter values. However, some models yield better results if you adjust solver parameters. Also, if you know information about your model's behavior, your simulation results can be improved if you provide this information to the solver.

Speeding Up the Simulation

Slow simulation speed can have many causes. Here are a few:

- Your model includes a MATLAB Fcn block. When a model includes a MATLAB Fcn block, the MATLAB interpreter is called at each time step, drastically slowing down the simulation. Use the built-in Fcn block or Math Function block whenever possible.
- Your model includes a MATLAB file S-function. MATLAB file S-functions also cause the MATLAB interpreter to be called at each time step. Consider either converting the S-function to a subsystem or to a C-MEX file S-function.
- Your model includes a Memory block. Using a Memory block causes the variable-order solvers (`ode15s` and `ode113`) to be reset back to order 1 at each time step.
- The maximum step size is too small. If you changed the maximum step size, try running the simulation again with the default value (`auto`).
- Did you ask for too much accuracy? The default relative tolerance (0.1% accuracy) is usually sufficient. For models with states that go to zero, if the absolute tolerance parameter is too small, the simulation can take too many steps around the near-zero state values. See the discussion of error in "Maximum order""Maximum order" in the online documentation.
- The time scale might be too long. Reduce the time interval.

- The problem might be stiff, but you are using a nonstiff solver. Try using `ode15s`.
- The model uses sample times that are not multiples of each other. Mixing sample times that are not multiples of each other causes the solver to take small enough steps to ensure sample time hits for all sample times.
- The model contains an algebraic loop. The solutions to algebraic loops are iteratively computed at every time step. Therefore, they severely degrade performance. For more information, see "Algebraic Loops" on page 2-39.
- Your model feeds a Random Number block into an Integrator block. For continuous systems, use the Band-Limited White Noise block in the Sources library.
- Your model contains a scope viewer that displays a large number of data points. Try adjusting the viewer parameter settings that can affect performance. For more information, see "How Scope Viewer Parameter Settings Can Affect Performance" on page 13-10.

Comparing Performance

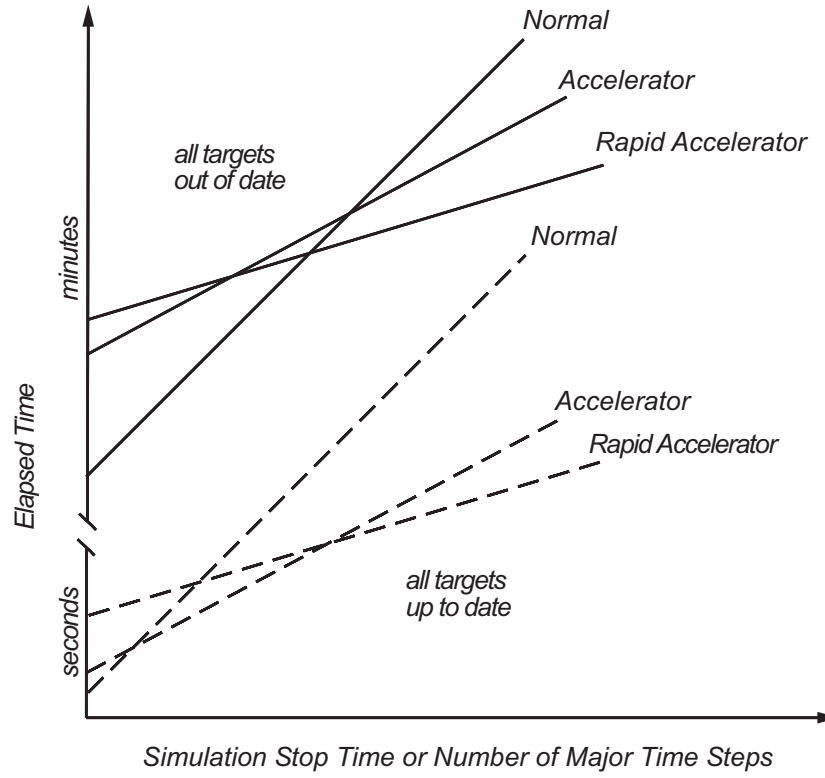
In this section...

Performance of the Simulation Modes

The Accelerator and Rapid Accelerator modes give the best speed improvement compared to Normal mode when simulation execution time exceeds the time required for code generation. For this reason, the Accelerator and Rapid Accelerator modes generally perform better than Normal mode when simulation execution times are several minutes or more. However, models with a significant number of Stateflow or Embedded MATLAB blocks might show only a small speed improvement over Normal mode because in Normal mode these blocks also simulate through code generation.

Including tunable parameters in your model can also increase the simulation time.

The figure shows in general terms the performance of a hypothetical model simulated in Normal, Accelerator, and Rapid Accelerator modes.



Performance When the Target Must Be Rebuilt

The solid lines in the figure show performance when the target code must be rebuilt ("all targets out of date"). For this hypothetical model, the time scale is on the order of minutes, but it could be longer for more complex models.

As generalized in the figure, the time required to compile the model in Normal mode is less than the time required to build either the Accelerator target or Rapid Accelerator executable. It is evident from the figure that for small simulation stop times Normal mode results in quicker overall simulation times than either Accelerator mode or Rapid Accelerator mode.

The crossover point where Accelerator mode or Rapid Accelerator mode result in faster execution times depends on the complexity and content of your model. For instance, those models running in Accelerator mode containing large

numbers of blocks using interpreted code (see “Selecting Blocks for Accelerator Mode” on page 17-14) might not run much faster than they would in Normal mode unless the simulation stop time is very large. Similarly, models with a large Stateflow or Embedded MATLAB content might not show much speed improvement over Normal mode unless the simulation stop times are long.

For illustration purposes, the graphic represents a model with a large number of Stateflow or Embedded MATLAB blocks. The curve labeled “Normal” would have much smaller initial elapsed time than shown if the model did not contain these blocks.

Performance When the Targets Are Up to Date

As shown by the broken lines in the figure (“all targets up to date”) the time for the Simulink software to determine if the Accelerator target or the Rapid Accelerator executable are up to date is significantly less than the time required to generate code (“all targets out of date”). You can take advantage of this characteristic when you wish to test various design tradeoffs.

For instance, you can generate the Accelerator mode target code once and use it to simulate your model with a series of gain settings. This is an especially efficient way to use the Accelerator or Rapid Accelerator modes because this type of change does not result in the target code being regenerated. This means the target code is generated the first time the model runs, but on subsequent runs the Simulink code spends only the time necessary to verify that the target is up to date. This process is much faster than generating code, so subsequent runs can be significantly faster than the initial run.

Because checking the targets is quicker than code generation, the crossover point is smaller when the target is up to date than when code must be generated. This means subsequent runs of your model might simulate faster in Accelerator or Rapid Accelerator mode when compared to Normal mode, even for short stop times.

Measuring Performance

You can use the `tic`, `toc`, and `sim` commands to compare Accelerator mode or Rapid Accelerator mode execution times to Normal mode.

1. Use `load_system` to load your model into memory without opening a window.

2. From the **Simulation** menu, select **Normal**.

3. Use the `tic`, `toc`, and `sim` commands at the command line prompt to measure how long the model takes to simulate in Normal mode:

   ```
   tic,[t,x,y]=sim('myModel',10000);toc
   ```

   `tic` and `toc` work together to record and return the elapsed time and display a message such as the following:

   ```
   Elapsed time is 17.789364 seconds.
   ```

4. Select either **Accelerator** or **Rapid Accelerator** from the **Simulation** menu, and build an executable for the model by clicking the **Start** button. The acceleration modes use this executable in subsequent simulations as long as the model remains structurally unchanged. "Code Regeneration in Accelerated Models" on page 17-7 discusses the things that cause your model to rebuild.

5. Rerun the compiled model at the command prompt:

   ```
   tic,[t,x,y]=sim('myModel',10000);toc
   ```

6. The elapsed time displayed shows the run time for the accelerated model. For example:

   ```
   Elapsed time is 12.419914 seconds.
   ```

The difference in elapsed times (5.369450 seconds in this example) shows the improvement obtained by accelerating your model.

Improving Acceleration Mode Performance

In this section...

Techniques

To get the best performance when accelerating your models:

- Verify that the Configuration Parameters dialog box settings are as follows:

On this pane...	Set...	To...
Solver Diagnostics	**Solver data inconsistency**	none
Data Validity Diagnostics	**Array bounds exceeded**	none
Optimization	**Signal storage reuse**	selected

- Disable Stateflow debugging and animation.
- Inline user-written S-functions (these are TLC files that direct the Real-Time Workshop software to create C code for the S-function). See "Controlling S-Function Execution" on page 17-15 for a discussion on how the Accelerator mode and Rapid Accelerator mode work with inlined S-functions.

  For information on how to inline S-functions, consult "Integrating External Code With Generated C and C++ Code".
- When logging large amounts of data (for instance, when using the Workspace I/O, To Workspace, To File, or Scope blocks), use decimation or limit the output to display only the last part of the simulation.
- Customize the code generation process to improve simulation speed. See "Customizing the Build Process" on page 17-20 for details.

C Compilers

On computers running the Microsoft Windows operating system, the Accelerator and Rapid Accelerator modes use the default 32-bit C compiler supplied by MathWorks to compile your model. If you have a C compiler installed on your PC, you can configure the `mex` command to use it instead. You might choose to do this if your C compiler produces highly optimized code since this would further improve acceleration, or if you wish to use a 64-bit compiler.

Note For an up-to-date list of 32- and 64-bit C compilers that are compatible with MATLAB software for all supported computing platforms, see:

```
http://www.mathworks.com/support/compilers/current_release/
```

Improving Simulation Accuracy

To check your simulation accuracy, run the simulation over a reasonable time span. Then, either reduce the relative tolerance to 1e-4 (the default is 1e-3) or reduce the absolute tolerance and run it again. Compare the results of both simulations. If the results are not significantly different, you can feel confident that the solution has converged.

If the simulation misses significant behavior at its start, reduce the initial step size to ensure that the simulation does not step over the significant behavior.

If the simulation results become unstable over time,

- Your system might be unstable.
- If you are using `ode15s`, you might need to restrict the maximum order to 2 (the maximum order for which the solver is A-stable) or try using the `ode23s` solver.

If the simulation results do not appear to be accurate,

- For a model that has states whose values approach zero, if the absolute tolerance parameter is too large, the simulation takes too few steps around areas of near-zero state values. Reduce this parameter value or adjust it for individual states in the Integrator dialog box.
- If reducing the absolute tolerances does not sufficiently improve the accuracy, reduce the size of the relative tolerance parameter to reduce the acceptable error and force smaller step sizes and more steps.

Certain modeling constructs can also produce unexpected or inaccurate simulation results.

- A Source block that inherits its sample time can produce different simulation results if, for example, the sample times of the downstream blocks are modified (see “How Propagation Affects Inherited Sample Times” on page 4-31).
- A Derivative block found in an algebraic loop can result in a loss in solver accuracy.

16

Simulink Debugger

Introduction to the Debugger

With the debugger, you run your simulation method by method. You can stop after each method to examine the execution results. In this way, you can pinpoint problems in your model to specific blocks, parameters, or interconnections.

Note Methods are functions that the Simulink software uses to solve a model at each time step during the simulation. Blocks are made up of multiple methods. "Block execution" in this documentation is shorthand for "block methods execution." Block diagram execution is a multi-step operation that requires execution of the different block methods in all the blocks in a diagram at various points during the process of solving a model at each time step during simulation, as specified by the simulation loop.

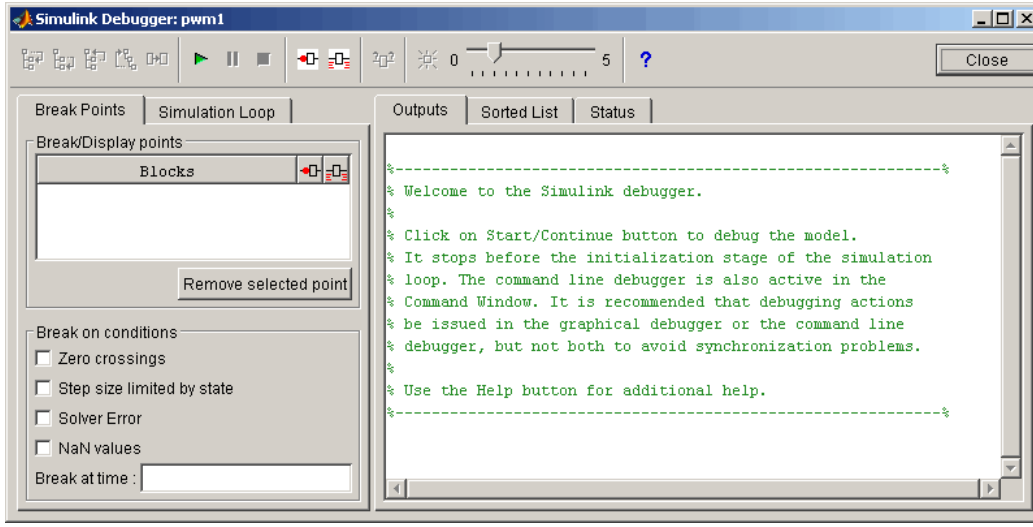
The debugger has both a graphical and a command-line user interface. The graphical interface allows you to access the most commonly used features of the debugger. The command-line interface gives you access to all of the capabilities in the debugger. If you can use either to perform a task, the documentation shows you first how to use the graphical interface, then the command-line interface.

Using the Debugger's Graphical User Interface

In this section...

Displaying the Graphical Interface

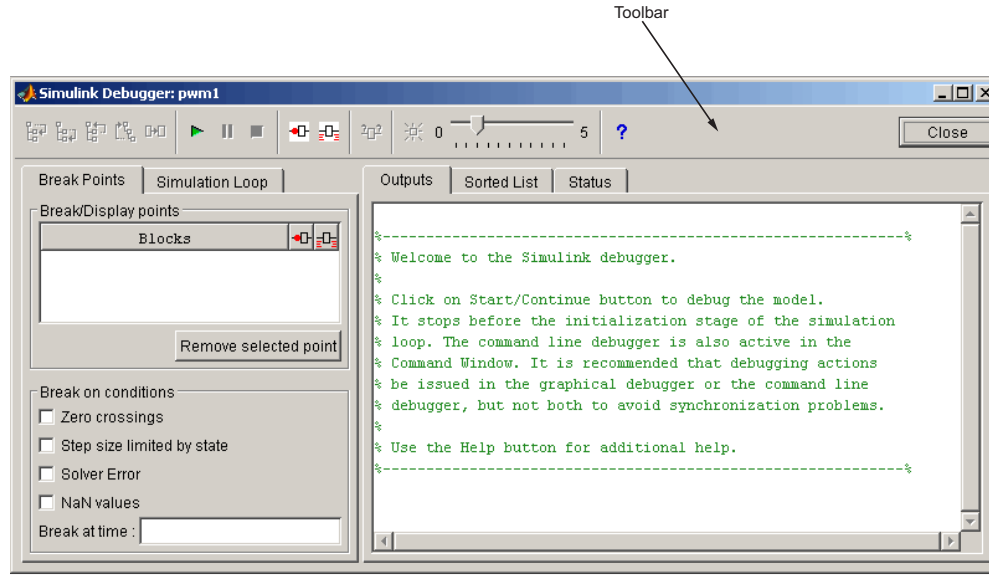
Select **Simulink Debugger** from a model window's **Tools** menu to display the debugger graphical interface.



Note The debugger graphical user interface does not display state or solver information. The command line interface does provide this information. See "Displaying System States" on page 16-38 and "Displaying Solver Information" on page 16-39.

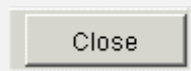
Toolbar

The debugger toolbar appears at the top of the debugger window.



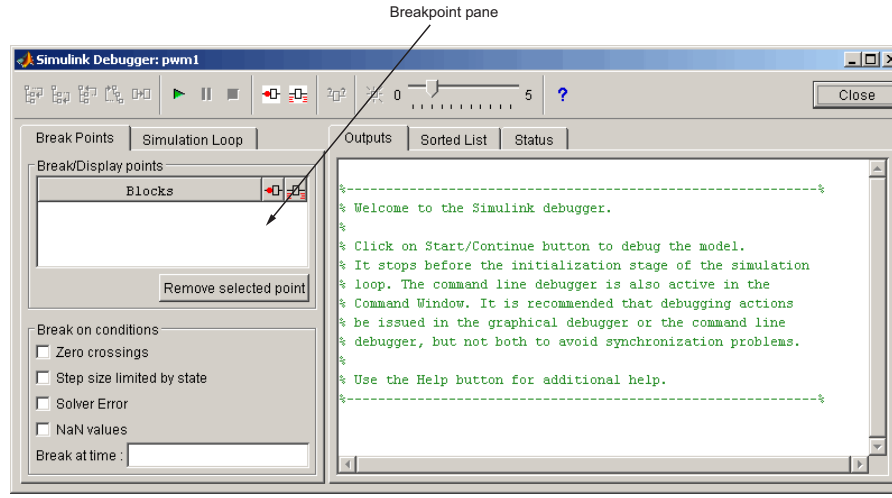
From left to right, the toolbar contains the following command buttons:

Button	Purpose
	Step into the next method (see "Stepping Commands" on page 16-22 for more information on this command, and the following stepping commands).
	Step over the next method.

Button	Purpose
	Step out of the current method.
	Step to the first method at the start of next time step.
	Step to the next block method.
	Start or continue the simulation.
	Pause the simulation.
	Stop the simulation.
	Break before the selected block.
	Display inputs and outputs of the selected block when executed (same as `trace gcb`).
	Display the current inputs and outputs of selected block (same as `probe gcb`).
	Toggle animation mode on or off (see "Animation Mode" on page 16-24). The slider next to this button controls the animation rate.
	Display help for the debugger.
	Close the debugger.

Breakpoints Pane

To display the **Breakpoints** pane, select the **Break Points** tab on the debugger window.

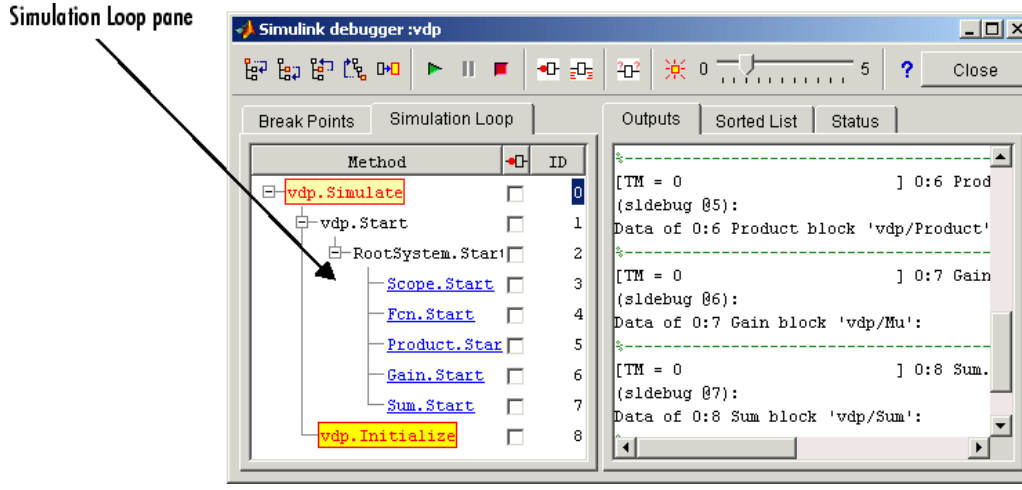


The **Breakpoints** pane allows you to specify block methods or conditions at which to stop a simulation. See “Setting Breakpoints” on page 16-28 for more information.

Note The debugger grays out and disables the **Breakpoints** pane when you select animation mode (see “Animation Mode” on page 16-24). This prevents you from setting breakpoints and indicates that animation mode ignores existing breakpoints.

Simulation Loop Pane

To display the **Simulation Loop** pane, select the **Simulation Loop** tab on the debugger window.



The **Simulation Loop** pane contains three columns:

- Method
- Breakpoints
- ID

Method Column

The **Method** column lists the methods that have been called thus far in the simulation as a method tree with expandable/collapsible nodes. Each node of the tree represents a method that calls other methods. Expanding a node shows the methods that the block method calls. Clicking a block method name highlights the corresponding block in the model diagram.

Whenever the simulation stops, the debugger highlights the name of the method where the simulation has stopped as well as the methods that invoked it. The highlighted method names indicate the current state of the method call stack.

Breakpoints Column

The breakpoints column consists of check boxes. Selecting a check box sets a breakpoint at the method whose name appears to the left of the check box. See “Setting Breakpoints from the Simulation Loop Pane” on page 16-30 for more information.

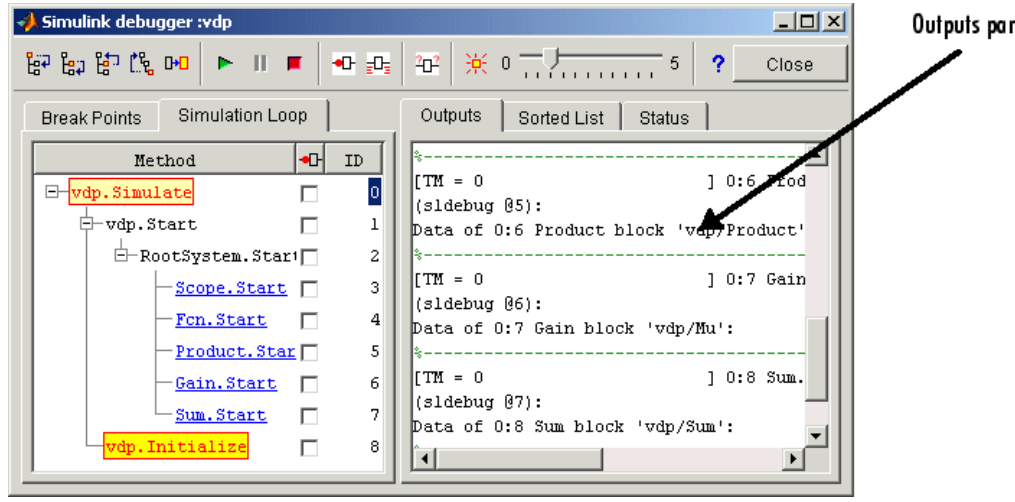
Note This column is disabled when its animation mode is selected (see “Animation Mode” on page 16-24), because in animation mode you can’t set breakpoints.

ID Column

The ID column lists the IDs of the methods listed in the **Methods** column. See “Method ID” on page 16-11 for more information.

Outputs Pane

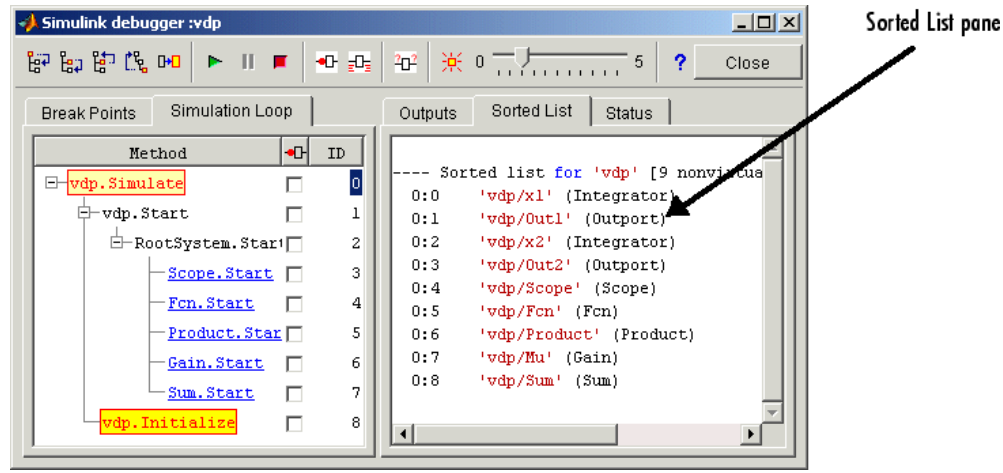
To display the **Outputs** pane, select the **Outputs** tab on the debugger window.



The Outputs pane displays the same debugger output that would appear in the MATLAB command window if the debugger were running in command-line mode. The output includes the debugger command prompt and the inputs, outputs, and states of the block at whose method the simulation is currently paused (see "Block Data Output" on page 16-21). The command prompt displays current simulation time and the name and index of the method in which the debugger is currently stopped (see "Block ID" on page 16-11).

Sorted List Pane

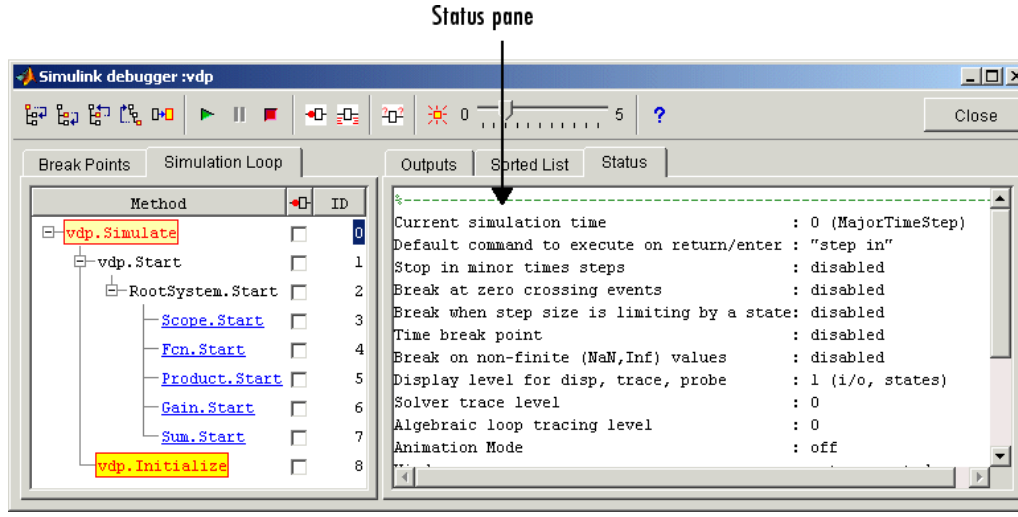
To display the **Sorted List** pane, select the **Sorted List** tab on the debugger window.



The **Sorted List** pane displays the sorted lists for the model being debugged. See "Displaying a Models Sorted Lists" on page 16-40 for more information.

Status Pane

To display the **Status** pane, select the **Status** tab on the debugger window.



The **Status** pane displays the values of various debugger options and other status information.

Using the Debugger's Command-Line Interface

In this section...

Controlling the Debugger

In command-line mode, you control the debugger by entering commands at the debugger command line in the MATLAB Command Window. The debugger accepts abbreviations for debugger commands. See "Simulink Debugger Commands" for a list of command abbreviations and repeatable commands.

Note You can repeat some commands by entering an empty command (i.e., by pressing the **Enter** key) at the command line.

Method ID

Some of the Simulink software commands and messages use method IDs to refer to methods. A method ID is an integer assigned to a method the first time the method is invoked. The debugger assigns method indexes sequentially, starting with 0.

Block ID

Some of the debugger commands and messages use block IDs to refer to blocks. Block IDs are assigned to blocks while generating the model's sorted lists during the compilation phase of the simulation. A block ID has the form `sysIdx:blkIdx`, where `sysIdx` is an integer identifying the system that contains the block (either the root system or a nonvirtual subsystem) and `blkIdx` is the position of the block in the system's sorted list. For example, the block ID`0:1` refers to the first block in the model's root system. The `slist` command shows the block ID for each debugged block in the model.

Accessing the MATLAB Workspace

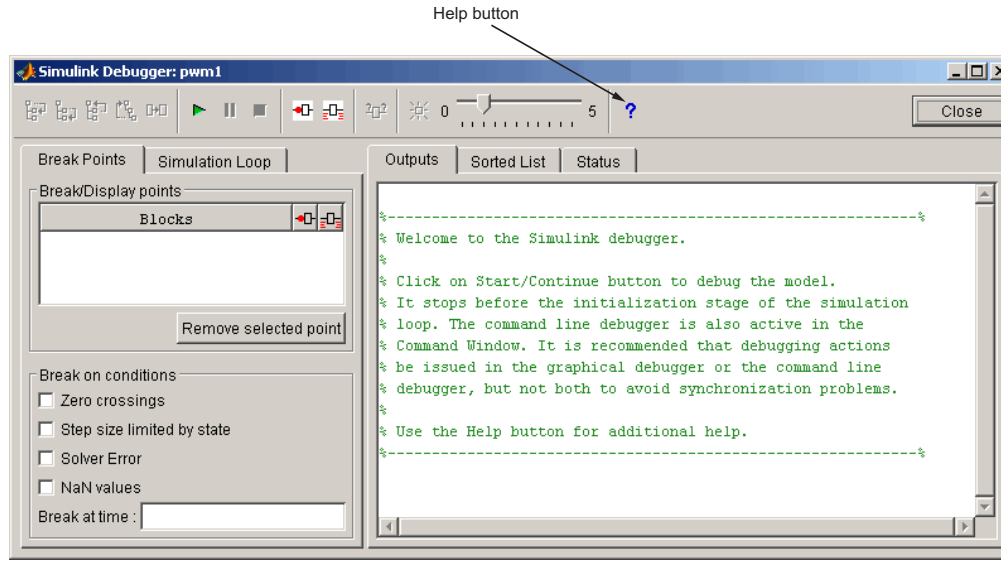
You can enter any MATLAB expression at the `sldebug` prompt. For example, suppose you are at a breakpoint and you are logging time and output of your model as `tout` and `yout`. The following command creates a plot.

```
(sldebug ...) plot(tout, yout)
```

You cannot display the value of a workspace variable whose name is partially or entirely the same as that of a debugger command by entering it at the debugger command prompt. You can, however, use the `eval` command to work around this problem. For example, use `eval('s')` to determine the value of `s` rather then `s(tep)` the simulation.

Getting Online Help

You can get online help on using the debugger by clicking the **Help** button on the debugger toolbar. Clicking the **Help** button displays help for the debugger in the MATLAB product Help browser.



In command-line mode, you can get a brief description of the debugger commands by typing `help` at the debug prompt.

Starting the Simulink Debugger

You can start the debugger from either a Simulink model window or from the MATLAB Command Window.

In this section...

Starting from a Model Window

1. In a model window, select **Tools > Simulink Debugger**.

   The debugger graphical user interface opens. See "Using the Debugger's Graphical User Interface" on page 16-3.

2. Continue selecting toolbar buttons.

Note When running the debugger in graphical user interface (GUI) mode, you must explicitly start the simulation. For more information, see"Starting a Simulation" on page 16-16.

Starting from the Command Window

1. In the MATLAB Command Window, enter either

   - the `sim` command. For example, enter

     ```
     sim('vdp', 'StopTime', '10', 'debug', 'on')
     ```

   - or the `sldebug` command. For example, enter

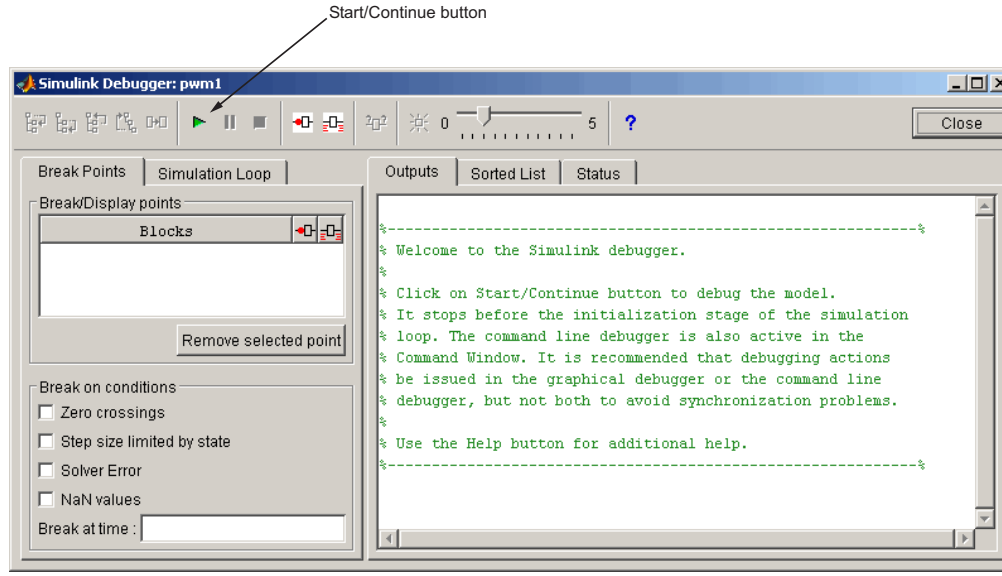
     ```
     sldebug 'vdp'
     ```

   In both cases, the demo model `vdp` loads into memory, starts the simulation, and stops the simulation at the first block in the model execution list.

2 Continue entering debugger commands.

Starting a Simulation

To start the simulation, click the **Start/Continue** button on the debugger toolbar.

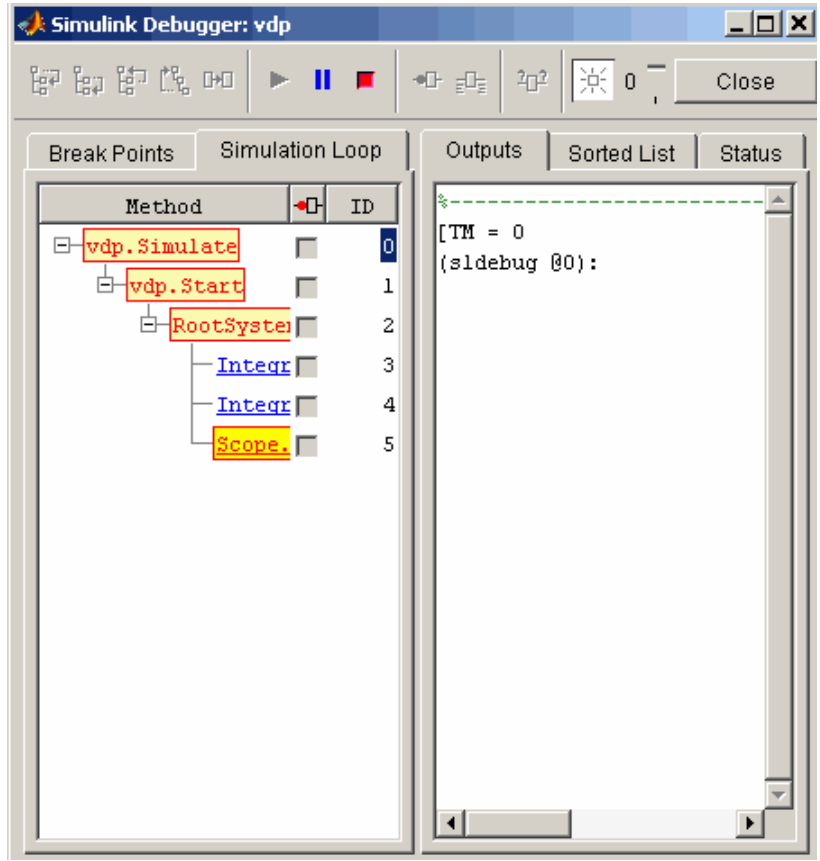


The simulation starts and stops at the first simulation method that is to be executed. It displays the name of the method in its **Simulation Loop** pane and in the debug pointer on the block diagram. The debug pointer indicates on the block diagram which block method is being executed at each step. At this point, you can

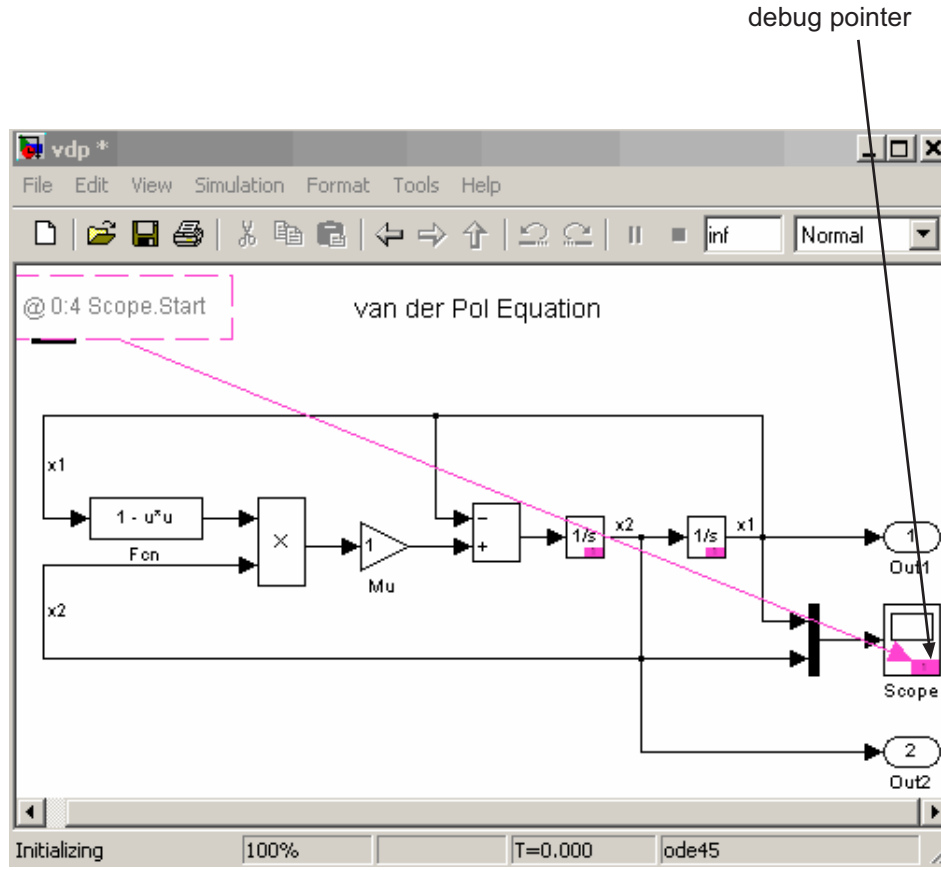
- Set breakpoints.
- Run the simulation step by step.
- Continue the simulation to the next breakpoint or end.
- Examine data.
- Perform other debugging tasks.

As the simulation progresses, the block diagram updates with debug pointers.

The debugger displays the name of the method in the Simulation Loop pane, as shown in the following figure:



The debugger also displays a graphical debug pointer (see “Debug Pointer” on page 16-26) in the block diagram of the model that you are debugging. The debug pointer points to the first block method to be executed.



The following sections explain how to use the debugger controls to perform these debugging tasks.

Note When you start the debugger in GUI mode, the debugger command-line interface is also active in the MATLAB Command Window. However, to prevent synchronization errors between the graphical and command-line interfaces, you should avoid using the command-line interface.

Running a Simulation Step by Step

In this section...

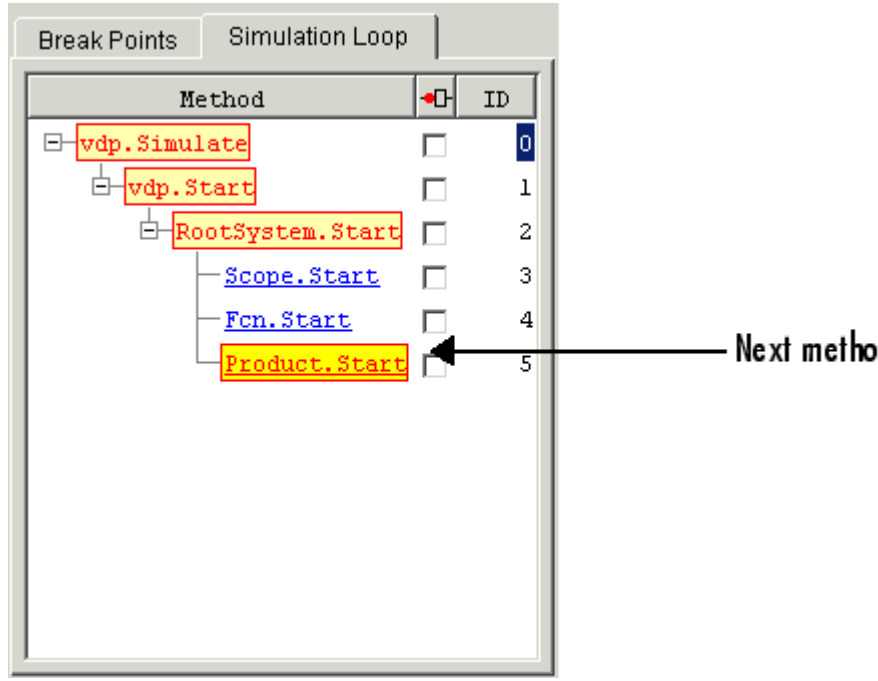
Introduction

The debugger provides various commands that let you advance a simulation from the method where it is currently suspended (the next method) by various increments (see "Stepping Commands" on page 16-22). For example, you can advance the simulation

- Into or over the next method
- Out of the current method
- To the top of the simulation loop.

After each advance, the debugger displays information that enables you to determine the point to which the simulation has advanced and the results of advancing the simulation to that point.

For example, in GUI mode, after each step command, the debugger highlights the current method call stack in the **Simulation Loop** pane. The call stack comprises the next method and the methods that invoked the next method either directly or indirectly. The debugger highlights the call stack by highlighting the names of the methods that make up the call stack in the **Simulation Loop** pane.



In command-line mode, you can use the `where` command to display the method call stack. If the next method is a block method, the debugger points the debug pointer at the block corresponding to the method (see "Debug Pointer" on page 16-26 for more information). If the block of the next method to be executed resides in a subsystem, the debugger opens the subsystem and points to the block in the subsystem block diagram.

Block Data Output

After executing a block method, the debugger prints any or all of the following block data in the debugger **Output** panel (in GUI mode) or, if in command line mode, the MATLAB Command Window:

- `Un = v`

  where `v` is the current value of the block's `n`th input.

- `Yn = v`

where v is the current value of the block's nth output.

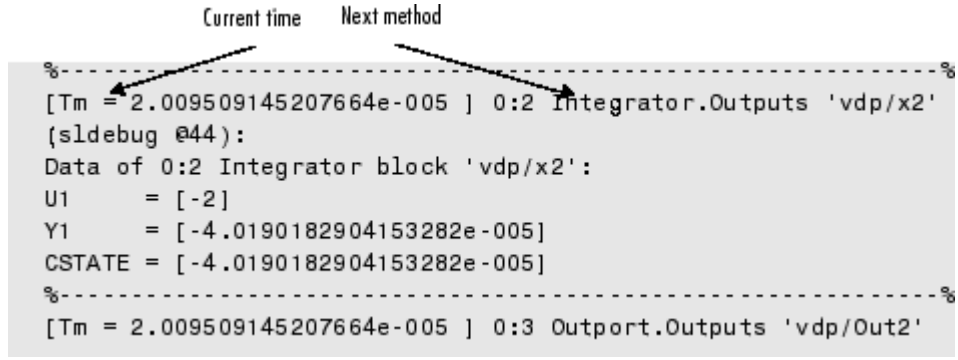
- `CSTATE = v`

  where v is the value of the block's continuous state vector.

- `DSTATE = v`

  where v is the value of the block's discrete state vector.

The debugger also displays the current time, the ID and name of the next method to be executed, and the name of the block to which the method applies in the MATLAB Command Window. The following example illustrates typical debugger outputs after a step command.



Stepping Commands

Command-line mode provides the following commands for advancing a simulation incrementally:

This command...	Advances the simulation...
`step [in into]`	Into the next method, stopping at the first method in the next method or, if the next method does not contain any methods, at the end of the next method
`step over`	To the method that follows the next method, executing all methods invoked directly or indirectly by the next method

This command...	Advances the simulation...
`step out`	To the end of the current method, executing any remaining methods invoked by the current method
`step top`	To the first method of the next time step (i.e., the top of the simulation loop)
`step blockmth`	To the next block method to be executed, executing all intervening model- and system-level methods
`next`	Same as `step over`

Buttons in the debugger toolbar allow you to access these commands in GUI mode.

Clicking a button has the same effect as entering the corresponding command at the debugger command line.

Continuing a Simulation

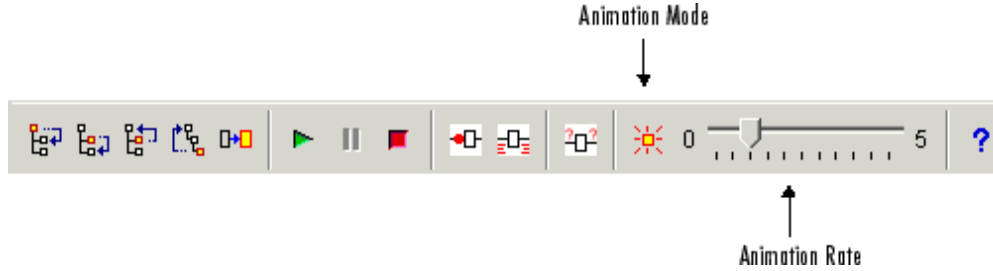
In GUI mode, the **Stop** button turns red when the debugger suspends the simulation for any reason. To continue the simulation, click the **Start/Continue** button. In command-line mode, enter `continue` to continue the simulation. By default, the debugger runs the simulation to the next breakpoint (see "Setting Breakpoints" on page 16-28) or to the end of the simulation, whichever comes first.

Animation Mode

In *animation mode*, the **Start/Continue** button or the `continue` command advances the simulation method by method, pausing after each method, to the first method of the next major time step. While running the simulation in animation mode, the debugger uses its debug pointer (see "Debug Pointer" on page 16-26) to indicate on the block diagram which block method is being executed at each step. The moving pointer shows the simulation progress.

Note In animation mode, the debugger does not allow you to set breakpoints and ignores any breakpoints that you set when animating the simulation.

To enable animation when running the debugger in GUI mode, click the **Animation Mode** button on the debugger toolbar.



Use the slider on the debugger toolbar to increase or decrease the delay between method invocations, and so slow down or speed up the animation rate. To disable animation mode when running the debugger in GUI mode, toggle the **Animation Mode** button on the toolbar.

To enable animation when running the debugger in command-line mode, enter the `animate` command at the command line. The `animate` command has an optional delay parameter for you to specify the length of the pause between method invocations (1 second by default), and thereby accelerate or slow down the animation. For example, the command

```
animate 0.5
```

causes the animation to run at twice its default rate. To disable animation mode when running the debugger in command-line mode, at the command line enter:

```
animate stop
```

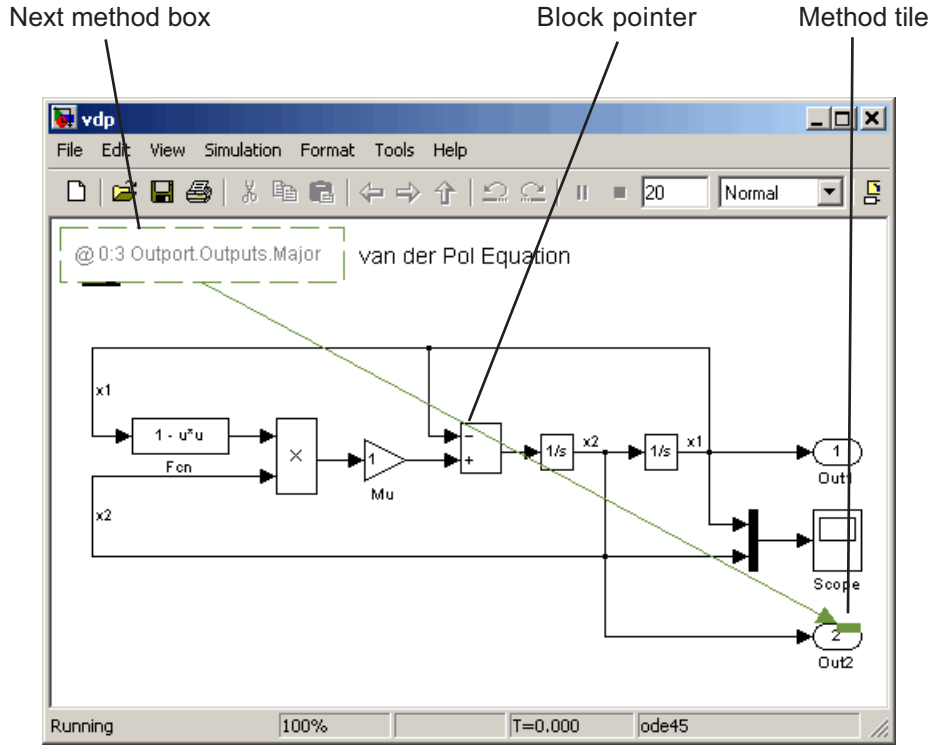
Running a Simulation Nonstop

The `run` command lets you run a simulation to the end of the simulation, skipping any intervening breakpoints. At the end of the simulation, the debugger returns you to the command line. To continue debugging a model, you must restart the debugger.

Note The GUI mode does not provide a graphical version of the `run` command. To run the simulation to the end, you must first clear all breakpoints and then click the **Start/Continue** button.

Debug Pointer

The debugger displays a debug pointer on the block diagram whenever it stops the simulation at a method.



The debug pointer is an annotation that indicates the next method to be executed when simulation resumes. It consists of the following elements:

- Next method box
- Block pointer
- Method tile

Next Method Box

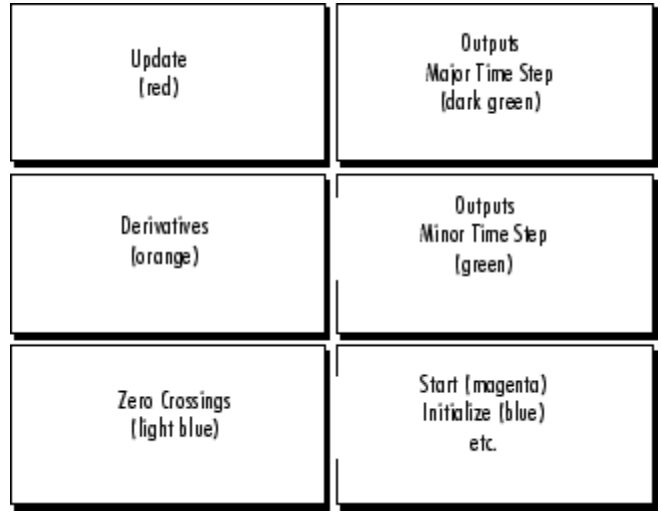
The next method box appears in the upper-left corner of the block diagram. It specifies the name and ID of the next method to be executed.

Block Pointer

The block pointer appears when the next method is a block method. It indicates the block on which the next method operates.

Method Tile

The method tile is a rectangular patch of color that appears when the next method is a block method. The tile overlays a portion of the block on which the next method executes. The color and position of the tile on the block indicate the type of the next block method as follows.



In animation mode, the tiles persist for the length of the current major time step and a number appears in each tile. The number specifies the number of times that the corresponding method has been invoked for the block thus far in the time step.

Setting Breakpoints

In this section...

About Breakpoints

The debugger allows you to define stopping points called breakpoints in a simulation. You can then run a simulation from breakpoint to breakpoint, using the debugger `continue` command. The debugger lets you define two types of breakpoints: unconditional and conditional. An unconditional breakpoint occurs whenever a simulation reaches a method that you specified previously. A conditional breakpoint occurs when a condition that you specified in advance arises in the simulation.

Breakpoints are useful when you know that a problem occurs at a certain point in your program or when a certain condition occurs. By defining an appropriate breakpoint and running the simulation via the `continue` command, you can skip immediately to the point in the simulation where the problem occurs.

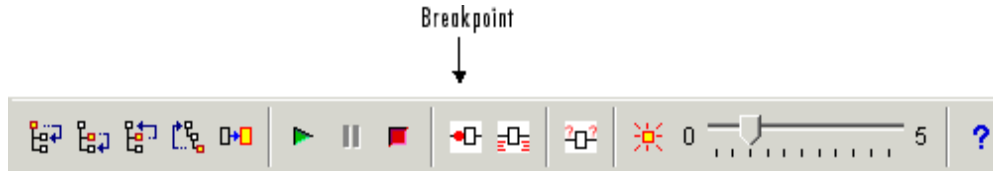
Setting Unconditional Breakpoints

You can set unconditional breakpoints from the:

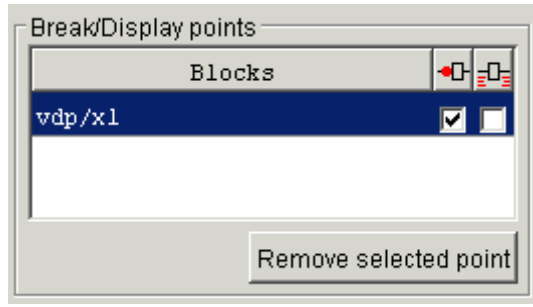
- Debugger toolbar
- **Simulation Loop** pane
- MATLAB product Command Window (command-line mode only)

Setting Breakpoints from the Debugger Toolbar

To set a breakpoint on a block's methods, select the block and then click the **Breakpoint** button on the debugger toolbar. If you set a break point on a block, the debugger stops at any method that the execution reaches in the block.



The debugger displays the name of the selected block in the **Break/Display points** panel of the **Breakpoints** pane.



Note Clicking the **Breakpoint** button on the toolbar sets breakpoints on the invocations of a block's methods in major time steps.

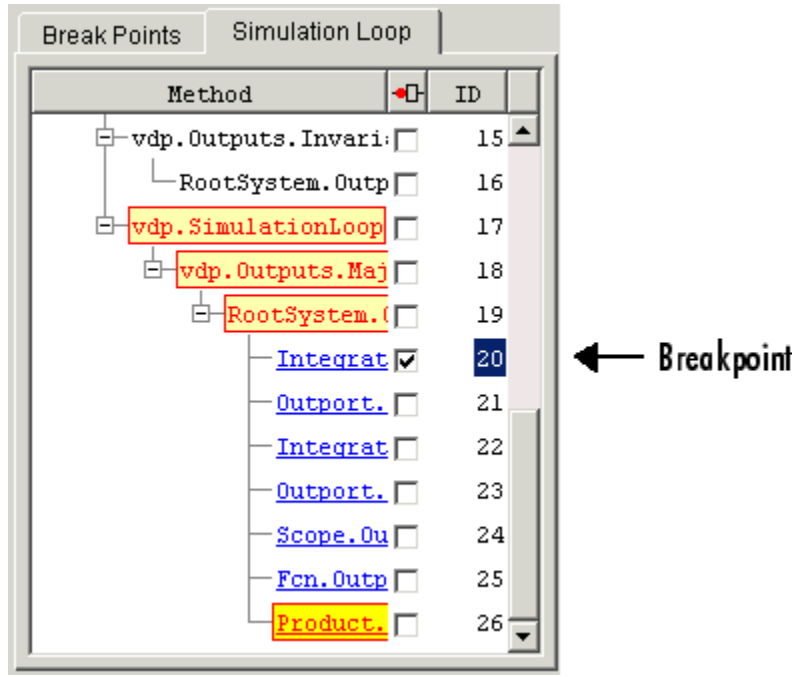
You can temporarily disable the breakpoints on a block by deselecting the check box in the breakpoints column of the panel. To clear the breakpoints on a block and remove its entry from the panel,

1. Select the entry.
2. Click the **Remove selected point** button on the panel.

Note You cannot set a breakpoint on a virtual block. A virtual block is purely graphical: it indicates a grouping or relationship among a model's computational blocks. The debugger warns you if you try to set a breakpoint on a virtual block. You can get a listing of a model's nonvirtual blocks, using the `slist` command (see "Displaying a Model's Nonvirtual Blocks" on page 16-42).

Setting Breakpoints from the Simulation Loop Pane

To set a breakpoint at a particular invocation of a method displayed in the Simulation Loop pane, select the check box next to the method's name in the breakpoint column of the pane.



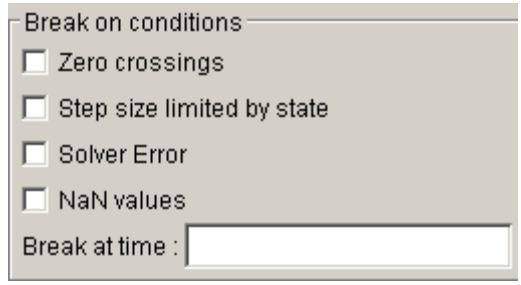
To clear the breakpoint, deselect the check box.

Setting Breakpoints from the Command Window

In command-line mode, use the `break` and `bafter` commands to set breakpoints before or after a specified method, respectively. Use the `clear` command to clear breakpoints.

Setting Conditional Breakpoints

You can use either the **Break on conditions** controls group on the debugger **Breakpoints** pane



or the following commands (in command-line mode) to set conditional breakpoints.

This command...	Causes the Simulation to Stop...
`tbreak [t]`	At a simulation time step
`ebreak`	At a recoverable error in the model
`nanbreak`	At the occurrence of an underflow or overflow (`NaN`) or infinite (`Inf`) value
`xbreak`	When the simulation reaches the state that determines the simulation step size
`zcbreak`	When a zero crossing occurs between simulation time steps

Setting Breakpoints at Time Steps

To set a breakpoint at a time step, enter a time in the debugger **Break at time** field (GUI mode) or enter the time using the `tbreak` command. This causes the debugger to stop the simulation at the `Outputs.Major` method of the model at the first time step that follows the specified time. For example, starting `vdp` in debug mode and entering the commands

```
tbreak 2
continue
```

causes the debugger to halt the simulation at the `vdp.Outputs.Major` method of time step `2.078` as indicated by the output of the `continue` command.

```
%------------------------------------------------------------
%
[TM = 2.078784598291364      ] vdp.Outputs.Major
(sldebug @18):
```

Breaking on Nonfinite Values

Selecting the debugger **NaN values** option or entering the `nanbreak` command causes the simulation to stop when a computed value is infinite or outside the range of values that is supported by the machine running the simulation. This option is useful for pinpointing computational errors in a model.

Breaking on Step-Size Limiting Steps

Selecting the **Step size limited by state** option or entering the `xbreak` command causes the debugger to stop the simulation when the model uses a variable-step solver and the solver encounters a state that limits the size of the steps that it can take. This command is useful in debugging models that appear to require an excessive number of simulation time steps to solve.

Breaking at Zero Crossings

Selecting the **Zero crossings** option or entering the `zcbreak` command causes the simulation to halt when a nonsampled zero crossing is detected in a model that includes blocks where zero crossings can arise. After halting, the ID, type, and name of the block in which the zero crossing was detected is

displayed. The block ID (`s:b:p`) consists of a system index `s`, block index `b`, and port index `p` separated by colons (see "Block ID" on page 16-11).

For example, setting a zero-crossing break at the start of execution of the `zeroxing` demo model,

```
>> sldebug zeroxing
%-------------------------------------------------------------------
%
[TM = 0                        ] zeroxing.Simulate
(sldebug @0): >> zcbreak
Break at zero crossing events              : enabled
```

and continuing the simulation

```
(sldebug @0): >> continue
```

results in a zero-crossing break at

```
2 Zero crossings detected at the following locations
  6  0:5:1  Saturate  'zeroxing/Saturation'
  7  0:5:2  Saturate  'zeroxing/Saturation'
ZeroCrossing Events detected. Interrupting model execution
%-------------------------------------------------------------------%
[Tm = 0.4                    ] zeroxing.zc.SearchLoop
(sldebug @55): >>
```

If a model does not include blocks capable of producing nonsampled zero crossings, the command prints a message advising you of this fact.

Breaking on Solver Errors

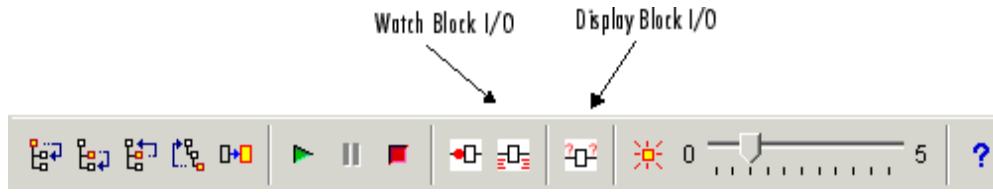
Selecting the debugger **Solver Errors** option or entering the `ebreak` command causes the simulation to stop if the solver detects a recoverable error in the model. If you do not set or disable this breakpoint, the solver recovers from the error and proceeds with the simulation without notifying you.

Displaying Information About the Simulation

In this section...

Displaying Block I/O

The debugger allows you to display block I/O by clicking the appropriate buttons on the debugger toolbar



or by entering the appropriate debugger command.

This command...	Displays a Blocks I/O...
`probe`	Immediately
`disp`	At every breakpoint any time execution stops
`trace`	Whenever the block executes

Note The two debugger toolbar buttons, Watch Block I/O () and Display Block I/O () correspond, respectively, to `trace gcb` and `probe gcb`. The `probe` and `disp` commands do not have a one-to-one correspondence with the debugger toolbar buttons.

Displaying I/O of a Selected Block

To display the I/O of a block, select the block and click  in GUI mode or enter the `probe` command in command-line mode. In the following table, the `probe gcb` command has a corresponding toolbar button. The other commands do not.

Command	Description
`probe`	Enter or exit `probe` mode. In `probe` mode, the debugger displays the current inputs and outputs of any block that you select in the model's block diagram. Typing any command causes the debugger to exit `probe` mode.
`probe gcb`	Display I/O of selected block. Same as  .
`probe s:b`	Print the I/O of the block specified by system number `s` and block number `b`.

The debugger prints the current inputs, outputs, and states of the selected block in the debugger **Outputs** pane (GUI mode) or the Command Window of the MATLAB product.

The `probe` command is useful when you need to examine the I/O of a block whose I/O is not otherwise displayed. For example, suppose you are using the `step` command to run a model method by method. Each time you step the simulation, the debugger displays the inputs and outputs of the current block. The `probe` command lets you examine the I/O of other blocks as well.

Displaying Block I/O Automatically at Breakpoints

The `disp` command causes the debugger to display a specified block's inputs and outputs whenever it halts the simulation. You can specify a block either by entering its block index or by selecting it in the block diagram and entering `gcb` as the `disp` command argument. You can remove any block from the debugger list of display points, using the `undisp` command. For example, to remove `block 0:0`, either select the block in the model diagram and enter `undisp gcb` or simply enter `undisp 0:0`.

Note Automatic display of block I/O at breakpoints is not available in the debugger GUI mode.

The `disp` command is useful when you need to monitor the I/O of a specific block or set of blocks as you step through a simulation. Using the `disp` command, you can specify the blocks you want to monitor and the debugger will then redisplay the I/O of those blocks on every step. Note that the debugger always displays the I/O of the current block when you step through a model block by block, using the `step` command. You do not need to use the `disp` command if you are interested in watching only the I/O of the current block.

Watching Block I/O

To watch a block, select the block and click  in the debugger toolbar or enter the `trace` command. In GUI mode, if a breakpoint exists on the block, you can set a watch on it as well by selecting the check box for the block in the watch column  of the **Break/Display points** pane. In command-line mode, you can also specify the block by specifying its block index in the `trace` command. You can remove a block from the debugger list of trace points using the `untrace` command.

The debugger displays a watched block's I/O whenever the block executes. Watching a block allows you obtain a complete record of the block's I/O without having to stop the simulation.

Displaying Algebraic Loop Information

The `atrace` command causes the debugger to display information about a model's algebraic loops (see "Algebraic Loops" on page 2-39) each time they are solved. The command takes a single argument that specifies the amount of information to display.

This command...	Displays for each algebraic loop...
`atrace 0`	No information
`atrace 1`	The loop variable solution, the number of iterations required to solve the loop, and the estimated solution error
`atrace 2`	Same as level 1
`atrace 3`	Level 2 plus the Jacobian matrix used to solve the loop
`atrace 4`	Level 3 plus intermediate solutions of the loop variable

Displaying System States

The `states` debug command lists the current values of the system's states in the MATLAB product Command Window. For example, the following sequence of commands shows the states of the bouncing ball demo (`sldemo_bounce`) after its first, second, and third time steps. However, before entering the debugger, turn off the **Block reduction** and the **Signal storage reuse** on the Optimization pane of the Configuration Parameters dialog box.

```
 sldebug sldemo_bounce
%------------------------------------------------------------------%
[TM = 0                      ] sldemo_bounce.Simulate
(sldebug @0): >> step top
%------------------------------------------------------------------%
[TM = 0                      ] sldemo_bounce.Outputs.Major
(sldebug @16): >> next
%------------------------------------------------------------------%
[TM = 0                      ] sldemo_bounce.Update
(sldebug @23): >> states

Continuous States:
Idx  Value                    (system:block:element  Name   'BlockName')
  0  10                       (0:4:0  CSTATE  'sldemo_bounce/Second-Order  Integrator')
  1. 15                       (0:4:1)

(sldebug @23): >> next
%------------------------------------------------------------------%
[Tm = 0                      ] sldemo_bounce.Solver
(sldebug @26): >> states

Continuous States:
Idx  Value                    (system:block:element  Name   'BlockName')
  0  10                       (0:4:0  CSTATE  'sldemo_bounce/Second-Order  Integrator')
  1. 15                       (0:4:1)

(sldebug @26): >> next
%------------------------------------------------------------------%
[TM = 0.01                   ] sldemo_bounce.Outputs.Major
(sldebug @16): >> states

Continuous States:
Idx  Value                    (system:block:element  Name   'BlockName')
  0  10.1495095               (0:4:0  CSTATE  'sldemo_bounce/Second-Order  Integrator')
  1. 14.9019                  (0:4:1)
```

Displaying Solver Information

The `strace` command allows you to pinpoint problems in solving a models differential equations that can slow down simulation performance. Executing this command causes the debugger to display solver-related information at the command line of the MATLAB product when you run or step through a simulation. The information includes the sizes of the steps taken by the solver, the estimated integration error resulting from the step size, whether a step size succeeded (i.e., met the accuracy requirements that the model specifies), the times at which solver resets occur, etc. If you are concerned about the time required to simulate your model, this information can help you to decide whether the solver you have chosen is the culprit and hence whether choosing another solver might shorten the time required to solve the model.

Displaying Information About the Model

In this section...

Displaying a Models Sorted Lists

In GUI mode, the debugger **Sorted List** pane displays lists of blocks for a models root system and each nonvirtual subsystem. Each list lists the blocks that the subsystems contains sorted according to their computational dependencies, alphabetical order, and other block sorting rules. In command-line mode, you can use the `slist` command to display a model's sorted lists.

```
---- Sorted list for 'vdp' [12 blocks, 9 nonvirtual blocks,
directFeed=0]
  0:0    'vdp/Integrator1' (Integrator)
  0:1    'vdp/Out1' (Outport)
  0:2    'vdp/Integrator2' (Integrator)
  0:3    'vdp/Out2' (Outport)
  0:4    'vdp/Fcn' (Fcn)
  0:5    'vdp/Product' (Product)
  0:6    'vdp/Mu' (Gain)
  0:7    'vdp/Scope' (Scope)
  0:8    'vdp/Sum' (Sum)
```

These displays include the block index for each command. You can use them to determine the block IDs of the models blocks. Some debugger commands accept block IDs as arguments.

Identifying Blocks in Algebraic Loops

If a block belongs to an algebraic list, the `slist` command displays an algebraic loop identifier in the entry for the block in the sorted list. The identifier has the form

```
algId=s#n
```

where `s` is the index of the subsystem containing the algebraic loop and `n` is the index of the algebraic loop in the subsystem. For example, the following entry for an Integrator block indicates that it participates in the first algebraic loop at the root level of the model.

```
0:1 'test/ss/I1' (Integrator, tid=0) [algId=0#1, discontinuity]
```

You can use the debugger `ashow` command to highlight the blocks and lines that make up an algebraic loop. See "Displaying Algebraic Loops" on page 16-43 for more information.

Displaying a Block

To determine the block in a models diagram that corresponds to a particular index, enter `bshow s:b` at the command prompt, where `s:b` is the block index. The `bshow` command opens the system containing the block (if necessary) and selects the block in the systems window.

Displaying a Models Nonvirtual Systems

The `systems` command displays a list of the nonvirtual systems in the model that you are debugging. For example, the clutch demo (`clutch`) contains the following systems:

```
sldebug clutch
[Tm=0                       ] **Start** of system 'clutch' outputs
(sldebug @0:0 'clutch/Clutch Pedal'): systems
 0   'clutch'
 1   'clutch/Locked'
 2   'clutch/Unlocked'
```

Note The `systems` command does not list subsystems that are purely graphical. That is, subsystems that the model diagram represents as Subsystem blocks but that are solved as part of a parent system. are not listed. In Simulink models, the root system and triggered or enabled subsystems are true systems. All other subsystems are virtual (that is, graphical) and do not appear in the listing from the `systems` command.

Displaying a Model's Nonvirtual Blocks

The `slist` command displays a list of the nonvirtual blocks in a model. The listing groups the blocks by system. For example, the following sequence of commands produces a list of the nonvirtual blocks in the Van der Pol (`vdp`) demo model.

```
sldebug vdp
[Tm=0                       ] **Start** of system 'vdp' outputs
(sldebug @0:0 'vdp/Integrator1'): slist
---- Sorted list for 'vdp' [12 blocks, 9 nonvirtual blocks,
directFeed=0]
  0:0    'vdp/Integrator1' (Integrator)
  0:1    'vdp/Out1' (Outport)
  0:2    'vdp/Integrator2' (Integrator)
  0:3    'vdp/Out2' (Outport)
  0:4    'vdp/Fcn' (Fcn)
  0:5    'vdp/Product' (Product)
  0:6    'vdp/Mu' (Gain)
  0:7    'vdp/Scope' (Scope)
  0:8    'vdp/Sum' (Sum)
```

Note The `slist` command does not list blocks that are purely graphical. That is, blocks that indicate relationships between or groupings among computational blocks.

Displaying Blocks with Potential Zero Crossings

The `zclist` command displays a list of blocks in which nonsampled zero crossings can occur during a simulation. For example, `zclist` displays the following list for the clutch sample model:

```
(sldebug @0:0 'clutch/Clutch Pedal'): zclist
  2:3    'clutch/Unlocked/Sign' (Signum)
  0:4    'clutch/Lockup Detection/Velocities Match' (HitCross)
  0:10   'clutch/Lockup Detection/Required Friction
           for Lockup/Abs' (Abs)
  0:11   'clutch/Lockup Detection/Required Friction for
           Lockup/ Relational Operator' (RelationalOperator)
```

```
0:18   'clutch/Break Apart Detection/Abs' (Abs)
0:20   'clutch/Break Apart Detection/Relational Operator'
         (RelationalOperator)
0:24   'clutch/Unlocked' (SubSystem)
0:27   'clutch/Locked' (SubSystem)
```

Displaying Algebraic Loops

The `ashow` command highlights a specified algebraic loop or the algebraic loop that contains a specified block. To highlight a specified algebraic loop, enter `ashow s#n`, where `s` is the index of the system (see "Identifying Blocks in Algebraic Loops" on page 16-40) that contains the loop and `n` is the index of the loop in the system. To display the loop that contains the currently selected block, enter `ashow gcb`. To show a loop that contains a specified block, enter `ashow s:b`, where `s:b` is the block's index. To clear algebraic-loop highlighting from the model diagram, enter `ashow clear`.

Displaying Debugger Status

In GUI mode, the debugger displays the settings of various debug options, such as conditional breakpoints, in its **Status** panel. In command-line mode, the `status` command displays debugger settings. For example, the following sequence of commands displays the initial debug settings for the `vdp` model:

```
sim('vdp', 'StopTime', '10', 'debug', 'on')
[Tm=0                      ] **Start** of system 'vdp' outputs
(sldebug @0:0 'vdp/Integrator1'): status
  Current simulation time: 0 (MajorTimeStep)
  Last command: ""
  Stop in minor times steps is disabled.
  Break at zero crossing events is disabled.
  Break when step size is limiting by a state is disabled.
  Break on non-finite (NaN,Inf) values is disabled.
  Display of integration information is disabled.
  Algebraic loop tracing level is at 0.
```

17

Accelerating Models

What Is Acceleration?

Acceleration is a mode of operation in the Simulink product that you can use to speed up the execution of your model. The Simulink software includes two modes of acceleration: *Accelerator* mode and the *Rapid Accelerator* mode. Both modes replace the normal interpreted code with compiled target code. Using compiled code speeds up simulation of many models, especially those where run time is long compared to the time associated with compilation and checking to see if the target is up to date.

The Accelerator mode works with any model that does not include "Algebraic Loops" on page 2-39, but performance decreases if a model contains blocks that do not support acceleration. The Accelerator mode supports the Simulink debugger and profiler. These tools assist in debugging and determining relative performance of various parts of your model. For more information, see "Using the Accelerator Mode with the Simulink Debugger" on page 17-27 and "Capturing Performance Data" on page 17-29.

The Rapid Accelerator mode works with only those models containing blocks that support code generation of a standalone executable. For this reason, Rapid Accelerator mode does not support the debugger or profiler. However, this mode generally results in faster execution than the Accelerator mode. When used with dual-core processors, the Rapid Accelerator mode runs Simulink and the MATLAB technical computing environment from one core while the rapid accelerator target runs as a separate process on a second core.

For more information about the performance characteristics of the Accelerator and Rapid Accelerator modes, and how to measure the difference in performance, see "Comparing Performance" on page 15-4.

How the Acceleration Modes Work

In this section...

Overview

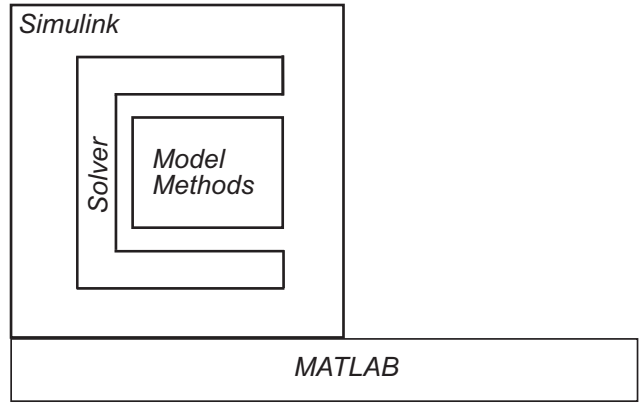
The Accelerator and Rapid Accelerator modes use portions of the Real-Time Workshop product to create an executable. These modes replace the interpreted code normally used in Simulink simulations, shortening model run time.

Although the acceleration modes use some Real-Time Workshop code generation technology, you do not need the Real-Time Workshop software installed to accelerate your model.

Note The code generated by the Accelerator and Rapid Accelerator modes is suitable only for speeding the simulation of your model. You must use the Real-Time Workshop product if you want to generate code for other purposes.

Normal Mode

In Normal mode, the MATLAB technical computing environment is the foundation on which the Simulink software is built.Simulink controls the solver and model methods used during simulation. Model methods include such things as computation of model outputs. Normal mode runs in one process.



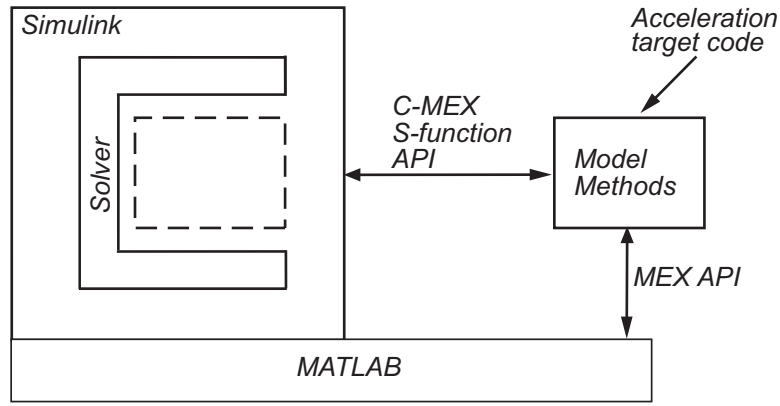
One Process

Accelerator Mode

The Accelerator mode generates and links code into a C-MEX S-function. Simulink uses this *acceleration target code* to perform the simulation, and the code remains available for use in later simulations.

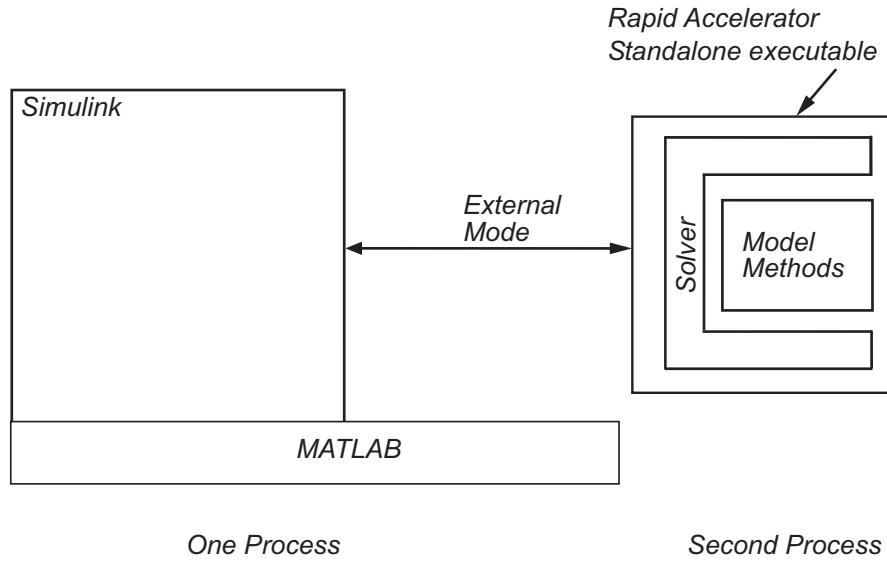
Simulink checks that the acceleration target code is up to date before reusing it. As explained in "Code Regeneration in Accelerated Models" on page 17-7, the target code regenerates if it is not up to date.

In Accelerator mode, the model methods are separate from the Simulink software and are part of the Acceleration target code. A C-MEX S-function API communicates with the Simulink software, and a MEX API communicates with MATLAB. The target code executes in the same process as MATLAB and Simulink.



Rapid Accelerator Mode

The Rapid Accelerator mode creates a *Rapid Accelerator standalone executable* from your model. This executable includes the solver and model methods, but it resides outside of MATLAB and Simulink. It uses External mode (see "Communicating With Code Executing on a Target System Using Simulink External Mode") to communicate with Simulink.



MATLAB and Simulink run in one process, and if a second processing core is available, the standalone executable runs there.

Code Regeneration in Accelerated Models

In this section...

Structural Changes That Cause Rebuilds

Changing the structure of your model causes the Rapid Accelerator mode to regenerate the standalone executable, and for the Accelerator mode to regenerate the target code and update (overwrite) the existing MEX-file.

Examples of model structure changes that result in a rebuild include:

- Changing the solver type, for example from `Variable-step` to `Fixed-step`
- Adding or deleting blocks or connections between blocks
- Changing the values of nontunable block parameters, for example, the **Seed** parameter of the Random Number block
- Changing the number of inputs or outputs of blocks, even if the connectivity is vectorized
- Changing the number of states in the model
- Selecting a different function in the Trigonometric Function block
- Changing signs used in a Sum block
- Adding a Target Language Compiler (TLC) file to inline an S-function
- Changing the `sim` command `output` argument when using the Rapid Accelerator mode
- Changing solver parameters such as stop time or `rel tol` when using the Rapid Accelerator mode

Determining If the Simulation Will Rebuild

The Accelerator and Rapid Accelerator modes use a checksum to determine if the model has changed, indicating that the code should be regenerated. The

checksum is an array of four integers computed using an MD5 checksum algorithm based on attributes of the model and the blocks it contains.

Use the `Simulink.BlockDiagram.getChecksum` command to obtain the checksum for your model. For example:

```
cs1 = Simulink.BlockDiagram.getChecksum('myModel');
```

Obtain a second checksum after you have altered your model. The code regenerates if the new checksum does not match the previous checksum. You can use the information in the checksum to determine why the simulation target rebuilt. For a detailed explanation of this procedure, see the demo model `slAccelDemoWhyRebuild`.

Parameter Handling in Rapid Accelerator Mode

In terms of model rebuilds, Block Diagram and Run-time parameters are handled differently than other parameters in rapid accelerator mode.

Some Block Diagram parameters can be changed during simulation without causing a rebuild. These Block Diagram parameters include the following:

BLOCK DIAGRAM PARAMETERS THAT DO NOT REQUIRE RAPID ACCELERATOR REBUILD	
Solver Parameters	**Loading and Logging Parameters**
AbsTol	Decimation
ConsecutiveZCsStepRelTol	FinalStateName
ExtrapolationOrder	InitialState
InitialStep	LimitDataPoints
MaxConsecutiveMinStep	LoadExternalInput
MaxConsecutiveZCs	LoadInitialState
MaxNumMinSteps	MaxDataPoints
MaxOrder	OutputOption
MaxStep	OutputSaveName

BLOCK DIAGRAM PARAMETERS THAT DO NOT REQUIRE RAPID ACCELERATOR REBUILD	
MinStep	SaveFinalState
NumberNwtonIterations	SaveFormat
OutputTimes	SaveOutput
Refine	SaveState
RelTol	SaveTime
SolverName	SignalLogging
StartTime	SignalLoggingName
StopTime	StateSaveName
ZCDetectionTol	TimeSaveName

Run-time parameters are collected within an *rtp* structure either by user specification via a `simset` option or through automatic collection during the compile phase. Changes to the Run-time parameters are supported if they are passed directly to `sim`. However, if they are passed graphically via the block diagram or programmatically via the `set_param` command, then a rebuild may be necessary. All other parameter changes may necessitate a rebuild.

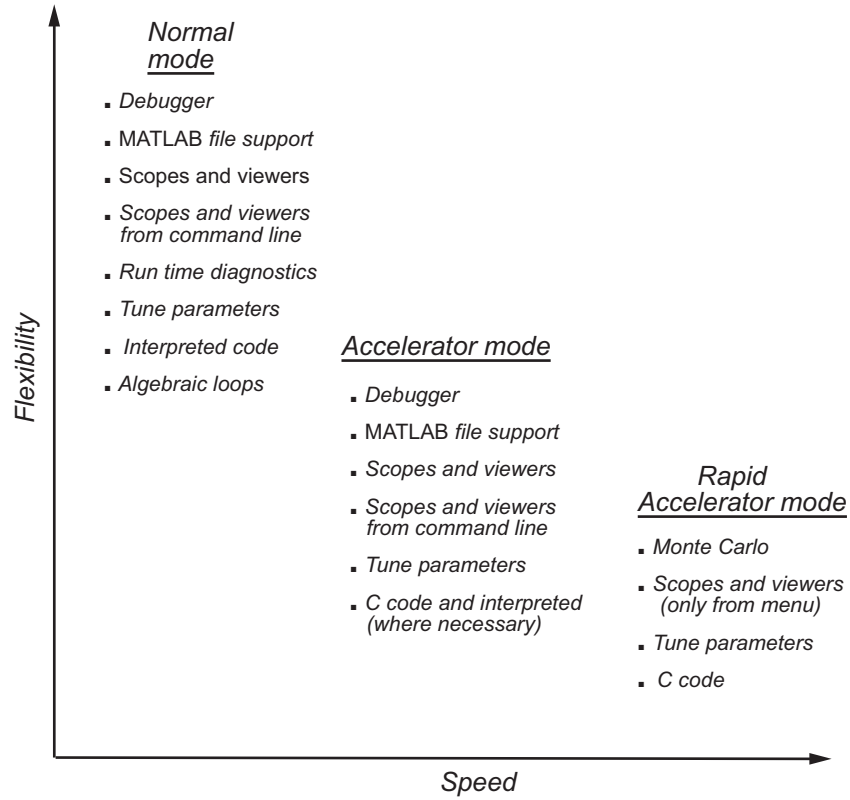
Parameter Changes:	**Passed Directly to `sim` command**	**Passed Graphically via Block Diagram or via `set_param` command**
Run-time	Rebuild *Not* Required	Rebuild May Be Required
Block Diagram (Solver and Logging Parameters)	Rebuild *Not* Required	Rebuild *Not* Required
Other	Rebuild May Be Required	Rebuild May Be Required

Choosing a Simulation Mode

In this section...

Tradeoffs

In general, you must trade off simulation speed against flexibility when choosing either Accelerator mode or Rapid Accelerator mode instead of Normal mode.



Normal mode offers the greatest flexibility for making model adjustments and displaying results, but it runs the slowest. Rapid Accelerator mode runs the fastest, but this mode does not support the debugger or profiler, and works only with those models for which C code is available for all of the blocks in the model. Accelerator mode lies between these two in performance and in interaction with your model.

Note An exception to this rule occurs when you run multiple simulations, each of which executes in less than one second in Normal mode. For example:

```
for i=1:100
sim(mdl); % executes in less than one second in Normal mode
end
```

For this set of conditions, you will typically obtain the best performance by simulating the model in Normal mode.

Comparing Modes

The following table compares the characteristics of Normal mode, Accelerator mode, and Rapid Accelerator mode.

If you want to...	Then use this mode...		
	Normal	Accelerator	Rapid Accelerator
Performance			
Run your model in a separate address space			✓
Efficiently run batch and Monte Carlo simulations			✓
Model Adjustment			
Change model parameters such as solver type, stop time without rebuilding	✓	✓	
Change block tunable parameters such as gain	✓	✓	✓
Model Requirement			

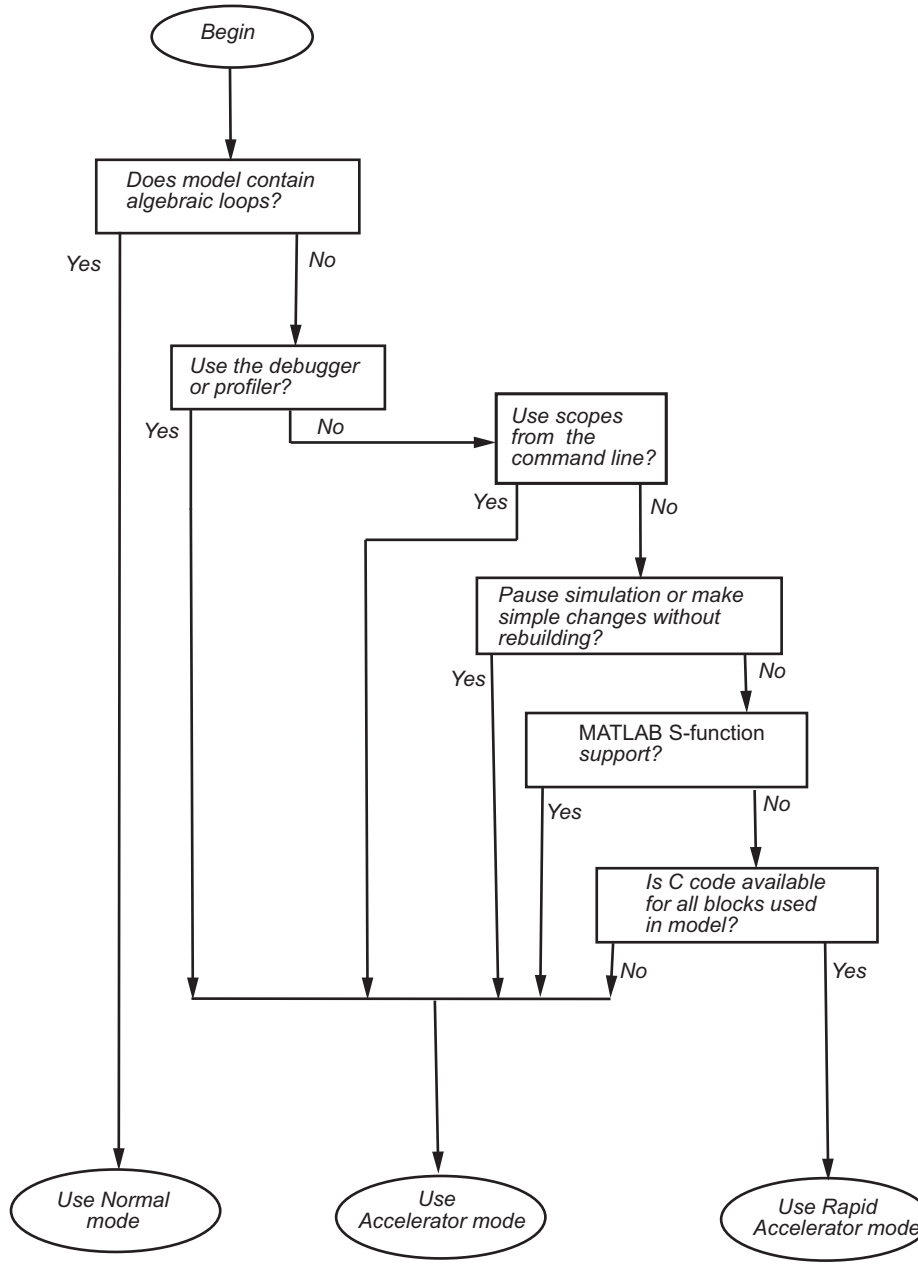
If you want to...	Then use this mode...		
	Normal	Accelerator	Rapid Accelerator
Accelerate your model even if C code is not used for all blocks		✓	
Support MATLAB S-Function blocks	✓	✓	
Permit algebraic loops in your model	✓		
Have your model work with the debugger or profiler	✓	✓	
Have your model include C++ code	✓	✓	
Data Display			
Use scopes and signal viewers	✓	✓	See "Using Scopes and Viewers with Rapid Accelerator Mode" on page 17-16
Use scopes and signal viewers when running your model from the command line	✓	✓	

Note Scopes and viewers do not update if you run your model from the command line in Rapid Accelerator mode.

Decision Tree

The following decision tree can help you select between Normal mode, Accelerator mode, or Rapid Accelerator mode.

See "Comparing Performance" on page 15-4 to understand how effective the accelerator modes will be in improving the performance of your model.


Begin
Does model contain algebraic loops?
Yes
No
Use the debugger or profiler?
Yes
No
Use scopes from the command line?
Yes
No
Pause simulation or make simple changes without rebuilding?
Yes
No
MATLAB S-function support?
Yes
No
Is C code available for all blocks used in model?
No
Yes
Use Normal mode
Use Accelerator mode
Use Rapid Accelerator mode

Designing Your Model for Effective Acceleration

In this section...

Selecting Blocks for Accelerator Mode

The Accelerator simulation mode runs the following blocks as if you were running Normal mode because these blocks do not generate code for the accelerator build. Consequently, if your model contains a high percentage of these blocks, the Accelerator mode may not increase performance significantly. All of these Simulink blocks use interpreted code.

- Display
- Embedded MATLAB Function
- From File
- From Workspace
- Inport (root level only)
- MATLAB Fcn
- Outport (root level only)
- Scope
- To File
- To Workspace
- Transport Delay
- Variable Transport Delay

- XY Graph

Note In some instances, Normal mode output might not precisely match the output from Accelerator mode because of slight differences in the numerical precision between the interpreted and compiled versions of a model.

Selecting Blocks for Rapid Accelerator Mode

Blocks that do not support code generation (such as SimEvents®), or blocks that generate code only for a specific target (such as vxWorks), cannot be simulated in Rapid Accelerator mode.

Additionally, Rapid Accelerator mode does not work if your model contains any of the following blocks:

- MATLAB Fcn
- Device driver S-functions, such as blocks from the XPC Target product, or those targeting Freescale™ MPC555

Note In some instances, Normal mode output might not precisely match the output from Rapid Accelerator mode because of slight differences in the numerical precision between the interpreted and compiled versions of a model.

Controlling S-Function Execution

Inlining S-functions using the Target Language Compiler increases performance with the Accelerator mode by eliminating unnecessary calls to the Simulink application program interface (API). By default, however, the Accelerator mode ignores an inlining TLC file for an S-function, even though the file exists. The Rapid Accelerator mode always uses the TLC file if one is available.

A device driver S-Function block written to access specific hardware registers on an I/O board is one example of why this behavior was chosen as the default. Because the Simulink software runs on the host system rather than

the target, it cannot access the targets I/O registers and so would fail when attempting to do so.

To direct the Accelerator mode to use the TLC file instead of the S-function MEX-file, specify `SS_OPTION_USE_TLC_WITH_ACCELERATOR` in the `mdlInitializeSizes` function of the S-function, as in this example:

```
static void mdlInitializeSizes(SimStruct *S)
{
/* Code deleted */
ssSetOptions(S, SS_OPTION_USE_TLC_WITH_ACCELERATOR);
}
```

Accelerator and Rapid Accelerator Mode Data Type Considerations

- Accelerator mode supports fixed-point signals and vectors up to 128 bits.
- Rapid Accelerator mode does not support fixed-point signals or vectors greater than 32 bits.
- Rapid Accelerator mode supports fixed-point parameters up to 128 bits.
- Rapid Accelerator mode supports fixed-point root inputs up to 32 bits
- Rapid Accelerator mode supports root inputs of Enumerated data type
- Rapid Accelerator mode does not support fixed-point data for the From Workspace block.
- Rapid Accelerator mode supports bus objects as parameters.
- The Accelerator mode and Rapid Accelerator mode store integers as compactly as possible.
- Simulink Fixed Point does not collect min, max, or overflow data in the Accelerator or Rapid Accelerator modes.

Using Scopes and Viewers with Rapid Accelerator Mode

Running the simulation from the command line or the menu determines behavior of scopes and viewers in Rapid Accelerator mode.

Scope or Viewer Type	Simulation Run from Menu	Simulation Run from Command Line
Simulink Scope blocks	Same support as Normal mode	• Logging is supported • Scope window is not updated
Simulink signal viewer scopes	Graphics are updated, but logging is not supported	Not supported
Other signal viewer scopes	Support limited to that available in External mode	Not supported
Signal logging	Not supported	Not supported
Multirate signal viewers	Not supported	Not supported

Rapid Accelerator mode does not support multirate signal viewers such as the Signal Processing Blockset spectrum scope or the Communications Blockset™ scatterplot, signal trajectory, or eye diagram scopes.

Note Although scopes and viewers do not update when you run Rapid Accelerator mode from the command line, they do update when you use the menu. "Running Acceleration Mode from the User Interface" on page 17-21 shows how to run Rapid Accelerator mode from the menu. "Interacting with the Acceleration Modes Programmatically" on page 17-24 shows how to run the simulation from the command line.

Factors Inhibiting Acceleration

You cannot use the Accelerator or Rapid Accelerator mode if your model:

- Passes array parameters to MATLAB S-functions that are not numeric, logical, or character arrays, are sparse arrays, or that have more than two dimensions
- Contains algebraic loops
- Uses Fcn blocks containing trigonometric functions having complex inputs

Rapid Accelerator mode does not support targets written in C++.

For Rapid Accelerator mode, model parameters must be one of these data types:

- `boolean`
- `uint8` or `int8`
- `uint16` or `int16`
- `uint32` or `int32`
- `single` or `double`
- fixed-point
- Enumerated

Reserved Keywords

Certain words are reserved for use by the Real-Time Workshop code language and by Accelerator mode and Rapid Accelerator mode. These keywords must not appear as function or variable names on a subsystem, or as exported global signal names. Using the reserved keywords results in the Simulink software reporting an error, and the model cannot be compiled or run.

The keywords reserved for the Real-Time Workshop product are listed in "Configuring Generated Identifiers". Additional keywords that apply only to the Accelerator and Rapid accelerator modes are:

muDoubleScalarAbs	muDoubleScalarCos	muDoubleScalarMod
muDoubleScalarAcos	muDoubleScalarCosh	muDoubleScalarPower
muDoubleScalarAcosh	muDoubleScalarExp	muDoubleScalarRound
muDoubleScalarAsin	muDoubleScalarFloor	muDoubleScalarSign
muDoubleScalarAsinh	muDoubleScalarHypot	muDoubleScalarSin
muDoubleScalarAtan,	muDoubleScalarLog	muDoubleScalarSinh
muDoubleScalarAtan2	muDoubleScalarLog10	muDoubleScalarSqrt

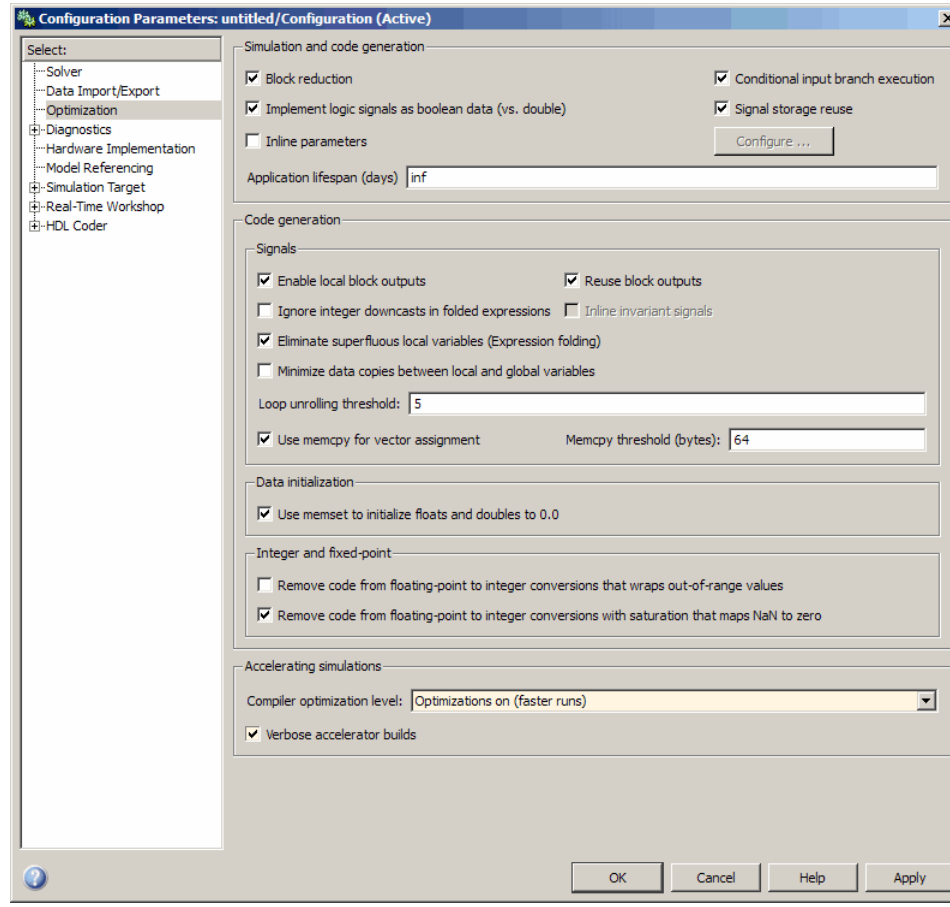
muDoubleScalarAtanh	muDoubleScalarMax	muDoubleScalarTan
muDoubleScalarCeil	muDoubleScalarMin	muDoubleScalarTanh

Performing Acceleration

In this section...

Customizing the Build Process

Compiler optimizations are off by default. This results in faster build times. To optimize acceleration of your model, set the compiler optimization level from the Optimization pane in the Configuration Parameters dialog box.



Select `Optimizations on (faster runs)` when you want to create optimized code. Code generation takes longer with this option, but the model runs faster.

Select **Verbose accelerator builds** to display progress information using code generation, and to see the compiler options in use.

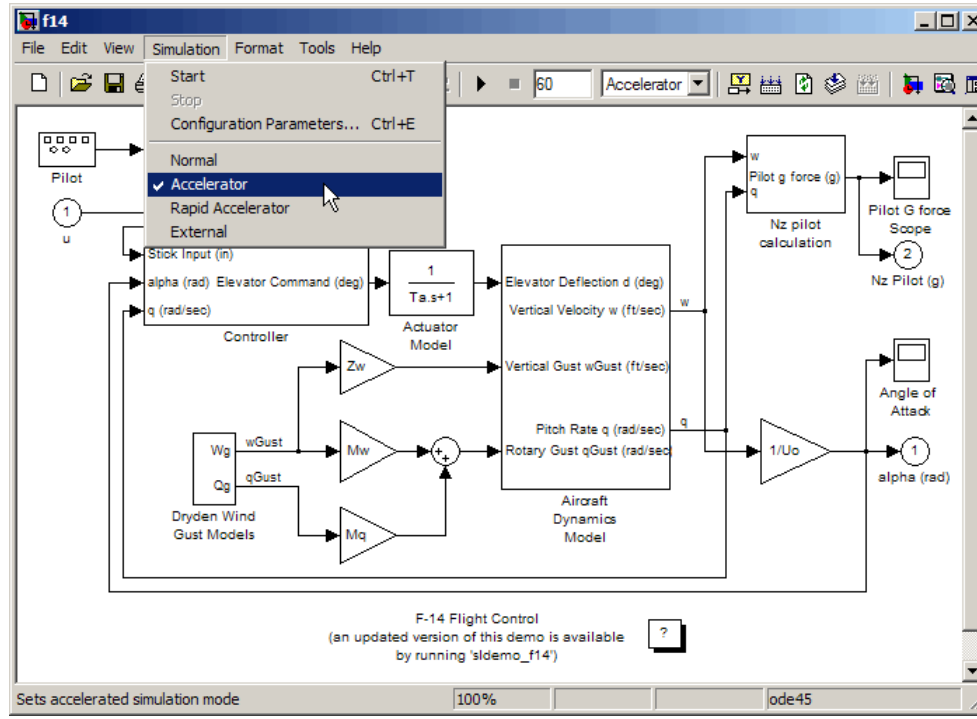
Running Acceleration Mode from the User Interface

To accelerate a model, first open it, and then from the **Simulation** menu, select either **Accelerator** or **Rapid Accelerator**. Then start the simulation.

The following example shows how to accelerate the already opened `f14` model using the Accelerator mode:

1 From the **Simulation** menu, select **Accelerator**.

Alternatively, you can select `Accelerator` from the model editor's toolbar.



2 From the **Simulation** menu, select **Start**.

The Accelerator and Rapid Accelerator modes first check to see if code was previously compiled for your model. If code was created previously, the Accelerator or Rapid Accelerator mode runs the model. If code was not previously built, they first generate and compile the C code, and then run the model.

For an explanation of why these modes rebuild your model, see "Code Regeneration in Accelerated Models" on page 17-7.

The Accelerator mode places the generated code in a subfolder of the working folder called `slprj/accel/`*modelname*`/`*modelname*`_accel_rtw` (for example, `f14_accel_rtw`), and places a compiled MEX-file in the current working folder.

The Rapid Accelerator mode places the generated code in a subfolder of the working folder called `slprj/raccel/`*modelname*`/`*modelname*`_raccel_rtw` (for example, `f14_raccel_rtw`).

Note The warnings that blocks generate during simulation (such as divide-by-zero and integer overflow) are not displayed when your model runs in Accelerator or Rapid Accelerator mode.

Making Run-Time Changes

A feature of the Accelerator and Rapid Accelerator modes is that simple adjustments (such as changing the value of a Gain or Constant block) can be made to the model while the simulation is still running. More complex changes (for example, changing from a `sin` to `tan` function) are not allowed during run time.

The Simulink software issues a warning if you attempt to make a change that is not permitted. The absence of a warning indicates that the change was accepted. The warning does not stop the current simulation, and the simulation continues with the previous values. If you wish to alter the model in ways that are not permitted during run time, you must first stop the simulation, make the change, and then restart the simulation.

In general, simple model changes are more likely to result in code regeneration when in Rapid Accelerator mode than when in Accelerator mode. For instance, changing the stop time in Rapid Accelerator mode causes code to regenerate, but does not cause Accelerator mode to regenerate code.

Interacting with the Acceleration Modes Programmatically

In this section...

Why Interact Programmatically?

You can build an accelerated model, select the simulation mode, and run the simulation from the command prompt or from MATLAB script. With this flexibility, you can create Accelerator mode MEX-files in batch mode, allowing you to build the C code and executable before running the simulations. When you use the Accelerator mode interactively at a later time, it will not be necessary to generate or compile MEX-files at the start of the accelerated simulations.

Building Accelerator Mode MEX-files

With the `accelbuild` command, you can build the Accelerator mode MEX-file without actually simulating the model. For example, to build an Accelerator mode simulation of `myModel`:

```
accelbuild myModel
```

Controlling Simulation

You can control the simulation mode from the command line prompt by using the `set_param` command:

```
set_param('modelname','SimulationMode','mode')
```

The simulation mode can be `normal`, `accelerator`, `rapid`, or `external`.

For example, to simulate your model with the Accelerator mode, you would use:

```
set_param('myModel','SimulationMode','accelerator')
```

However, a preferable method is to specify the simulation mode within the `sim` command:

```
simOut = sim(`myModel', `SimulationMode', `accelerator');
```

You can use `gcs` ("get current system") to set parameters for the currently active model (that is, the active model window) rather than *`modelname`* if you do not wish to explicitly specify the model name.

For example, to simulate the currently opened system in the Rapid Accelerator mode, you would use:

```
simOut = sim(gcs,'SimulationMode','rapid');
```

Simulating Your Model

You can use `set_param` to configure the model parameters (such as the simulation mode and the stop time), and use the `sim` command to start the simulation:

```
sim('modelname', 'ReturnWorkspaceOutputs', 'on');
```

However, the preferred method is to configure model parameters directly using the `sim` command, as shown in the previous section.

You can substitute `gcs` for *`modelname`* if you do not want to explicitly specify the model name.

Unless target code has already been generated, the `sim` command first builds the executable and then runs the simulation. However, if the target code has already been generated and no significant changes have been made to the model (see "Code Regeneration in Accelerated Models" on page 17-7 for a description), the `sim` command executes the generated code without regenerating the code. This process lets you run your model after making simple changes without having to wait for the model to rebuild.

Simulation Example

The following sequence shows how to programmatically simulate `myModel` in Rapid Accelerator mode for 10,000 seconds.

First open `myModel`, and then type the following in the Command Window:

```
simOut = sim('myModel', `SimulationMode', `rapid'...
`StopTime', `10000');
```

Use the `sim` command again to resimulate after making a change to your model. If the change is minor (adjusting the gain of a gain block, for instance), the simulation runs without regenerating code.

Customizing the Acceleration Build Process

You can programmatically control the Accelerator mode and Rapid Accelerator mode build process and the amount of information displayed during the build process. See "Customizing the Build Process" on page 17-20 for details on why doing so might be advantageous.

Controlling the Build Process

Use the `SimCompilerOptimization` parameter to control the acceleration build process. The permitted values are `on` or `off`. The default is `off`.

Enter the following at the command prompt to turn on compiler optimization:

```
set_param('myModel', 'SimCompilerOptimization', 'on')
```

Controlling Verbosity During Code Generation

Use the `AccelVerboseBuild` parameter to display progress information during code generation. The permitted values are `on` or `off`. The default is `off`.

Enter the following at the command prompt to turn on verbose build:

```
set_param('myModel', 'AccelVerboseBuild', 'on')
```

Using the Accelerator Mode with the Simulink Debugger

In this section...

Advantages of Using Accelerator Mode with the Debugger

The Accelerator mode can shorten the length of your debugging sessions if you have large and complex models. For example, you can use the Accelerator mode to simulate a large model and quickly reach a distant break point.

For more information on the debugger, see Chapter 16, "Simulink Debugger".

Note You cannot use the Rapid Accelerator mode with the debugger.

How to Run the Debugger

To run your model in the Accelerator mode with the debugger:

1. From the **Simulation** menu, select **Accelerator**.
2. At the command prompt, enter:

   ```
   sldebug modelname
   ```

3. At the debugger prompt, set a time break:

   ```
   tbreak 10000
   continue
   ```

4. Once you reach the breakpoint, use the debugger command `emode` (execution mode) to toggle between Accelerator and Normal mode.

When to Switch Back to Normal Mode

You must switch to Normal mode to step through the simulation by blocks, and when you want to use the following debug commands:

- `trace`
- `break`
- `zcbreak`
- `nanbreak`

Capturing Performance Data

In this section...

What Is the Profiler?

The profiler captures data while your model runs and identifies the parts of your model requiring the most time to simulate. You use this information to decide where to focus your model optimization efforts.

Note You cannot use the Rapid Accelerator mode with the Profiler.

Performance data showing the time spent executing each function in your model is placed in a report called the *simulation profile*.

How the Profiler Works

The following pseudocode summarizes the execution model on which the Profiler is based.

```
Sim()
 ModelInitialize().
 ModelExecute()
  for t = tStart to tEnd
  Output()
  Update()
  Integrate()
   Compute states from derivs by repeatedly calling:
    MinorOutput()
    MinorDeriv()
   Locate any zero crossings by repeatedly calling:
    MinorOutput()
```

```
    MinorZeroCrossings()
  EndIntegrate
  Set time t = tNew.
 EndModelExecute
 ModelTerminate
EndSim
```

According to this conceptual model, your model is executed by invoking the following functions zero, one, or more times, depending on the function and the model.

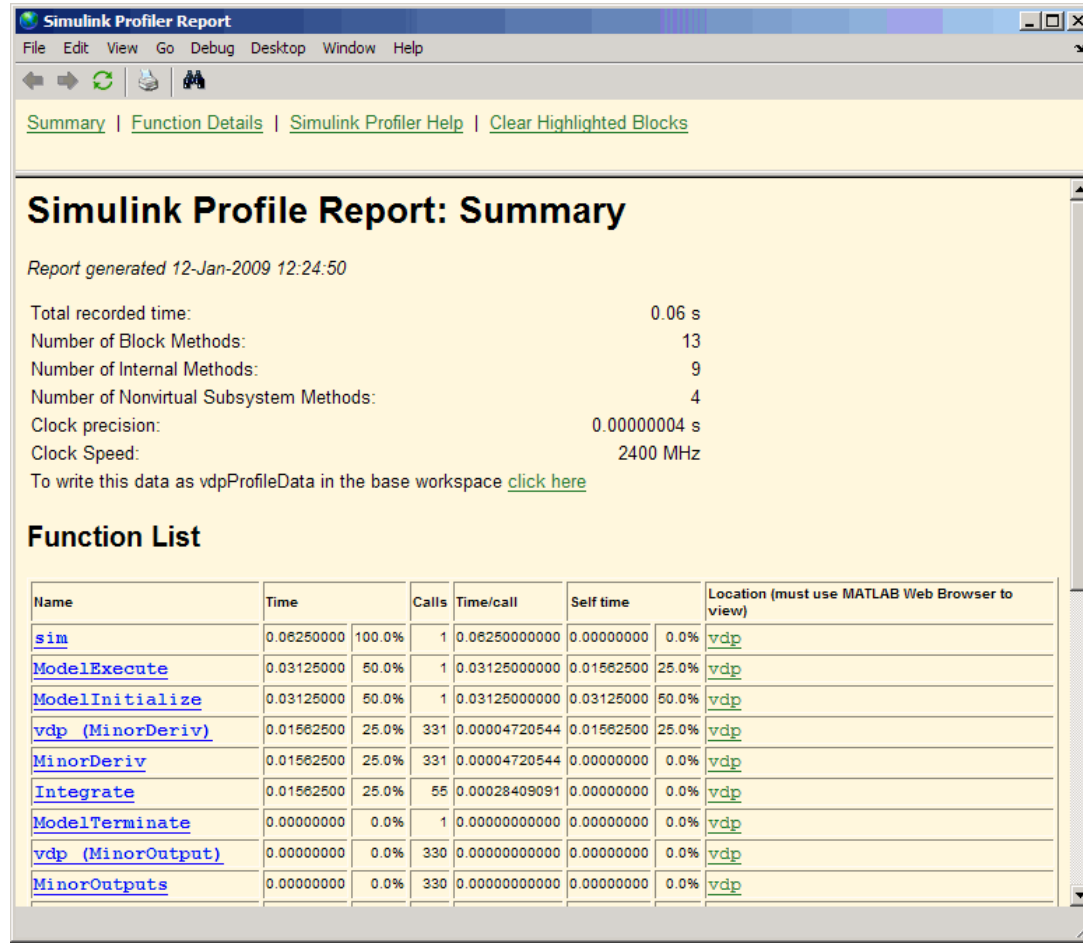
Function	Purpose	Level
`sim`	Simulate the model. This top-level function invokes the other functions required to simulate the model. The time spent in this function is the total time required to simulate the model.	System
`ModelInitialize`	Set up the model for simulation.	System
`ModelExecute`	Execute the model by invoking the output, update, integrate, etc., functions for each block at each time step from the start to the end of simulation.	System
`Output`	Compute the outputs of a block at the current time step.	Block
`Update`	Update a block's state at the current time step.	Block
`Integrate`	Compute a block's continuous states by integrating the state derivatives at the current time step.	Block
`MinorOutput`	Compute a block's output at a minor time step.	Block

Function	Purpose	Level
`MinorDeriv`	Compute a block's state derivatives at a minor time step.	Block
`MinorZeroCrossings`	Compute a block's zero-crossing values at a minor time step.	Block
`ModelTerminate`	Free memory and perform any other end-of-simulation cleanup.	System
`Nonvirtual Subsystem`	Compute the output of a nonvirtual subsystem at the current time step by invoking the output, update, integrate, etc., functions for each block that it contains. The time spent in this function is the time required to execute the nonvirtual subsystem.	Block

The Profiler measures the time required to execute each invocation of these functions and generates a report at the end of the model that describes how much time was spent in each function.

Enabling the Profiler

To profile a model, open the model and select **Profiler** from the **Tools** menu. Then start the simulation. When the simulation finishes, the Simulink code generates and displays the simulation profile for the model in the Help browser.


Simulink Profiler Report
File Edit View Go Debug Desktop Window Help
Summary | Function Details | Simulink Profiler Help | Clear Highlighted Blocks
Simulink Profile Report: Summary
Report generated 12-Jan-2009 12:24:50
Total recorded time: 0.06 s
Number of Block Methods: 13
Number of Internal Methods: 9
Number of Nonvirtual Subsystem Methods: 4
Clock precision: 0.00000004 s
Clock Speed: 2400 MHz
To write this data as vdpProfileData in the base workspace click here
Function List
Name | Time | | Calls | Time/call | Self time | | Location (must use MATLAB Web Browser to view)
sim | 0.06250000 | 100.0% | 1 | 0.06250000000 | 0.00000000 | 0.0% | vdp
ModelExecute | 0.03125000 | 50.0% | 1 | 0.03125000000 | 0.01562500 | 25.0% | vdp
ModelInitialize | 0.03125000 | 50.0% | 1 | 0.03125000000 | 0.03125000 | 50.0% | vdp
vdp (MinorDeriv) | 0.01562500 | 25.0% | 331 | 0.00004720544 | 0.01562500 | 25.0% | vdp
MinorDeriv | 0.01562500 | 25.0% | 331 | 0.00004720544 | 0.00000000 | 0.0% | vdp
Integrate | 0.01562500 | 25.0% | 55 | 0.00028409091 | 0.00000000 | 0.0% | vdp
ModelTerminate | 0.00000000 | 0.0% | 1 | 0.00000000000 | 0.00000000 | 0.0% | vdp
vdp (MinorOutput) | 0.00000000 | 0.0% | 330 | 0.00000000000 | 0.00000000 | 0.0% | vdp
MinorOutputs | 0.00000000 | 0.0% | 330 | 0.00000000000 | 0.00000000 | 0.0% | vdp

Summary Section

The summary file displays the following performance totals.

Item	Description
Total Recorded Time	Total time required to simulate the model
Number of Block Methods	Total number of invocations of block-level functions (e.g., `Output()`)
Number of Internal Methods	Total number of invocations of system-level functions (e.g., `ModelExecute`)
Number of Nonvirtual Subsystem Methods	Total number of invocations of nonvirtual subsystem functions
Clock Precision	Precision of the profiler's time measurement

The summary section then shows summary profiles for each function invoked to simulate the model. For each function listed, the summary profile specifies the following information.

Item	Description
Name	Name of function. This item is a hyperlink. Clicking it displays a detailed profile of this function.
Time	Total time spent executing all invocations of this function as an absolute value and as a percentage of the total simulation time
Calls	Number of times this function was invoked
Time/Call	Average time required for each invocation of this function, including the time spent in functions invoked by this function

Item	Description
Self Time	Average time required to execute this function, excluding time spent in functions called by this function
Location	Specifies the block or model executed for which this function is invoked. This item is a hyperlink. Clicking it highlights the corresponding icon in the model diagram. The link works only if you are viewing the profile in the Help browser.

Detailed Profile Section

This section contains detailed profiles for each function invoked to simulate the model. Each detailed profile contains all the information shown in the summary profile for the function. In addition, the detailed profile displays the function (parent function) that invoked the profiled function and the functions (child functions) invoked by the profiled function. Clicking the name of the parent or a child function takes you to the detailed profile for that function.

Note Enabling the Profiler on a parent model does not enable profiling for referenced models. You must enable profiling separately for each submodel. Profiling occurs only if the submodel executes in Normal mode. See Chapter 5, "Referencing a Model" for more information.

How to Save Simulink Profiler Results

You can save the Profiler report to a variable in the MATLAB workspace, and subsequently, to a `mat` file. At a later time, you can regenerate and review the report.

To save the Profiler report for a model *vdp* to the variable *profile1* and to the data file `report1.mat`, complete the following steps:

1. In the **Simulink Profiler Report** window, click **click here**. Simulink saves the report data to the variable *vdpProfileData*.
2. Navigate to the MATLAB command window.

3. To review the report, at the command line enter:

```
slprofreport(vdpProfileData)
```

4. To save the data to a variable named *profile1* in the base workspace, enter:

```
profile1 = vdpProfileData;
```

5. To save the data to a `mat` file named `report1`, enter:

```
save report1 profile1
```

To view the report at a later time, from the MATLAB command window, enter:

```
% Load the mat file and recreate the profile1 object
load report1
% Recreate the html report from the object
slprofreport(profile1);
```

Managing Blocks

18

Working with Blocks

About Blocks

In this section...

What Are Blocks?

Blocks are the elements from which the Simulink software builds models. You can model virtually any dynamic system by creating and interconnecting blocks in appropriate ways. This section discusses how to use blocks to build models of dynamic systems. Most blocks contain fields called *block parameters* that you can use to enter values that customize the behavior of the block. Be careful not to confuse block parameters with Simulink parameters, which are objects of type `simulink.parameter` that exist in the base workspace. See Chapter 19, "Working with Block Parameters" for information about setting and changing block parameters.

Block Data Tips

Information about a block is displayed in a pop-up window when you allow the pointer to hover over the block in the diagram view. To disable this feature or control what information a data tip includes, select **Block data tips options** from the Simulink **View** menu.

Virtual Blocks

When creating models, you need to be aware that Simulink blocks fall into two basic categories: nonvirtual blocks and virtual blocks. Nonvirtual blocks play an active role in the simulation of a system. If you add or remove a nonvirtual block, you change the model's behavior. Virtual blocks, by contrast, play no active role in the simulation; they help organize a model graphically. Some Simulink blocks are virtual in some circumstances and nonvirtual in others. Such blocks are called conditionally virtual blocks. The following table lists Simulink virtual and conditionally virtual blocks.

Block Name	Condition Under Which Block Is Virtual
Bus Assignment	Virtual if input bus is virtual.
Bus Creator	Virtual if output bus is virtual.
Bus Selector	Virtual if input bus is virtual.
Demux	Always virtual.
Enable	Virtual unless connected directly to an Outport block.
From	Always virtual.
Goto	Always virtual.
Goto Tag Visibility	Always virtual.
Ground	Always virtual.
Inport	Virtual *unless* the block resides in a conditionally executed or atomic subsystem *and* has a direct connection to an Outport block.
Mux	Always virtual.
Outport	Virtual when the block resides within any subsystem block (conditional or not), and does *not* reside in the root (top-level) Simulink window.
Selector	Virtual only when **Number of input dimensions** specifies `1` and **Index Option** specifies `Select all`, `Index vector (dialog)`, or `Starting index (dialog)`.
Signal Specification	Always virtual.
Subsystem	Virtual unless the block is conditionally executed or the **Treat as atomic unit** check box is selected. You can check if a block is virtual with the `IsSubsystemVirtual` block property. See "Block-Specific Parameters" in the *Simulink Reference*.
Terminator	Always virtual.
Trigger	Virtual when the output port is *not* present.

Adding Blocks

In this section...

Ways to Add Blocks

You can add blocks to a model in several ways.

Method	When to Use
Browse or search libraries with the Library Browser	• You are not sure which block to add. • You do not have a familiar model from which to copy blocks.
Copy blocks from a model	• You know where in a model a block is that you want to copy. • You want to replicate many of the parameter settings of an existing block.

Method	When to Use
Use the Most Frequently Used Blocks pane or context menu	• You want to add a block that you have used frequently and recently. • You are working on multiple models that share several of the same blocks. • You do not have a familiar model from which to copy similar blocks.
Add blocks programmatically with the `add_block` function	• You want to replicate most of the parameter settings of a block. • You are working on multiple models that share several of the same blocks.

Adding Blocks by Browsing or Searching with the Library Browser

To browse or search for a block from a block library installed on your system, use the Library Browser. You can browse a list of block libraries or search for blocks whose names include the search string you specify.

When you find the block you want, select that block in the Library Browser and drag the block into your model. See "Populating a Model" on page 3-4 for more information.

Copying Blocks from a Model

To copy a block from a model in the Model Editor:

1. Select the block you want to copy.
2. Choose **Edit > Copy**.
3. If you have multiple model windows open, make the target model window the active window.
4. Choose **Edit > Paste**.

When you copy a block, the parameters use default values.

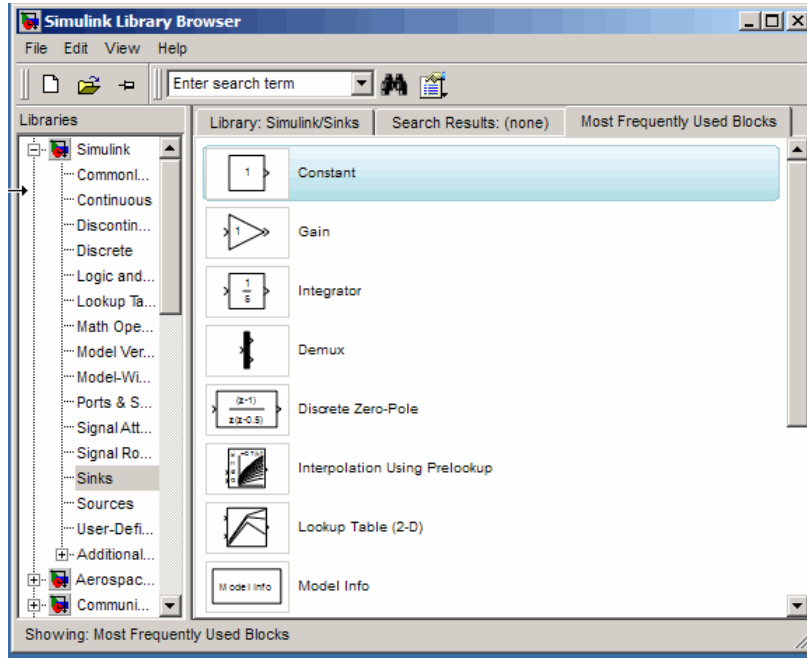
See “Copying and Moving Blocks from One Window to Another” on page 18-9 for details.

Adding Frequently Used Blocks

When using the same block repeatedly, you can save time by using the **Most Frequently Used Blocks** feature in the Library Browser or Model Editor.

Selecting Your Most Frequently Used Blocks From the Library Browser

Open the **Most Frequently Used Blocks** pane with the third tab in the Library Browser.



To add a block to a model, select the block from the list and do either one of the following:

- Drag the block into your model.
- Select **Add to <model_name>** at the top of the context menu for the block.

Selecting Your Most Frequently Used Blocks from the Model Editor

In the Model Editor, you can view a list of your most frequently used blocks. Right-click anywhere in the model except with the cursor directly on a block or signal. In the context menu, select **Most Frequently Used Blocks**.

What Blocks Appear in the Most Frequently Used Blocks Lists

The Most Frequently Used Blocks pane lists blocks that you have added most often, with the most frequently used block at the top. The list reflects your ongoing modeling activity. For example, if you add several Gain blocks, the Gain block appears in the list if the list:

- Does not already include the Gain block
- Has less than 25 blocks
- Has 25 blocks, but you added more Gain blocks than the number of instances of the least frequently used block in the list

The list displays blocks that you rename as instances of the library block. For example, if you rename several Gain blocks to be MyGain1, MyGain2, and so on, those blocks count as Gain blocks.

When you close and reopen the Library Browser, the list reflects the blocks that you added up through the previous session. The list updates only when the Library Browser is open.

The list does *not* reflect blocks that you:

- Add programmatically
- Include in subsystems (In other words, if you add a subsystem that uses a specific type of block repeatedly, the list does not reflect that activity.)

The list in the Model Editor is the same as the Library Browser list, except that the Model Editor list includes only five blocks.

Adding Blocks Programmatically

To add a block programmatically, use the `add_block` function.

The `add_block` function copies the parameter values of the source block to the new block. You can use `add_block` to specify values for parameters of the new block.

Editing Blocks

In this section...

Copying and Moving Blocks from One Window to Another

As you build your model, you often copy blocks from Simulink block libraries or other libraries or models into your model window. To do this:

1. Open the appropriate block library or model window.
2. Drag the block to copy into the target model window. To drag a block, position the cursor over the block, then press and hold down the mouse button. Move the cursor into the target window, then release the mouse button.

You can also drag blocks from the Simulink Library Browser into a model window. See "Browsing Block Libraries" on page 3-5 for more information.

Note The names of Sum, Mux, Demux, Bus Creator, and Bus Selector blocks are hidden when you copy them from the Simulink block library to a model. This is done to avoid unnecessarily cluttering the model diagram. (The shapes of these blocks clearly indicate their respective functions.)

You can also copy blocks by using the **Copy** and **Paste** commands from the **Edit** menu:

1. Select the block you want to copy.
2. Choose **Copy** from the **Edit** menu.

3 Make the target model window the active window.

4 Choose **Paste** from the **Edit** menu.

Simulink assigns a name to each copied block. If it is the first block of its type in the model, its name is the same as its name in the source window. For example, if you copy the Gain block from the Math library into your model window, the name of the new block is Gain. If your model already contains a block named Gain, Simulink adds a sequence number to the block name (for example, Gain1, Gain2). You can rename blocks; see "Manipulating Block Names" on page 18-27.

When you copy a block, the new block inherits all the original block's parameter values.

For more ways to add blocks, see "Adding Blocks" on page 18-4.

add blocks

Moving Blocks in a Model

To move a single block from one place to another in a model window, drag the block to a new location. Simulink automatically repositions lines connected to the moved block.

To move more than one block, including connecting lines:

1 Select the blocks and lines. If you need information about how to select more than one block, see "Selecting Multiple Objects" on page 3-7.

2 Drag the objects to their new location and release the mouse button.

To move a block, disconnecting lines:

1 Select the block.

2 Press the **Shift** key, then drag the block to its new location and release the mouse button.

You can also move a block by selecting the block and pressing the arrow keys.

Moving blocks from one window to another is similar to copying blocks, except that you hold down the **Shift** key while you select the blocks.

You can use the **Undo** command from the **Edit** menu to remove an added block.

Aligning Blocks

You can use tools to manually align blocks. These tools include a grid snap feature and smart guides that indicate when a block center or port aligns with the center or port of another block. You can also use commands that align a group of blocks automatically (see "Aligning, Distributing, and Resizing Groups of Blocks Automatically" on page 3-24 for details).

Grid Snap. Simulink uses an invisible five-pixel grid to simplify the alignment of blocks. When you move a block to a new location, the block snaps to the nearest line on the grid. You can display the grid and change its spacing.

To display the grid, enter the following command at the MATLAB command prompt.

```
set_param('<model name>','showgrid','on')
```

The default width of the grid is 20 pixels. To change the grid spacing, enter

```
set_param('<model name>','gridspacing',<number of pixels>)
```

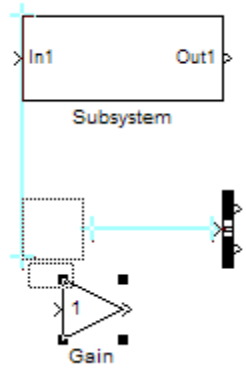
For example, to change the grid spacing to `25` pixels, enter

```
set_param('<model name>','gridspacing',25)
```

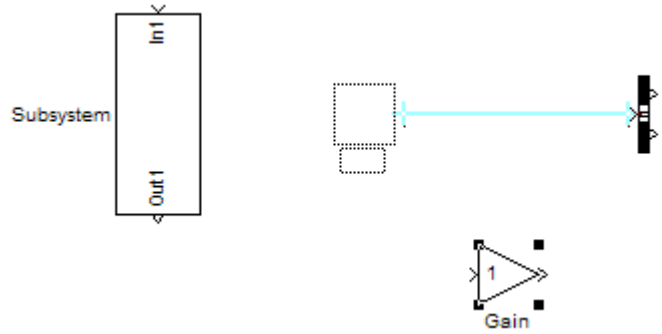
Note The new spacing must be a multiple of five pixels to ensure that the displayed grid aligns with the invisible snap grid.

For either of the above commands, you can also select the model, then enter `gcs` instead of `<model name>`.

Smart Guides. When you move a block, smart guides appear by default to indicate when the block ports, center, or edges are aligned with the ports, centers, and edges of other blocks in the same diagram. For example, the following figure shows a snapshot of a Gain block that you drag from one position in a diagram to another. The dotted outline indicates the position to which the Gain block has been dragged. The blue smart guides indicate that if you drop the Gain block at this position, its left edge will be aligned with the left edge of the Subsystem block and its output port will be aligned with the input port of the Mux block.



When you drag a block, one of its alignment features, for example, a port, may match more than one alignment feature of another block. In this case, Simulink displays a line for one of the features, using the following precedence order: ports, centers, edges. For example, in the following drag-and-drop snapshot, the Gain block's center aligns with the Subsystem's center and the Gain block's output port aligns with the Mux block's input port. However, because ports take precedence over centers, Simulink draws a guide only for the ports.



You can turn smart guides off or on (the default) by selecting **Format > Smart Guides**.

Positioning Blocks Programmatically

You can position (and resize) a block programmatically, using its Position parameter. For example, the following command

```
set_param(gcb, 'Position', [5 5 20 20]);
```

moves the currently selected block to a location 5 points down and 5 points to the right of the top left corner of the block diagram and sets the block's height and width to 15 points, respectively.

Note The maximum size of a block diagram's height and width is 32767 points. An error message appears if you try to move or resize a block to a position that exceeds the diagram's boundaries.

Copying Blocks in a Model

You can copy blocks in a model as follows. While holding down the **Ctrl** key, select the block with the left mouse button, then drag it to a new location. You can also do this by dragging the block using the right mouse button. Duplicated blocks have the same parameter values as the original blocks. Sequence numbers are added to the new block names.

Note The model editor sorts block names alphabetically when generating names for copies pasted into a model. This action can cause the names of pasted blocks to be out of order. For example, suppose you copy a row of 16 gain blocks named Gain, Gain1, Gain2...Gain15 and paste them into the model. The names of the pasted blocks occur in the following order: Gain16, Gain17, Gain24...Gain23.

Deleting Blocks

To delete one or more blocks, select the blocks to be deleted and press the **Delete** or **Backspace** key. You can also choose **Clear** or **Cut** from the **Edit** menu. The **Cut** command writes the blocks into the clipboard, which enables you to paste them into a model. Using the **Delete** or **Backspace** key or the **Clear** command does not enable you to paste the block later.

You can use the **Undo** command from the **Edit** menu to replace a deleted block.

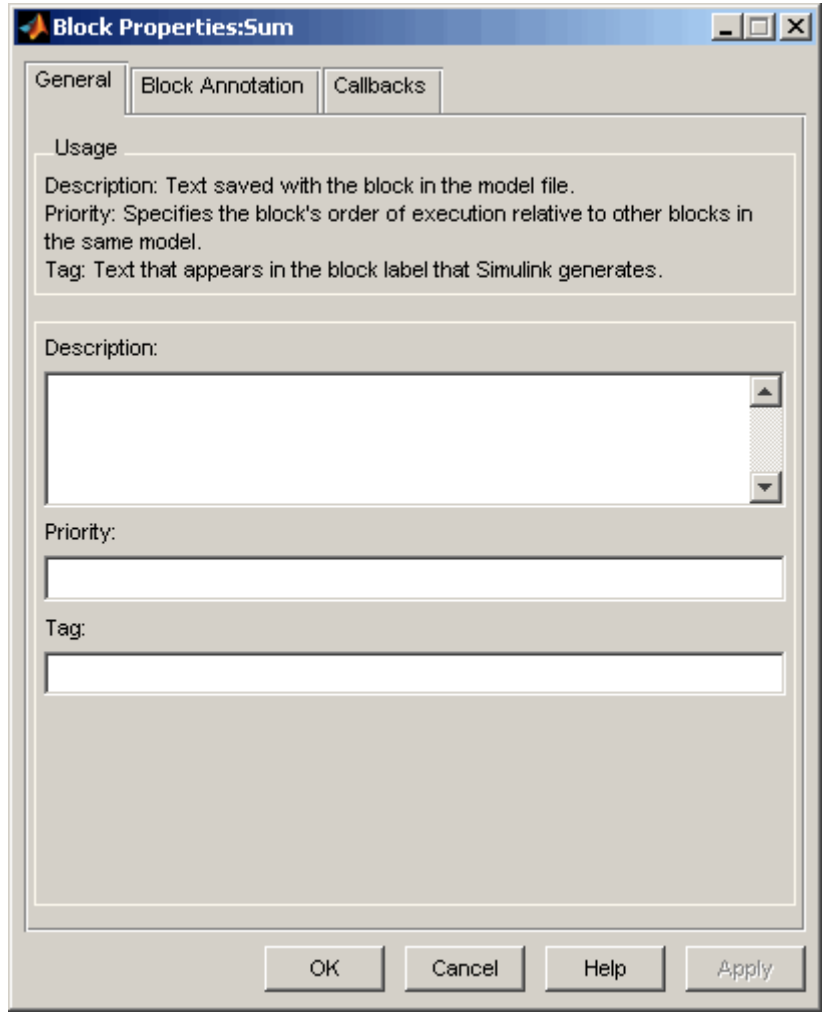
Block Properties Dialog Box

The Block Properties dialog box lets you set a block's properties. To display this dialog, select the block in the model window and then select **Block Properties** from the **Edit** menu.

The dialog box contains the following tabbed panes:

General Pane

This pane allows you to set the following properties.



Description

Brief description of the block's purpose.

Priority

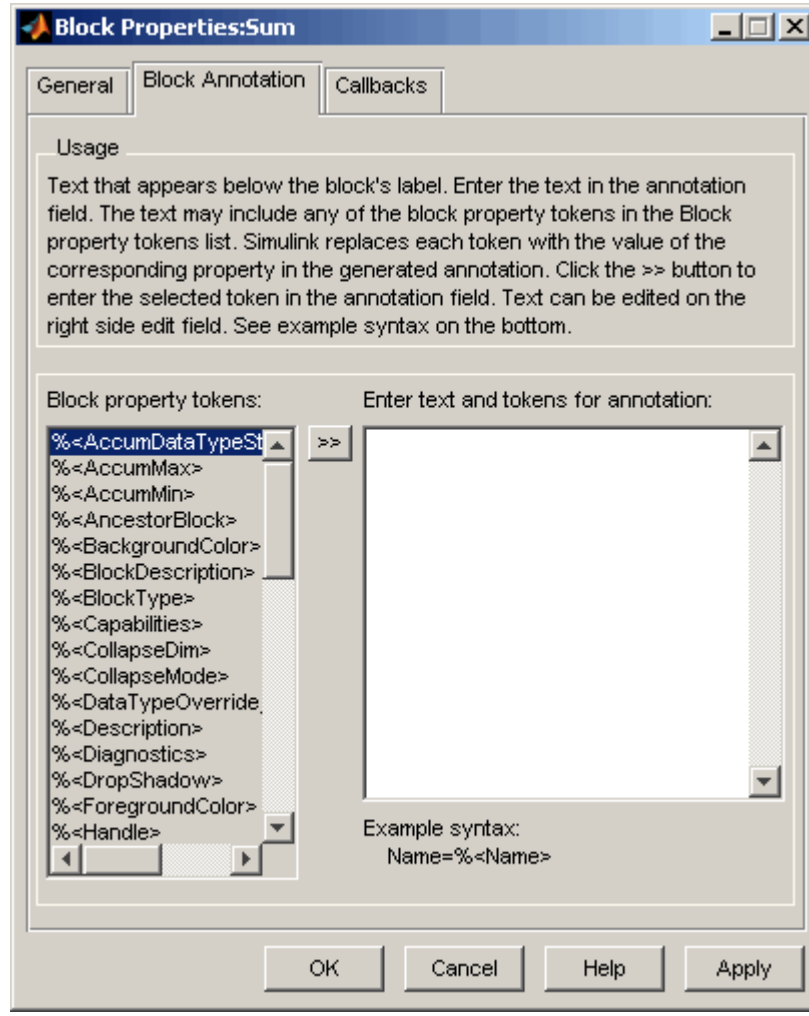
Execution priority of this block relative to other blocks in the model. See "Assigning Block Priorities" on page 18-47 for more information.

Tag

Text that is assigned to the block's Tag parameter and saved with the block in the model. You can use the tag to create your own block-specific label for a block.

Block Annotation Pane

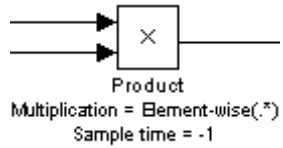
The block annotation pane allows you to display the values of selected block parameters in an annotation that appears beneath the block's icon.



Enter the text of the annotation in the text field that appears on the right side of the pane. The text can include any of the block property tokens that appear in the list on the left side of the pane. A block property token is simply the name of a block parameter preceded by %< and followed by >. When displaying the annotation, the Simulink software replaces the tokens with the values of the corresponding block parameters. For example, suppose that you enter the following text and tokens for a Product block:

```
Multiplication = %<Multiplication>
Sample time = %<SampleTime>
```

In the model editor window, the annotation appears as follows:

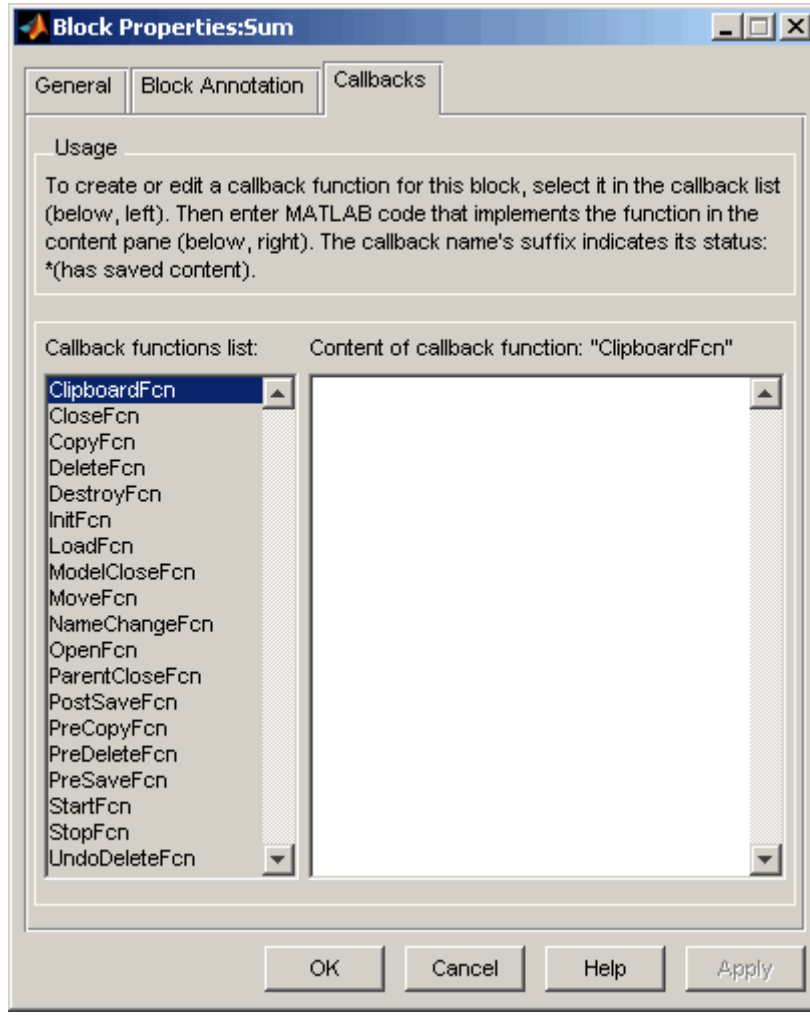


The block property token list on the left side of the pane lists all the parameters that are valid for the currently selected block (see "Model and Block Parameters" in the *Simulink Reference*). To add one of the listed tokens to the text field on the right side of the pane, select the token and then click the button between the list and the text field.

You can also create block annotations programmatically. See "Creating Block Annotations Programmatically" on page 18-21.

Callbacks Pane

The **Callbacks Pane** allows you to specify implementations for a block's callbacks (see "Using Callback Functions" on page 3-54).



To specify an implementation for a callback, select the callback in the callback list on the left side of the pane. Then enter MATLAB commands that implement the callback in the right-hand field. Click **OK** or **Apply** to save the change. Simulink appends an asterisk to the name of the saved callback to indicate that it has been implemented.

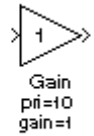
Creating Block Annotations Programmatically

You can use a block's `AttributesFormatString` parameter to display selected block parameters beneath the block as an "attributes format string," i.e., a string that specifies values of the block's attributes (parameters). "Model and Block Parameters" in *Simulink Reference* describes the parameters that a block can have. Use the Simulink `set_param` function to set this parameter to the desired attributes format string.

The attributes format string can be any text string that has embedded parameter names. An embedded parameter name is a parameter name preceded by `%<` and followed by `>`, for example, `%<priority>`. Simulink displays the attributes format string beneath the block's icon, replacing each parameter name with the corresponding parameter value. You can use line-feed characters (`\n`) to display each parameter on a separate line. For example, specifying the attributes format string

```
pri=%<priority>\ngain=%<Gain>
```

for a Gain block displays



If a parameter's value is not a string or an integer, Simulink displays `N/S` (not supported) for the parameter's value. If the parameter name is invalid, Simulink displays `???` as the parameter value.

Changing a Block's Appearance

In this section...

Changing a Block's Orientation

By default, a block is oriented so that its input ports are on the left, and its output ports are on the right. You can change the orientation of a block by rotating it 90 degrees around its center or flipping it 180 degrees around its horizontal or vertical axis.

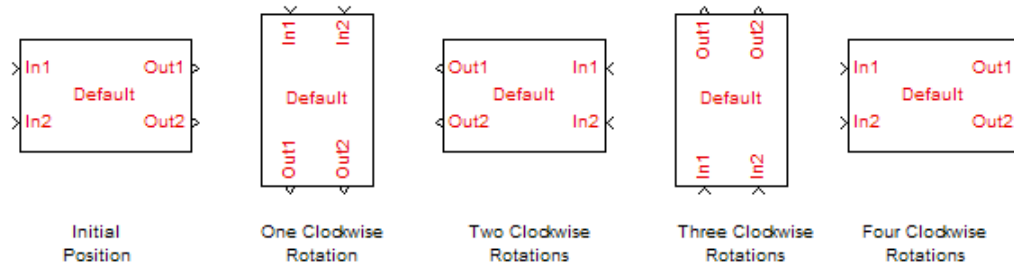
How to Rotate a Block

You can rotate a block 90 degrees by selecting one of these commands from the **Format** menu:

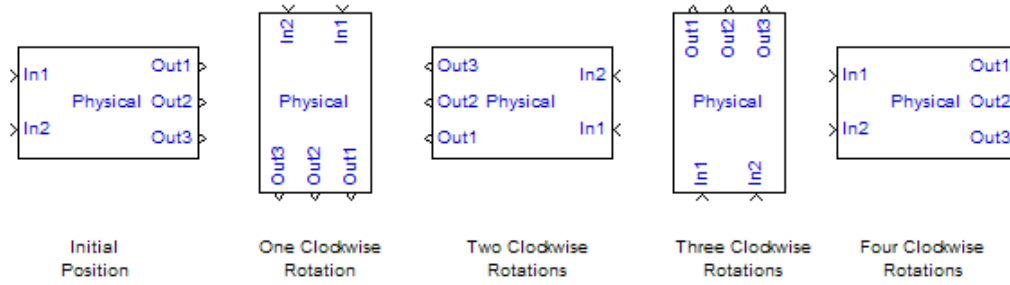
- **Rotate Block > Clockwise (Ctrl+R)**
- **Rotate Block > Counterclockwise**

A rotation command effectively moves a block's ports from its sides to its top and bottom or from its top and bottom to its size, depending on the initial orientation of the block. The final positions of the block's ports depend on the block's *port rotation type*.

Port Rotation Type. After rotating a block clockwise, Simulink may, depending on the block, reposition the block's ports to maintain a left-to-right port numbering order for ports along the top and bottom of the block and a top-to-bottom port numbering order for ports along the left and right sides of the block. A block whose ports are reordered after a clockwise rotation is said to have a *default port rotation* type. This policy helps to maintain the left-right and top-down block diagram orientation convention used in control system modeling applications. All nonmasked blocks and all masked blocks by default have the default rotation policy. The following figure shows the effect of using the **Rotate Block > Clockwise** command on a block with the default rotation policy.



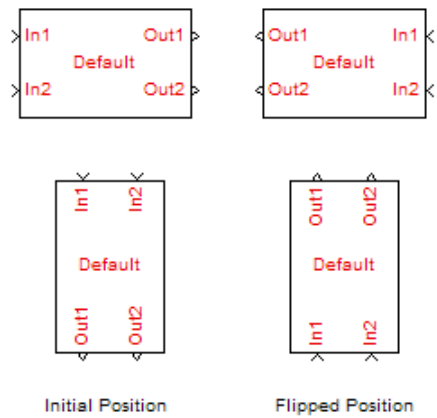
A masked block can optionally specify that its ports not be reordered after a clockwise rotation (see "Port Rotation"). Such a block is said to have a *physical port rotation* type. This policy facilitates layout of diagrams in mechanical and hydraulic systems modeling and other applications where diagrams do not have a preferred orientation. The following figure shows the effect of clockwise rotation on a block with a physical port rotation type



How to Flip a Block

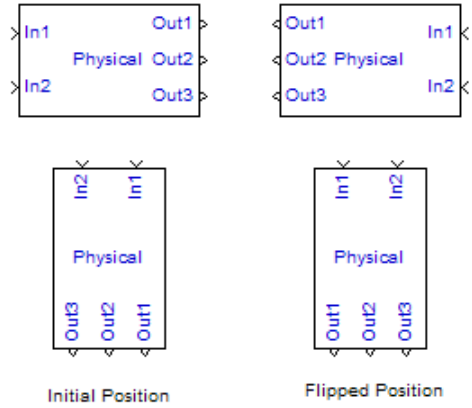
Simulink provides a set of commands that allow you to flip a block 180 degrees about its horizontal or vertical axis. The commands effectively move a block's input and output ports to opposite sides of the block or reverse the ordering of the ports, depending on the block's port rotation type.

A block with the default rotation type has one flip command: **Format > Flip Block** (**Ctr+I**). This command effectively moves the block's input and output ports to the side of the block opposite to the side on which they are initially located, i.e., from the left to the right side or from the top to the bottom side.

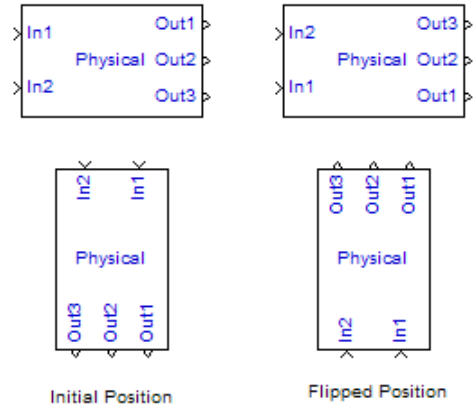


A block with a physical rotation type has two flip commands: **Format > Flip Block > Left-Right** or **Format > Flip Block > Up-Down**. The effect of these commands depends on the initial position of the ports.

Left-Right Flip. If the block's ports initially reside on the left and right sides of the block, the **Left-Right** command reverses the sides on which the input and ports are located. If the ports are located on the top and bottom of the block, the command reverses the order of the ports without changing their sides.



Up-Down Flip. If the block's ports reside on the top and bottom of the block, the **Up-Down** command reverses the sides on which the input and ports are located. If the ports are located on the left and right sides of the block, the command reverses the order of the ports without changing their sides.

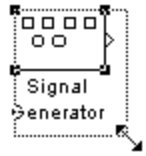


Resizing a Block

To change the size of a block, select it, then drag any of its selection handles. While you hold down the mouse button, a dotted rectangle shows the new block size. When you release the mouse button, the block is resized.

For example, the following figure below shows a Signal Generator block being resized. The lower-right handle was selected and dragged to the cursor position. When the mouse button is released, the block takes its new size.

This figure shows a block being resized:



Tip Use the model editor's resize blocks commands to make one block the same size as another (see "Aligning, Distributing, and Resizing Groups of Blocks Automatically" on page 3-24).

Displaying Parameters Beneath a Block

You can cause Simulink to display one or more of a block's parameters beneath the block. You specify the parameters to be displayed in the following ways:

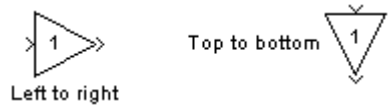
- By entering an attributes format string in the **Attributes format string** field of the block's **Block Properties** dialog box (see "Block Properties Dialog Box" on page 18-15)
- By setting the value of the block's `AttributesFormatString` property to the format string, using `set_param`

Using Drop Shadows

You can add a drop shadow to a block by selecting the block, then choosing **Show Drop Shadow** from the **Format** menu. When you select a block with a drop shadow, the menu item changes to **Hide Drop Shadow**. The following figure shows a Subsystem block with a drop shadow:

Manipulating Block Names

All block names in a model must be unique and must contain at least one character. By default, block names appear below blocks whose ports are on the sides, and to the left of blocks whose ports are on the top and bottom, as the following figure shows:



Note Simulink commands interprets a forward slash, i.e., /, as a block path delimiter. For example, the path `vdp/Mu` designates a block named `Mu` in the model named `vdp`. Therefore, avoid using forward slashes (/) in block names to avoid causing Simulink to interpret the names as paths.

Changing Block Names

You can edit a block name in one of these ways:

- To replace the block name, click the block name, double-click or drag the cursor to select the entire name, then enter the new name.
- To insert characters, click between two characters to position the insertion point, then insert text.
- To replace characters, drag the mouse to select a range of text to replace, then enter the new text.

When you click the pointer anywhere else in the model or take any other action, the name is accepted or rejected. If you try to change the name of a block to a name that already exists, Simulink displays an error message.

You can modify the font used in a block name by selecting the block, then choosing the **Font** menu item from the **Format** menu. Select a font from the **Set Font** dialog box. This procedure also changes the font of any text that appears inside the block.

You can cancel edits to a block name by choosing **Undo** from the **Edit** menu.

Note If you change the name of a library block, all links to that block become unresolved.

Changing the Location of a Block Name

You can change the location of the name of a selected block in two ways:

- By dragging the block name to the opposite side of the block.
- By choosing the **Flip Name** command from the **Format** menu. This command changes the location of the block name to the opposite side of the block.

For more information about block orientation, see "How to Rotate a Block" on page 18-22.

Changing Whether a Block Name Appears

To change whether the name of a selected block is displayed, choose a menu item from the **Format** menu:

- The **Hide Name** menu item hides a visible block name. When you select **Hide Name**, it changes to **Show Name** when that block is selected.
- The **Show Name** menu item shows a hidden block name.

Specifying a Block's Color

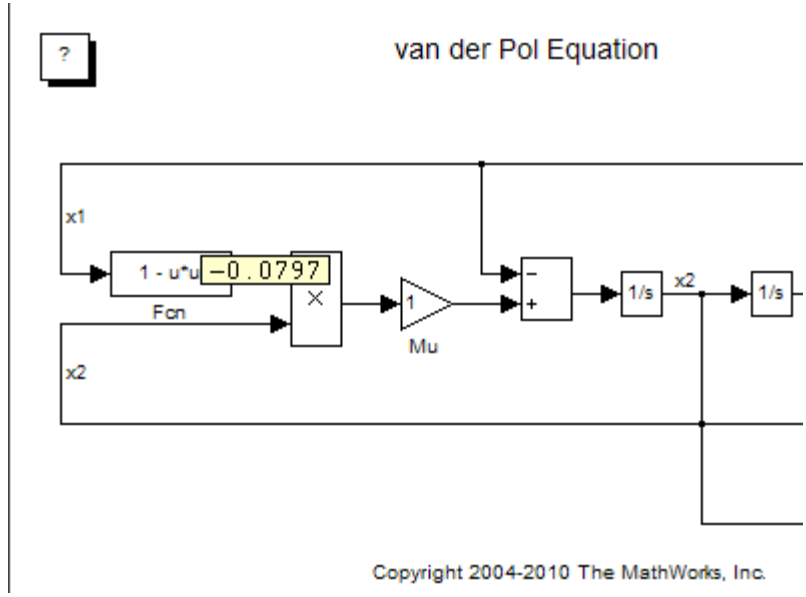
See "Specifying Block Diagram Colors" on page 3-9 for information on how to set the color of a block.

Displaying Block Outputs

In this section...

Block Output Data Tips

For many blocks, Simulink can display block output (port values) as data tips on the block diagram while a simulation is running. The following model shows a port value data tip for the Fcn block, displaying an output value of `0.0797`.



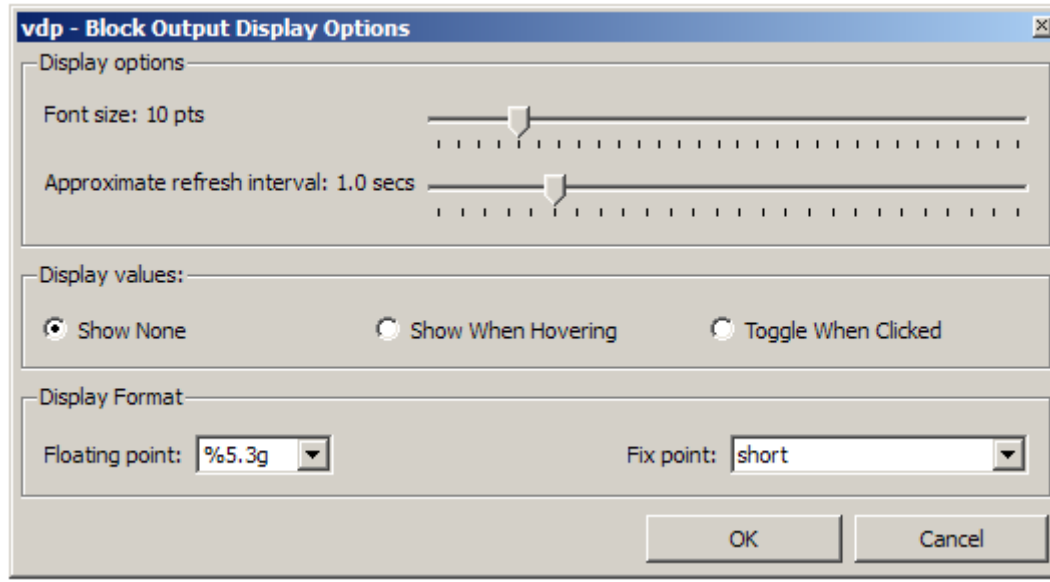
Note The block output display feature has limitations for models with:

- Accelerated modes
- Signal storage reuse
- Signals with some complex data types, such as bus signals

See "Port Value Display Limitations" on page 18-32.

Setting Block Output Data Tip Options

You can set data tip options by selecting **Port Values > Options** from the Model Editor **View** menu and using the Block Output Display Options dialog box.



Enabling Block Output Display

To turn block output display on or off, in the **Display values** section of the dialog box, select one these options:

- **Show None**

  Turns off block output display.

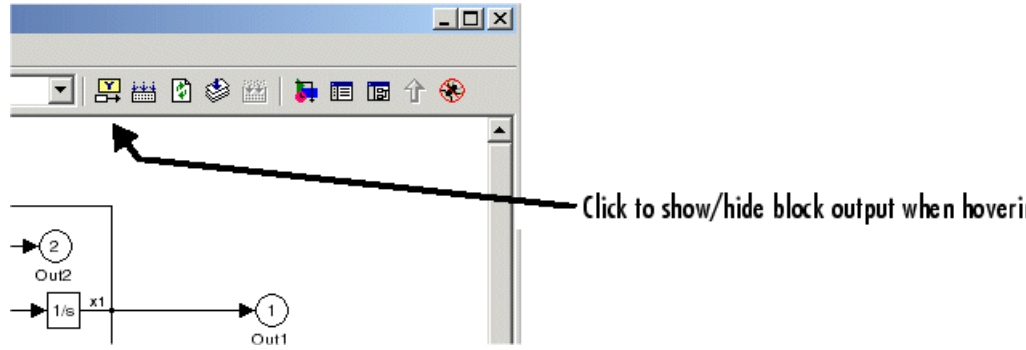
- **Show When Hovering**

  Displays output port values for the block under the mouse cursor.

- **Toggle When Clicked**

  Displays output port values when you select a block. Reselecting that block turns off the display.

Simulink on Microsoft Windows platforms also has a Model Editor output display button to enable or disable block output display when hovering.



Controlling the Block Output Display

You can specify block output display formatting and how frequently the display updates.

Block Output Data Tip Display Characteristic	What You Specify
Text size	To increase the size of the output display text, move the **Font size** slider to the right.
Floating point data format	Choose a floating point format from the **Display Format** list.

Block Output Data Tip Display Characteristic	What You Specify
Fixed-point data format	Choose a fixed-point format from the **Display Format** list.
Refresh interval (rate at which Simulink updates the output display) The refresh rate is approximate and is independent of simulation time.	To increase the interval, move the **Refresh interval** slider to the right.

Displayed Value When No Data Is Available

Simulink displays `xx.xx` when you toggle or hover on a block, indicating that no block output is available. You see the `xx.xx` value if you did any of the following actions:

- Did not run the simulation
- Did not enable the block output display option before running the simulation
- Did not toggle on a block during simulation

Also, if you toggle or hover on a block that Simulink optimizes out of a simulation (such as a virtual subsystem block), then you see block output during simulation. However, if you pause or stop the simulation, and you toggle or hover on that same block, then Simulink displays `xx.xx`.

Port Value Display Limitations

Performance

Enabling the hovering option, or toggling at least one block, slows down the simulation.

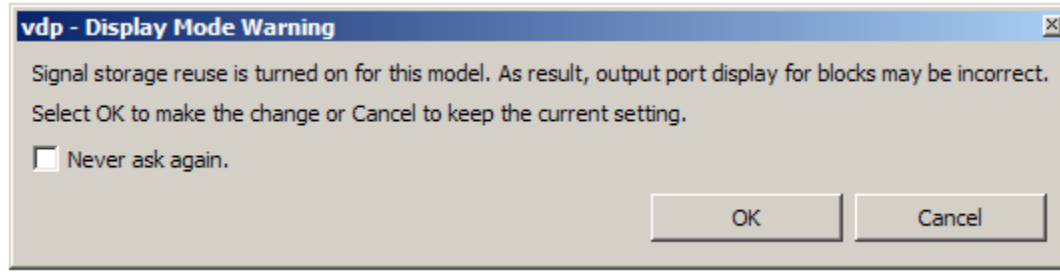
Accelerated Modes

Port values do not update in a model that simulates in any Accelerated mode. The limitation exists whether the model itself specifies accelerated simulation

or the model is subordinate to a model that specifies accelerated simulation. See Chapter 17, “Accelerating Models”, , and “Testing and Refining Concept Models With Standalone Rapid Simulations” for more information.

Signal Storage Reuse

A model with the **Signal storage reuse** parameter enabled displays a warning when you set **Display values** to `Show When Hovering` or `Toggle When Clicked`.



Do one of the following steps:

- Click **Cancel** to avoid enabling block output display.
- Click **OK** to enable block output display, despite the possibility that values for output ports could be incorrect.
- Click **OK** to enable block output display, and then disable the **Configuration Parameters > Optimization** pane **Signal storage reuse** parameter. Disabling signal storage reuse increases the amount of memory used during simulation.

Signal Data Types

The port value displays for ports connected to most kinds of signals, including signals with built-in data types (such as `double`, `int32`, or `Boolean`), `DYNAMICALLY_TYPED`, and several other data types. However, no data displays for signals with some complex data types, such as bus signals.

Controlling and Displaying the Sorted Order

In this section...

What Is Sorted Order?

During the updating phase of simulation, Simulink determines the order in which to invoke the block methods during simulation. This block invocation ordering is the *sorted order*.

You cannot set this order, but you can assign priorities to nonvirtual blocks to indicate to Simulink their execution order relative to other blocks. Simulink always honors block priority settings, unless there is a conflict with data dependencies. To confirm the results of priorities that you have set, or to debug your model, display and review the sorted order of your nonvirtual blocks and subsystems.

Note For more information about block methods and execution, see:

- "Block Methods" on page 2-16
- "Conditional Execution Behavior" on page 6-24

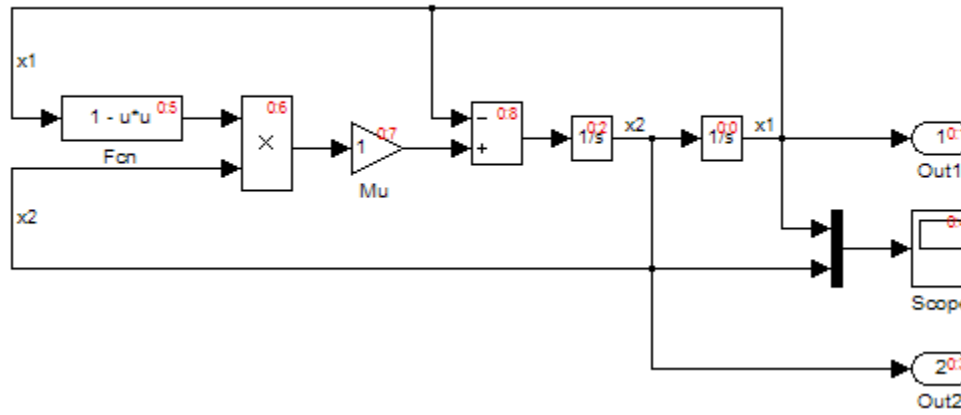
Displaying the Sorted Order

To display the sorted order of the `vdp` demo model:

1 Open the van der Pol equation demo model:

```
vdp
```

2 In the model window, select **Format > Block Displays > Sorted Order**.



Simulink displays a notation in the top-right corner of each nonvirtual block and each nonvirtual subsystem. These numbers indicate the order in which the blocks execute. The first block to execute has a sorted order of `0`.

For example, in the van der Pol equation model, the Integrator block with the sorted order `0:0` executes first. The Out1 block, with the sorted order `0:1`, executes second. Similarly, the remaining blocks execute in numeric order from `0:2` to `0:8`.

You can save the sorted order setting with your model. To display the sorted order when you reopen the model, select **Edit > Update diagram**.

Sorted Order Notation

The sorted order notation varies depending on the type of block. The following table summarizes the different formats of sorted order notation. Each format is described in detail in the sections that follows the table.

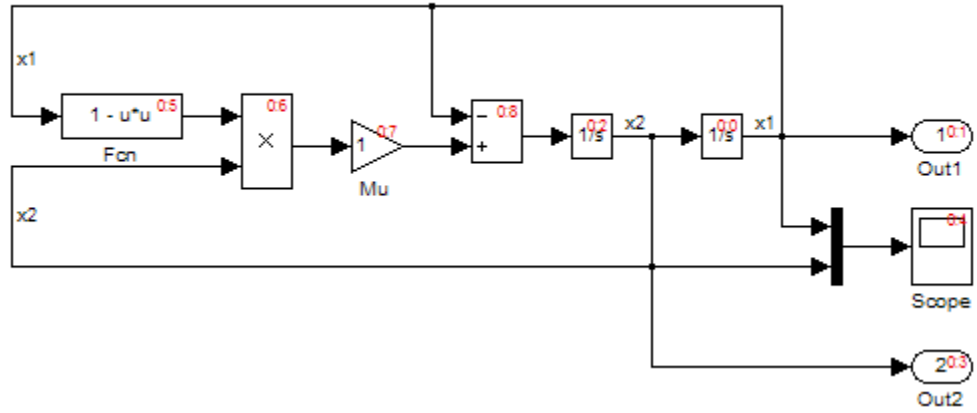
Block Type	Sorted Order Notation	Description
"Nonvirtual Blocks" on page 18-37	`s:b`	• `s` is the system index of the model or subsystem. For root-level models, `s` is always `0`. • `b` specifies the block position within the sorted order for the designated execution context.
"Nonvirtual Subsystems" on page 18-38	`s:b{` s_i`}`	• `s` is the system index of the model or subsystem. • `b` specifies the block position within the sorted order for the designated execution context. • s_i is the subsystem index.
"Virtual Blocks and Subsystems" on page 18-40	Not applicable	Virtual blocks do not execute.
"Function-Call Subsystems" on page 18-41	One initiator: `s:F{` s_i`}`	• `s` is the system index of the model or subsystem. • `F` indicates a function-call subsystem. • s_i is the subsystem index.
	Two or more initiators: • `s:F{` s_i`}` when the initiators all execute at the same level of the model hierarchy • `M:F{`s_i`}`, when the initiators execute at different levels of the model hierarchy	• `s` is the system index of the initiators. • `F` indicates a function-call subsystem. • s_i is the subsystem index. • `M` indicates that the initiators execute at different levels of the model hierarchy.

Block Type	Sorted Order Notation	Description
"Function-Call Split Blocks" on page 18-43	*s*:B*b*	• *s* is a system index of the model or subsystem. • B indicates a branch of the function-call signal. • *b* specifies the index of each subsystem connected to each branch of the given function-call signal.
"Bus-Capable Blocks" on page 18-44	*s*:B	• *s* is a system index of the model or subsystem. • B indicates a bus-capable block.

- "Nonvirtual Blocks" on page 18-37
- "Nonvirtual Subsystems" on page 18-38
- "Virtual Blocks and Subsystems" on page 18-40
- "Function-Call Subsystems" on page 18-41
- "Function-Call Split Blocks" on page 18-43
- "Bus-Capable Blocks" on page 18-44

Nonvirtual Blocks

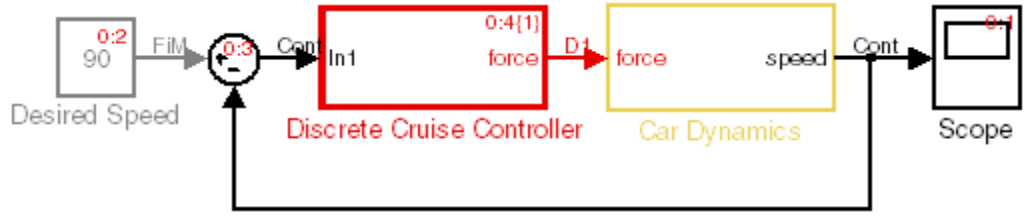
In the van der Pol equation model, all the nonvirtual blocks in the model have a sorted order. The system index for the top-level model is 0, and the block execution order ranges from 0 to 8.



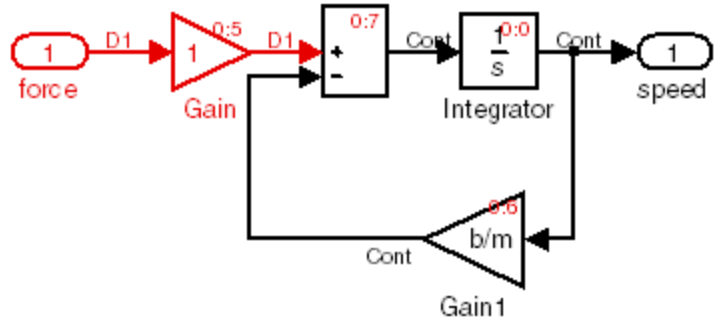
Nonvirtual Subsystems

The following model contains an atomic, nonvirtual subsystem named Discrete Cruise Controller.

When you enable the sorted order display for the root-level system, Simulink displays the sorted order of the blocks.



The Scope block in this model has the lowest sorted order, but its input depends on the output of the Car Dynamics subsystem. The Car Dynamics subsystem is virtual, so it does not have a sorted order and does not execute as an atomic unit. However, the blocks within the subsystem execute at the root level, so the Integrator block in the Car Dynamics subsystem executes first. The Integrator block sends its output to the Scope block in the root-level model, which executes second.

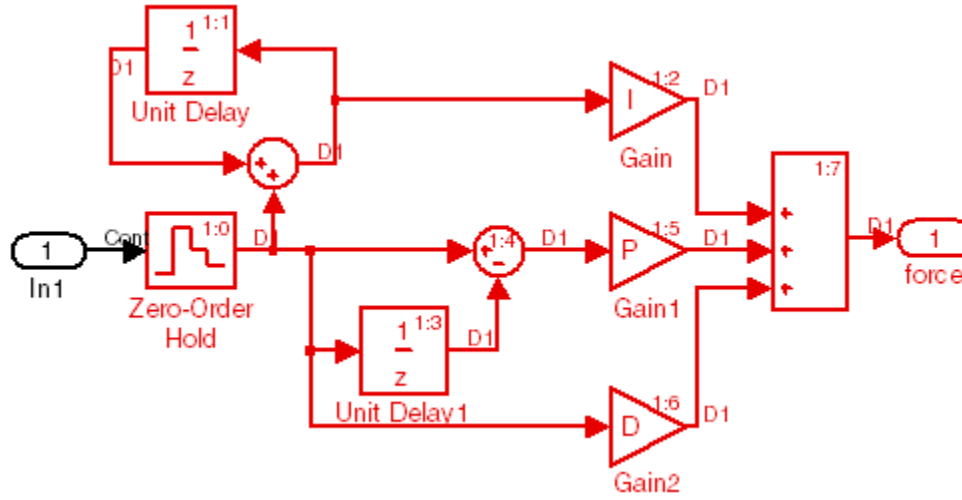


The Discrete Cruise Controller subsystem has a sorted order of `0:4{1}`:

- `0` indicates that this atomic subsystem is part of the root level of the hierarchal system comprised of the primary system and the two subsystems.
- `4` indicates that the atomic subsystem is the fifth block that Simulink executes relative to the blocks within the root level.
- `{1}` represents the subsystem index. This index does *not* indicate the relative order in which the atomic subsystem runs.

The sorted order of each block inside the Discrete Cruise Controller subsystem has the form `1:`*b*, where:

- `1` is the system index for that subsystem.
- *b* is the block position in the execution order. In the Discrete Cruise Controller subsystem, the sorted order ranges from `0` to `7`.

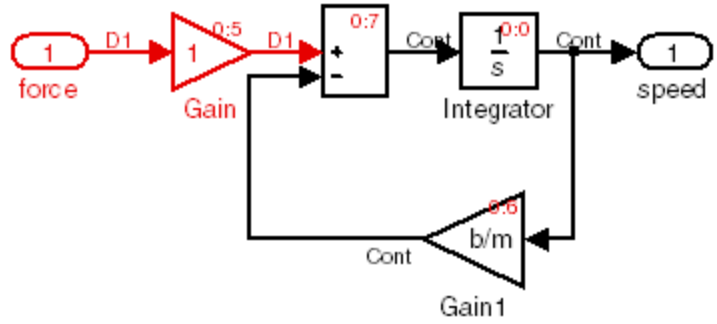


Virtual Blocks and Subsystems

Virtual blocks, such as the Mux block, exist only graphically and do not execute. Consequently, they are not part of the sorted order and do not display any sorted order notation.

Virtual subsystems do not execute as a unit, and like a virtual block, are not part of the sorted order. The blocks inside the virtual subsystem are part of the root-level system sorted order, and therefore share the system index.

In the model in “Nonvirtual Subsystems” on page 18-38, the virtual subsystem Car Dynamics does not have a sorted order. However, the blocks inside the subsystem have a sorted order in the execution context of the root-level model. The blocks have the same system index as the root-level model. The Integrator block inside the Car Dynamics subsystem has a sorted order of `0:0`, indicating that the Integrator block is the first block executed in the context of the top-level model.

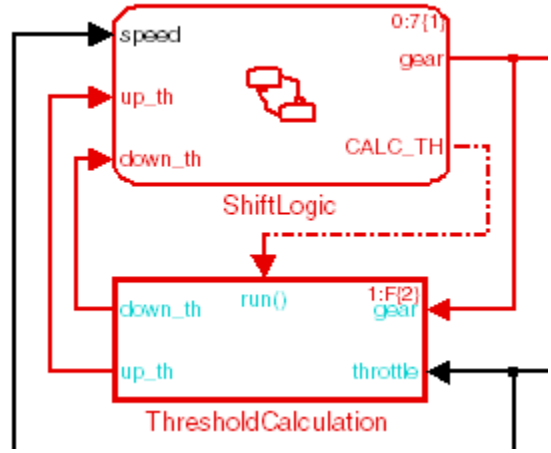


Function-Call Subsystems

Single Initiator. For each function-call subsystem or model attached to a single initiator, Simulink assigns the block position `F`. The function-call subsystem (or model) executes when the initiator invokes the function-call subsystem (or model) and, therefore, does not have a sorted order independent of its initiator. Specifically, for a subsystem that connects to one initiator, Simulink uses the notation `s:F{`s_i`}`, where s is the index of the system that contains the initiator.

For example, open the `sldemo_autotrans` demo model and display the sorted order. The sorted order for the ThresholdCalculation subsystem is `1:F{2}`:

- `1` is the index of the system that contains the initiator, in this case, the ShiftLogic Stateflow chart.
- `F` indicates that this function-call subsystem connects to one initiator.
- `2` is the system index for the ThresholdCalculation subsystem.

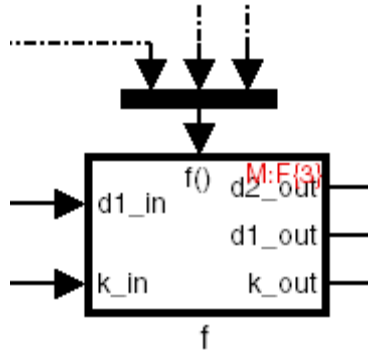


Multiple Initiators. For a function-call subsystem that connects to more than one initiator, the sorted order notation depends on the execution context of the initiators:

- If the initiators all execute at the same level of the model hierarchy, the notation is `s:F{`s_i`}`.
- If the initiators execute at different levels of the model hierarchy, the notation is `M:F{`s_i`}`

For example, open the `sl_subsysm_fncall6` demo model. The f subsystem has three initiators, two from the Stateflow chart, Chart1, and one from the Stateflow chart, Chart.

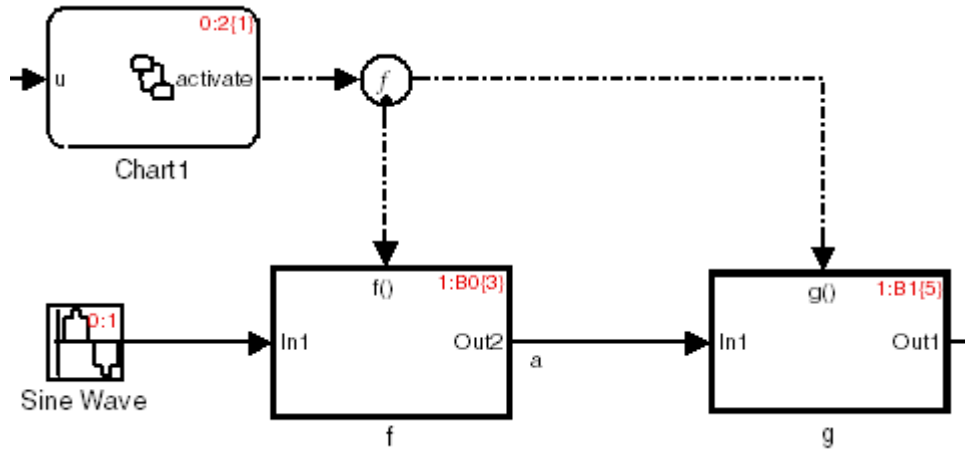
Because Chart1 has a system index of `2` and Chart has a system index of `1`, the initiators execute at different levels in the model hierarchy. The Function-Call Subsystem f has a sorted order notation of `M:F{3}`.



Function-Call Split Blocks

When a function-call signal is branched using a Function-Call Split block, Simulink displays the order in which subsystems (or models) that connect to the branches execute when the initiator invokes the function call. Simulink uses the notation `s:Bb` to indicate this order, where B stands for branch. The block position `b` ranges from `0` to one less than the total number of subsystems (or models) that connect to branches (`B0`, `B1`, etc.). When the function-call is invoked, the subsystems execute in ascending order based on this number.

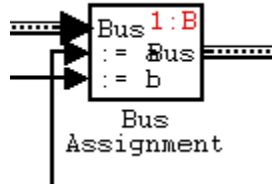
For example, open the `sl_subsys_fcncall11` demo model and display the sorted order. The sorted order indicates that the subsystem f (`B0`) executes before the subsystem g (`B1`).



Bus-Capable Blocks

A bus-capable block does not execute as a unit and therefore does not have a unique sorted order. Such a block displays its sorted order as `s:B` where `B` stands for bus.

For example, open the `sldemo_bus_arrays` demo model and display the sorted order. Open the For Each Subsystem to see that the sorted order for the Bus Assignment block appears as `1:B`.



For more information, see “Bus-Capable Blocks” on page 30-11.

How Simulink Determines the Sorted Order

Direct-Feedthrough Ports Impact on Sorted Order

To ensure that the sorted order reflects data dependencies among blocks, Simulink categorizes block input ports according to the dependency of the block outputs on the block input ports. An input port whose current value determines the current value of one of the block outputs is a *direct-feedthrough* port. Examples of blocks that have direct-feedthrough ports include:

- Gain
- Product
- Sum

Examples of blocks that have non-direct-feedthrough inputs:

- Integrator — Output is a function of its state.
- Constant — Does not have an input.
- Memory — Output depends on its input from the previous time step.

Rules for Sorting Blocks

To sort blocks, Simulink uses the following rules:

- If a block drives the direct-feedthrough port of another block, the block must appear in the sorted order ahead of the block that it drives.

  This rule ensures that the direct-feedthrough inputs to blocks are valid when Simulink invokes block methods that require current inputs.

- Blocks that do not have direct-feedthrough inputs can appear anywhere in the sorted order as long as they precede any direct-feedthrough blocks that they drive.

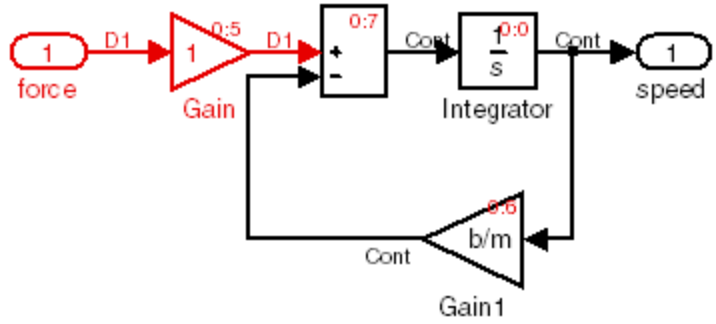
  Placing all blocks that do not have direct-feedthrough ports at the beginning of the sorted order satisfies this rule. This arrangement allows Simulink to ignore these blocks during the sorting process.

Applying these rules results in the sorted order. Blocks without direct-feedthrough ports appear at the beginning of the list in no particular

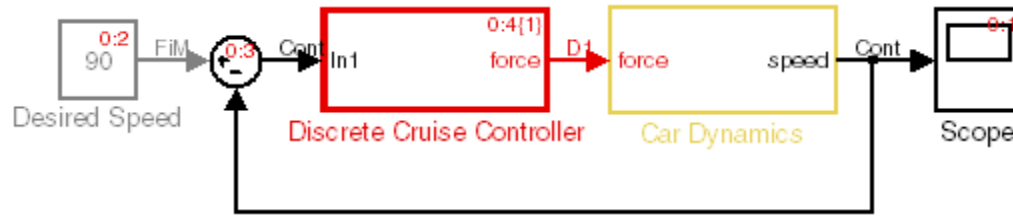
order. These blocks are followed by blocks with direct-feedthrough ports arranged such that they can supply valid inputs to the blocks which they drive.

The following model, from "Nonvirtual Subsystems" on page 18-38, illustrates this result. The following blocks do not have direct-feedthrough and therefore appear at the beginning of the sorted order of the root-level system:

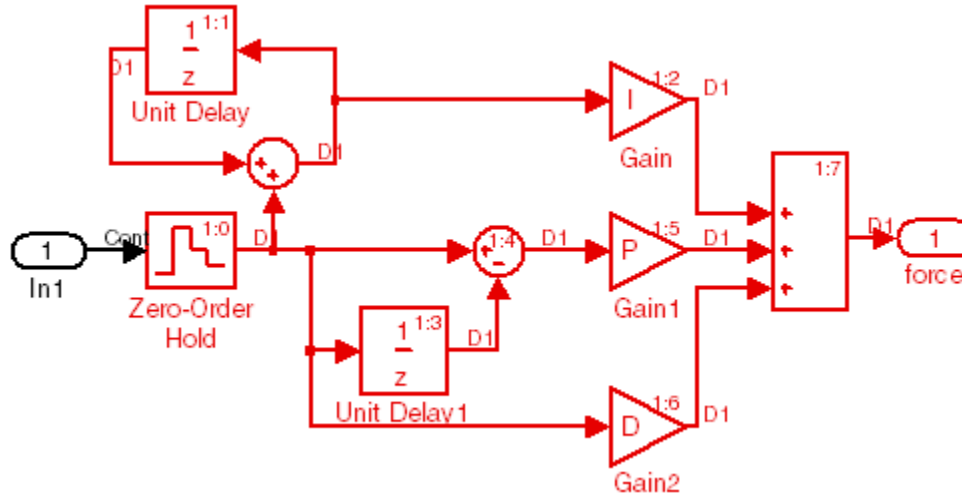
- Integrator block in the Car Dynamics virtual subsystem



- Speed block in the root-level model



Inside the Discrete Cruise Controller subsystem, all the Gain blocks, which have direct-feedthrough ports, run before the Sum block that they drive.



Assigning Block Priorities

You can assign a priority to a nonvirtual block or to an entire subsystem. Higher priority blocks appear before lower priority blocks in the sorted order. The lower the number, the higher the priority.

- "Assigning Block Priorities Programmatically" on page 18-47
- "Assigning Block Priorities Interactively" on page 18-47

Assigning Block Priorities Programmatically

To set priorities programmatically, use the command:

```
set_param(b,'Priority','n')
```

where

- `b` is the block path.
- `n` is any valid integer. (Negative integers and 0 are valid priority values.)

Assigning Block Priorities Interactively

To set the priority of a block or subsystem interactively:

1 Right-click the block and select **Block Properties**.

2 On the **General** tab, in the **Priority** field, enter the priority.

Rules for Block Priorities

Simulink honors the block priorities that you specify unless they violate data dependencies. ("Block Priority Violations" on page 18-51 describes situations that cause block property violations.)

In assessing priority assignments, Simulink attempts to create a sorted order such that the priorities for the individual blocks within the root-level system or within a nonvirtual subsystem are honored relative to one another.

Three rules pertain to priorities:

- "Priorities Are Relative" on page 18-48
- "Priorities Are Hierarchical" on page 18-49
- "Lack of Priority May Not Result in Low Priority" on page 18-50

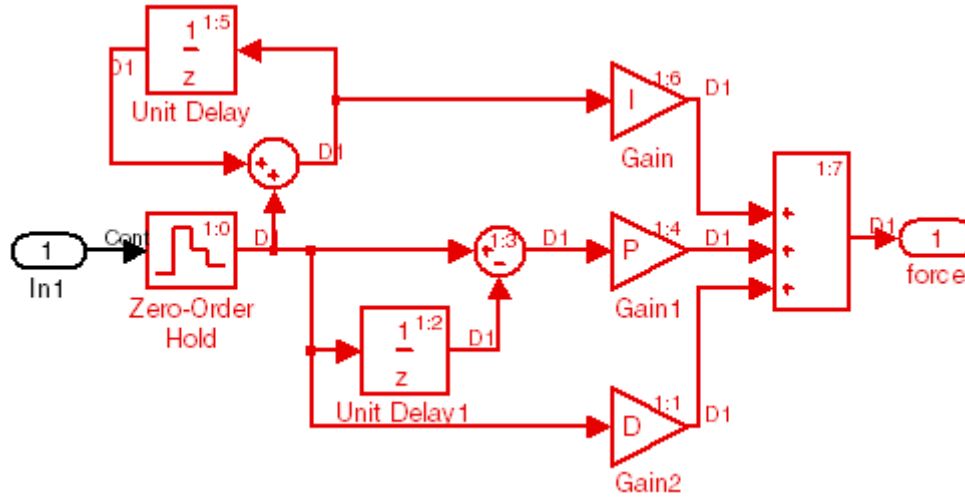
Priorities Are Relative

Priorities are relative; the priority of a block is relative to the priority of the blocks within the same system or subsystem.

For example, suppose you set the following priorities in the Discrete Cruise Controller subsystem in the model in "Nonvirtual Subsystems" on page 18-38.

Block	Priority
Gain	3
Gain1	2
Gain2	1

After updating the diagram, the sorted order for the Gain blocks is as follows.



The sorted order values of the Gain, Gain1, and Gain2 blocks reflect the respective priorities assigned: Gain2 has highest priority and executes before Gain1 and Gain; Gain1 has second priority and executes after Gain2; and Gain executes after Gain1. Simulink takes into account the assigned priorities relative to the other blocks in that subsystem.

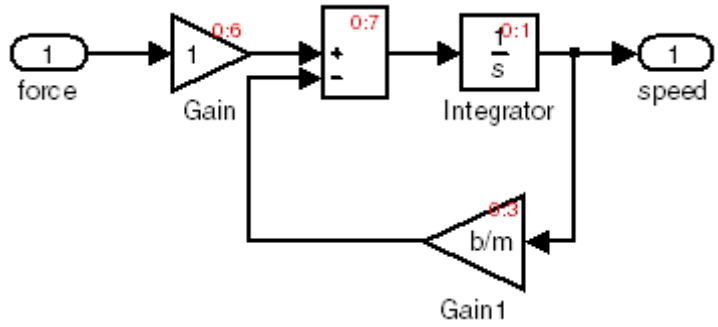
The Gain blocks are not the first, second, and third blocks to execute. Nor do they have consecutive sorted orders. The sorted order values do not necessarily correspond to the priority values. Simulink arranges the blocks so that their priorities are honored relative to each other.

Priorities Are Hierarchical

In the Car Dynamics virtual subsystem, suppose you set the priorities of the Gain blocks as follows.

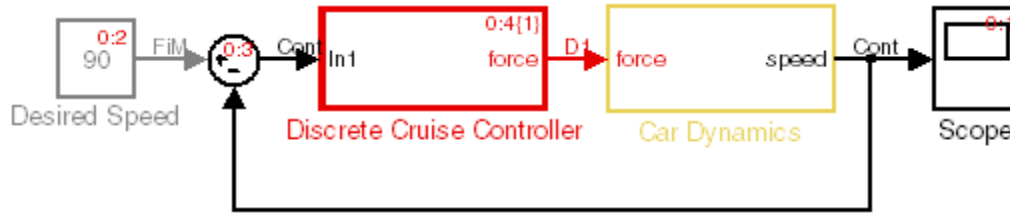
Block	Priority
Gain	2
Gain1	1

After updating the diagram, the sorted order for the Gain blocks is as illustrated. With these priorities, Gain1 always executes before Gain.



You can set a priority of 1 to one block in each of the two subsystems because of the hierarchal nature of the subsystems within a model. Simulink never compares the priorities of the blocks in one subsystem to the priorities of blocks in any other subsystem.

For example, consider this model again.



The blocks within the Car Dynamics virtual subsystem are part of the root-level system hierarchy and are part of the root-level sorted order. The Discrete Cruise Controller subsystem has an independent sorted order with the blocks arranged consecutively from 1:0 to 1:7.

Lack of Priority May Not Result in Low Priority

A lack of priority does not necessarily result in a low priority (higher sorting order) for a given block. Blocks that do not have direct-feedthrough ports execute before blocks that have direct-feedthrough ports, regardless of their priority.

If a model has two atomic subsystems, A and B, you can assign priorities of 1 and 2 respectively to A and B. This priority causes all the blocks in A to

execute before any of the blocks in B. The blocks within an atomic subsystem execute as a single unit, so the subsystem has its own system index and its own sorted order.

Block Priority Violations

Simulink software honors the block priorities that you specify unless they violate data dependencies. If Simulink is unable to honor a block priority, it displays a `Block Priority Violation` diagnostic message.

As an example:

1. Open the `sldemo_bounce` demo model.

   Notice that the output of the Memory block provides the input to the Coefficient of Restitution Gain block.

2. Set the priority of the Coefficient of Restitution block to `1`, and set the priority of the Memory block to `2`.

   Setting these priorities specifies that the Coefficient of Restitution block executes before the Memory block. However, the Coefficient of Restitution block depends on the output of the Memory block, so the priorities violate the data dependencies.

3. In the model window, enable sorted order by selecting **Format > Block display > Sorted order**.

4. Select **Edit > Update diagram**.

   The block priority violation warning appears in the MATLAB Command Window. The warning includes the priority for the respective blocks:

   ```
   Warning: Unable to honor user-specified priorities.
   'sldemo_bounce/Memory' (pri=[3]) has to execute
   before 'sldemo_bounce/Coefficient of  Restitution'
    (pri=[1]) to satisfy data dependencies
   ```

5. Remove the priorities from the Coefficient of Restitution and Memory blocks and update the diagram again to see the correct sorted order.

Accessing Block Data During Simulation

In this section...

About Block Run-Time Objects

Simulink provides an application programming interface, called the block run-time interface, that enables programmatic access to block data, such as block inputs and outputs, parameters, states, and work vectors, while a simulation is running. You can use this interface to access block run-time data from the MATLAB command line, the Simulink Debugger, and from Level-2 MATLAB S-functions (see "Writing S-Functions in MATLAB" in the online Simulink documentation).

Note You can use this interface even when the model is paused or is running or paused in the debugger.

The block run-time interface consists of a set of Simulink data object classes (see "Working with Data Objects" on page 25-37) whose instances provide data about the blocks in a running model. In particular, the interface associates an instance of `Simulink.RunTimeBlock`, called the block's run-time object, with each nonvirtual block in the running model. A run-time object's methods and properties provide access to run-time data about the block's I/O ports, parameters, sample times, and states.

Accessing a Run-Time Object

Every nonvirtual block in a running model has a RuntimeObject parameter whose value, while the simulation is running, is a handle for the blocks' run-time object. This allows you to use `get_param` to obtain a block's run-time object. For example, the following statement

```
rto = get_param(gcb,'RuntimeObject');
```

returns the run-time object of the currently selected block.

Note Virtual blocks (see "Virtual Blocks" on page 18-2) do not have run-time objects. Blocks eliminated during model compilation as an optimization also do not have run-time objects (see "Block reduction"). A run-time object exists only while the model containing the block is running or paused. If the model is stopped, `get_param` returns an empty handle. When you stop or pause a model, all existing handles for run-time objects become empty.

Listening for Method Execution Events

One application for the block run-time API is to collect diagnostic data at key points during simulation, such as the value of block states before or after blocks compute their outputs or derivatives. The block run-time API provides an event-listener mechanism that facilitates such applications. For more information, see the *Simulink Reference* for the `add_exec_event_listener` command. For an example of using method execution events, enter

```
sldemo_msfcn_lms
```

at the MATLAB command line. This Simulink model contains the S-function `adapt_lms.m`, which performs a system identification to determine the coefficients of an FIR filter. The S-function's `PostPropagationSetup` method initializes the block run-time object's DWork vector such that the second vector stores the filter coefficients calculated at each time step.

In the Simulink model, double-clicking on the annotation below the S-function block executes its `OpenFcn`. This function first opens a figure for plotting the FIR filter coefficients. It then executes the function `add_adapt_coef_plot.m` to add a `PostOutputs` method execution event to the S-function's block run-time object using the following lines of code.

```
% Get the full path to the S-function block
blk = 'sldemo_msfcn_lms/LMS Adaptive';

% Attach the event-listener function to the S-function
h   = add_exec_event_listener(blk, ...
```

```
'PostOutputs', @plot_adapt_coefs);
```

The function `plot_adapt_coefs.m` is registered as an event listener that is executed after every call to the S-function's `Outputs` method. The function accesses the block run-time object's DWork vector and plots the filter coefficients calculated in the `Outputs` method. The calling syntax used in `plot_adapt_coefs.m` follows the standard needed for any listener. The first input argument is the S-function's block run-time object, and the second argument is a structure of event data, as shown below.

```
function plot_adapt_coefs(block, eventData)

% The figure's handle is stored in the block's UserData
hFig  = get_param(block.BlockHandle,'UserData');
tAxis = findobj(hFig, 'Type','axes');

tAxis = tAxis(2);
tLines = findobj(tAxis, 'Type','Line');

% The filter coefficients are stored in the block run-time
%   object's second DWork vector.
est = block.Dwork(2).Data;

set(tLines(3),'YData',est);
```

Synchronizing Run-Time Objects and Simulink Execution

Run-time objects can be used at the MATLAB command line to obtain the value of a block's output by entering the following commands.

```
rto = get_param(gcb,'RuntimeObject')
rto.OutputPort(1).Data
```

However, the displayed data may not be the block's true output if the run-time object is not synchronized with the Simulink execution. Simulink only ensures the run-time object and Simulink execution are synchronized when the run-time object is used either within a Level-2 MATLAB S-function or in an event listener callback. When called at the MATLAB command line, the run-time object can return incorrect output data if other blocks in the model are allowed to share memory.

To ensure the `Data` field contains the correct block output, turn off the **Signal storage reuse** option (see "Signal storage reuse") on the **Optimization** pane in the **Configuration Parameters** dialog box.

Configuration a Block for Code Generation

Use the **State Attributes** pane of a Block Parameters dialog box to specify Real-Time Workshop code generation options for blocks with discrete states. See "Block State Storage and Interfacing Considerations" in the *Real-Time Workshop User's Guide* for more information.

19

Working with Block Parameters

About Block Parameters

Most Simulink blocks have attributes whose values you can specify to customize the block. Some attributes are common to all Simulink blocks, such as a block's name and foreground color. Other attributes are specific to a block, such as the gain of a Gain block. Simulink associates a *block parameter* with each user-specifiable attribute of a block. Block parameters fall into two categories. A *mathematical parameter* is a parameter used to compute the value of a block's output, such as a Gain block's **Gain** parameter. All other parameters are *configuration parameters*, such as a Gain block's **Name** parameter.

A parameterized block effectively represents a family of similar blocks. For example, when creating a model, you can set the **Constant value** parameter of each instance of the Constant block separately so that each instance behaves differently. Because it allows each standard block to represent a family of blocks, block parameterization greatly increases the modeling power of the standard Simulink libraries.

You specify a block attribute value by setting its associated block parameter. For example, to set the foreground color of a block to red, you set the value of its foreground color parameter to the string `'red'`. You can set the value programmatically, using the `set_param` command, or by using the block's Block Parameters dialog box. See "Common Block Parameters" and "Block-Specific Parameters" for the names, usages, and valid settings for Simulink block parameters.

You can use MATLAB expressions to specify block parameter values. The expressions can include the names of workspace variables. Simulink evaluates the expressions before running a simulation, resolving any names to values as described in "Resolving Symbols" on page 3-75. Be careful not to confuse Simulink block parameters with Simulink parameter objects. See "Block Parameters" on page 2-9`Simulink.Parameter` for more information.

A *tunable parameter* is a block parameter whose value can be changed during simulation without recompiling the model. In general, you can change the values of mathematical parameters, but not configuration parameters. If a parameter is not tunable and simulation is running, the dialog box control that sets the parameter value is disabled.

If you change a tunable parameter value programmatically while simulation is running, Simulink pauses the simulation, makes the change, then resumes the simulation after the change is complete. Opening the dialog box of a source block with tunable parameters causes a running simulation to pause. While the simulation is paused, you can edit the parameter values displayed by the dialog box. You must close the dialog box to have the changes take effect and allow the simulation to continue. Tunable parameter changes take effect at the start of the next time step after simulation resumes.

You can use the **Inline parameters** option on the **Optimization** pane of the **Configuration Parameters** dialog box to specify that all parameters in your model are nontunable except for those that you specify. This can speed up execution of large models and enable generation of faster code from your model. See "Configuration Parameters Dialog Box" for more information.

You can separately define each MATLAB variable intended for use in block parameter expressions. However, this technique has several disadvantages, such as cluttering the base workspace and providing no convenient way to group related parameters. To avoid these disadvantages, you can combine numeric base workspace variables into a MATLAB structure, then:

- Dereference the structure fields to provide values used in block parameter expressions
- Pass a whole structure as an argument to a masked subsystem or a referenced model
- Set the structure to be tunable or nontunable as you could a separately defined variable

A structure used for any of these purposed can contain only numeric data. See "Using Structure Parameters" on page 19-18 for more information.

Setting Block Parameters

You can use the Simulink `set_param` command to set the value of any Simulink block parameter. In addition, you can set many block parameters via Simulink dialog boxes and menus. These include:

- **Format** menu

  The Model Editor's **Format** menu allows you to specify attributes of the currently selected block that are visible on the model's block diagram, such as the block's name and color (see "Changing a Block's Appearance" on page 18-22 for more information).

- **Block Properties** dialog box

  Specifies various attributes that are common to all blocks (see "Block Properties Dialog Box" on page 18-15 for more information).

- **Block Parameter** dialog box

  Every block has a dialog box that allows you to specify values for attributes that are specific to that type of block. See "Displaying a Block's Parameter Dialog Box" on page 19-4 for information on displaying a block's parameter dialog box. For information on the parameter dialog of a specific block, see "Blocks — Alphabetical List" in the online Simulink reference.

- Model Explorer

  The Model Explorer allows you to quickly find one or more blocks and set their properties, thus facilitating global changes to a model, for example, changing the gain of all of a model's Gain blocks. See "The Model Explorer: Overview" on page 8-2 for more information.

Displaying a Block's Parameter Dialog Box

To display a block's parameter dialog box, double-click the block in the model or library window. You can also display a block's parameter dialog box by selecting the block in the model's block diagram and choosing **BLOCK Parameters** from the model window's **Edit** menu or from the block's context (right-click) menu, where **BLOCK** is the name of the block you selected, e.g., **Constant Parameters**.

Note Double-clicking a block to display its parameter dialog box works for all blocks with parameter dialog boxes except for Subsystem blocks and the Model block. You must use the Model Editor's **Edit** menu or the block's context menu to display a Subsystem or Model block's parameter dialog box.

Specifying Parameter Values

In this section...

About Parameter Values

Many block parameters, including mathematical parameters, accept MATLAB expression strings as values. When Simulink compiles a model, for example, at the start of a simulation or when you update the model, Simulink sets the compiled values of the parameters to the result of evaluating the expressions.

Using Workspace Variables in Parameter Expressions

Block parameter expressions can include variables defined in the model's mask and model workspaces and in the MATLAB workspace. Using a workspace variable facilitates updating a model that sets multiple block parameters to the same value, i.e., it allows you to update multiple parameters by setting the value of a single workspace variable. For more information, see "Resolving Symbols" on page 3-75 and "Specifying Numeric Values with Symbols" on page 3-77.

Using a workspace variable also allows you to change the value of a parameter during simulation without having to open a block's parameter dialog box. For more information, see "Using Tunable Parameters" on page 19-13.

Note If you plan to generate code from a model, you can use workspace variables to specify the name, data type, scope, volatility, tunability, and other attributes of variables used to represent the parameter in the generated code. For more information, see "Parameter Considerations" in the Real-Time Workshop documentation.

Resolving Variable References in Block Parameter Expressions

When evaluating a block parameter expression that contains a variable, Simulink by default searches the workspace hierarchy. If the variable is not defined in any workspace, Simulink halts compilation of the model and displays an error message. See "Resolving Symbols" on page 3-75 and "Specifying Numeric Values with Symbols" on page 3-77 for more information.

Using Parameter Objects to Specify Parameter Values

You can use `Simulink.Parameter` objects in parameter expressions to specify parameter values. For example, `K` and `2*K` are both valid parameter expressions where `K` is a workspace variable that references a `Simulink.Parameter` object. In both cases, Simulink uses the parameter object's `Value` property as the value of `K`. See "Resolving Symbols" on page 3-75 and "Specifying Numeric Values with Symbols" on page 3-77for more information.

Using parameter objects to specify parameters can facilitate tuning parameters in some applications. See "Using a Parameter Object to Specify a Parameter As Noninlined" on page 19-17 and "Parameterizing Model References" on page 5-40 for more information.

Note Do not use expressions of the form `p.Value` where `p` is a parameter object in block parameter expressions. Such expressions cause evaluation errors when Simulink compiles the model.

Determining Parameter Data Types

When Simulink compiles a model, each of the model's blocks determines a data type for storing the values of its parameters whose values are specified by MATLAB parameter expressions.

Most blocks use internal rules to determine the data type assigned to a specific parameter. Exceptions include the Gain block, whose parameter dialog box allows you to specify the data type assigned to the compiled value of its Gain parameter. You can configure your model to check whether the data type assigned to a parameter can accommodate the parameter value specified by the model (see "Data Validity Diagnostics Overview").

Obtaining Parameter Information

You can use `get_param` to find the system and block parameter values for your model. See "Model and Block Parameters" for a list of arguments `get_param` accepts.

The model's signal attributes and parameter expressions must be evaluated before some parameters are properly reported. This evaluation occurs during the simulation compilation phase. Alternatively, you can compile your model without first running it, and then obtain parameter information. For instance, to access the port width, data types, and dimensions of the blocks in your model, enter the following at the command prompt:

```
modelname([],[],[],'compile')
q=get_param(gcb,'PortHandles');
get_param(q.Inport,'CompiledPortDataType')
get_param(q.Inport,'CompiledPortWidth')
get_param(q.Inport,'CompiledPortDimensions')
modelname([],[],[],'term')
```

Checking Parameter Values

In this section...

About Value Checking

Many blocks perform range checking of their mathematical parameters. Generally, blocks that allow you to enter minimum and maximum values check to ensure that the values of applicable parameters lie within the specified range.

Blocks That Perform Parameter Range Checking

The following blocks perform range checking for their parameters:

Block	Parameters Checked
Constant	**Constant value**
Data Store Memory	**Initial value**
Gain	**Gain**
Interpolation Using Prelookup	**Table data**
Lookup Table	**Table data**
Lookup Table (2-D)	**Table data**
Lookup Table (n-D)	**Table data**
Relay	**Output when on** **Output when off**
Repeating Sequence Interpolated	**Vector of output values**

Block	Parameters Checked
Repeating Sequence Stair	**Vector of output values**
Saturation	**Upper limit** **Lower limit**

Specifying Ranges for Parameters

In general, use the **Output minimum** and **Output maximum** parameters that appear on a block parameter dialog box to specify a range of valid values for the block parameters. The following exceptions apply:

- For the Gain block, use the **Parameter minimum** and **Parameter maximum** fields to specify a range for the **Gain** parameter.
- For the Data Store Memory block, use the **Minimum** and **Maximum** fields to specify a range for the **Initial value** parameter.

When specifying minimum and maximum values that constitute a range, enter only expressions that evaluate to a scalar, real number with `double` data type. The default value, `[]`, is equivalent to `-Inf` for the minimum value and `Inf` for the maximum value. The scalar values that you specify are subject to expansion, for example, when the block parameters that Simulink checks are nonscalar (see "Scalar Expansion of Inputs and Parameters" on page 29-29).

Note You cannot specify the minimum or maximum value as `NaN`.

Specifying Ranges for Complex Numbers

When you specify a minimum or maximum value for a parameter that is a complex number, the specified minimum and maximum apply separately to the real part and to the imaginary part of the complex number. If the value of either part of the number is less than the minimum, or greater than the maximum, the complex number is outside the specified range. No range checking occurs against any combination of the real and imaginary parts, such as `(sqrt(a^2+b^2))`

Performing Parameter Range Checking

You can initiate parameter range checking in the following ways:

- When you click the **OK** or **Apply** button on a block parameter dialog box, the block performs range checking for its parameters. However, the block checks only the parameters that it can readily evaluate. For example, the block does not check parameters that use an undefined workspace variable.
- When you start a simulation or select **Update Diagram** from the Simulink **Edit** menu, Simulink performs parameter range checking for all blocks in that model.

Simulink performs parameter range checking by comparing the values of applicable block parameters with both the specified range (see "Specifying Ranges for Parameters" on page 19-10) and the block data type. That is, Simulink performs the following check:

```
DataTypeMin   MinValue   VALUE   MaxValue   DataTypeMax
```

where

- `DataTypeMin` is the minimum value representable by the block data type.
- `MinValue` is the minimum value the block should output, specified by, e.g., **Output minimum**.
- `VALUE` is the numeric value of a block parameter.
- `MaxValue` is the maximum value the block should output, specified by, e.g., **Output maximum**.
- `DataTypeMax` is the maximum value representable by the block data type.

When Simulink detects a parameter value that violates the check, it displays an error message. For example, consider a model that contains a Constant block whose

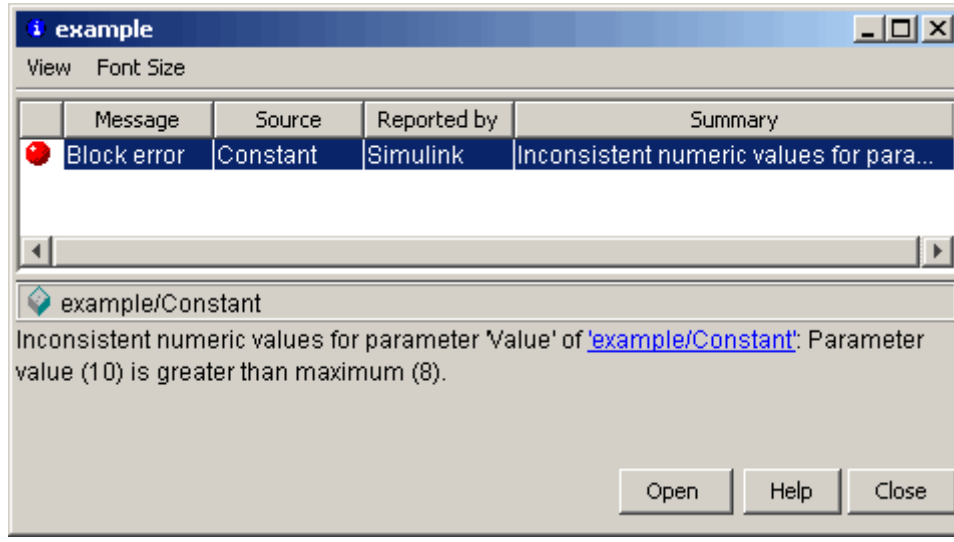
- **Constant value** parameter specifies the variable `const`, which you have yet to define in a workspace.
- **Output minimum** and **Output maximum** parameters are set to `2` and `8`, respectively.

- **Output data type** parameter is set to `uint8`.

In this situation, Simulink does not perform parameter range checking when you click the **OK** button on the Constant block dialog box because the variable `const` is undefined. But suppose you define its value by entering

```
const = 10
```

at the MATLAB prompt, and then you update the diagram (see "Updating a Block Diagram" on page 1-27). Simulink displays the following error message:



Using Tunable Parameters

In this section...

About Tunable Parameters

Simulink lets you change the values of many block parameters during simulation. Such parameters are called *tunable parameters*. In general, only parameters that represent mathematical variables, such as the Gain parameter of the Gain block, are tunable. Parameters that specify the appearance or structure of a block, e.g., the number of inputs of a Sum block, or when it is evaluated, e.g., a block's sample time or priority, are not tunable.

You can tell whether a particular parameter is tunable by examining its edit control in the block's dialog box or Model Explorer during simulation. If the control is disabled, the parameter is nontunable. You cannot tune inline parameters. See "Inlining Parameters" on page 19-16 for more information.

Tuning a Block Parameter

You can use a block's dialog box or the Model Explorer to modify the tunable parameters of any block, except a source block (see "Changing Source Block Parameters During Simulation" on page 19-14). To use the block's parameter dialog box, open the block's parameter dialog box, change the value displayed in the dialog box, and click the dialog box's **OK** or **Apply** button.

You can also tune a parameter at the MATLAB command line, using either the `set_param` command or by assigning a new value to the MATLAB workspace variable that specifies the parameter's value. In either case, you must update the model's block diagram for the change to take effect (see "Updating a Block Diagram" on page 1-27).

Changing Source Block Parameters During Simulation

Opening the dialog box of a source block with tunable parameters (see "Source Blocks with Tunable Parameters" on page 19-14) causes a running simulation to pause. While the simulation is paused, you can edit the parameter values displayed on the dialog box. When you close the dialog box, the simulation to continues. The parameter value changes take effect at the beginning of the next time step after simulation resumes. Starting a simulation causes any open dialog boxes associated with source blocks with tunable parameters to close.

Note If you enable the **Inline parameters** option, Simulink does not pause the simulation when you open a source block's dialog box because all of the parameter fields are disabled and can be viewed but cannot be changed.

While a simulation is running, the Model Explorer disables the parameter fields that it displays for a source block with tunable parameters. As a result, you cannot use the Model Explorer to change the block's parameters. However, while the simulation is running the Model Explorer displays a **Modify** button in the dialog view for the block. Clicking the **Modify** button opens the block's dialog box. Note that this causes the simulation to pause. You can then change the block's parameters. You must close the dialog box to have the changes take effect and allow the simulation to continue. Your changes appear in the Model Explorer after you close the dialog box.

Source Blocks with Tunable Parameters

Source blocks with tunable parameters include the following blocks.

- Simulink source blocks, including
  - Band-Limited White Noise
  - Chirp Signal
  - Constant
  - Pulse Generator
  - Ramp
  - Random Number

  - Repeating Sequence
  - Signal Generator
  - Sine Wave
  - Step
  - Uniform Random Number
- User-developed masked subsystem blocks that have one or more tunable parameters and one or more output ports, but no input ports.
- S-Function and MATLAB file (level 2) S-Function blocks that have one or more tunable parameters and one or more output ports but no input ports.

Inlining Parameters

In this section...

About Inlined Parameters

The **Inline parameters** option (see "Inline parameters") controls how mathematical block parameters appear in code generated from the model. When this optimization is off (the default), a model's mathematical block parameters appear as variables in the generated code. As a result, you can tune the parameters both during simulation and when executing the code.

When **Inline parameters** is on, the parameters appear in the generated code as inlined numeric constants. This reduces the generated code's memory and processing requirements. However, because the inlined parameters appear as constants in the generated code, you cannot tune them during code execution. To ensure that simulation and generated code execution fully correspond, Simulink prevents you from changing the values of block parameters during simulation when **Inline parameters** option is on.

Specifying Some Parameters as Noninline

Suppose that you want to take advantage of the **Inline parameters** optimization while retaining the ability to tune some of your model's parameters. You can do this by declaring some parameters as *noninline*, using either the "Model Parameter Configuration Dialog Box" or a `Simulink.Parameter` object. In either case, you must use a workspace variable to specify the value of the parameter.

When compiling a model with the inline parameters option on, Simulink checks to ensure that the data types of the workspace variables used to specify the model's noninline parameters are compatible with code generation. If not, Simulink halts the compilation and displays an error. See "Tunable Workspace Parameter Data Type Considerations" for more information.

Note The documentation for the Real-Time Workshop refers to workspace variables used to specify the value of noninline parameters as *tunable workspace parameters*. In this context, the term *parameter* refers to a workspace variable used to specify a parameter as opposed to the parameter itself.

Using a Parameter Object to Specify a Parameter As Noninlined

If you use a parameter object to specify a parameter's value (see "Using Parameter Objects to Specify Parameter Values" on page 19-7), you can also use the object to specify the parameter as noninlined. To do this, set the parameter object's `RTWInfo.StorageClass` property to any value but `'Auto'` (the default).

```
K=Simulink.Parameter;
K.RTWInfo.StorageClass = 'SimulinkGlobal';
```

If you set the `RTWInfo.StorageClass` property to any value other than `Auto`, you should not include the parameter in the tunable parameters table in the model's **Model Parameter Configuration** dialog box.

Note Simulink halts model compilation and displays an error message if it detects a conflict between the properties of a parameter as specified by a parameter object and the properties of the parameter as specified in the **Model Parameter Configuration** dialog box.

Using Structure Parameters

In this section...

About Structure Parameters

Separately defining all base workspace variables used in block parameter expressions can clutter the base workspace and result in very long lists of arguments to subsystems and referenced models. The technique provides no way to conveniently group related base workspace variables, or to configure generated code to reflect the variables' relationships.

To minimize the disadvantages of separately defining workspace variables used by block parameters, you can group numeric variables by specifying their names and values as the fields of a MATLAB structure in the base workspace. A MATLAB structure that Simulink uses in block parameter expressions is called a *structure parameter*. You can use structure parameters to:

- Simplify and modularize the base workspace by using multiple structures to group related variables and to prevent name conflicts
- Dereference the structure in block parameter expressions to provide values from structure fields rather than separate variables
- Pass all the fields in a structure to a subsystem or referenced model with a single argument.
- Improve generated code to use structures rather multiple separate variables

For information about creating and using MATLAB structures, see Structures in the MATLAB documentation. You can use all the techniques described

there to manipulate structure parameters. This section assumes that you know those techniques, and provides only information that is specific to Simulink.

For information on structure parameters in the context of generated code for a model, see "Structure Parameters and Generated Code". For an example of how to convert a model that uses unstructured workspace variables to a model that uses structure parameters, see `sldemo_applyVarStruct`.

Defining Structure Parameters

Defining a structure parameter is syntactically the same as defining any MATLAB structure, as described in Structures. Every field in a MATLAB structure that functions as a structure parameter must have a numeric data type, even if Simulink never uses the field. Different fields can have different numeric types.

In structure parameters, numeric types include enumerated types, by virtue of their underlying integers. The value of a structure parameter field, can be a real or complex scalar, vector, or multidimensional array. However, a structure that contains any multidimensional array cannot be tuned. See "Tuning Structure Parameters" on page 19-21.

MATLAB structure, including those used as structure parameters, can have substructures to any depth. Structures and substructures at any level behave identically, so the following instructions refer only to structures unless substructures are specifically the point.

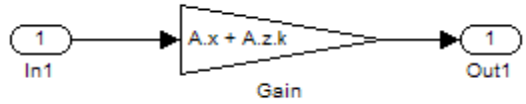
Referencing Structure Parameters

You can use MATLAB syntax, as described in Structures, to dereference a structure parameter field anywhere in a block parameter expression that a MATLAB variable can appear. You cannot specify a structure name in a mathematical block parameter expression, because that would pass a structure rather than a number. For example, suppose you have defined the following parameter structure:

```
A          /* Root structure
|__x          /* Numeric field
|__y          /* Numeric field
```

```
|__z          /* Substructure
   |__ m          /* Numeric field
   |__ n          /* Numeric field
   |__ k          /* Numeric field
```

Given this structure, you can specify an individual field, such as `A.x`, in a block parameter expression, thereby passing only `x` to the block. The effect is exactly the same as if `x` were a separate base workspace variable whose value was the same as the value of `A.x`. Similarly, you could reference `A.z.m`, `A.z.n`, etc. The next figure shows an example that uses a Gain block:



The Gain block's **Gain** parameter is the value of `A.x + A.z.k`, a numeric expression. You could not reference `A` or `A.z` to provide a **Gain** parameter value, because neither resolves to a numeric value.

Structure Parameter Arguments

You can use a parameter structure field as a masked subsystem or model reference argument by referencing the field, as described in the previous section, in Subsystem block mask, or Model block. For example, suppose you have defined the parameter structure used in the previous example.:

```
A          /* Root structure
|__x          /* Numeric field
|__y          /* Numeric field
|__z          /* Substructure
   |__ m          /* Numeric field
   |__ n          /* Numeric field
   |__ k          /* Numeric field
```

You could then:

1. Use a whole structure parameter as a masked subsystem argument or a referenced model argument by referencing the structure's name

2 Dereference the structure as needed in the subsystem mask code, the subsystem itself, or the referenced model.

For example, you could pass `A`, providing access to everything in the root structure, or `A.z`, providing access only to that substructure. The dereferencing syntax for arguments is the same as in any other context, as described in Structures.

When you pass a structure parameter to a referenced model, the structure definitions must be identical in the parent model and the submodel, including any unused fields. See "Systems and Subsystems" on page 2-11, Chapter 21, "Working with Block Masks", and "Using Model Arguments" on page 5-41 more information about passing and using arguments.

Tuning Structure Parameters

You can declare a structure parameter to be tunable using the same techniques that you use to make an ordinary base workspace parameter tunable:

- Clear **Configuration Parameters > Optimization > Inline parameters**. See "Inline parameters" for more information.
- Set **Inline parameters**, then specify the parameter structure as tunable in the Model Parameter Configuration Dialog Box.
- Associate a `Simulink.Parameter` object with the structure parameter, and specify the object's storage class as anything other than `auto`.

A tunable structure parameter can contain a nontunable numeric field (like a multidimensional array) without affecting the tunability of the rest of the structure. You cannot define individual substructures or fields within a structure parameter to be tunable. Only the name of the root level of the structure appears in the Model Configuration Parameter dialog box, and only the root can have a `Simulink.Parameter` object assigned to it.

For more information about tunability, see "Inlining Parameters" on page 19-16 and "Using Tunable Parameters" on page 19-13. For simplicity, those sections mention only separately defined base workspace variables, but all of the information applies without change to tunable structure parameters.

Parameter Structure Limitations

- You cannot define individual substructures or fields within a structure parameter as tunable.
- Tunable structure parameters do not support context sensitivity.

20

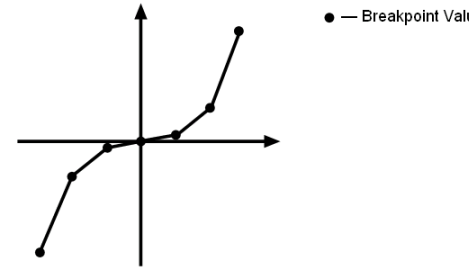
Working with Lookup Tables

About Lookup Table Blocks

A *lookup table* block uses an array of data to map input values to output values, approximating a mathematical function. Given input values, Simulink performs a "lookup" operation to retrieve the corresponding output values from the table. If the lookup table does not define the input values, the block estimates the output values based on nearby table values.

The following example illustrates a one-dimensional lookup table that approximates the function $y = x^3$. The lookup table defines its output (y) data discretely over the input (x) range `[-3, 3]`. The following table and graph illustrate the input/output relationship:

x	-3	-2	-1	0	1	2	3
y	-27	-8	-1	0	1	8	27

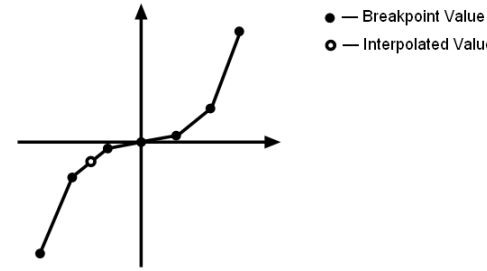


An input of -2 enables the table to look up and retrieve the corresponding output value (-8). Likewise, the lookup table outputs 27 in response to an input of 3.

When the lookup table block encounters an input that does not match any of the table's x values, it can interpolate or extrapolate the answer. For instance, the lookup table does not define an input value of -1.5; however, the block can linearly interpolate the nearest data points (-2, -8) and (-1, -1) to estimate and return a value of -4.5.

Linearly interpolated value

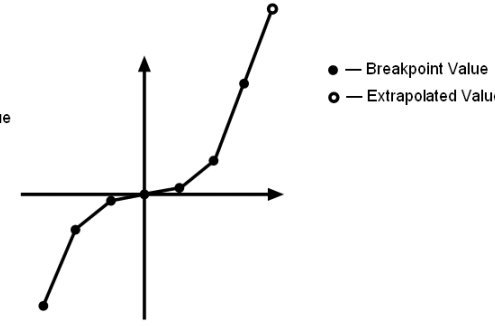
x	-3	-2	-1.5	-1	0	1	2	3
y	-27	-8	-4.5	-1	0	1	8	27



Similarly, although the lookup table does not include data for *x* values beyond the range of `[-3, 3]`, the block can extrapolate values using a pair of data points at either end of the table. Given an input value of 4, the lookup table block linearly extrapolates the nearest data points (2, 8) and (3, 27) to estimate an output value of 46.

Linearly extrapolated value

x	-3	-2	-1	0	1	2	3	4
y	-27	-8	-1	0	1	8	27	46



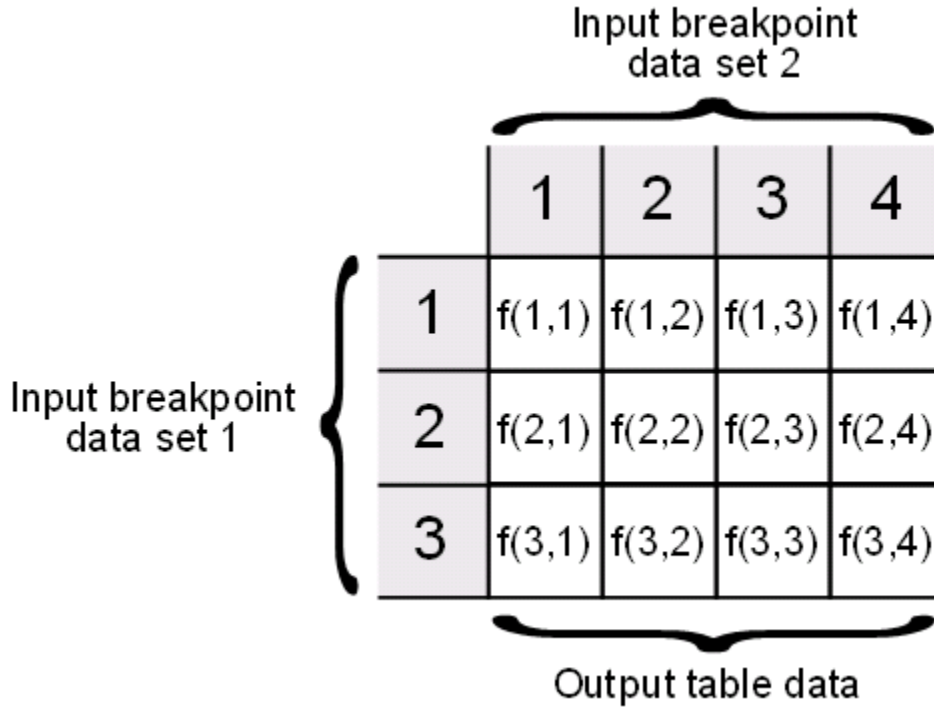
Since table lookups and simple estimations can be faster than mathematical function evaluations, using lookup table blocks might result in speed gains when simulating a model. Consider using lookup tables in lieu of mathematical function evaluations when:

- An analytical expression is expensive to compute.
- No analytical expression exists, but the relationship has been determined empirically.

Simulink provides a broad assortment of lookup table blocks, each geared for a particular type of application. The sections that follow outline the different offerings, suggest how to choose the lookup table best suited to your application, and explain how to interact with the various lookup table blocks.

Anatomy of a Lookup Table

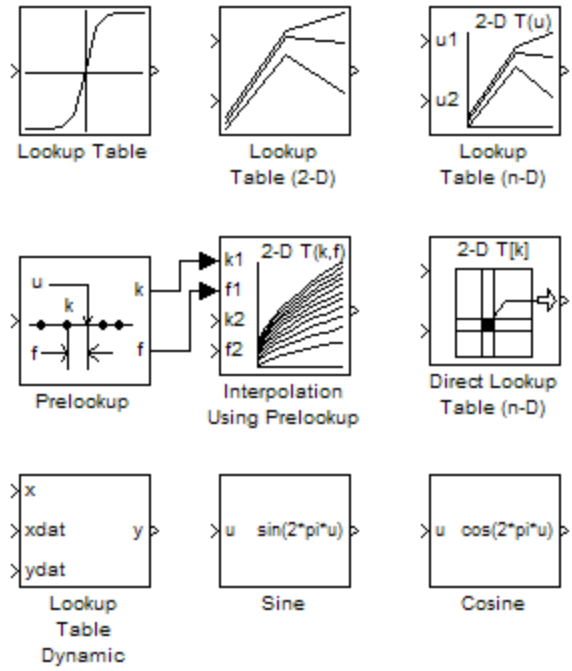
The following figure illustrates the anatomy of a two-dimensional lookup table. Vectors or *breakpoint data sets* and an array, referred to as *table data*, constitute the lookup table.



Each breakpoint data set is an index of input values for a particular dimension of the lookup table. The array of table data serves as a sampled representation of a function evaluated at the breakpoint values. Lookup table blocks use breakpoint data sets to relate a table's input values to the output values that it returns.

Lookup Tables Block Library

Several lookup table blocks appear in the Lookup Tables block library.



The following table summarizes the purpose of each block in the library.

Block Name	Description
Lookup Table	Approximate a one-dimensional function.
Lookup Table (2-D)	Approximate a two-dimensional function.
Lookup Table (n-D)	Approximate an N-dimensional function.
Prelookup	Compute index and fraction for Interpolation Using Prelookup block.
Interpolation Using Prelookup	Use precalculated index and fraction values to accelerate approximation of N-dimensional function.
Direct Lookup Table (n-D)	Index into an N-dimensional table to retrieve the corresponding outputs.
Lookup Table Dynamic	Approximate a one-dimensional function using a dynamically specified table.
Sine	Use a fixed-point lookup table to approximate the sine wave function.
Cosine	Use a fixed-point lookup table to approximate the cosine wave function.

Guidelines for Choosing a Lookup Table

In this section...

Data Set Dimensionality

In some cases, the dimensions of your data set dictate which of the lookup table blocks is right for your application. If you are approximating a one-dimensional function, consider using either the Lookup Table or Lookup Table Dynamic block. If you are approximating a two-dimensional function, consider the Lookup Table (2-D) block. Blocks such as the Lookup Table (n-D) and Direct Lookup Table (n-D) allow you to approximate a function of *N* variables.

Data Set Numeric and Data Types

The numeric and data types of your data set influence the decision of which lookup table block is most appropriate. Although all lookup table blocks support real numbers, the Direct Lookup Table (n-D) and Lookup Table (n-D) blocks also support complex table data. All lookup table blocks support integer and fixed-point data in addition to `double` and `single` data types.

Note For the Direct Lookup Table (n-D) block, fixed-point types are supported for the table data, output port, and optional table input port.

Data Accuracy and Smoothness

The desired accuracy and smoothness of the data returned by a lookup table determine which of the blocks should be used. Most blocks provide options

to perform interpolation and extrapolation, improving the accuracy of values that fall between or outside of the table data, respectively. For instance, the Lookup Table, Lookup Table (2-D), and Lookup Table Dynamic blocks perform linear interpolation and extrapolation, while the Lookup Table (n-D) block performs either linear or cubic spline interpolation and extrapolation. In contrast, the Direct Lookup Table (n-D) block performs table lookups without any interpolation or extrapolation. You can achieve a mix of interpolation and extrapolation methods by using the Prelookup block with the Interpolation Using Prelookup block.

Dynamics of Table Inputs

The dynamics of the lookup table inputs impact which of the lookup table blocks is ideal for your application. The blocks use a variety of index search methods to relate the lookup table inputs to the table's breakpoint data sets. Most of the lookup table blocks offer a binary search algorithm, which performs well if the inputs change significantly from one time step to the next. The Lookup Table (n-D) and Prelookup blocks offer a linear search algorithm. Using this algorithm with the option that resumes searching from the previous result performs well if the inputs change slowly. Certain lookup table blocks also provide a search algorithm that is tailored for breakpoint data sets composed of evenly spaced breakpoints. Note that you can achieve a mix of index search methods by using the Prelookup block with the Interpolation Using Prelookup block.

Efficiency of Performance

When the efficiency with which lookup tables operate is important, consider using the Prelookup block with the Interpolation Using Prelookup block. These blocks separate the table lookup process into two components — an index search that relates inputs to the table data, followed by an interpolation and extrapolation stage that computes outputs. These blocks enable you to perform a single index search and then reuse the results to look up data in multiple tables. Also, the Interpolation Using Prelookup block can perform sub-table selection, where the block interpolates a portion of the table data instead of the entire table. For example, if your 3-D table data constitutes a stack of 2-D tables to be interpolated, you can specify a selection port input to select one or more of the 2-D tables from the stack for interpolation. A full 3-D interpolation has 7 sub-interpolations but a 2-D interpolation requires only 3 sub-interpolations. As a result, significant speed improvements are possible

when some dimensions of a table are used for data stacking and not intended for interpolation. These features make table lookup operations more efficient, reducing computational effort and thus simulation time.

Summary of Lookup Table Block Features

Use the following table to identify features that correspond to particular lookup table blocks, then select the block that best meets your requirements.

Feature	Lookup Table	Lookup Table (2-D)	Lookup Table Dynamic	Lookup Table (n-D)	Direct Lookup Table (n-D)	Prelookup	Interp. Using Prelookup
Interpolation Methods							
Flat (none)	•	•	•	•	•	•	•
Linear	•	•	•	•		•	•
Cubic spline				•			
Extrapolation Methods							
Clipping	•	•	•	•	•	•	•
Linear	•	•	•	•		•	•
Cubic spline				•			
Numeric & Data Type Support							
Complex				•	•		
Double, Single	•	•	•	•	•	•	•
Integer	•	•	•	•	•	•	•
Fixed point	•	•	•	•	•	•	•
Index Search Methods							
Binary	•	•	•	•		•	
Linear				•		•	
Evenly spaced points				•	•	•	
Start at previous index				•		•	
Miscellaneous							
Sub-table selection					•		•
Dynamic breakpoint data						•	
Dynamic table data			•		•		•
Input range checking				•	•	•	•

Entering Breakpoints and Table Data

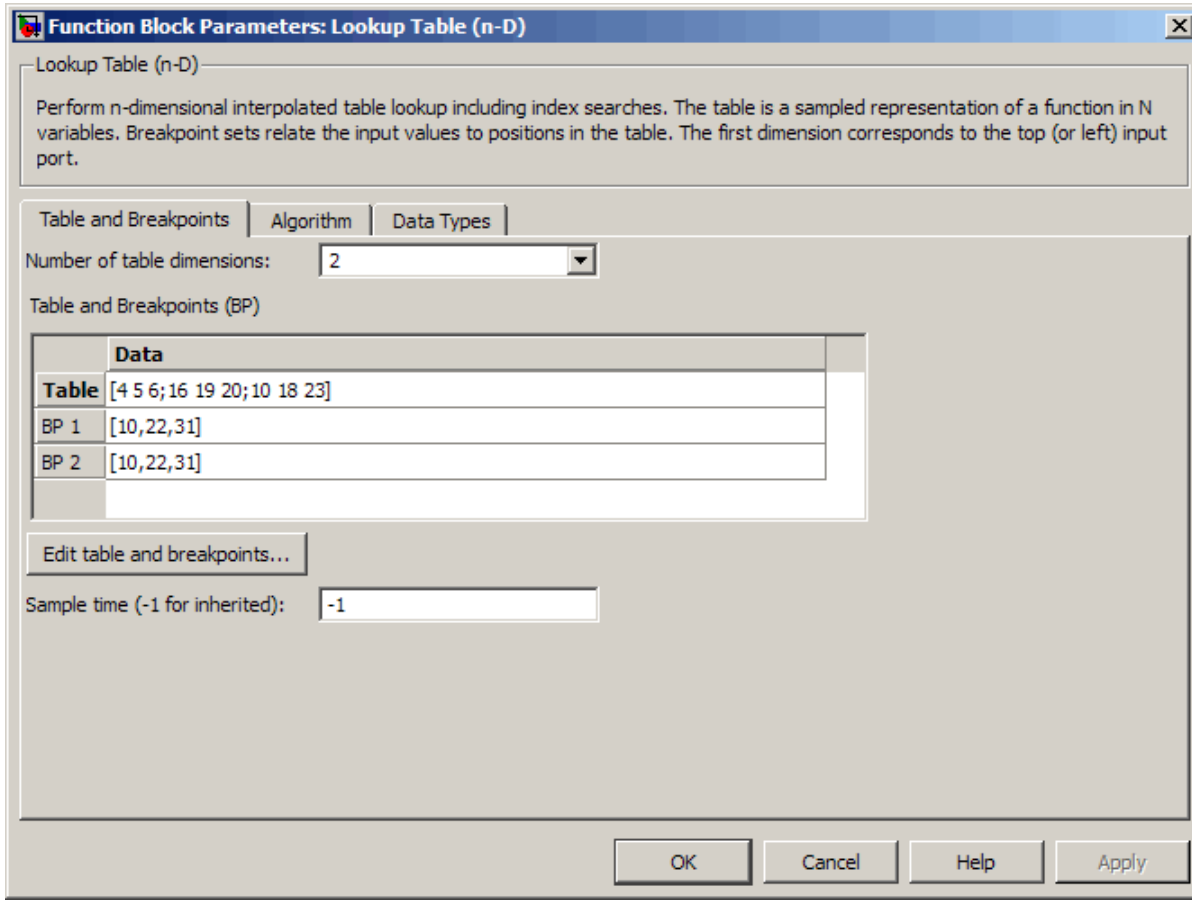
In this section...

Entering Data in a Block Parameter Dialog Box

Use the following procedure to populate a Lookup Table (n-D) block using the parameter dialog box. In this example, the lookup table approximates the function $y = x^3$ over the range `[-3, 3]`.

1. Copy a Lookup Table (n-D) block from the Lookup Tables block library to a Simulink model.
2. In the model window, double-click the Lookup Table (n-D) block.

The block parameter dialog box appears.



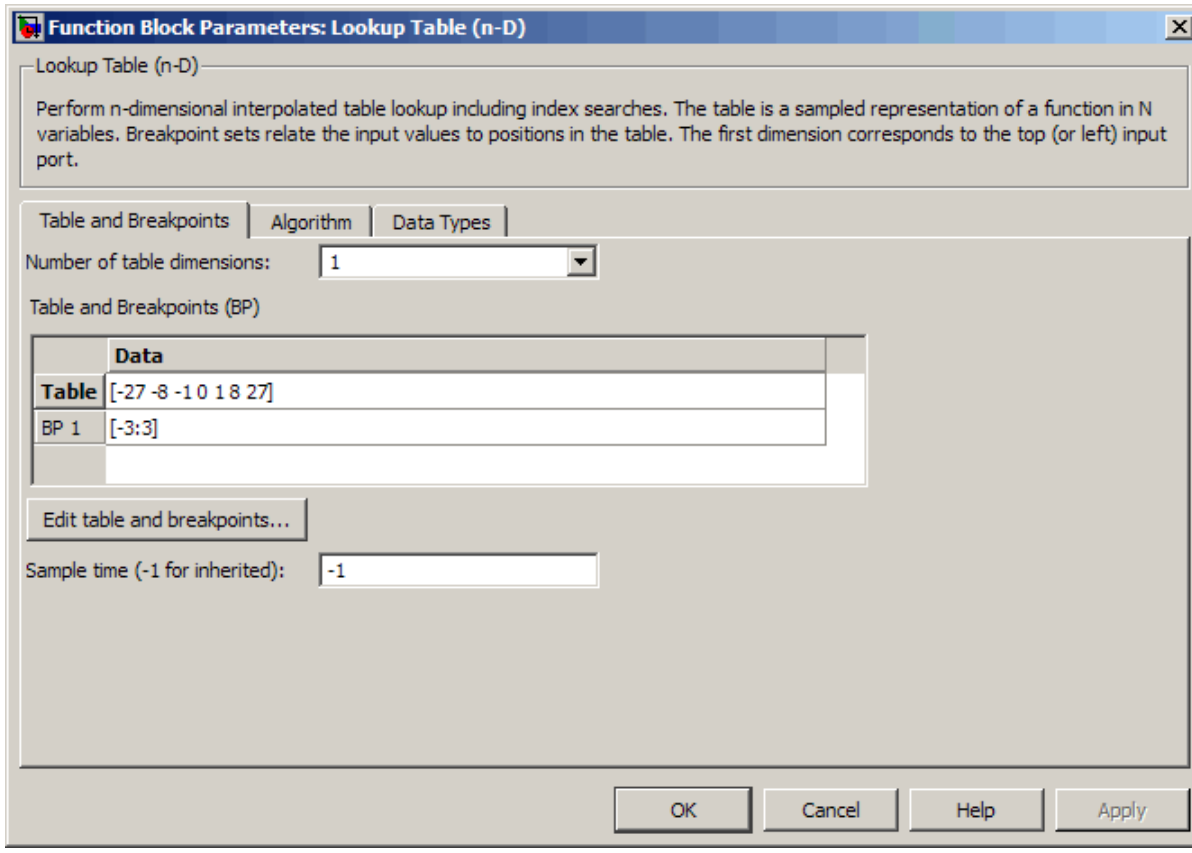
The dialog box displays the default values for the block.

3 Enter the table dimensions, table data, and breakpoint data set in the specified fields of the dialog box:

- In the **Number of table dimensions** field, enter `1`.
- In the **Table** field, enter `[-27 -8 -1 0 1 8 27]`.
- In the **BP 1** field, enter `[-3:3]`.

- Click **Apply**.

The block dialog box looks something like this:



4 Click **OK** to apply the changes and close the dialog box.

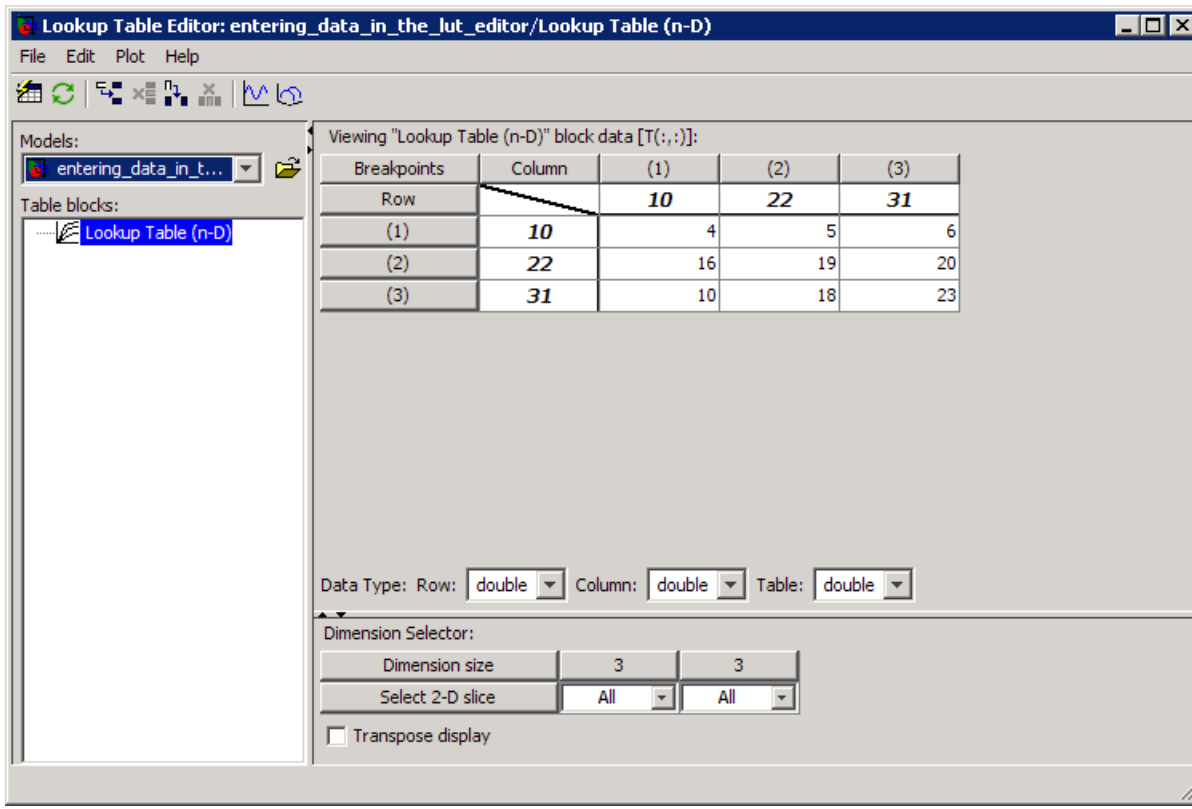
Entering Data in the Lookup Table Editor

Use the following procedure to populate a Lookup Table (n-D) block using the Lookup Table Editor. In this example, the lookup table approximates the function $z = x^2 + y^2$ over the input ranges `x = [0, 2]` and `y = [0, 2]`.

1 Copy a Lookup Table (n-D) block from the Lookup Tables block library to a Simulink model.

2 Open the Lookup Table Editor by selecting **Lookup Table Editor** from the Simulink **Tools** menu or by clicking **Edit table and breakpoints** on the dialog box of the Lookup Table (n-D) block.

The Lookup Table Editor appears.



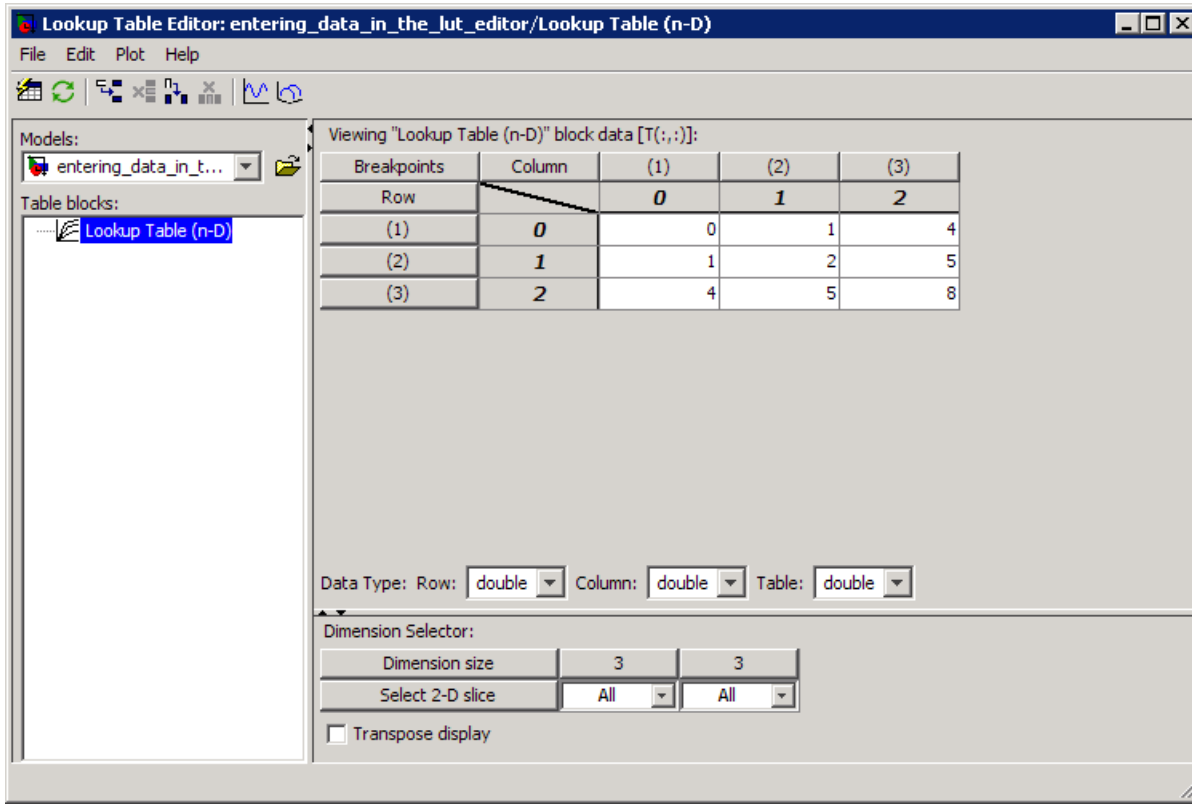
It displays the default data for the Lookup Table (n-D) block.

3 Under **Viewing "Lookup Table (n-D)" block data**, enter the breakpoint data sets and table data in the appropriate cells. To change the default

data, double-click a cell, enter the new value, and then press **Enter** or click outside the field to confirm the change:

- In the cells associated with the **Row Breakpoints**, enter each of the values `[0 1 2]`.
- In the cells associated with the **Column Breakpoints**, enter each of the values `[0 1 2]`.
- In the table data cells, enter the values in the array `[0 1 4; 1 2 5; 4 5 8]`.

The Lookup Table Editor should look similar to the following.



4 In the Lookup Table Editor, select **File > Update Block Data** to update the data in the Lookup Table (n-D) block.

5 Close the Lookup Table Editor.

Entering Data Using Inports of the Lookup Table Dynamic Block

Use the following procedure to populate a Lookup Table Dynamic block using that block's inports. In this example, the lookup table approximates the function $y = 3x^2$ over the range `[0, 10]`.

1 Copy a Lookup Table Dynamic block from the Lookup Tables block library to a Simulink model.

2 Copy the blocks needed to implement the equation $y = 3x^2$ to the Simulink model:

- A Constant block to define the input range, from the Sources library
- A Math Function block to square the input range, from the Math Operations library
- A Gain block to multiply the signal by 3, also from the Math Operations library

3 Assign the following parameter values to the Constant, Math Function, and Gain blocks using their dialog boxes:

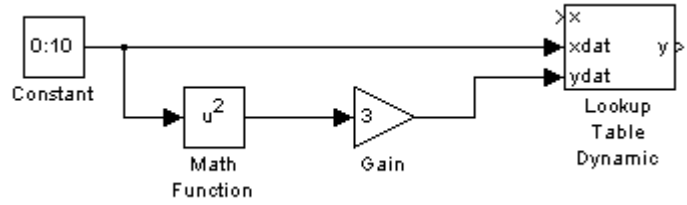
Block	Parameter	Value
Constant	**Constant value**	`0:10`
Math Function	**Function**	`square`
Gain	**Gain**	`3`

4 Input the breakpoint data set to the Lookup Table Dynamic block by connecting the outport of the Constant block to the inport of the Lookup Table Dynamic block labeled **xdat**. This signal is the input breakpoint data set for *x*.

5 Input the table data to the Lookup Table Dynamic block by branching the output signal from the Constant block and connecting it to the Math

Function block. Then connect the Math Function block to the Gain block. Finally, connect the Gain block to the inport of the Lookup Table Dynamic block labeled **ydat**. This signal is the table data for *y*.

The model should look similar to the following.



Characteristics of Lookup Table Data

In this section...

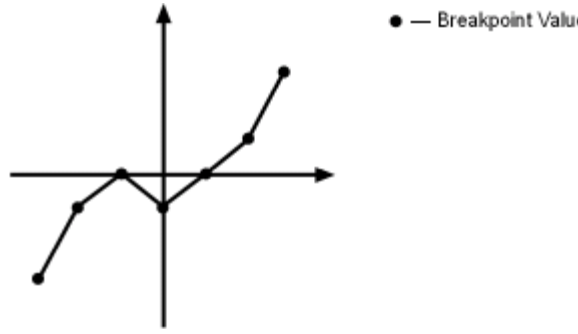
Sizes of Breakpoint Data Sets and Table Data

The following constraints apply to the sizes of breakpoint data sets and table data associated with lookup table blocks:

- The memory limitations of your system constrain the overall size of a lookup table.
- Lookup tables must use consistent dimensions so that the overall size of the table data reflects the size of each breakpoint data set.

To illustrate the second constraint, consider the following vectors of input and output values that create the relationship in the plot.

```
Vector of input values:   [-3 -2 -1  0 1 2 3]
Vector of output values:  [-3 -1  0 -1 0 1 3]
```



In this example, the input and output data are the same size (1-by-7), making the data consistently dimensioned for a 1-D lookup table.

The following input and output values define the 2-D lookup table that is graphically shown.

```
Row index input values:    [1 2 3]
Column index input values: [1 2 3 4]
Table data:                [11 12 13 14; 21 22 23 24; 31 32 33 34]
```

	1	2	3	4
1	11	12	13	14
2	21	22	23	24
3	31	32	33	34

In this example, the sizes of the vectors representing the row and column indices are 1-by-3 and 1-by-4, respectively. Consequently, the output table must be of size 3-by-4 for consistent dimensions.

Monotonicity of Breakpoint Data Sets

The first stage of a table lookup operation involves relating inputs to the breakpoint data sets. The search algorithm requires that input breakpoint sets be *monotonically increasing*, that is, each successive element is equal to or greater than its preceding element. For example, the vector

```
A = [0   0.5   1   1.9   2   2   2   2.1   3]
```

repeats the value `2` while all other elements are increasingly larger than their predecessors; hence, `A` is monotonically increasing.

For lookup tables with data types other than `double` or `single`, the search algorithm requires an additional constraint due to quantization effects. In such cases, the input breakpoint data sets must be *strictly monotonically increasing*, that is, each successive element must be greater than its preceding element. Consider the vector

```
B = [0   0.5   1   1.9   2   2.1   2.17   3]
```

in which each successive element is greater than its preceding element, making `B` strictly monotonically increasing.

Note Although a breakpoint data set is strictly monotonic in `double` format, it might not be so after conversion to a fixed-point data type.

Formulation of Evenly Spaced Breakpoints

You can represent evenly spaced breakpoints in a data set by using one of these methods.

Formulation	Example	When to Use This Formulation
`[first_value:spacing:last_value]`	`[10:10:200]`	The lookup table does *not* use `double` or `single`.
`first_value + spacing * [0:(last_value-first_value)/spacing]`	`1 + (0.02 * [0:450])`	The lookup table uses `double` or `single`.

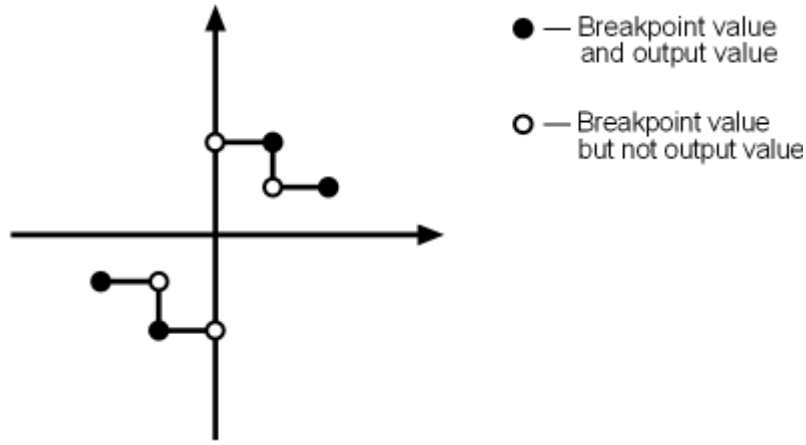
Because floating-point data types cannot precisely represent some numbers, the second formulation works better for `double` and `single`. For example, use `1 + (0.02 * [0:450])` instead of `[1:0.02:10]`.

Tip Do not use the MATLAB `linspace` function to define evenly spaced breakpoints. Simulink uses a tighter tolerance to check whether a breakpoint set has even spacing. If you use `linspace` to define breakpoints for your lookup table, Simulink considers the breakpoints to be unevenly spaced.

Representation of Discontinuities in Lookup Tables

You can represent discontinuities in lookup tables that have monotonically increasing breakpoint data sets. To create a discontinuity, repeat an input value in the breakpoint data set with different output values in the table data. For example, these vectors of input (x) and output (y) values associated with a 1-D lookup table create the step transitions depicted in the plot that follows.

```
Vector of input values:   [-2 -1 -1  0 0 1 1 2]
Vector of output values:  [-1 -1 -2 -2 2 2 1 1]
```



This example has discontinuities at x = -1, 0, and +1.

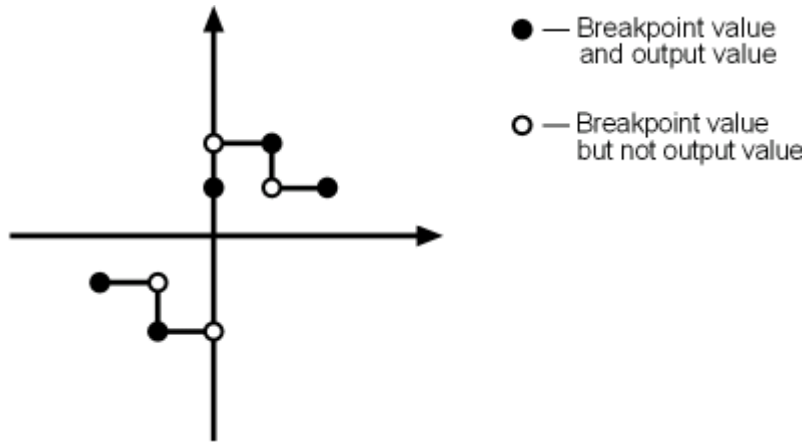
When there are two output values for a given input value, the block chooses the output according to these rules:

- If the input signal is less than zero, the block returns the output value associated with the last occurrence of the input value in the breakpoint data set. In this example, if the input is -1, y is -2, marked with a solid circle.
- If the input signal is greater than zero, the block returns the output value associated with the first occurrence of the input value in the breakpoint data set. In this example, if the input is 1, y is 2, marked with a solid circle.
- If the input signal is zero and there are two output values specified at the origin, the block returns the average of those output values. In this example, if the input is 0, y is 0, the average of the two output values -2 and 2 specified at x = 0.

When there are three points specified at the origin, the block generates the output associated with the middle point. The following example demonstrates this special rule.

```
Vector of input values:   [-2 -1 -1  0 0 0 1 1 2]
```

```
Vector of output values:  [-1 -1 -2 -2 1 2 2 1 1]
```



In this example, three points define the discontinuity at the origin. When the input is 0, y is 1, the value of the middle point.

You can apply this same method to create discontinuities in breakpoint data sets associated with multidimensional lookup tables.

Methods for Estimating Missing Points

In this section...

About Estimating Missing Points

The second stage of a table lookup operation involves generating outputs that correspond to the supplied inputs. If the inputs match the values of indices specified in breakpoint data sets, the block outputs the corresponding values. However, if the inputs fail to match index values in the breakpoint data sets, Simulink estimates the output. In the block parameter dialog box, you can specify how to compute the output in this situation. The available lookup methods are described in the following sections.

Interpolation Methods

When an input falls between breakpoint values, the block interpolates the output value using neighboring breakpoints. Most lookup table blocks have the following interpolation methods available:

- `None (Flat)` — Disables interpolation and uses the rounding operation titled `Use Input Below`. For more information, see "Rounding Methods" on page 20-25.
- `Linear interpolation` — Fits a line between the adjacent breakpoints, and returns the point on that line corresponding to the input.
- `Cubic spline interpolation` — Fits a cubic spline to the adjacent breakpoints, and returns the point on that spline corresponding to the input.

Note Blocks such as the Lookup Table Dynamic block do not allow you to choose an interpolation method. The `Interpolation-Extrapolation` option in the **Lookup Method** field of its block parameter dialog box performs linear interpolation.

Each interpolation method includes a trade-off between computation time and the smoothness of the result. Although rounding is quickest, it is the least smooth. Linear interpolation is slower than rounding but generates smoother results, except at breakpoints where the slope changes. Cubic spline interpolation is the slowest method but produces the smoothest results.

Extrapolation Methods

When an input falls outside the range of a breakpoint data set, the block extrapolates the output value from a pair of values at the end of the breakpoint data set. Most lookup table blocks have the following extrapolation methods available:

- `None (Clip to Range)` or `(Use End Values)` — Disables extrapolation and returns the table data corresponding to the end of the breakpoint data set range.
- `Linear extrapolation` — Fits a line between the first or last pair of breakpoints, depending if the input is less than the first or greater than the last breakpoint, respectively. This method returns the point on that line corresponding to the input.
- `Cubic spline extrapolation` — Fits a cubic spline to the first or last pair of breakpoints, depending if the input is less than the first or greater than the last breakpoint, respectively. This method returns the point on that spline corresponding to the input.

Note Blocks such as the Lookup Table Dynamic block do not allow you to choose an extrapolation method. The `Interpolation-Extrapolation` option in the **Lookup Method** field of its block parameter dialog box performs linear extrapolation.

In addition to these methods, some lookup table blocks, such as the Lookup Table (n-D) block, allow you to select an action to perform when encountering situations that require extrapolation. For instance, you can specify that Simulink generate either a warning or an error when the lookup table inputs are outside the ranges of the breakpoint data sets. To specify such an action, select it from the **Action for out-of-range input** list on the block parameter dialog box.

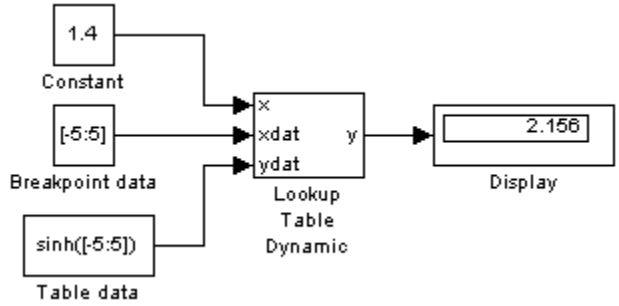
Rounding Methods

If an input falls between breakpoint values or outside the range of a breakpoint data set and you do not specify interpolation or extrapolation, the block rounds the value to an adjacent breakpoint and returns the corresponding output value. Most lookup table blocks let you select one of the following rounding methods:

- `Use Input Nearest` — Returns the output value corresponding to the nearest input value.
- `Use Input Below` — Returns the output value corresponding to the breakpoint value that is immediately less than the input value. If no breakpoint value exists below the input value, it returns the breakpoint value nearest the input value.
- `Use Input Above` — Returns the output value corresponding to the breakpoint value that is immediately greater than the input value. If no breakpoint value exists above the input value, it returns the breakpoint value nearest the input value.

Example Output for Lookup Methods

In the following model, the Lookup Table Dynamic block accepts a vector of breakpoint data given by `[-5:5]` and a vector of table data given by `sinh([-5:5])`.



The Lookup Table Dynamic block outputs the following values when using the specified lookup methods and inputs.

Lookup Method	Input	Output	Comment
`Interpolation-Extrapolation`	`1.4`	`2.156`	N/A
	`5.2`	`83.59`	N/A
`Interpolation-Use End Values`	`1.4`	`2.156`	N/A
	`5.2`	`74.2`	The block uses the value for `sinh(5.0)`.
`Use Input Above`	`1.4`	`3.627`	The block uses the value for `sinh(2.0)`.
	`5.2`	`74.2`	The block uses the value for `sinh(5.0)`.
`Use Input Below`	`1.4`	`1.175`	The block uses the value for `sinh(1.0)`.
	`-5.2`	`-74.2`	The block uses the value for `sinh(-5.0)`.
`Use Input Nearest`	`1.4`	`1.175`	The block uses the value for `sinh(1.0)`.

Lookup Table Editor

In this section...

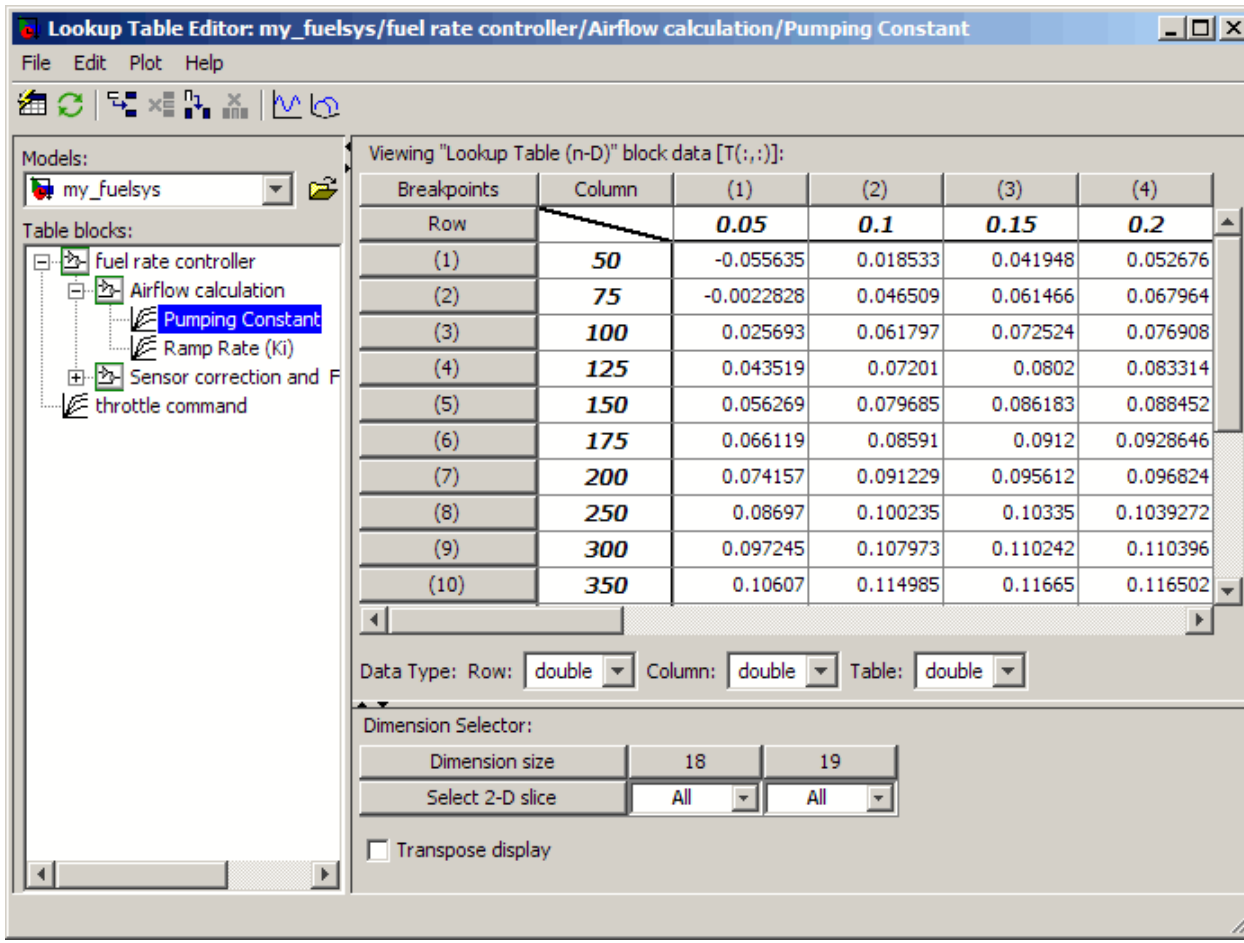
When to Use the Lookup Table Editor

Use the Lookup Table Editor to inspect and change the table elements of any lookup table block in a model, including custom blocks that you create using the Simulink Mask Editor (see "Editing Custom Lookup Table Blocks" on page 20-58). You can also use a block parameter dialog box to edit a table. However, you must open the subsystem containing the block first and then its parameter dialog box. With the Lookup Table Editor, you can skip these steps.

Note You cannot use the Lookup Table Editor to change the dimensions of a lookup table. You must use the block parameter dialog box for this purpose.

Layout of the Lookup Table Editor

To open the editor, select **Lookup Table Editor** from the Simulink **Tools** menu. The editor appears.

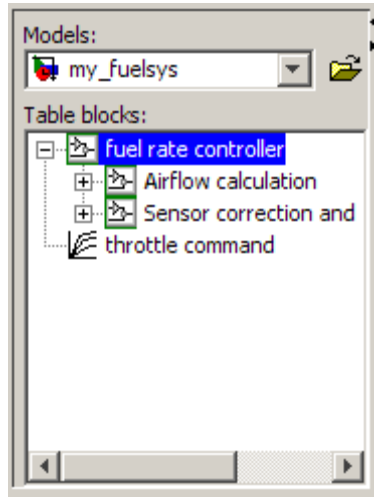


The editor contains two panes and a toolbar.

- Use the left pane to browse and select lookup table blocks in any open model (see “Browsing Lookup Table Blocks” on page 20-30).
- Use the right pane to edit the lookup table of the selected block (see “Editing Table Values” on page 20-31).
- Use the toolbar for one-click access to frequently-used commands in the editor. Each toolbar button has a tooltip that explains its function.

Browsing Lookup Table Blocks

The **Models** list in the upper-left corner of the Lookup Table Editor lists the names of all models open in the current MATLAB session. To browse lookup table blocks for any open models, select the model name from the list. A tree-structured view of lookup table blocks for the selected model appears in the **Table blocks** field beneath the **Models** list.



The tree view initially lists all lookup table blocks that reside at the model root level. It also displays any subsystems that contain lookup table blocks. Clicking the expand button (+) to the left of the subsystem name expands the tree to show lookup table blocks in that subsystem. The expanded view also shows any subsystems in the expanded subsystem. You can continue expanding subsystem nodes to display lookup table blocks at any level in the model hierarchy.

Clicking any lookup table block in the tree view displays the lookup table for that block in the right pane, so that you can edit the table (see “Editing Table Values” on page 20-31).

Note If you want to browse the lookup table blocks in a model that is not currently open, you can tell the Lookup Table Editor to open the model. To do this, select **File > Open Model** in the editor.

Editing Table Values

In the **Viewing "Lookup Table (n-D)" block data** table view of the Lookup Table Editor, you can edit the lookup table of the block currently selected in the adjacent tree view.

Viewing "Lookup Table (n-D)" block data [T(:,:)]:

Breakpoints	Column	(1)	(2)	(3)
Row		0.05	0.1	0.15
(1)	50	-0.055635	0.018533	0.041948
(2)	75	-0.0022828	0.046509	0.061466
(3)	100	0.025693	0.061797	0.072524
(4)	125	0.043519	0.07201	0.0802
(5)	150	0.056269	0.079685	0.086183
(6)	175	0.066119	0.08591	0.0912
(7)	200	0.074157	0.091229	0.095612

The table view displays the entire table if it is one- or two-dimensional or a two-dimensional slice of the table if the table has more than two dimensions (see "Displaying N-Dimensional Tables in the Editor" on page 20-55). To change any value that appears, double-click the value. The Lookup Table Editor replaces the value with an edit field containing the value. Edit the value and then press **Enter** or click outside the field to confirm the change.

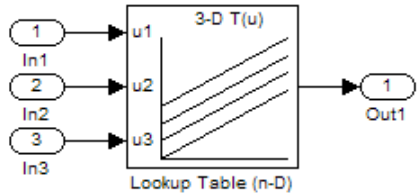
In the **Data Type** below the table, you can specify the data type by row or column, or for the entire table. By default, the data type is `double`. To change the data type, select the pop-up index list for the table element for which you want to change the data type.

The Lookup Table Editor records your changes by maintaining a copy of the table. To update the copy that the lookup table block maintains, select **File > Update Block Data** in the Lookup Table Editor. To restore

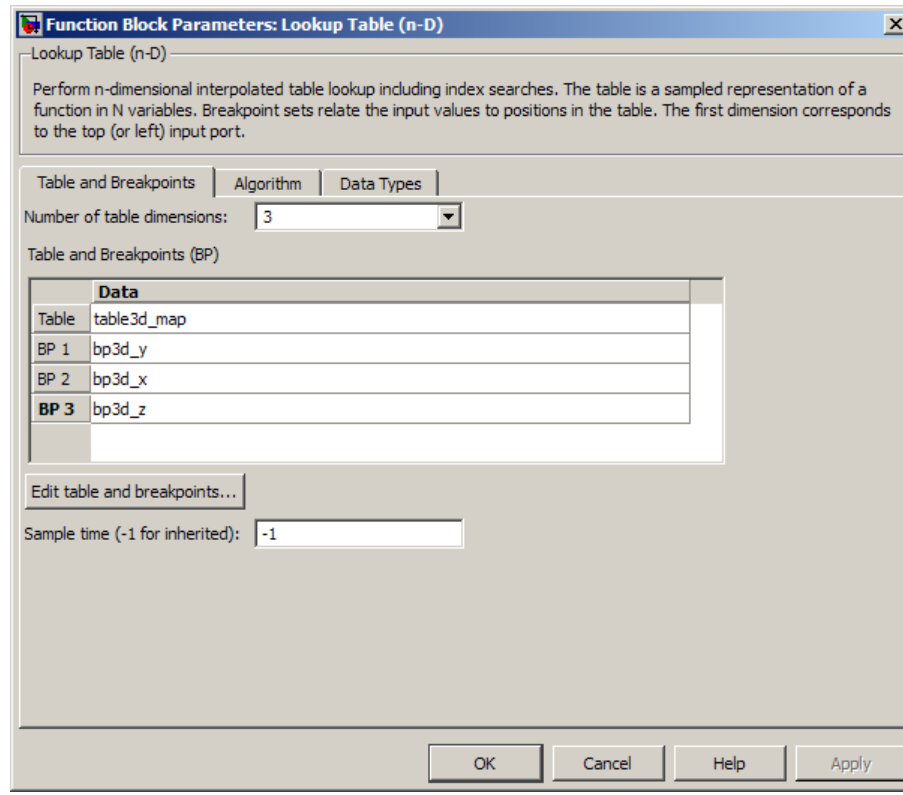
the Lookup Table Editor's copy to the values stored in the block, select **File > Reload Block Data**.

Working with Table Data of Standard Format

Suppose that you specify a 3-D lookup table in a Lookup Table (n-D) block.



You use workspace variables to define the breakpoint and table data:



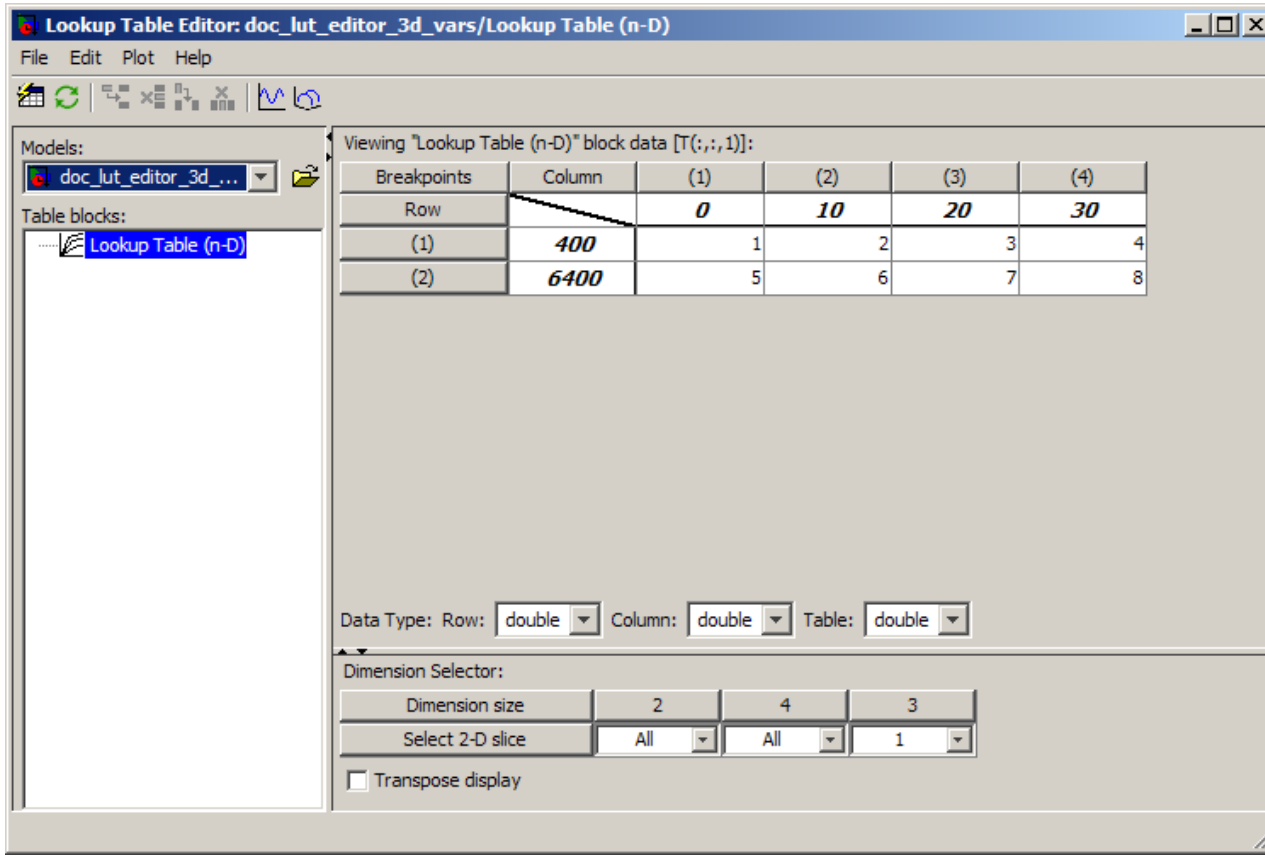
The table data uses the default Simulink format:

```
table3d_map(:,:,1) =

     1     2     3     4
     5     6     7     8

table3d_map(:,:,2) =

    11    12    13    14
    15    16    17    18

table3d_map(:,:,3) =

   111   112   113   114
   115   116   117   118
```

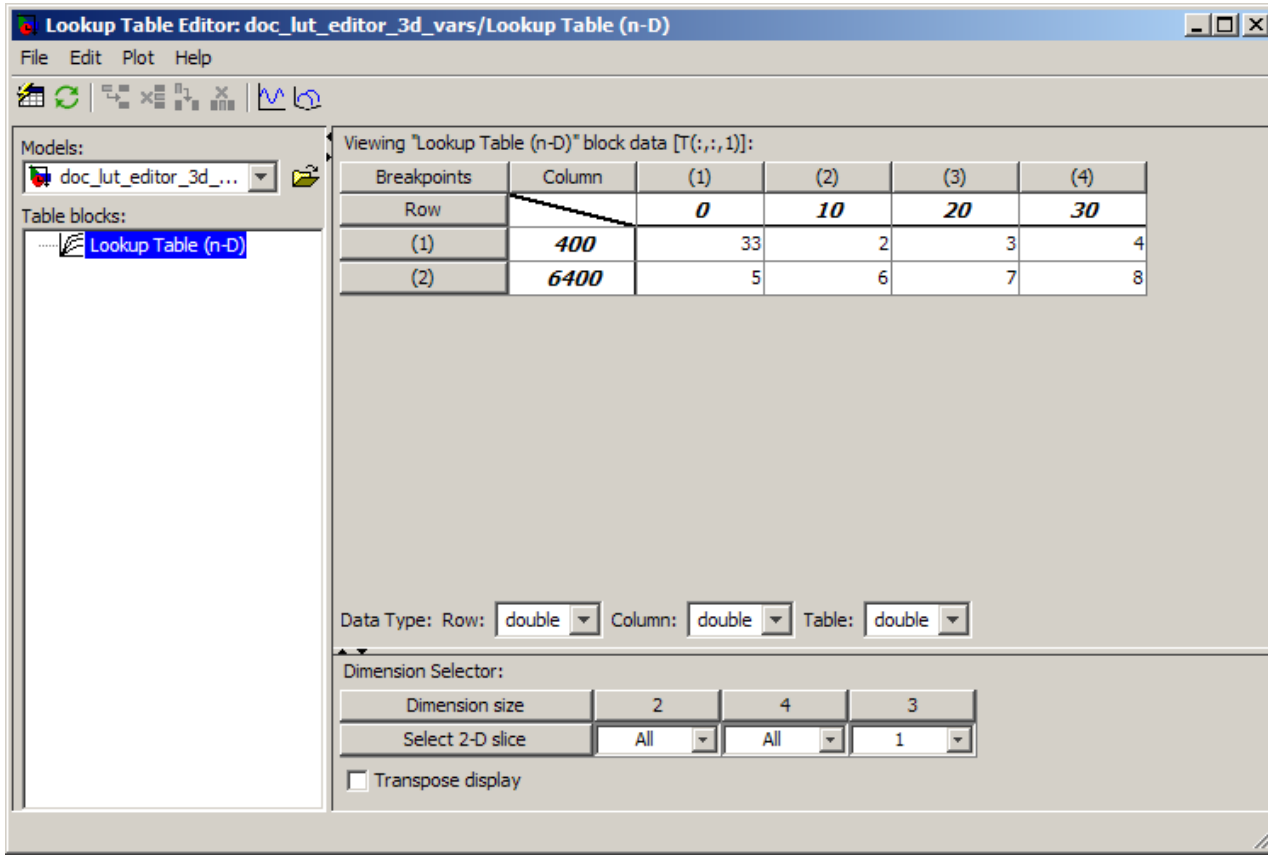
The breakpoint sets have the following values:

```
bp3d_y =

   400  6400

bp3d_x =

     0    10    20    30

bp3d_z =

     0    10    20
```

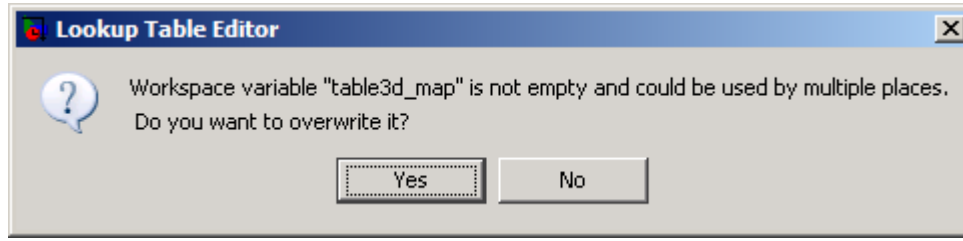
When you click **Edit table and breakpoints** to open the Lookup Table Editor, you see:



Suppose that you change a value in the Lookup Table Editor as follows:

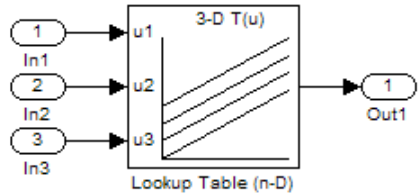


When you select **File > Update Block Data**, you can propagate the change to `table3d_map`, the workspace variable that contains the table data for the Lookup Table (n-D) block. To propagate the change, click **Yes** in the pop-up window that asks if you want to overwrite the workspace variable:

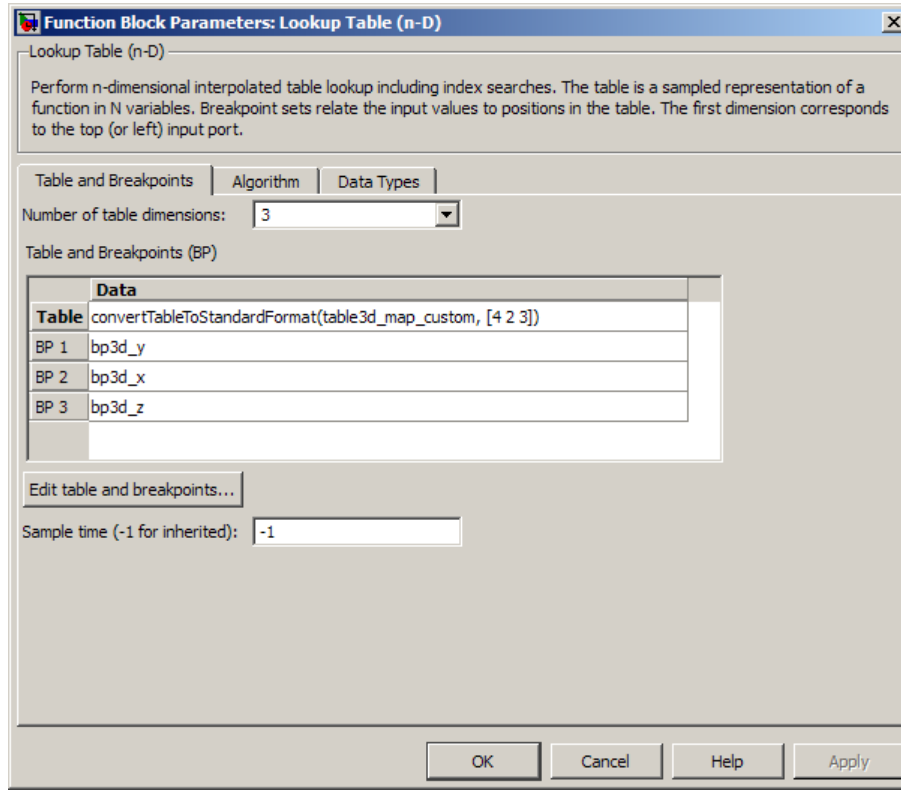


Working with Table Data of Nonstandard Format

Suppose that you specify a 3-D lookup table in a Lookup Table (n-D) block.



You use workspace variables to define the breakpoint and table data:



The table data uses a nonstandard format for representing 3-D table data that differs from the default Simulink format:

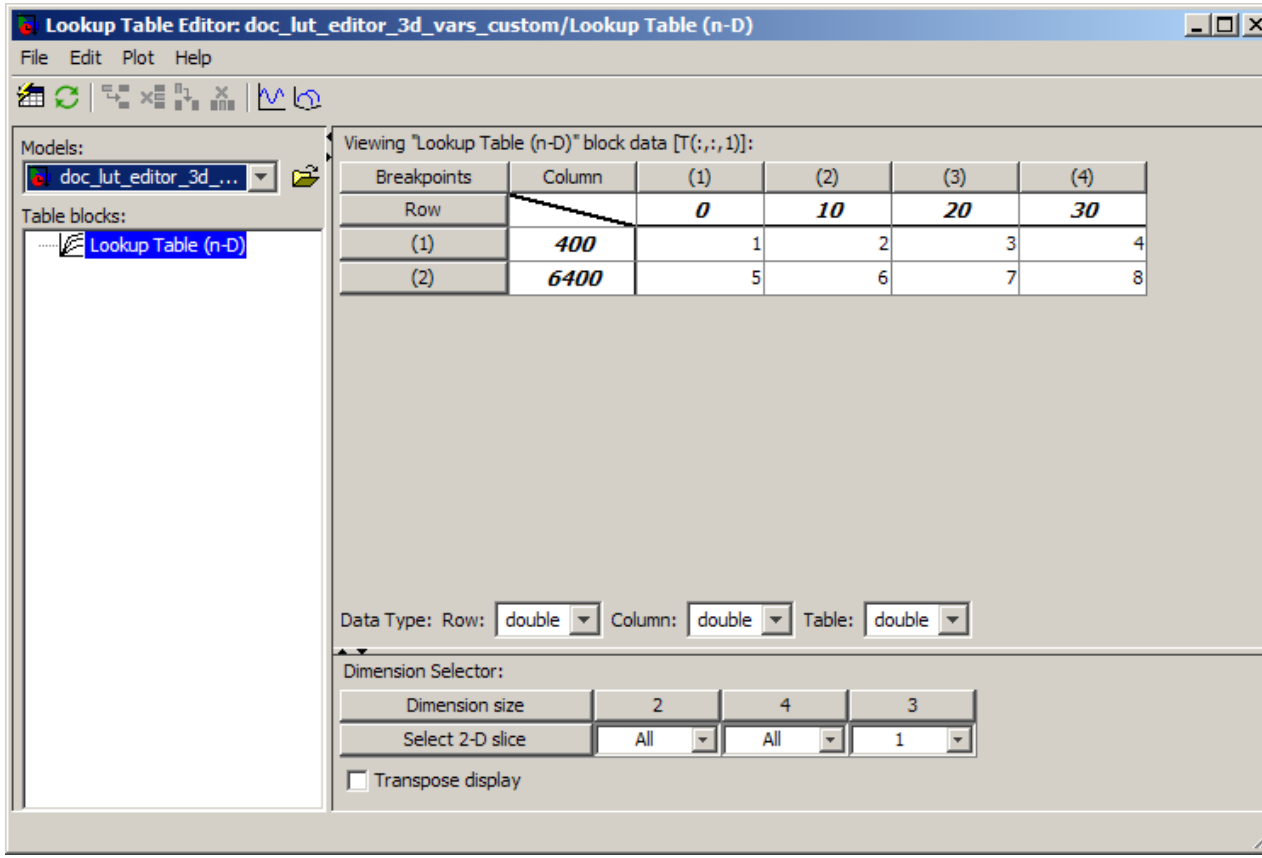
```
table3d_map_custom =

     1     2     3     4
     5     6     7     8
    11    12    13    14
    15    16    17    18
   111   112   113   114
   115   116   117   118
```

The expression in the **Table** edit field converts the table data from a nonstandard format to the default Simulink format.

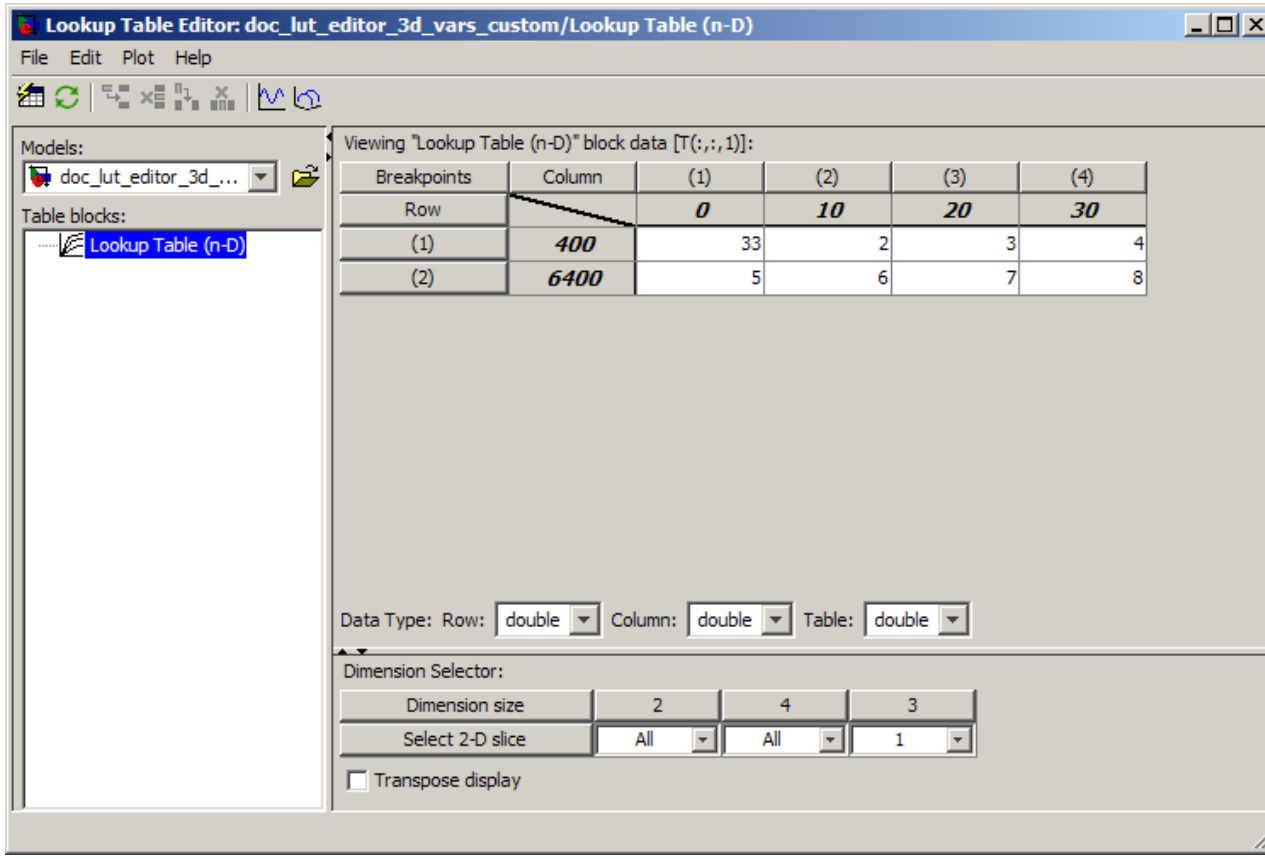
The breakpoint sets have the following values:

```
bp3d_y =

   400  6400

bp3d_x =

     0    10    20    30

bp3d_z =

     0    10    20
```

When you click **Edit table and breakpoints** to open the Lookup Table Editor, you see:



Suppose that you change a value in the Lookup Table Editor as follows:



When you select **File > Update Block Data**, you cannot propagate the change to `table3d_map_custom`, the workspace variable that contains the nonstandard table data for the Lookup Table (n-D) block. To propagate the change, you must register a customization function that resides on the MATLAB search path. For details, see "Example of Propagating a Change for Table Data of Nonstandard Format" on page 20-46.

How to Propagate Changes in the Lookup Table Editor to Workspace Variables of Nonstandard Format

Step	Task	Reference
1	Register a customization function for the Lookup Table Editor.	"How to Register a Customization Function for the Lookup Table Editor" on page 20-42
2	Select the appropriate responses when prompted in the Lookup Table Editor.	"How to Respond to Prompts in the Lookup Table Editor" on page 20-46

How to Register a Customization Function for the Lookup Table Editor

To register a customization function for the Lookup Table Editor:

1. In MATLAB, create a file named `sl_customization.m` to register your customization:

```
function sl_customization(cm)

cm.LookupTableEditorCustomizer.getTableConvertToCustomInfoFcnHandle{end+1} = ...
@myConversionInfoFunction;

end
```

   The string *`myConversionInfoFunction`* represents a function name of your choice.

2. In your `sl_customization.m` file, define a function that returns a `blkInfo` object.

```
function blkInfo = myConversionInfoFunction(blk, tableStr)

    blkInfo.allowTableConvertLocal = false;
    blkInfo.tableWorkSpaceVarName = '';
    blkInfo.tableConvertFcnHandle = [];
```

```
    % Directions for converting table data of block type 1
    if strcmp(get_param(blk, 'BlockType'), 'block_type_1')
        blkInfo.allowTableConvertLocal = true;
        blkInfo.tableWorkSpaceVarName = 'variable_name_1';
    end

    % Directions for converting table data of block type 2
    if strcmp(get_param(blk, 'BlockType'), 'block_type_2')
        blkInfo.allowTableConvertLocal = true;
        blkInfo.tableWorkSpaceVarName = 'variable_name_2';
    end

    ......

    % Directions for converting table data of block type N
    if strcmp(get_param(blk, 'BlockType'), 'block_type_N')
        blkInfo.allowTableConvertLocal = true;
        blkInfo.tableWorkSpaceVarName = 'variable_name_N';
    end

    if blkInfo.allowTableConvertLocal
        blkInfo.tableConvertFcnHandle = @myConvertTableDataFcn;
    end

end
```

For each type of lookup table block that contains nonstandard table data, specify the following three properties:

- `allowTableConvertLocal` — tells the Lookup Table Editor if table data conversion is allowed for a block
- `tableWorkSpaceVarName` — specifies the name of the workspace variable that has a nonstandard table format
- `tableConvertFcnHandle` — specifies the handle for the conversion function

Tip You can specify more restrictive `if` conditions in this function. For example, to specify that table data conversion occur for a block with a given name, you can use:

```
if strcmp(strrep(blk,sprintf('\n'), ' '), 'full_block_path')
    blkInfo.allowTableConvertLocal = true;
    blkInfo.tableWorkSpaceVarName = 'variable_name';
end
```

When the `allowTableConvertLocal` property is true:

- The table data for that block can be converted to the nonstandard format of the workspace variable whose name matches `tableWorkSpaceVarName`.
- The function that converts table data corresponds to the handle that `tableConvertFcnHandle` specifies.

  You can use any alphanumeric name for the conversion function. The string *`myConvertTableDataFcn`* represents a function name of your choice.

3. In your `sl_customization.m` file, define the function that converts table data from the Lookup Table Editor format to the nonstandard format of your workspace variable.
4. Verify that your `sl_customization.m` file is complete.
5. Put `sl_customization.m` on the MATLAB search path.

Note You can have multiple files with the name `sl_customization.m` on the search path.

6. At the MATLAB prompt, enter the following command to refresh all Simulink customizations.

```
sl_refresh_customizations
```

What Happens When Multiple Customization Functions Exist

If you have multiple `sl_customization.m` files on the search path, the following happens:

- At the start of a MATLAB session, Simulink loads each customization file on the path and executes the function at the top. Executing each function establishes the customizations for that session.
- When you select **File > Update Block Data** in the Lookup Table Editor, the editor checks the list of function handles in the cell array for `cm.LookupTableEditorCustomizer.getTableConvertToCustomInfoFcnHandle`.

If the cell array...	Changes in the Lookup Table Editor...
Is empty	Cannot propagate to workspace variables with nonstandard format
Contains one or more function handles	Can propagate to workspace variables with nonstandard format, depending on the value of the `allowTableConvertLocal` property

- The `allowTableConvertLocal` property controls whether or not table data for a block is converted from the standard format in the Lookup Table Editor to a nonstandard format in a workspace variable.

If a customization function specifies this block property to be...	Then table data is...
`true`	Converted to the nonstandard format in the workspace variable
`false`	Not converted to the nonstandard format in the workspace variable
`true`, but another customization function specifies the property to be `false`	Not converted and the Lookup Table Editor issues an error

How to Respond to Prompts in the Lookup Table Editor

When you select **File > Update Block Data** in the Lookup Table Editor, several prompts appear. Click **Yes** when asked if you want to:

- Overwrite workspace variables for breakpoint data
- Overwrite workspace variables for table data

Example of Propagating a Change for Table Data of Nonstandard Format

Suppose that you want to propagate a change from the Lookup Table Editor to the workspace variable `table3d_map_custom`, which uses a nonstandard format. Follow these steps:

1. Create a file named `sl_customization.m` with the following contents:

```
function sl_customization(cm)

cm.LookupTableEditorCustomizer.getTableConvertToCustomInfoFcnHandle{end+1} = ...
@myGetTableConvertInfoFcn;

end
```

   In this file:

   - The `sl_customization` function takes a single argument `cm`, which is the handle to a customization manager object.
   - The handle `@myGetTableConvertInfoFcn` is added to the list of function handles in the cell array for `cm.LookupTableEditorCustomizer.getTableConvertToCustomInfoFcnHandle`.

   You can use any alphanumeric name for the function whose handle you add to the cell array. In this example, the function name is `myGetTableConvertInfoFcn`.

2. In your `sl_customization.m` file, define the `myGetTableConvertInfoFcn` function.

```
function blkInfo = myGetTableConvertInfoFcn(blk, tableStr)
```

```
        blkInfo.allowTableConvertLocal = false;
        blkInfo.tableWorkSpaceVarName = '';
        blkInfo.tableConvertFcnHandle = [];

        % Convert table data for Lookup Table (n-D) blocks
        if strcmp(get_param(blk, 'BlockType'), 'Lookup_n-D')
            blkInfo.allowTableConvertLocal = true;
            blkInfo.tableWorkSpaceVarName = 'table3d_map_custom';
        end

        % Convert table data for Interpolation Using Prelookup blocks
        if strcmp(get_param(blk, 'BlockType'), 'Interpolation_n-D')
            blkInfo.allowTableConvertLocal = true;
            blkInfo.tableWorkSpaceVarName = 'table4d_map_custom';
        end

        % Convert table data for Direct Lookup Table (n-D) blocks
        if strcmp(get_param(blk, 'BlockType'), 'LookupNDDirect')
            blkInfo.allowTableConvertLocal = true;
            blkInfo.tableWorkSpaceVarName = 'table4d_map_custom';
        end

        if blkInfo.allowTableConvertLocal
            blkInfo.tableConvertFcnHandle = @myConvertTableFcn;
        end

    end
```

The `myGetTableConvertInfoFcn` function returns the `blkInfo` object, which contains three fields:

- `allowTableConvertLocal` — tells the Lookup Table Editor if table data conversion is allowed for a block
- `tableWorkSpaceVarName` — specifies the name of the workspace variable that has a nonstandard table format
- `tableConvertFcnHandle` — specifies the handle for the conversion function

When the `allowTableConvertLocal` property is true:

- The table data for that block is converted to the nonstandard format of the workspace variable whose name matches `tableWorkSpaceVarName`.
- The function that converts table data corresponds to the handle that `tableConvertFcnHandle` specifies.

  You can use any alphanumeric name for the conversion function. In this example, the function name is `myConvertTableFcn`.

3 In your `sl_customization.m` file, define the `myConvertTableFcn` function, which includes a separate function call to `convertTable_3D`. An example of an implementation is shown below:

```
% This function converts LUT block table from Simulink format to
% nonstandard format used in workspace variable (for 1D to 4D table)
function cMap = myConvertTableFcn(data)

    mapDim = size(data);

    numDim = length(mapDim);

    if numDim < 3
        cMap = data;
    elseif numDim == 3
        cMap = convertTable_3D(data);
    else % numDim == 4 , currently only supports up to 4D
        for i = 1:mapDim(numDim)
            dataSub = data(:,:,:,i);
            iStart = (i-1)*mapDim(1)*mapDim(3) + 1;
            iEnd = i*mapDim(1)*mapDim(3);
            cMap(iStart:iEnd,:) = convertTable_3D(dataSub);
        end
    end
end

% This function converts LUT block table from Simulink format to
% nonstandard format used in workspace variable (for 3D table)
function cMap = convertTable_3D(data)

    % figure out the row and column number of the 3D table data
    mapDim = size(data);
```

```
    numCol = mapDim(2);
    numRow = mapDim(1)*mapDim(3);

    cMap = zeros(numRow, numCol);

    for i = 1:mapDim(3)
        rowBegin = (i-1)*mapDim(1)+1;
        rowEnd = i*mapDim(1);
        cMap(rowBegin:rowEnd, :) = data(:,:,i);
    end
end
```

4 Verify that your `sl_customization.m` file is complete:

```
function sl_customization(cm)

cm.LookupTableEditorCustomizer.getTableConvertToCustomInfoFcnHandle{end+1} = ...
@myGetTableConvertInfoFcn;

% This function converts LUT block table from Simulink format to
% nonstandard format used in workspace variable (for 1D to 4D table)
function cMap = myConvertTableFcn(data)

    mapDim = size(data);

    numDim = length(mapDim);

    if numDim < 3
        cMap = data;
    elseif numDim == 3
        cMap = convertTable_3D(data);
    else % numDim == 4 , currently only supports up to 4D
        for i = 1:mapDim(numDim)
            dataSub = data(:,:,:,i);
            iStart = (i-1)*mapDim(1)*mapDim(3) + 1;
            iEnd = i*mapDim(1)*mapDim(3);
            cMap(iStart:iEnd,:) = convertTable_3D(dataSub);
        end
    end
```

```
end

% This function converts LUT block table from Simulink format to
% nonstandard format used in workspace variable (for 3D table)
function cMap = convertTable_3D(data)

    % figure out the row and column number of the 3D table data
    mapDim = size(data);

    numCol = mapDim(2);
    numRow = mapDim(1)*mapDim(3);

    cMap = zeros(numRow, numCol);

    for i = 1:mapDim(3)
        rowBegin = (i-1)*mapDim(1)+1;
        rowEnd = i*mapDim(1);
        cMap(rowBegin:rowEnd, :) = data(:,:,i);
    end
end

function blkInfo = myGetTableConvertInfoFcn(blk, tableStr)

    blkInfo.allowTableConvertLocal = false;
    blkInfo.tableWorkSpaceVarName = '';
    blkInfo.tableConvertFcnHandle = [];

    % Convert table data for Lookup Table (n-D) blocks
    if strcmp(get_param(blk, 'BlockType'), 'Lookup_n-D')
        blkInfo.allowTableConvertLocal = true;
        blkInfo.tableWorkSpaceVarName = 'table3d_map_custom';
    end

    % Convert table data for Interpolation Using Prelookup blocks
    if strcmp(get_param(blk, 'BlockType'), 'Interpolation_n-D')
        blkInfo.allowTableConvertLocal = true;
        blkInfo.tableWorkSpaceVarName = 'table4d_map_custom';
    end

    % Convert table data for Direct Lookup Table (n-D) blocks
```

```
        if strcmp(get_param(blk, 'BlockType'), 'LookupNDDirect')
            blkInfo.allowTableConvertLocal = true;
            blkInfo.tableWorkSpaceVarName = 'table4d_map_custom';
        end

        if blkInfo.allowTableConvertLocal
            blkInfo.tableConvertFcnHandle = @myConvertTableFcn;
        end

    end

    end
```

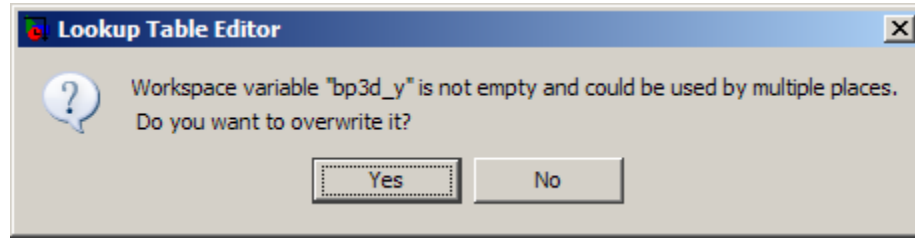
5 Put `sl_customization.m` on the MATLAB search path.

6 At the MATLAB prompt, enter the following command to refresh all Simulink customizations.

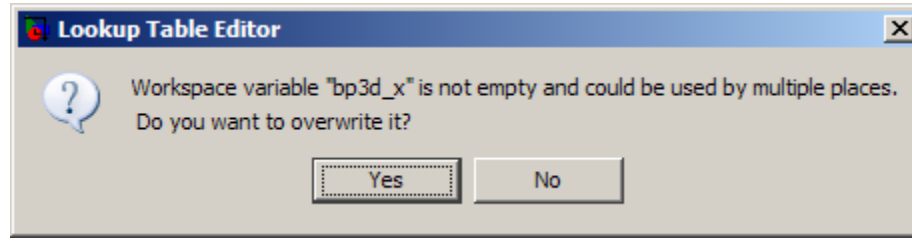
```
sl_refresh_customizations
```

7 In the Lookup Table Editor, select **File > Update Block Data**. Several pop-up windows appear:

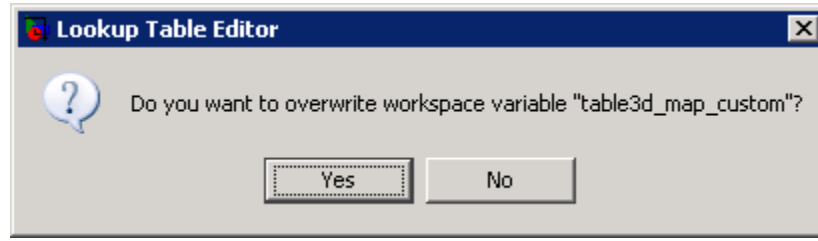
a Click **Yes** to overwrite the workspace variable `bp3d_y`.



b Click **Yes** to overwrite the workspace variable `bp3d_x`.



c Click **Yes** to overwrite the workspace variable `table3d_map_custom`.

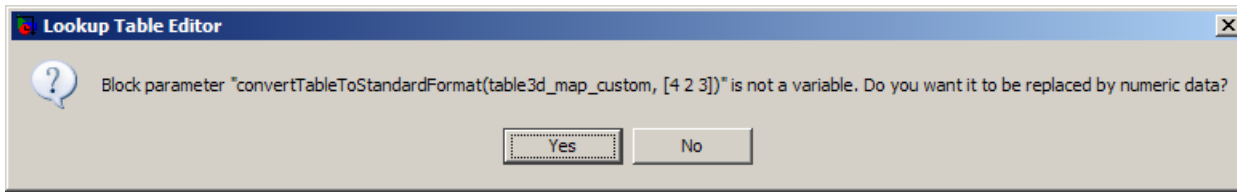


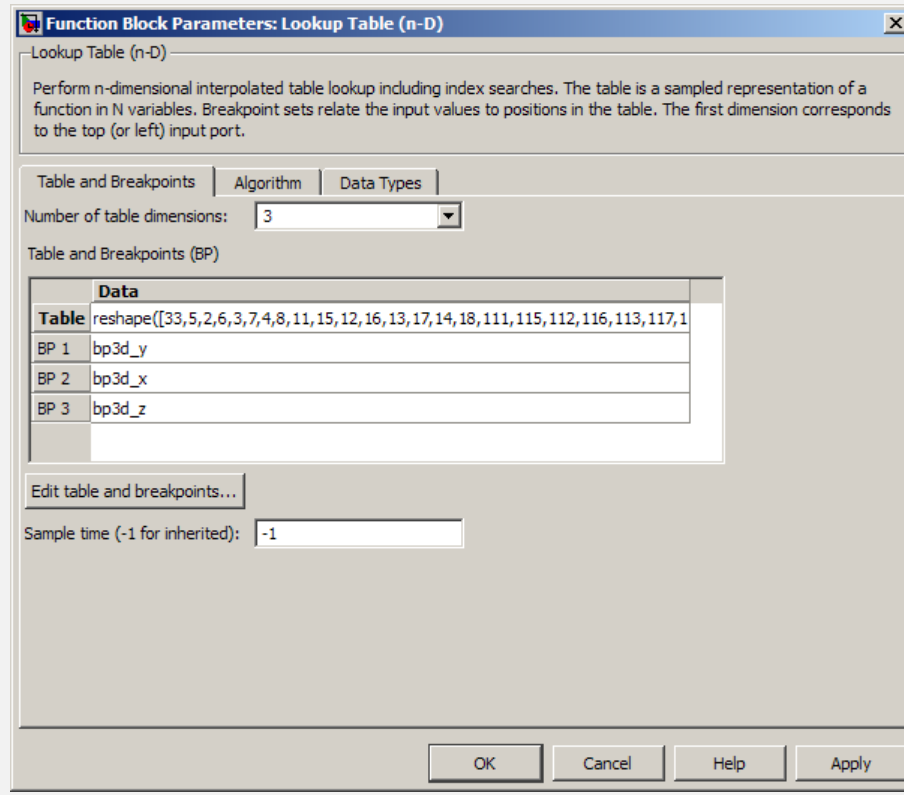
8 If you check the value of `table3d_map_custom` in the base workspace, you now see:

```
table3d_map_custom =

    33     2     3     4
     5     6     7     8
    11    12    13    14
    15    16    17    18
   111   112   113   114
   115   116   117   118
```

The change that you make to the table data in the Lookup Table Editor propagates to the workspace variable.

Note If you click **No** to the question of whether to overwrite the workspace variable `table3d_map_custom`, you get another question:



If you click...	Then...
Yes	The block dialog box replaces the expression in the **Table** field with numeric data. 
No	Your Lookup Table Editor changes for the table data do not appear in the block dialog box.

Adding and Removing Rows and Columns in a Table

In the Lookup Table Editor, you can add and remove rows or columns of a table in the following cases:

- Tables that are one- or two-dimensional
- Tables defined only by breakpoints (that are inherently one-dimensional)

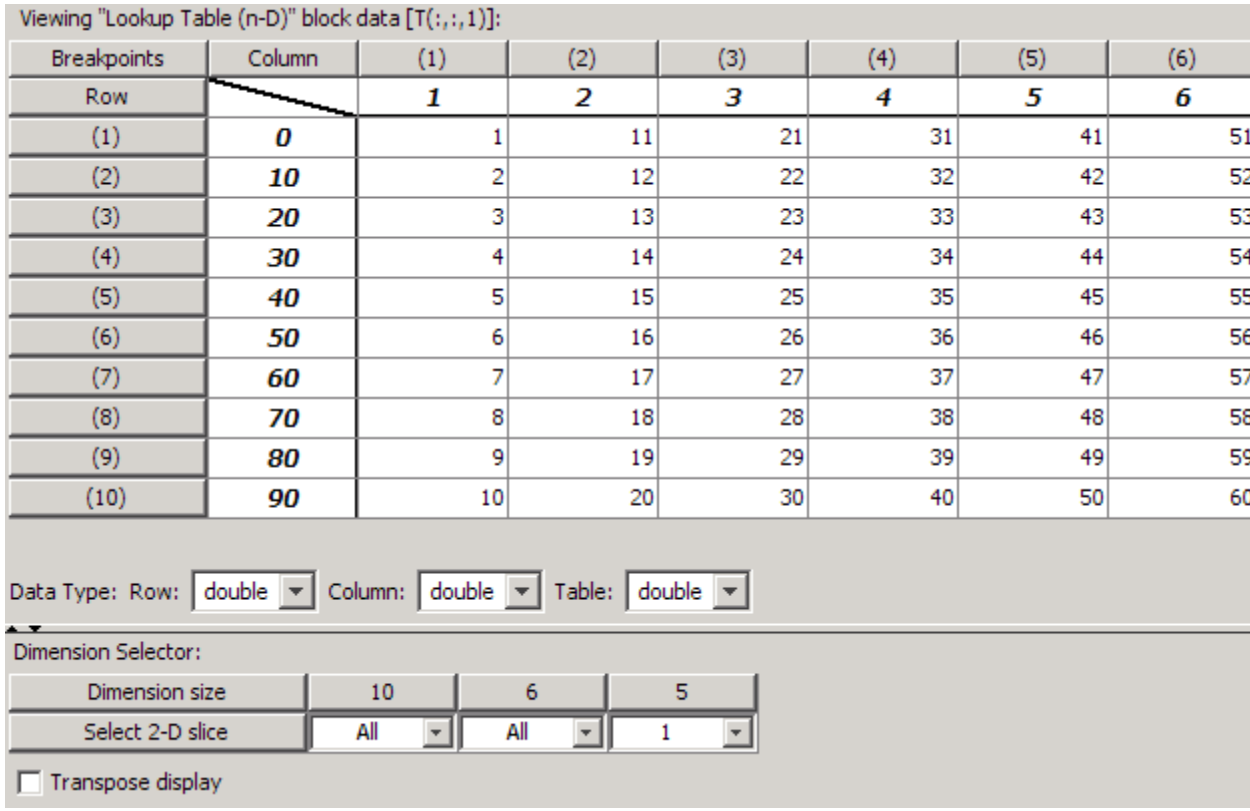
In those cases, follow these instructions to add or remove columns of a table in the Lookup Table Editor.

To perform this action:	Use one of these methods:
Add a row or column to a table that appears in the table view	• Select **Edit > Add Row** or **Edit > Add Column** in the editor • Click the Add Row button  or the Add Column button  in the toolbar
Remove a row or column from the table that appears in the table view	• Highlight the row or column to remove and then select **Edit > Remove Row(s)** or **Edit > Remove Column(s)** in the editor • Highlight the row or column to remove and then click the Remove Row button  or the Remove Column button  in the toolbar

The menu items and toolbar buttons for adding and removing rows and columns are not available for any other cases. To add or remove a row or column for a table with more than two dimensions, you must use the block parameter dialog box.

Displaying N-Dimensional Tables in the Editor

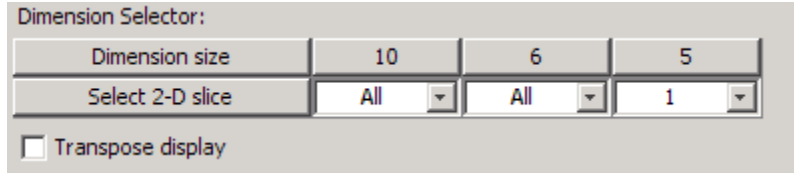
If the lookup table of the block currently selected in the Lookup Table Editor's tree view has more than two dimensions, the table view displays a two-dimensional slice of the table.



The **Dimension Selector** specifies which slice currently appears and lets you select another slice. The selector consists of a 2-by-`N` array of controls, where `N` is the number of dimensions in the lookup table. Each column corresponds to a dimension of the lookup table. The first column corresponds to the first dimension of the table, the second column to the second dimension of the table, and so on. The **Dimension size** row of the selector array displays the size of each dimension. The **Select 2-D slice** row specifies which dimensions of the table correspond to the row and column axes of the slice and the indices that select the slice from the remaining dimensions.

To select another slice of the table, specify the row and column axes of the slice in the first two columns of the **Select 2-D slice** row. Then select the indices of the slice from the pop-up index lists in the remaining columns.

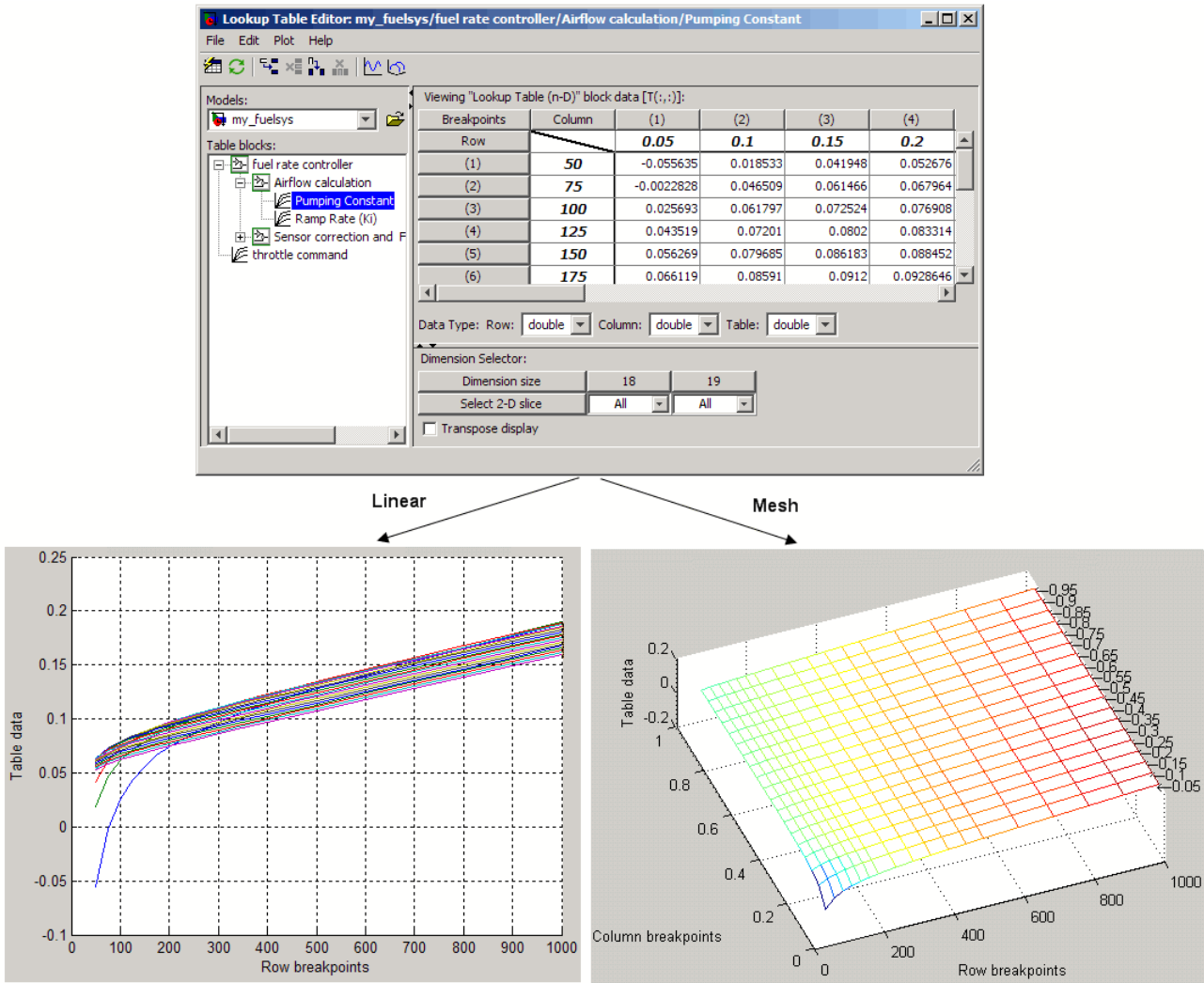
For example, the following selector displays slice (:,:,1) of a 3-D lookup table.



To transpose the table display, select the **Transpose display** check box.

Plotting Lookup Tables

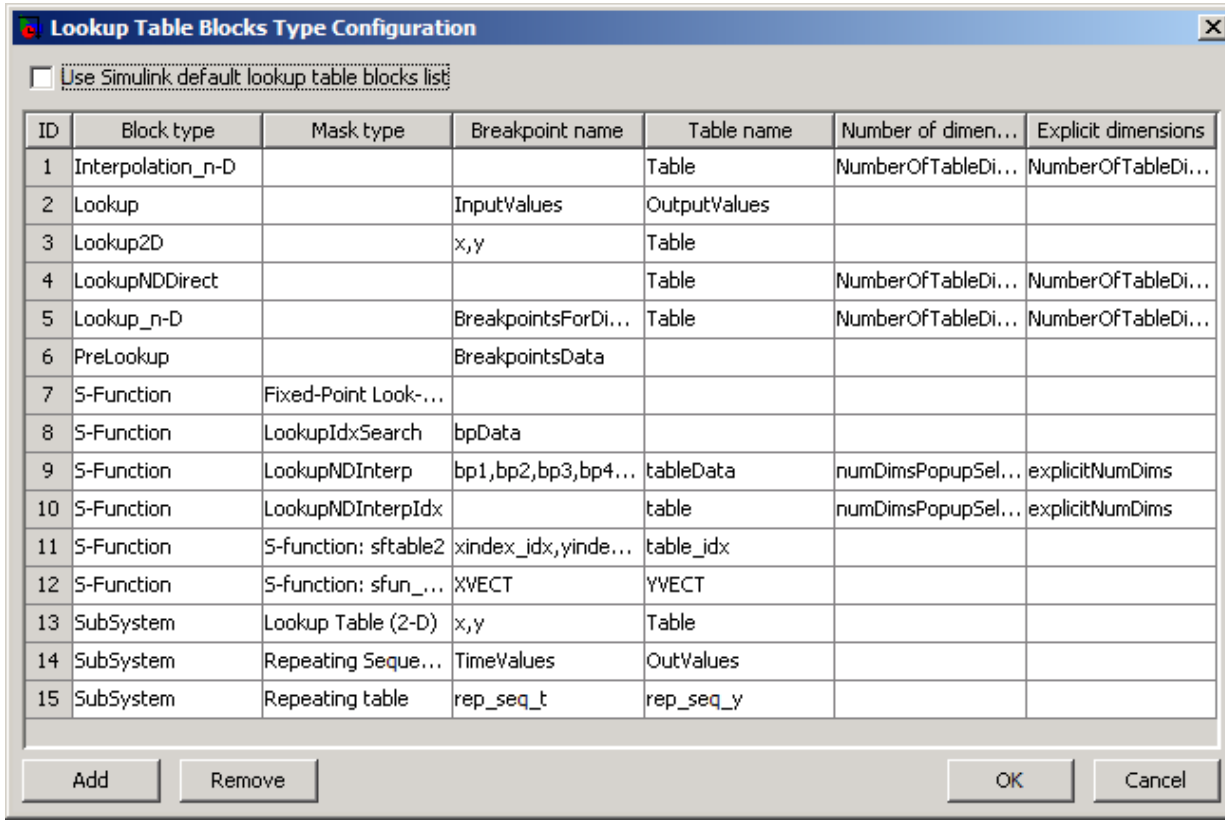
To display a linear or mesh plot of the table or table slice in the Lookup Table Editor, select **Plot > Linear** or **Plot > Mesh**.



Editing Custom Lookup Table Blocks

You can use the Lookup Table Editor to edit custom lookup table blocks that you or others have created. To do this, you must first configure the Lookup Table Editor to recognize the custom lookup table blocks in your model. After you configure the Lookup Table Editor to recognize custom blocks, you can edit them as if they were standard blocks.

To configure the Lookup Table Editor to recognize custom blocks, select **File > Configure**. The Lookup Table Blocks Type Configuration dialog box appears.



By default, the dialog box displays a table of the lookup table block types that the Lookup Table Editor currently recognizes. This table includes the

standard blocks. Each row of the table displays key attributes of a lookup table block type.

Adding a Custom Lookup Table Block Type

To add a custom block to the list of recognized types:

1. Click **Add** on the dialog box.

   A new row appears at the bottom of the block type table.

2. Enter information for the custom block in the new row under these headings.

Field Name	Description
Block type	Block type of the custom block. The block type is the value of the block's `BlockType` parameter.
Mask type	Mask type of the custom block. The mask type is the value of the block's `MaskType` parameter.
Breakpoint name	Names of the block parameters that store the breakpoints.
Table name	Name of the block parameter that stores the table data.
Number of dimensions	Leave empty.
Explicit dimensions	Leave empty.

3. Click **OK**.

Removing Custom Lookup Table Block Types

To remove a custom lookup table block type from the list that the Lookup Table Editor recognizes, select the custom entry in the table of the Lookup Table Blocks Type Configuration dialog box. Then click **Remove**.

To remove all custom lookup table block types, select the **Use Simulink default lookup table blocks list** check box at the top of the dialog box.

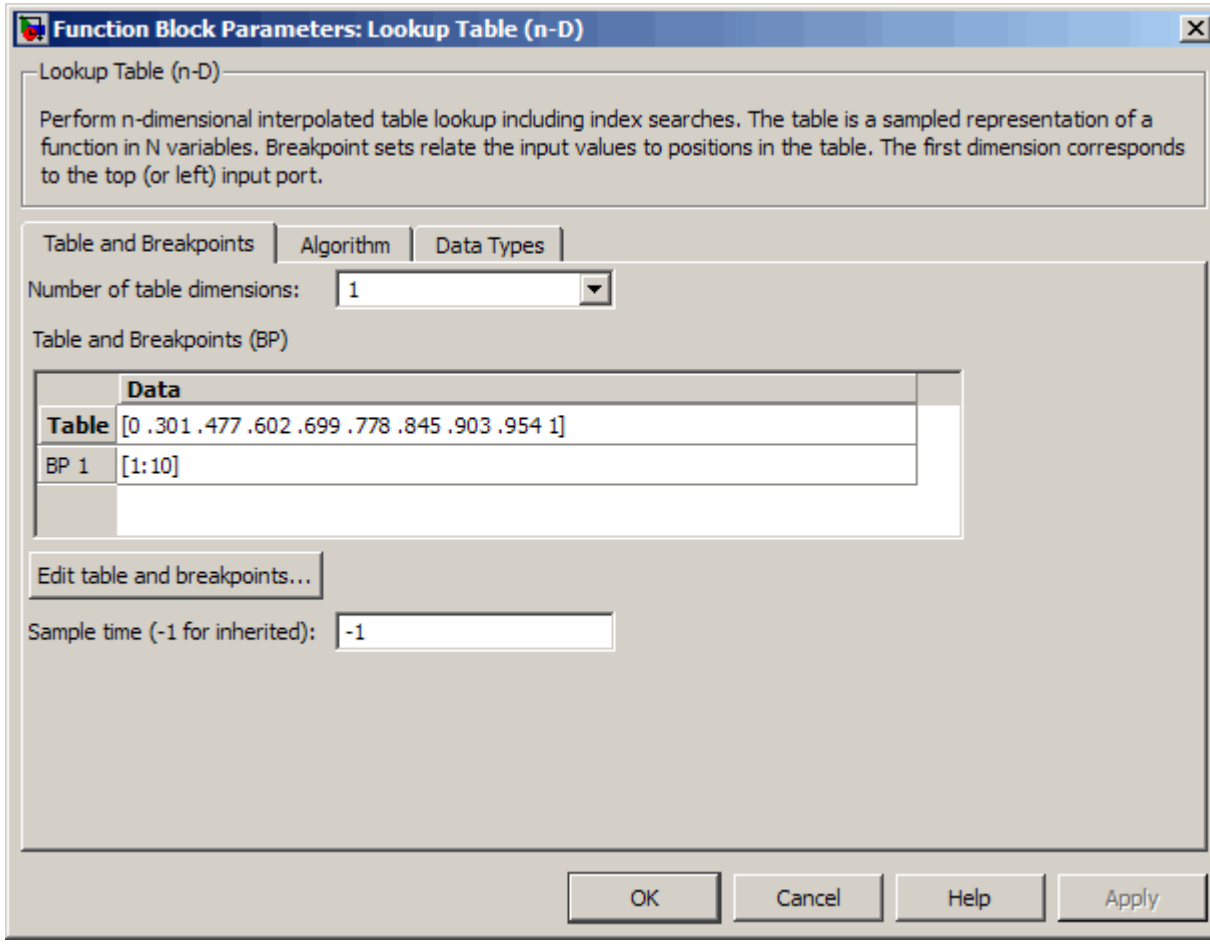
Example of a Logarithm Lookup Table

Suppose you want to approximate the common logarithm (base 10) over the input range [1, 10] without performing an expensive computation. You can perform this approximation using a lookup table block as described in the following procedure.

1. Copy the following blocks to a Simulink model:
   - A Constant block to input the signal, from the Sources library
   - A Lookup Table (n-D) block to approximate the common logarithm, from the Lookup Tables library
   - A Display block to display the output, from the Sinks library
2. Assign the table data and breakpoint data set to the Lookup Table (n-D) block:
   a. In the **Number of table dimensions** field, enter `1`.
   b. In the **Table** field, enter `[0 .301 .477 .602 .699 .778 .845 .903 .954 1]`.

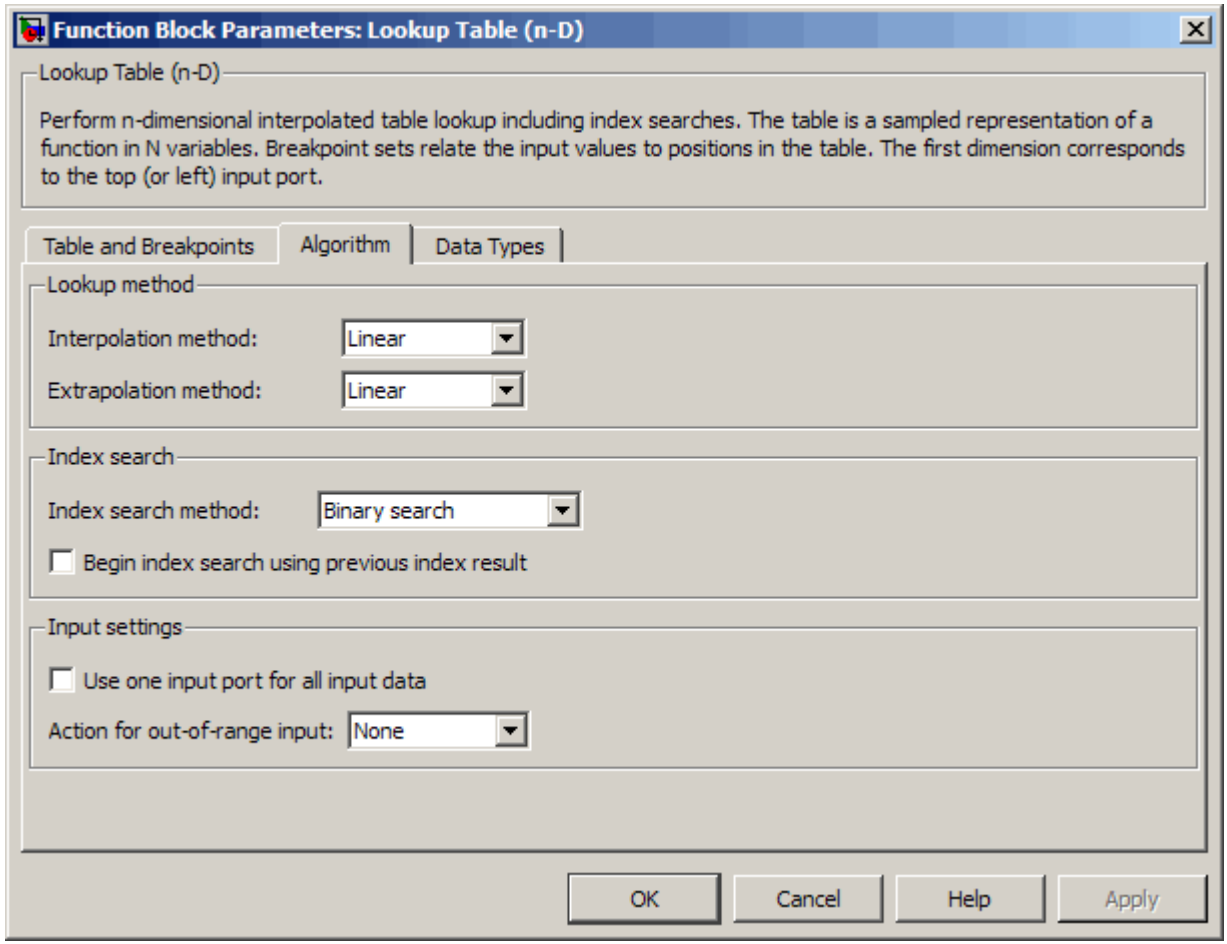
      Alternatively, you can enter the MATLAB expression `log10(1:10)` in this field, which evaluates to the equivalent vector of output values.
   c. In the **BP 1** field, enter `[1:10]`.
   d. Click **Apply**.

The dialog box looks something like this:



3 Click the **Algorithm** tab in the Lookup Table (n-D) block dialog box.

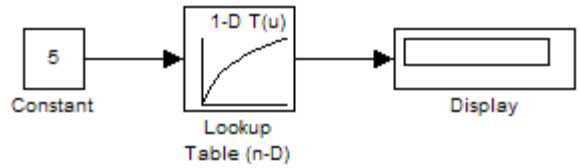
By default, the **Interpolation method** and **Extrapolation method** are both `Linear`.



Click **OK** to close the dialog box.

4 Double-click the Constant block to open the parameter dialog box, and change the **Constant value** parameter to `5`. Click **OK** to apply the changes and close the dialog box.

5 Connect the blocks as follows.



6 Start simulation.

The following behavior applies to the Lookup Table (n-D) block.

Value of the Constant Block	Action by the Lookup Table (n-D) Block	Example of Block Behavior	
		Input Value	Output Value
Equals a breakpoint	Returns the corresponding output value	5	0.699
Falls between breakpoints	Linearly interpolates the output value using neighboring breakpoints	7.5	0.874
Falls outside the range of the breakpoint data set	Linearly extrapolates the output value from a pair of values at the end of the breakpoint data set	10.5	1.023

Examples for Prelookup and Interpolation Blocks

The following examples show the benefits of using Prelookup and Interpolation Using Prelookup blocks.

Action	Benefit	Example
Use an index search to relate inputs to table data, followed by an interpolation and extrapolation stage that computes outputs	Enables reuse of index search results to look up data in multiple tables, which reduces simulation time	To open the model, type `sldemo_bpcheck` at the command prompt.
Set breakpoint and table data types explicitly	Lowers memory required to store: • Breakpoint data that uses a smaller type than the input signal • Table data that uses a smaller type than the output signal	To open the model, type `sldemo_interp_memory` at the command prompt.
	Provides easier sharing of: • Breakpoint data among Prelookup blocks • Table data among Interpolation Using Prelookup blocks	To open the model, type `fxpdemo_lookup_shared_param` at the command prompt.
	Enables reuse of utility functions during Real-Time Workshop code generation	To open the model, type `fxpdemo_prelookup_utilfcn` at the command prompt.
Set the data type for intermediate results explicitly	Enables use of higher precision for internal computations than for table data or output data	To open the model, type `fxpdemo_interp_precision` at the command prompt.

Lookup Table Glossary

The following table summarizes the terminology used to describe lookup tables in the Simulink user interface and documentation.

Term	Meaning
breakpoint	A single element of a breakpoint data set. A breakpoint represents a particular input value to which a corresponding output value in the table data is mapped.
breakpoint data set	A vector of input values that indexes a particular dimension of a lookup table. A lookup table uses breakpoint data sets to relate its input values to the output values that it returns.
extrapolation	A process for estimating values that lie beyond the range of known data points.
interpolation	A process for estimating values that lie between known data points.
lookup table	An array of data that maps input values to output values, thereby approximating a mathematical function. Given a set of input values, a “lookup” operation retrieves the corresponding output values from the table. If the lookup table does not explicitly define the input values, Simulink can estimate an output value using interpolation, extrapolation, or rounding.
monotonically increasing	The elements of a set are ordered such that each successive element is greater than or equal to its preceding element.

Term	Meaning
rounding	A process for approximating a value by altering its digits according to a known rule.
strictly monotonically increasing	The elements of a set are ordered such that each successive element is greater than its preceding element.
table data	An array that serves as a sampled representation of a function evaluated at a lookup table's breakpoint values. A lookup table uses breakpoint data sets to index the table data, ultimately returning an output value.

Working with Block Masks

What Are Masks?

A mask is a custom user interface for a Simulink block. The mask hides the native user interface of the underlying block, substituting an icon and a parameters dialog box defined by the mask. You can apply a mask to any Subsystem block, Model block, or S-Function block. The block can optionally reside in a user-defined library.

Masking a block changes only the user interface of the block, not its underlying characteristics. For example, masking a nonatomic subsystem does not make it act as an atomic subsystem, and masking a virtual block does not convert it to a nonvirtual block. You cannot save a mask separately from the block that it masks, or create a freestanding mask definition and apply it to more than one block.

The icon and parameters dialog boxes for a mask can provide any capability that a native block icon and dialog box can provide. When you set mask parameter values, the mask can use the values to dynamically change the mask icon and dialog box, and to calculate values to be used under the mask. A mask on a subsystem can dynamically change the subsystem to reflect mask parameter values.

Why Use a Mask?

Masks can provide interface customization, logic encapsulation, and data hiding. For example, although defining a subsystem simplifies the graphical appearance of a model, the simplification does not provide a user interface that is specific to the subsystem. The lack of a subsystem-specific interface has several possible disadvantages, including:

- The subsystem icon is generic: it does not indicate the meaning of the subsystem, and cannot change to provide information about parameter settings in the subsystem.
- The subsystem parameters that need to be changed to control behavior may be distributed among many subsystem blocks, making the parameters hard to find.
- The parameter names in the blocks comprising the subsystem reflect only the generic purpose of each block, rather than the parameter's purpose in the context of the model.
- Making any change to the subsystem requires exposing its complete contents in an editor, which makes the subsystem vulnerable to unintended changes.
- Because the subsystem has no separate parameters dialog box, no Block Help information is available for the subsystem, as it would be for a built-in block.

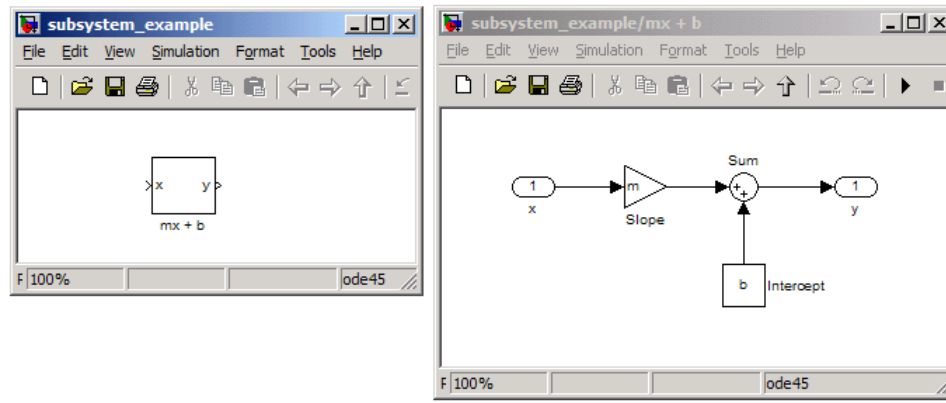
Masking a subsystem can address all of these problems. A subsystem mask can:

- Display a meaningful icon that updates dynamically and reflects values within the subsystem.
- Define customized user-settable parameters whose names reflect the purpose of the subsystem.
- Provide a parameters dialog box that gives access only to parameters that should be exposed.
- Shows customized Block Help and Online Help information that is specific to the subsystem.

The mask thereby encapsulates the subsystem under an interface that reflects the subsystem as the user sees it, as distinct from the subsystem's architecture, and provides the look and feel of a built-in Simulink block. Similar advantages apply to masks on Model blocks and S-Function blocks.

Masked Subsystem Example

The next figure shows a Subsystem block that models the equation for a line, `y = mx + b`. The techniques for creating such a subsystem appear in "Creating Subsystems" on page 3-37. The subsystem is not atomic, so the Subsystem block is just a graphical abbreviation for the underlying blocks:



Double-clicking an unmasked Subsystem block opens a separate window that displays the contents of the subsystem, as shown in the above figure. This subsystem contains a Gain block, named `Slope`, whose **Gain** parameter is specified as `m`, and a Constant block, named `Intercept`, whose **Constant value** parameter is specified as `b`. These parameters represent the slope and intercept of a line. To examine this model, click `subsystem_example` or execute:

```
run([docroot '/toolbox/simulink/ug/examples/masking/subsystem_example.mdl'])
```

The organization of this model has several disadvantages:

- Although the block gives some indication of its purpose by showing the calculation that it performs, the icon adds no specific information.
- Only the values of the **Gain** and **Constant value** parameters are relevant outside the subsystem, but editing the subsystem displays its entire contents.

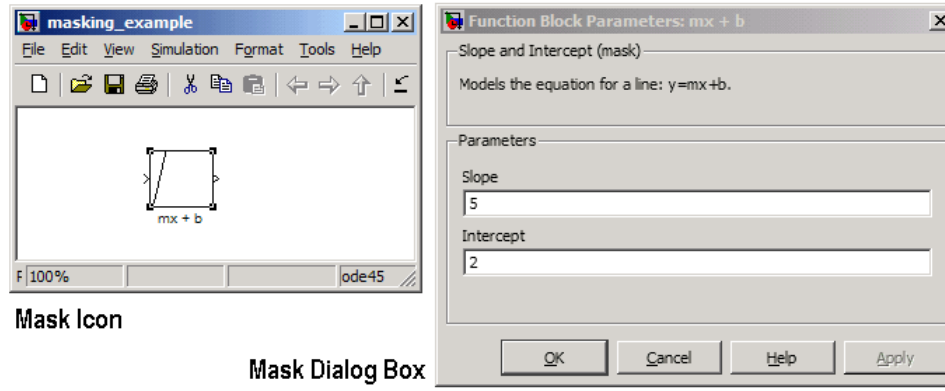
- The names of the block parameters within the subsystem relate to Simulink architecture rather than to the purpose of the subsystem.

You can overcome these problems by applying a mask to the Subsystem block. This mask can:

- Provide an icon that reflects the purpose of the subsystem
- Show only the parameters that are used outside the subsystem
- Give those parameters names that relate to the subsystem's purpose

The next figure shows the above model with a mask applied to the Subsystem block. To examine this model, click `masking_example` or execute:

```
run([docroot '/toolbox/simulink/ug/examples/masking/masking_example.mdl'])
```



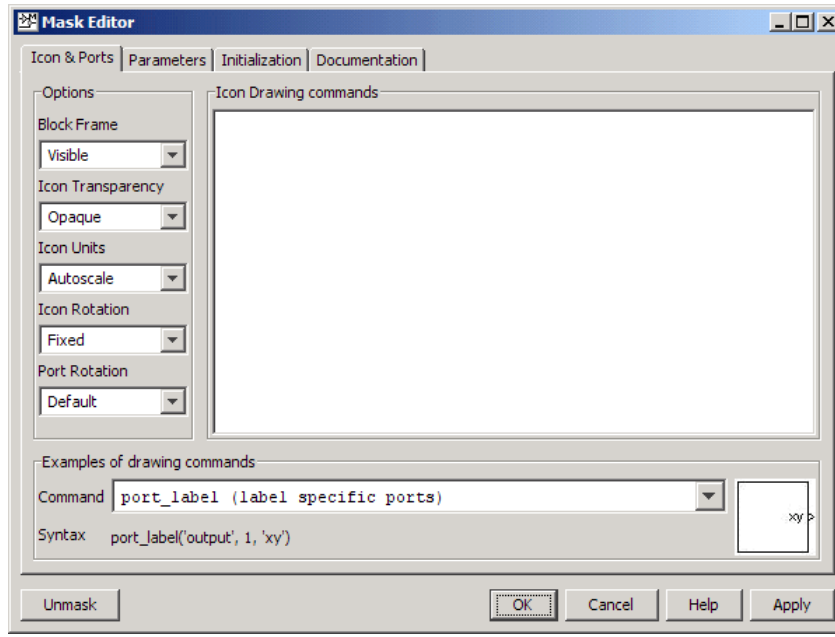
Masking the subsystem has created a self-contained functional unit. A customized mask icon replaces the default Subsystem block icon. Double-clicking the mask icon opens a customized Mask Parameters dialog box, which replaces the Subsystem block dialog box. The Mask Parameters dialog box shows two parameters: **Slope**, which provides the value of `m` in the subsystem Gain block, and **Intercept**, which provides the value of `b` in the subsystem Constant block.

These parameters are the only constructs within the subsystem that are of interest outside the subsystem, so the mask has been designed to hide everything else. The mask parameters are currently set to `5` and `2`,

respectively. These values are not part of the mask itself, but were entered just as if they were the values of ordinary block parameters. The parameter values are available to all the blocks in the underlying subsystem. The mask icon displays a line that reflects the current value of the **Slope** parameter.

Roadmap for Masking Blocks

The Mask Editor provides the capabilities necessary for creating, changing, and removing a Subsystem, Model, or S-Function block mask. When you first open the Mask Editor, it looks like this:



The Mask Editor provides four tabbed panes, which you can use to perform any masking operation:

- "Icon & Ports Pane" — Specifies code that draws and controls the icon representing the masked block.
- "Parameters Pane" — Specifies mask parameters and code that executes when a parameter value changes.
- "Initialization Pane" — Specifies code that executes as needed to initialize the mask and underlying block.
- "Documentation Pane" — Specifies documentation that describes the block in its dialog box and in Online Help.

Use the preceding links as needed to access the Mask Editor reference. Definitions and instructions for masking a block appear in “Creating a Block Mask” on page 21-11:

If the block to be masked resides in a user-defined library, you will also need the information in “Masks on Blocks in User Libraries” on page 21-33:

After you have defined a block mask, you can perform various operations on it, as described in “Operating on Existing Masks” on page 21-35.

If you want to define a mask that can use mask parameter values to dynamically change the mask icon and dialog box, or calculate values to be used under the mask, first read the sections listed above as needed, then read: “Roadmap for Dynamic Masks” on page 21-38

All dynamic masking techniques require MATLAB programming, which is described in *MATLAB Programming Fundamentals*.

Mask Terminology

The rest of this chapter assumes that you know the following definitions:

Mask Icon — An icon that replaces the standard icon for a masked block when the masked block appears in a model. You can accept a default icon or provide drawing code that defines the icon.

Mask Parameters — Optional parameters that link to block parameters that exist under the mask. Setting a mask parameter sets the associated block parameter.

Mask Initialization Code — Optional MATLAB code that runs when needed to initialize the masked subsystem. You can use initialization code to modify a masked subsystem to reflect current parameter values.

Mask Callback Code — Optional MATLAB code that runs whenever a mask parameter value changes. You can use callback code to modify a mask dialog box to reflect current parameter values.

Mask Documentation — Optional information that names and briefly describes the masked block, and provides Help information about how to use it.

Mask Dialog Box — A dialog box that replaces the masked block's standard parameters dialog box. The mask dialog box displays a block description, contains controls that enable a user to set mask parameter values, and provides Help information.

Mask Workspace — If the mask uses mask parameters or initialization code, it has a mask workspace that holds parameter and temporary values used by the mask.

Creating a Block Mask

In this section...

Introduction

This section describes techniques for masking any type of block. The techniques are the same whether you mask a Subsystem block, Model block, or S-Function block. The masked block can optionally be included in a user-defined library, as described in "Masks on Blocks in User Libraries" on page 21-33. When you mask a Model block, one special consideration applies, as described in "Masking a Model Block" on page 21-31. Masking an S-Function block requires no special provisions.

In practice, most masks are subsystem masks, because Model blocks and S-Function blocks already provide a high degree of encapsulation. For simplicity, the instructions and examples in this section refer specifically to a subsystem, and the mask does not dynamically change its dialog box or the subsystem under the mask. Instructions for masks that make dynamic changes begin in "Roadmap for Dynamic Masks" on page 21-38, which assumes that you understand everything in this section.

This section demonstrates only some of the capabilities of the Mask Editor. See "Simulink Mask Editor" for complete reference information. The section assumes that you know the definitions in "Mask Terminology" on page 21-10 and are familiar with the "Masked Subsystem Example" on page 21-5.

This section illustrates the described operations by constructing the mask described in "Masked Subsystem Example" on page 21-5. You can read the section and apply the operations to your own model, or you can use the section as a tutorial, as follows:

1. Open the unmasked source model by clicking `subsystem_example` or executing:

   ```
   run([docroot '/toolbox/simulink/ug/examples/masking/subsystem_example.mdl'])
   ```

2. Save the model in a writable working folder.

3. Optionally open the completed example by clicking `masking_example` or executing:

   ```
   run([docroot '/toolbox/simulink/ug/examples/masking/masking_example.mdl'])
   ```

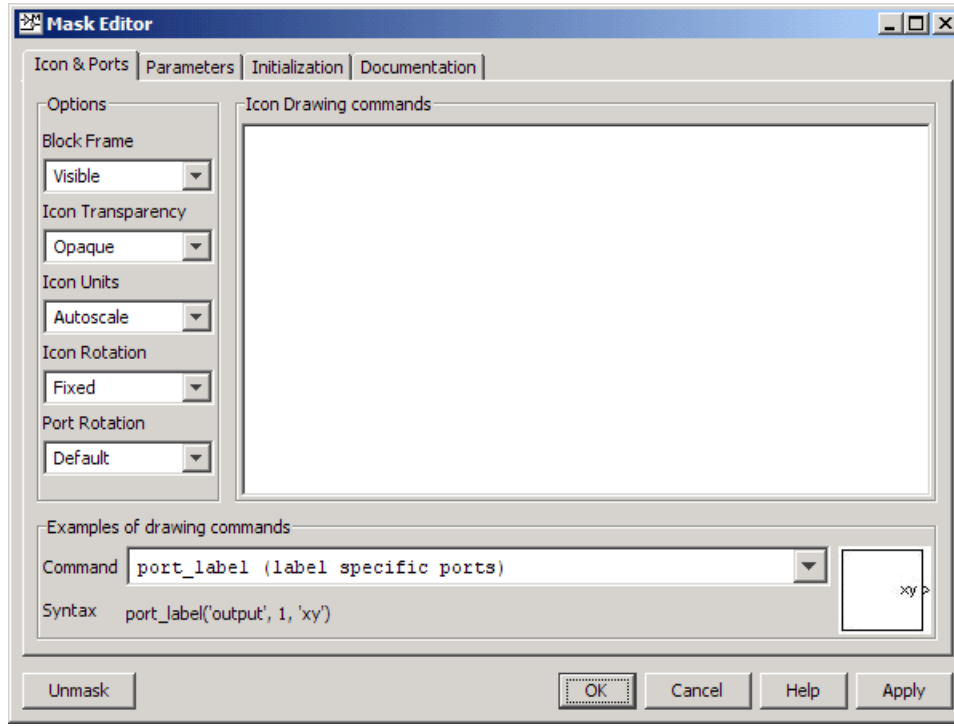
4. Execute the instructions in this section on the copy you made of `subsystem_example` to implement the capabilities in `masking_example`.

Opening the Mask Editor

The Simulink Mask Editor provides all of the capabilities necessary for masking a block. To invoke the editor on an unmasked block:

- Select the Subsystem block.
- From the **Edit** menu or the context menu of the block, choose **Mask Subsystem**.

The Mask Editor opens:



You can define mask components in any order, as long as the final result is correct. You can also open the Mask Editor on block that is already masked, as described in “Changing a Block Mask” on page 21-35.

Applying Changes

Click **Apply** to make changes within the model, or **OK** to make changes within the model and close the editor. Save the model to permanently save the changes. If you close the model without saving it, all unsaved Mask Editor changes are lost.

Defining a Mask Icon

A mask icon replaces the standard icon for a masked block when the masked block appears in a model. Mask icons can contain descriptive text, graphics,

images, state equations, one or more plots, or a transfer function. Simulink uses the commands and variables that you supply to draw the mask icon.

Use the Mask Editor **Icon & Ports** pane to specify the icon for a masked block. This pane is always selected by default when you open the Mask Editor. See the "Icon & Ports Pane" reference for information about all **Icon & Ports** pane capabilities. This section gives an example of their use.

To define a mask icon, enter:

- Any variables necessary for drawing the icon
- Commands to draw the icon

Variables

For model efficiency, use the **Icon & Ports** pane to run MATLAB code and to define variables used by the mask icon drawing commands. Simulink executes the MATLAB code in the **Icon & Ports** pane only when the block icon needs to be drawn. If you include variables used by mask icon drawing commands in the **Initialization** pane, Simulink evaluates the variables as part of simulation and code generation. For details, see "Understanding Mask Code Execution" on page 21-57.

Drawing Commands

To draw an icon, enter one or more of the commands described in "Mask Icon Drawing Commands" in the **Icon Drawing commands** text box. Use only these commands to draw a mask icon. To see examples of drawing command syntax, use the pull-down list in the **Examples of drawing commands** pane.

The drawing commands can access all variables defined in the mask workspace.

You can include MATLAB comments at the end of a drawing command or on their own line, as in the following examples:

```
image(imread('engine.jpg'))   % Use engine icon for subsystem

% Use engine icon for subsystem
image(imread('engine.jpg'))
```

If any drawing command cannot successfully execute, the icon displays three question marks.

Example of Defining a Mask Icon

This example illustrates how to define a mask icon that is accurate, regardless of the shape of the block.

The mask icon in `masking_example` displays a line that reflects the slope of the line modeled in the masked subsystem. To define this icon in your copy of `subsystem_example.mdl`:

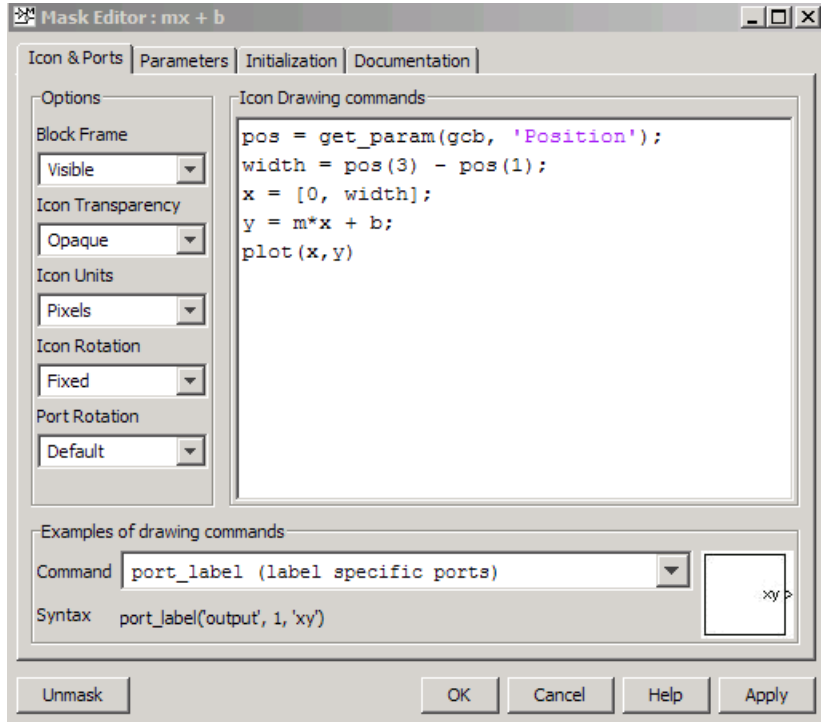
1. Type the following command into the **Icon Drawing commands** pane:

   ```
   pos = get_param(gcb, 'Position');
   width = pos(3) - pos(1);
   x = [0, width];
   y = m*x + b;
   plot(x,y)
   ```

2. Under **Options**, set **Icon Units** to `Pixels`.

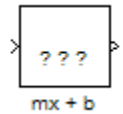
   The pull-down lists under **Options** allow you to specify the icon frame visibility, icon transparency, drawing context, icon rotation, and port rotation.

   The **Icon & Ports** pane now looks like this:



3 Click **Apply**.

If Simulink cannot evaluate all commands in the **Icon Drawing commands** pane to obtain a displayable result, the content of the icon is three question marks. In `masking_example`, three question marks appear at this point because the variable `m` has not yet been defined:



Defining Mask Initialization

The initialization code is MATLAB code that you specify and that Simulink runs to initialize the masked subsystem at critical times, such as model

loading and the start of a simulation run (see “Initialization Command Execution” on page 21-58). You can use the initialization code to set the initial values of the mask parameters.

The masked subsystem initialization code can refer only to variables in its local workspace.

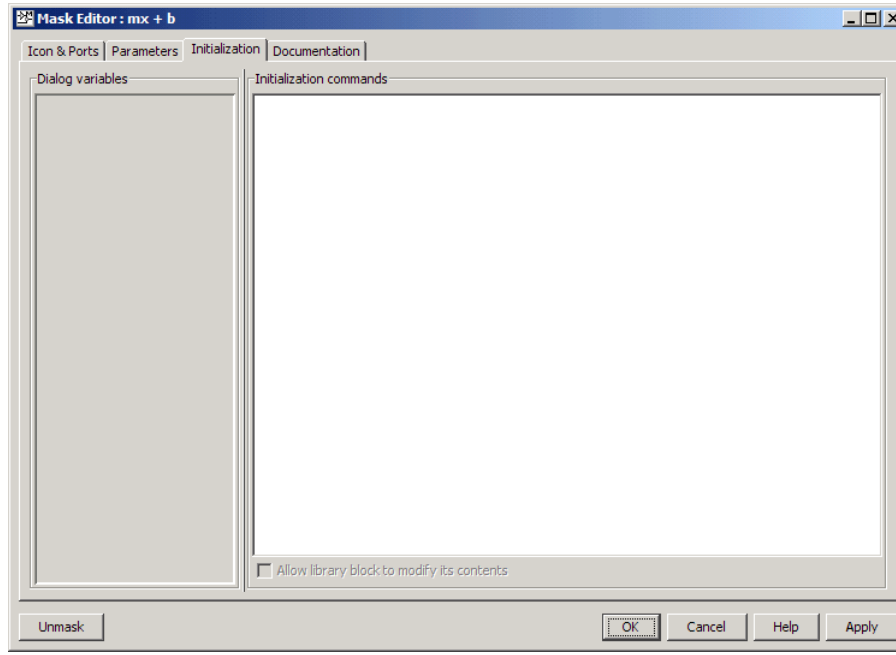
When you reference the block within, or copy the block into, a model, the Mask Parameters dialog box displays the specified default values. You cannot use mask initialization code to change mask parameter default values in a library block or any other block.

Mask Editor Initialization Pane

Use the Mask Editor **Initialization** pane to enter MATLAB commands that initialize a masked block. Reference information about the **Initialization** pane appears in “Initialization Pane”.

The **Initialization** pane has two sections:

- **Dialog variables** list
- **Initialization commands** edit area



Dialog variables

The **Dialog variables** list displays the names of the variables associated with the mask parameters of the subsystem (that is, the parameters defined in the **Parameters** pane).

You can copy the name of a parameter from this list and paste it into the adjacent **Initialization commands** field, using the Simulink keyboard copy and paste commands.

You can also use the list to change the names of mask parameter variables. To change a name, double-click the name in the list. An edit field containing the existing name appears. Edit the existing name and press **Enter** or click outside the edit field to confirm your changes.

Initialization Commands

Enter the initialization commands in this field. You can enter any valid MATLAB expression, consisting of MATLAB functions and scripts, operators,

and variables defined in the mask workspace. Initialization commands cannot access base workspace variables.

Terminate initialization commands with a semicolon to avoid echoing results to the MATLAB Command Window.

For information on debugging initialization commands, see “Initialization Command Limitations” on page 21-19 and .

Initialization Command Limitations

Mask initialization commands must observe the following rules:

- Do not use initialization code to create dynamic mask dialog boxes (that is, dialog boxes whose appearance or control settings change depending on changes made to other control settings). Instead, use the mask callbacks that are specifically for this purpose. For more information, see “Creating Dynamic Mask Dialog Boxes” on page 21-48.
- Avoid using `set_param` commands on blocks residing in another masked subsystem that you are initializing. Trying to set parameters of blocks in lower-level masked subsystems can trigger unresolvable symbol errors if lower-level masked subsystems reference symbols defined by higher-level masked subsystems. Suppose, for example, a masked subsystem A contains masked subsystem B, which contains Gain block C, whose Gain parameter references a variable defined by B. Suppose also that subsystem A has initialization code that contains the following command:

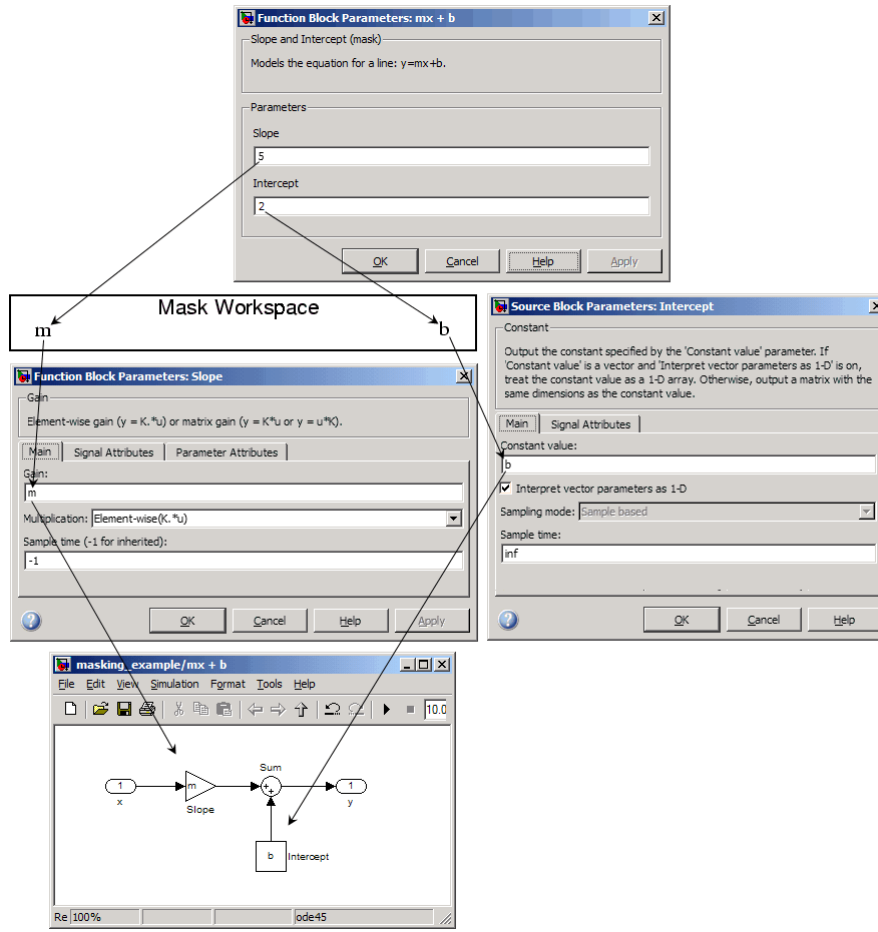
  ```
  set_param([gcb '/B/C'], 'SampleTime', '-1');
  ```

  Simulating or updating a model containing A causes an unresolvable symbol error.

Understanding Mask Parameters

Mask parameters provide the connection between the Mask Parameters dialog box and the underlying block. Each mask parameter appears in the Mask Parameters dialog box as a control, such as an edit box, a pop-up control, a check box, or a data type control. Setting the value of this control sets the value of an associated mask parameter that is defined in the mask workspace. The underlying block specifies that parameter as the value of one or more block parameters, and accesses the value of the corresponding

control in the Mask Parameters dialog box. The next figure illustrates this relationship for the `masking_example`.



In this figure, the Mask Parameters dialog box (top) contains edit-box controls for two parameters: **Slope**, which is associated with the mask workspace variable `m`, and **Intercept**, which is associated with the mask workspace variable `b`. In the subsystem (bottom), the Gain block named `Slope` specifies its **Gain** parameter as `m`, and the Constant block named `Intercept` specifies

its **Constant value** parameter as `b`, as shown in the two Block Parameters dialog boxes (middle).

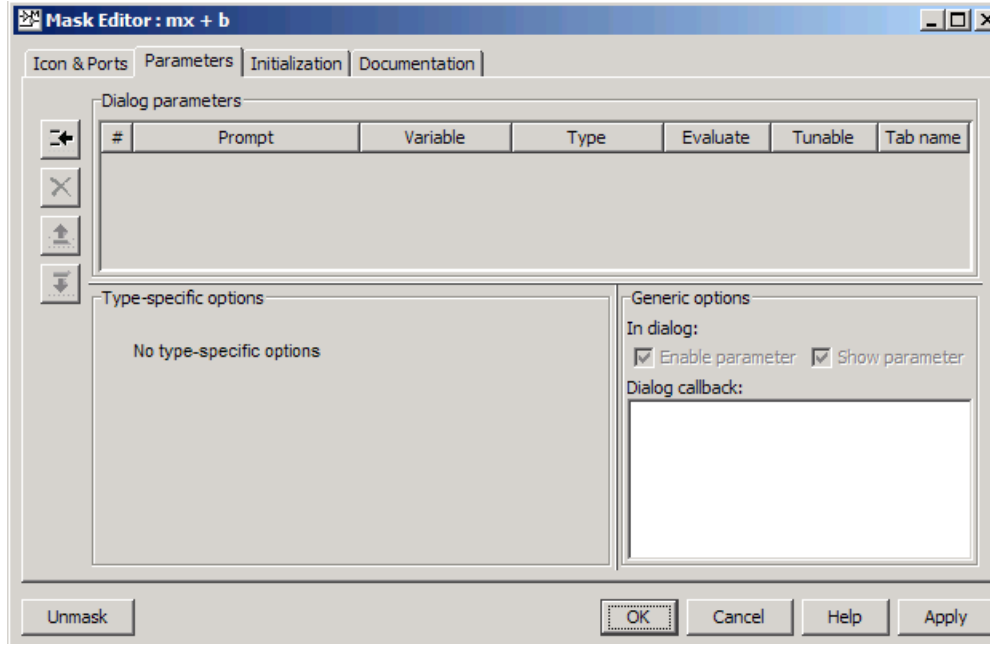
When the user of the masked block sets the values of **Slope** and **Intercept** in the Mask Parameters dialog box, Simulink automatically assigns the mask parameter values to the corresponding mask workspace variables, `m` and `b`, respectively. For example, as shown in the diagram above, when the masked block user sets the **Slope** parameter in the Mask Parameters dialog box to `5`, Simulink sets the `m` variable in the mask workspace to `5`. The Gain block uses `5` as its **Gain** parameter value, because the **Gain** parameter in the Gain block has a value of `m`.

Before simulation begins, Simulink tries to resolve the Gain block's **Gain** parameter `m` and the Constant block's **Constant Value** parameter `b` to numeric values by searching up the workspace hierarchy, as described in "Resolving Symbols" on page 3-75. Because a mask exists, Simulink searches the mask workspace first. There it finds `m` and `b` defined, so it successfully resolves the two block parameters. For example, the **Slope** parameter in the Mask Parameters dialog box is defined in the Mask Editor to be `m`, and the **Gain** parameter in the Gain block is also defined to be `m`.

If no mask exists (and therefore, no mask workspace), but the subsystem itself does not change, Simulink performs the same hierarchical search seeking a value for `m` and `b`, and the search for each value must succeed before simulation can begin. Therefore, the existence of a mask affects hierarchical search only by providing a mask workspace that Simulink searches first.

Defining Mask Parameters

Be sure you have read "Understanding Mask Parameters" on page 21-19 before reading this section. Use the Mask Editor **Parameters** pane to specify block mask parameters.



For reference information about all **Parameters** pane capabilities, see the "Parameters Pane". This section gives an example of their use.

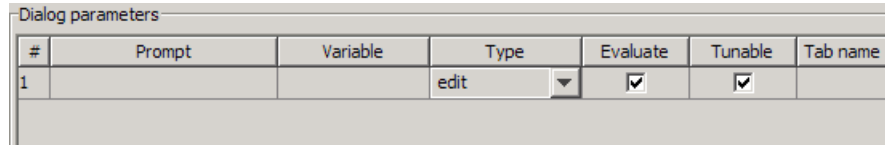
The parameters pane defines both the individual mask parameters and the organization of the Mask Parameters dialog box. For each mask parameter, a row exists **Dialog parameters** table on the **Parameters** pane . The fields in this row are:

- **Prompt** — A prompt that represents the parameter in the Mask Parameters dialog box
- **Variable** — A variable in the mask workspace that corresponds to the mask parameter
- **Type** — The type of control that represents the mask parameter in the Mask Parameters dialog box
- **Evaluate** — Whether Simulink uses the value of the mask parameter literally, or evaluates it

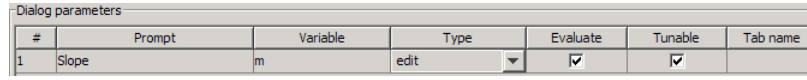
- **Tunable** — Whether the parameter is editable (tunable) while simulation is running
- **Tab name** — The name of the tab, if any, on which the control appears in the mask dialog box

Parameters appear in the Mask Parameters dialog box in the same order that the corresponding parameter definitions appear in the **Dialog parameters** table. To define the mask parameters used in the `masking_example`:

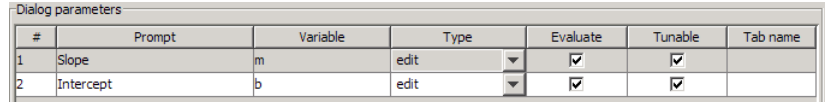
1. Click the **Add** button  at the upper left of the **Parameters** pane to create a new parameter:



2. Edit the **Prompt** field to specify `Slope` and the **Variable** field to specify `m`:

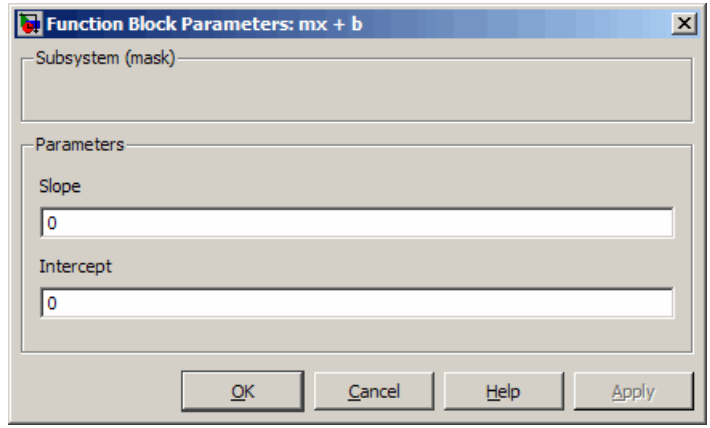


3. Click **Add** to create a second parameter, and specify its **Prompt** as `Intercept` and its **Variable** as `b`.

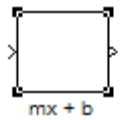


4. Click **Apply** to save the parameter definitions.

Double-click the masked subsystem to see the current Mask Parameters dialog box:



The variables `m` and `b` now exist in the mask workspace. The GUI parameters in the Mask Parameters dialog box are mapped to the corresponding workspace variables. By default, these variables are of type `double` and have a default value of `0`. The mask icon now shows an initial **Slope** of `0`:



See the "Parameters Pane" reference for information about all **Parameters** pane capabilities.

Mask Parameters Dialog Box Callback Code

Enter the MATLAB code that you want the Simulink software to execute when a user applies a change to the selected parameter (selects the **Apply** or **OK** button on the Mask Parameters dialog box). You can use such callbacks to create dynamic dialog boxes, which are dialog boxes whose appearance changes, depending on changes to control settings made by the user (for example, enabling an edit field when a user checks a check box). See "Creating Dynamic Mask Dialog Boxes" on page 21-48 more information.

Note Callbacks are not intended to be used to alter the contents of a masked subsystem. Altering a masked subsystem's contents in a callback, for example, by adding or deleting blocks or changing block parameter values, can trigger errors during model update or simulation. If you need to modify the contents of a masked subsystem, use the mask's initialization code to perform the modifications (see "Initialization Pane").

The callback can create and reference variables only in the base workspace of the block. If the callback needs the value of a mask parameter, it can use `get_param` to obtain the value. For example:

```
if str2num(get_param(gcb, 'g'))<0
 error('Gain is negative.')
end
```

For information on debugging dialog box callbacks, see .

Defining Mask Documentation

A block mask can display three types of documentation. They are all optional, but in practice essentially all masks provide them.

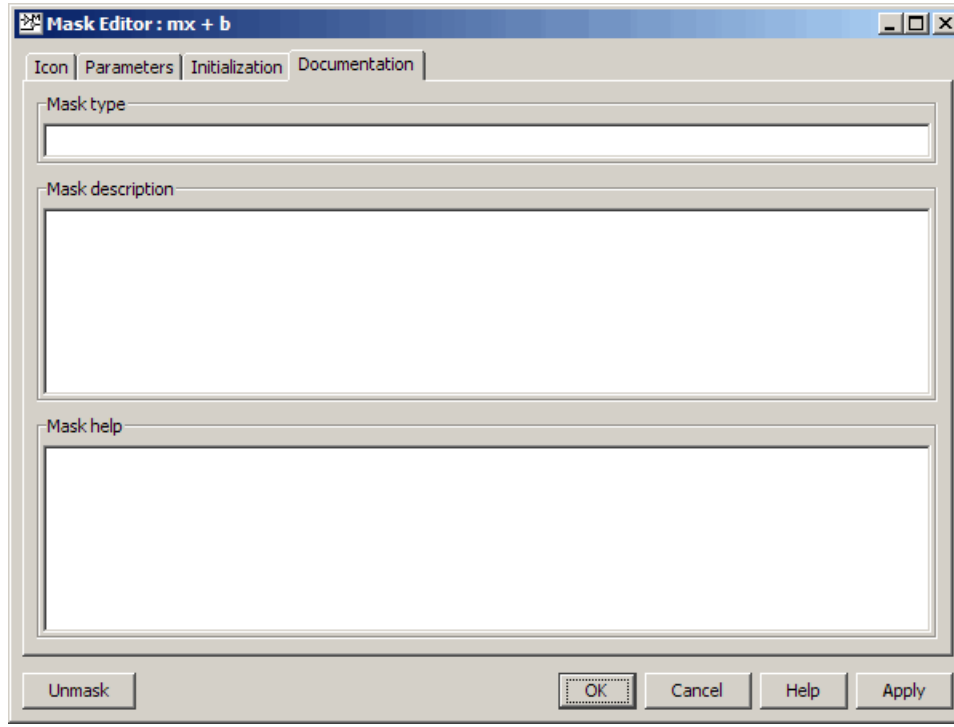
Mask type — A name that appears at the top of the Mask Parameters dialog box. When Simulink displays the Mask Parameters dialog box, it adds `(mask)` to the mask type. You cannot use newlines in the text.

Mask description — Summary text that describe the purpose of the masked block. The description appears in the Mask Parameters dialog box under the mask type. You can use newlines and multiple blanks for formatting.

Mask help — Provides additional information that appears when the user clicks the **Help** button on the Mask Parameters dialog box. The text can be:

- Plain text. Use newlines and multiple blanks for formatting.
- HTML text and graphics. Any standard HTML tag can appear.
- A URL that points to information, which can be text or HTML.
- A `web` or `eval` command that returns text or HTML to display.

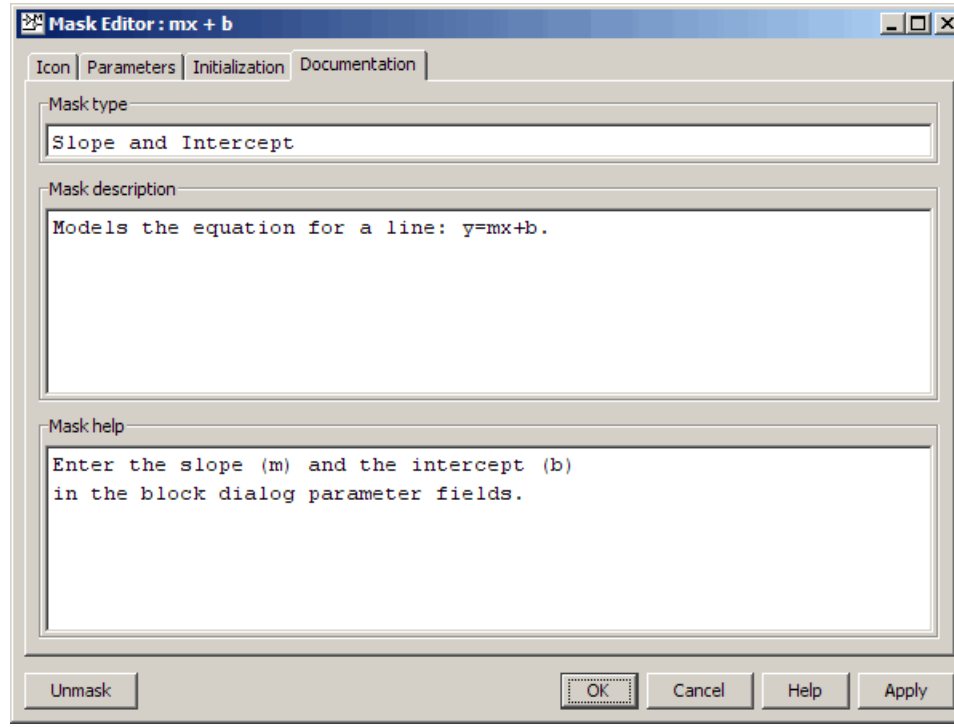
Use the Mask Editor **Documentation** pane to specify the **Mask type**, **Mask description**, and **Mask Help** for a masked block:



For information about all **Documentation** pane capabilities, see the "Documentation Pane" reference.

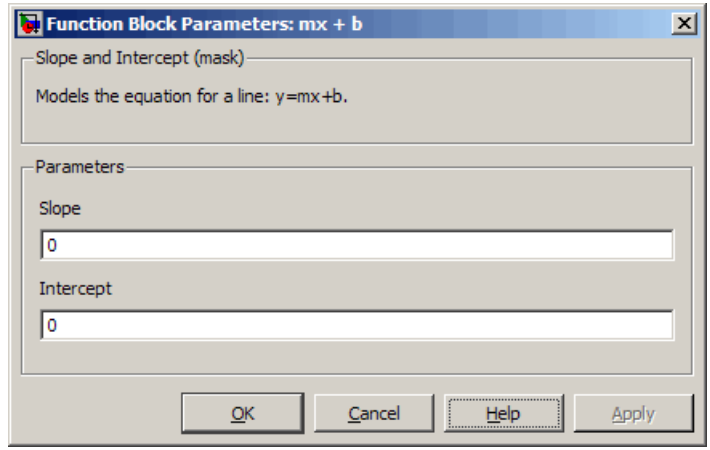
To specify mask documentation, enter text in the three fields of the **Documentation** pane. To define the `masking_example` documentation:

1. Enter the text shown below in the **Mask type**, **Mask description**, and **Mask help** fields:

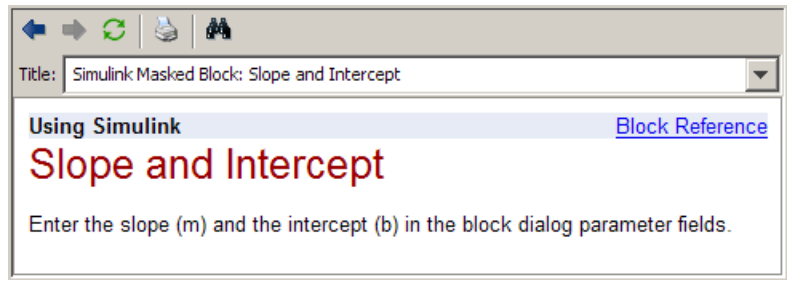


2 Click **Apply**.

The Mask Parameters dialog box closes if it is open. Double-click the masked subsystem to open the dialog box:



In the Mask Parameters dialog box, the mask type and description now show the text that you entered in the **Documentation** pane. Simulink adds `(mask)` to the Mask type to indicate that the dialog box shows a mask rather than a native block dialog box. To see the mask help, click the **Help** button. The help text appears in the MATLAB Help browser:



You can use the full capabilities of the MATLAB Help browser for the help that you access from a Mask Parameters dialog box.

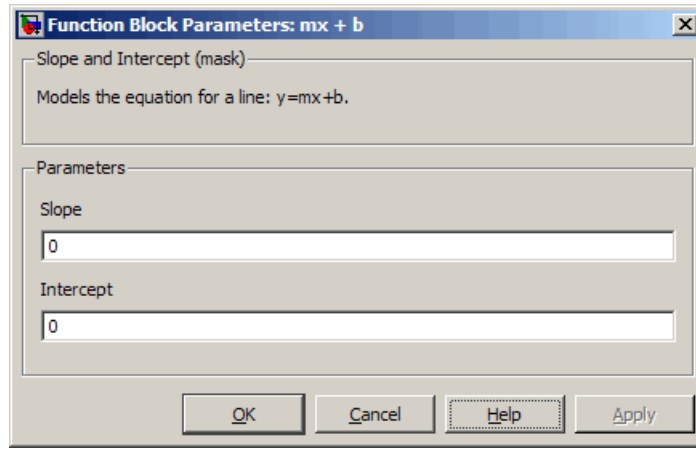
Using a Block Mask

Once you have completed the operations described above, click **OK** to apply any final changes to the mask and close the Mask Editor. If you want to save the mask for later examination, save the model. If you close a model without saving it, all unsaved Mask Editor changes are lost.

You can now use the masked Subsystem block `mx + b` exactly as you could if it were an instance of a built-in block whose capabilities are those of the subsystem and whose interface is that of the mask:

1. Double-click the masked block `mx + b`.

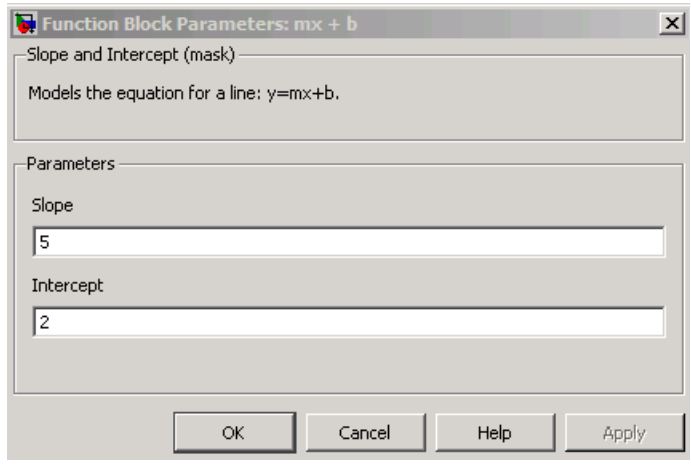
   The Mask Parameters dialog box opens:



2. Change the parameter values so that **Slope** = `5` and **Intercept** = `2`.

3. Click **Apply**.

   The Mask Parameters dialog box and the mask icon now look like this:



When you click **Apply**, Simulink assigns the value of **Slope** to the mask workspace parameter `m`, and the value of **Intercept** to the mask workspace parameter `b`, as described in "Understanding Mask Parameters" on page 21-19. The blocks in the subsystem that reference `m` and `b` will use those values during simulation. The mask icon now reflects **Slope** = `5` via the drawing command `plot(x,y)`, as described in "Defining a Mask Icon" on page 21-13. The mask documentation is as defined in "Defining Mask Documentation" on page 21-25.

Masking a Model Block

In this section...

Special Considerations for Masking a Model Block

You can use all techniques described in "Creating Dynamic Masked Subsystems" on page 21-53 to mask a Model block, except for how you specify the model name and what workspace you use for variables.

Specifying the Model Name

If a mask specifies the name of the model referenced by a Model block, or by any Model block in a masked subsystem, the name of the referenced model must be given literally, rather than obtained by evaluating a workspace variable. This requirement exists because Simulink updates model reference targets before evaluating block parameters. To enforce the requirement, use one of these approaches, depending on which user interaction you prefer for the Mask Parameters dialog box:

- To restrict the user to specifying one of a predefined set of models, use a pop-up control to specify the name of the referenced model. Clear the **Evaluate** parameter for the pop-up control. Clearing the **Evaluate** parameter causes the control to provide a textual rather than a numeric value.
- To allow the user to specify any model as the referenced model, use an edit control to specify the name of the referenced model. Clear the **Evaluate** parameter for the edit control. Clearing the **Evaluate** parameter causes the name that the user provides to be interpreted literally.

See "Defining Mask Parameters" on page 21-21 for information about defining Pop-Up and Edit controls.

Workspace for Variables

The mask workspace of a Model block is not visible to the model that it references. Any variables used by the referenced model must resolve to workspaces that the referenced model defines, or to the MATLAB base workspace.

Masks on Blocks in User Libraries

In this section...

About Masks and User-Defined Libraries

You can mask a block that will be included in a user library or already resides in a user library, or you can mask an instance of a user library block that you have copied into a model. For example, a user library block might provide the capabilities that a model needs, but its native interface might be inappropriate or unhelpful in the context of the particular model. Masking the block could give it a more appropriate user interface.

Masking a Block for Inclusion in a User Library

You can create a custom block by encapsulating a block diagram that defines the block's behavior in a masked subsystem and then placing the masked subsystem in a library. You can also apply a mask to any other type of block that supports masking, then include the block in a library.

Masking a block that will later be included in a library requires no special provisions. Create the block and its mask as described in this chapter, and include the block in the library as described in "Creating Block Libraries" on page 23-14.

Masking a Block that Resides in a User Library

Creating or changing a library block mask immediately changes the block interface in all models that access the block using a library reference, but has no effect on instances of the block that already exist as separate copies. To apply or change a library block mask:

1 Open the library that contains the block.

2 Choose **Edit > Unlock Library**.

You can now apply, change, or remove a mask as you could if the block did not reside in a library. In addition, you can specify non-default values for block mask parameters. When the block is referenced within or copied into a model, the specified default values appear on the block's Mask Parameters dialog box. By default, edit fields have a value of zero, check boxes are cleared, and drop-down lists select the first item in the list. To change the default for any field:

1 Fill in the desired default values or change check box or drop-down list settings

2 Click **Apply** or **OK** to save the changed values into the library block mask.

Be sure to save the library after changing the mask of any block that it contains. Saving the library will automatically relock it. Complete information about user libraries appears in Chapter 23, "Working with Block Libraries". Additional information relating to masked library blocks appears in "Creating Block Libraries" on page 23-14.

Masking a Block Copied from a User Library

A block that was copied from a user library, as distinct from a block accessed by using a library reference, has no special status with respect to masking. You can add a mask to the copied block, or change or remove any mask that it already has.

Operating on Existing Masks

In this section...

Changing a Block Mask

You can change an existing mask by reopening the Mask Editor and using the same techniques that you used to create the mask:

1. Select the masked block.
2. Choose **Edit Mask** from the **Edit** menu or the block's context menu.

The Mask Editor reopens, showing the existing mask definition. Change the mask as needed. After you change a mask, be sure to save the model before closing it, or the changes will be lost.

Viewing Mask Parameters

To display a masked block's Mask Parameters dialog box, either double-click the block or select it and choose **Mask Parameters** from the **Edit** menu or the block's context menu.

To display the Block Parameters dialog box that double-clicking would display if no mask existed, select the masked block and choose ***BlockType* Parameters** from the **Edit** menu or the context menu for the block.

Looking Under a Block Mask

To see the block diagram under a masked Subsystem block, or the model referenced by a masked Model block, select the block and choose **Look Under**

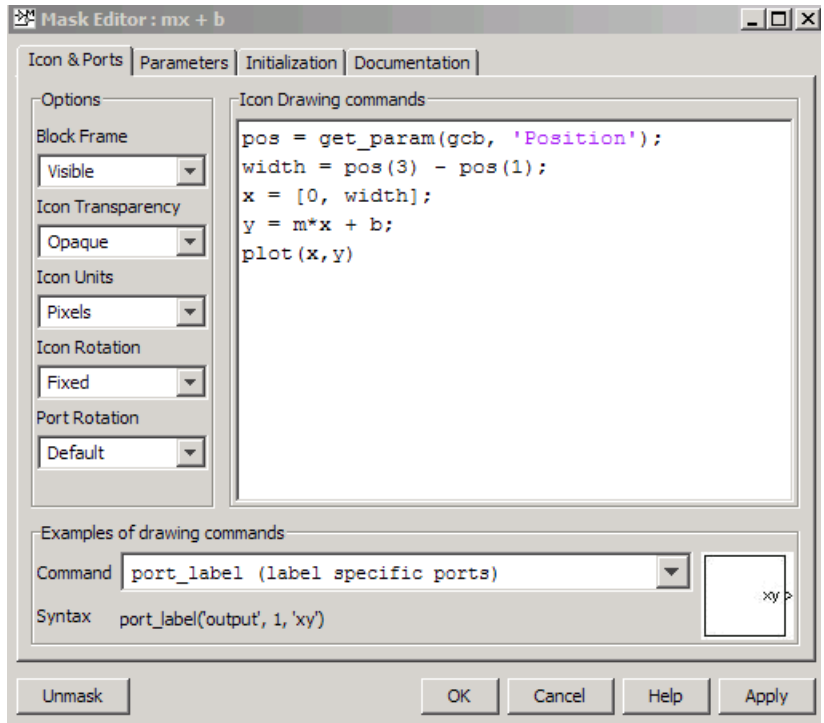
Mask from the **Edit** menu or the block's context menu. The block diagram or referenced model opens in a separate window.

Removing and Caching a Mask

To remove a mask from a block and cache it for possible restoration later:

1. Select the block.
2. Choose **Edit Mask** from the **Edit** menu or the context menu of the block.

   The Mask Editor opens and displays the existing mask, for example:



3. Click **Unmask** in the lower left corner of the Mask Editor.

The Mask Editor removes the mask from the block, saves the mask in a cache for possible restoration, then closes. The editor caches masks separately for

each block, so removing a mask from one block has no effect on a mask cached for any other block. Closing the Mask Editor has no effect on cached masks.

When you have removed and cached a mask, you can later restore it, as described in "Restoring a Cached Mask" on page 21-37, or delete it, as described in "Permanently Deleting a Mask" on page 21-37. The removed cached mask has no further effect unless you restore it.

Restoring a Cached Mask

As long as a model remains open, you can restore a mask that you removed as described in "Removing and Caching a Mask" on page 21-36.

1. Select the block.
2. Choose **Mask** ***BlockType*** from the **Edit** menu or the block's context menu.

   The Mask Editor reopens, showing the cached masked definition.
3. Modify the definition if needed, using the techniques in "Roadmap for Masking Blocks" on page 21-8.
4. Click **Apply** or **OK** to restore the mask, including any changes that you made.

If you made any changes, be sure to save the model before closing it, or the changes will be lost.

Permanently Deleting a Mask

To delete a mask permanently, first remove it as described in "Removing and Caching a Mask" on page 21-36, then save and close the model. You do not need to close the model immediately after removing a mask that you intend to delete. The removed mask remains in the cache and has no further effect unless you restore it.

Roadmap for Dynamic Masks

You can use the Mask Editor to perform all of the mask operations referenced in "Roadmap for Masking Blocks" on page 21-8 without writing MATLAB code. You can also use MATLAB code to perform the following dynamic mask operations:

- Calculate values assigned under the mask rather than using the values that the user specified
- Change a Mask Parameters dialog box to reflect parameter values specified by the user
- Change the architecture of a masked subsystem to reflect parameter values set by the user

To perform any of these operations, you will need to understand all topics listed in "Roadmap for Masking Blocks" on page 21-8 that relate to your situation, and in particular the `masking_example` shown in "Masked Subsystem Example" on page 21-5 and constructed in "Creating a Block Mask" on page 21-11. You can then read the following sections as needed:

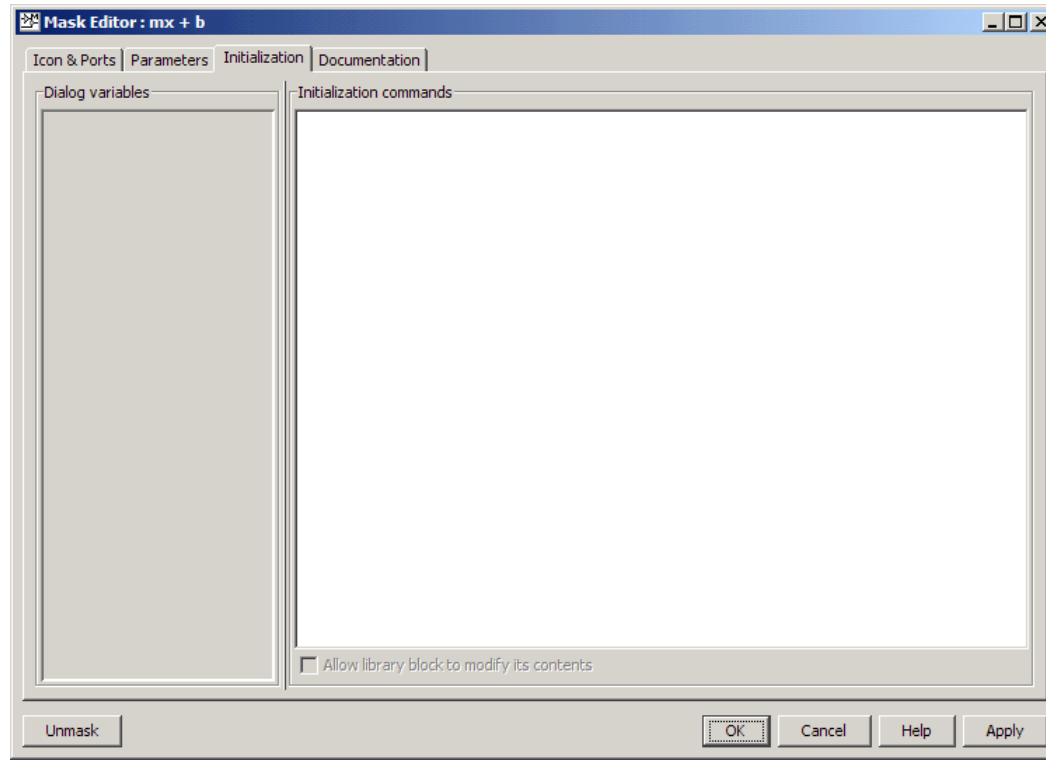
- "Calculating Values Used Under the Mask" on page 21-39
- "Creating Dynamic Mask Dialog Boxes" on page 21-48
- "Creating Dynamic Masked Subsystems" on page 21-53

These operations require using the "Parameters Pane" and the "Initialization Pane" to specify MATLAB code. For information about MATLAB programming, see *MATLAB Programming Fundamentals*.

Calculating Values Used Under the Mask

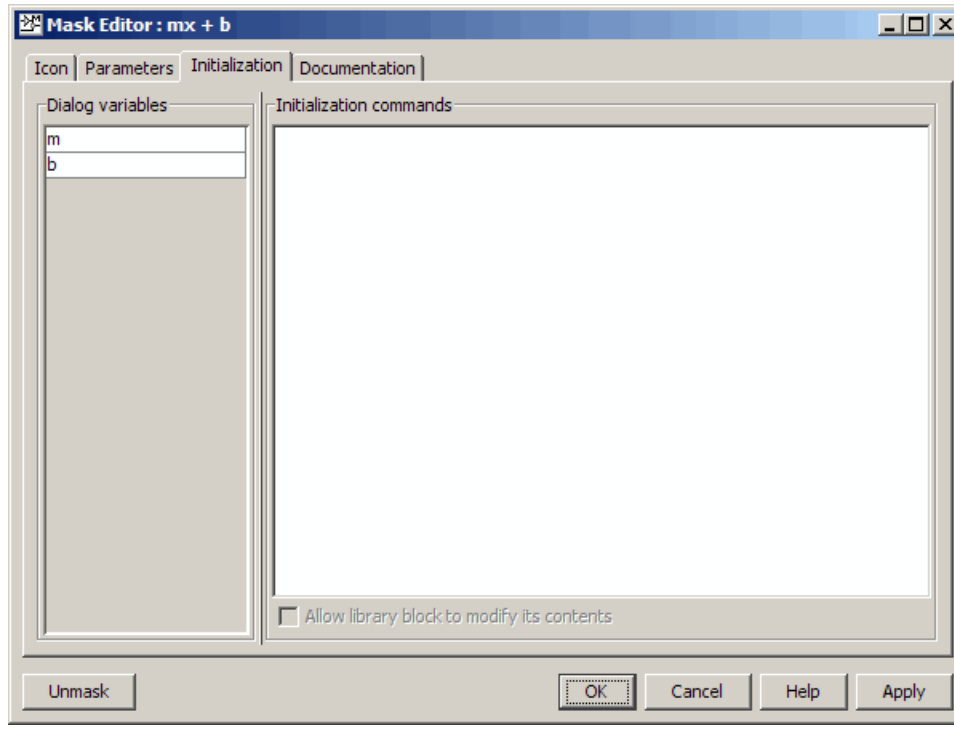
The `masking_example` assigns the values input using the Mask Parameters dialog box directly to block parameters underneath the mask, as described in "Understanding Mask Parameters" on page 21-19. The assignment occurs because the block parameter and the mask parameter have the same name, so the search that always occurs when a block parameter needs a value finds the mask parameter value automatically, as described in "Resolving Symbols" on page 3-75.

You can use the Mask Editor to insert any desired calculation between a value in the Mask Parameters dialog box and an underlying block parameter:



See the “Initialization Pane” reference for reference information about all **Initialization** pane capabilities. This section shows you how to use it for calculating block parameter values.

To calculate a value for a block parameter, first break the link between the mask and block parameters by giving them different names. To facilitate such changes, the Dialog variables subpane lists all mask parameters. The **Initialization** pane looks like this:



You cannot use mask initialization code to change mask parameter default values in a library block or any other block.

You can use the initialization code for a masked block to link mask parameters indirectly to block parameters. In this approach, the initialization code creates variables in the mask workspace whose values are functions of the

mask parameters and that appear in expressions that set the values of parameters of blocks concealed by the mask.

If you need both the string entered and the evaluated value, clear the **Evaluate** option. To get the value of a base workspace variable entered as the literal value of the mask parameter, use the MATLAB `evalin` command in the mask initialization code. For example, suppose the user enters the string `'gain'` as the literal value of the mask parameter `k` where `gain` is the name of a base workspace variable. To obtain the value of the base workspace variable, use the following command in the initialization code for the mask:

```
value = evalin('base', k)
```

These values are stored in variables in the *mask workspace*. A masked block can access variables in its mask workspace. A workspace is associated with each masked subsystem that you create. The current values of the subsystem's parameters are stored in the workspace as well as any variables created by the block's initialization code and parameter callbacks.

Controlling Masks Programmatically

In this section...

Using the get_param and set_param Commands

The Simulink software defines a set of masked block parameters that define the current state of the masked block dialog box. You can use the Mask Editor to inspect and set many of these parameters. The `get_param` and `set_param` commands also let you inspect and set mask dialog box parameters. The `set_param` command allows you to set parameters that change the appearance of a dialog box while the dialog box is open. This ability to change the appearance of the dialog box while the dialog box is open allows you to create dynamic masked dialog box.

For example, you can use the `set_param` command in mask callback functions to be invoked when a user changes the values of user-defined parameters. The callback functions, in turn, can use `set_param` commands to change the values of predefined parameters of the masked block dialog box, and hence its state. For example, the callback function can hide, show, enable, or disable a user-defined parameter control.

Use the `'mask'` option of the `open_system` command to open the Mask Parameters dialog box for a block at the MATLAB command line or in a MATLAB program.

You can use `get_param` and `set_param` to access this mask parameter.

You can customize every feature of the Mask Parameters dialog box, including which parameters appear on the dialog box, the order in which they appear, parameter prompts, the controls used to edit the parameters, and the parameter callbacks (code used to process parameter values entered by the user).

However, changing the mask parameter value with `set_param` does *not* change the value of the underlying block variable. You cannot use `get_param` or `set_param` to access the value of the underlying variable, because it is hidden by the mask.

The `set_param` and `get_param` commands are insensitive to case differences in mask variable names. For example, suppose a model named `MyModel` contains a masked subsystem named `A` that defines a mask variable named `Volume`. Then, the following line of code returns the value of the `Volume` parameter.

```
get_param('MyModel/A', 'voLUME')
```

However, case does matter when using a mask variable as the value of a block parameter inside the masked subsystem. For example, suppose a Gain block inside the masked subsystem `A` specifies `VOLUME` as the value of its Gain parameter. This variable name does not resolve in the masked subsystem's workspace, as it contains a mask variable named `Volume`. If the base workspace does not contain a variable named `VOLUME`, simulating `MyModel` produces an error.

Predefined Masked Dialog Box Parameters

The following predefined parameters are associated with masked dialog boxes.

MaskCallbacks

The value of this parameter is a cell array of strings that specify callback expressions for the user-defined parameter controls for the dialog box. The first cell defines the callback for the first parameter control, the second for the second parameter control, etc. The callbacks can be any valid MATLAB expressions, including expressions that invoke MATLAB commands. This capability means that you can implement complex callbacks as MATLAB program files.

You can use either the Mask Editor or the MATLAB command line to specify mask callbacks. To use the Mask Editor to enter a callback for a parameter, enter the callback in the **Callback** field for the parameter.

The easiest way to set callbacks for a mask dialog box at the MATLAB command is to first select the corresponding masked dialog box in a model

or library window and then to issue a `set_param` command at the MATLAB command line. For example, the following code

```
set_param(gcb,'MaskCallbacks',{'parm1_callback', '',...
'parm3_callback'});
```

defines callbacks for the first and third parameters of the masked dialog box for the currently selected block. To save the callback settings, save the model or library containing the masked block.

MaskDescription

The value of this parameter is a string specifying the description of this block. You can change a masked block's description dynamically by setting this parameter in a mask callback.

MaskDisplay

The value of this parameter is string that specifies the MATLAB code for the block icon.

MaskEnables

The value of this parameter is a cell array of strings that define the enabled state of the user-defined parameter controls for this dialog box. The first cell defines the enabled state of the control for the first parameter, the second for the second parameter, etc. A value of `'on'` indicates that the corresponding control is enabled for user input; a value of `'off'` indicates that the control is disabled.

You can enable or disable user input dynamically by setting this parameter in a callback. For example, the following command in a callback

```
set_param(gcb,'MaskEnables',{'on','on','off'});
```

disables the third control of the dialog box of the currently open masked block. Disabled controls are colored gray to indicate visually that they are disabled.

MaskInitialization

The value of this parameter is string that specifies the initialization commands for the mask workspace.

MaskPrompts

The value of this parameter is a cell array of strings that specify prompts for user-defined parameters. The first cell defines the prompt for the first parameter, the second for the second parameter, and so on.

MaskType

The value of this parameter is the mask type of the block associated with this dialog box.

MaskValues

The value of this parameter is a cell array of strings that specify the values of user-defined parameters for this dialog box. The first cell defines the value for the first parameter, the second for the second parameter, and so on.

MaskVisibilities

The value of this parameter is a cell array of strings that specify the visibility of the user-defined parameter controls for this dialog box. The first cell defines the visibility of the control for the first parameter, the second for the second parameter, etc. A value of `'on'` indicates that the corresponding control is visible; a value of `'off'` indicates that the control is hidden.

You can hide or show user-defined parameter controls dynamically by setting this parameter in the callback for a control. For example, the following command in a callback

```
set_param(gcb,'MaskVisibilities',{'on','off','on'});
```

would hide the control for the currently selected block's second user-defined mask parameter. Simulink expands or shrinks a dialog box to show or hide a control, respectively.

Note For a full list of predefined masked block parameters see the Mask Parameters reference page.

Notes on Mask Parameter Storage

1. The `MaskPromptString` parameter stores the **Prompt** field values for all mask dialog box parameters as a string, with individual values separated by vertical bars (|), for example:

   ```
   "Slope:|Intercept:"
   ```

2. The `MaskStyleString` parameter stores the **Type** field values for all mask dialog box parameters as a string, with individual values separated by commas. The **Popup strings** values appear after the `popup` type, as shown in this example:

   ```
   "edit,checkbox,popup(red|blue|green)"
   ```

3. The `MaskValueString` parameter stores the values of all mask dialog box parameters as a string, with individual values separated by a vertical bar (|). The order of the values is the same as the order in which the parameters appear on the dialog box, for example:

   ```
   "2|5"
   ```

4. The `MaskVariables` parameter stores the **Variable** field values for all mask dialog box parameters as a string, with individual assignments separated by semicolons. A sequence number indicates the prompt that is associated with a variable. A special character preceding the sequence number indicates whether the parameter value is evaluated or used literally. An at-sign (`@`) indicates evaluation; an ampersand (`&`) indicates literal usage. For example:

   ```
   "a=@1;b=&2;"
   ```

   This string defines two **Variable** field values:

- The value entered in the first parameter field is evaluated in the MATLAB workspace, and the result is assigned to variable `a` in the mask workspace.
- The value entered in the second parameter field is not evaluated, but is assigned literally to variable `b` in the mask workspace.

Creating Dynamic Mask Dialog Boxes

In this section...

Setting Nested Masked Block Parameters

Avoid using `set_param` commands to set parameters of blocks residing in masked subsystems that reside in the masked subsystem being initialized. Trying to set parameters of blocks in lower-level masked subsystems can trigger unresolvable symbol errors if lower-level masked subsystems reference symbols defined by higher-level masked subsystems. Suppose, for example, a masked subsystem A contains masked subsystem B, which contains Gain block C, whose Gain parameter references a variable defined by B. Suppose also that subsystem A's initialization code contains the command

```
set_param([gcb '/B/C'], 'SampleTime', '-1');
```

Simulating or updating a model containing A causes an unresolvable symbol error.

About Dynamic Masked Dialog Boxes

You can create dialogs for masked blocks whose appearance changes in response to user input. Features of masked dialog boxes that can change in this way include

- Visibility of parameter controls

  Changing a parameter can cause the control for another parameter to appear or disappear. The dialog expands or shrinks when a control appears or disappears, respectively.

- Enabled state of parameter controls

Changing a parameter can cause the control for another parameter to be enabled or disabled for input. A disabled control is grayed to indicate visually that it is disabled.

- Parameter values

  Changing a mask dialog box parameter can cause related mask dialog box parameters to be set to appropriate values.

Creating a dynamic masked dialog box entails using the Mask Editor in combination with the `set_param` command. Specifically, you use the Mask Editor to define parameters of the dialog box, both static and dynamic. For each dynamic parameter, you enter a callback function that defines how the dialog box responds to changes to that parameter (see "Mask Parameters Dialog Box Callback Code" on page 21-24). The callback function can in turn use the `set_param` command to set mask dialog box parameters that affect the appearance and settings of other controls on the dialog box (see "Setting Masked Block Dialog Box Parameters" on page 21-49). Finally, you save the model or library containing the masked subsystem to complete the creation of the dynamic masked dialog box.

Show parameter

The selected parameter appears on the Mask Parameters dialog box only if this option is checked (the default).

Enable parameter

Clearing this option grays the prompt of the selected parameter and disables the edit control of the prompt.

Setting Masked Block Dialog Box Parameters

The following example creates a mask dialog box with two parameters. The first parameter is a pop-up menu that selects one of three gain values: `2`, `5`, or `User-defined`. The selection in this pop-up menu determines the visibility of an edit field for specifying the gain.

1. Mask a subsystem: from the **Edit** menu or the context menu of the block, choose **Mask *BlockType***.

2 Select the **Parameters** pane on the Mask Editor.

3 Add a parameter.

- Enter `Gain:` in the **Prompt** field
- Enter `gain` in the **Variable** field
- Select `popup` in the **Type** field
- Uncheck **Evaluate** in the **Generic options** group. This step turns the visibility of this parameter off, by default.

4 Enter the following three values in the **Popups (one per line)** field:

```
2
5
User-defined
```

5 Enter the following code in the **Dialog callback** field:

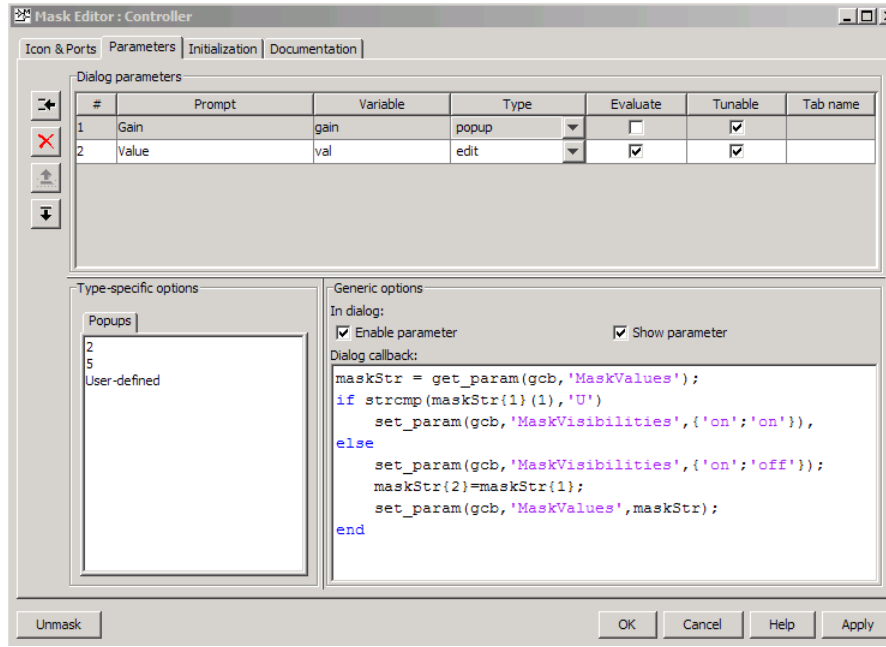
```
% Get the mask parameter values. This is a cell
%   array of strings.
maskStr = get_param(gcb,'MaskValues');

% The pop-up menu is the first mask parameter.
%   Check the value selected in the pop-up
if strcmp(maskStr{1}(1),'U'),

    % Set the visibility of both parameters on when
    %   User-defined is selected in the pop-up.

    set_param(gcb,'MaskVisibilities',{'on';'on'}),

else

    % Turn off the visibility of the Value field
    %   when User-defined is not selected.

    set_param(gcb,'MaskVisibilities',{'on';'off'}),

    % Set the string in the Values field equal to the
    % string selected in the Gain pop-up menu.
```

```
    maskStr{2}=maskStr{1};
    set_param(gcb,'MaskValues',maskStr);
end
```

6 Add a second parameter.

- Enter `Value:` in the **Prompt** field
- Enter `val` in the **Variable** field
- Uncheck **Show parameter** in the **Generic options** group. This step turns the visibility of this parameter off, by default.

7 Select **Apply** on the Mask Editor. The Mask Editor now looks like this when the `gain` parameter is selected and comments are removed from the mask callback code:



Double-clicking on the new masked subsystem opens the Mask Parameters dialog box. Selecting `2` or `5` for the **Gain** parameter hides the **Value** parameter, while selecting `User-defined` makes the **Value** parameter

visible. Note that any blocks in the masked subsystem that need the gain value should reference the mask variable `val` as the `set_param` in the `else` code assures that `val` contains the current value of the gain when `2` or `5` is selected in the popup.

Creating Dynamic Masked Subsystems

In this section...

Allow library block to modify its contents

This check box is enabled only if the masked subsystem resides in a library. Checking this option allows the block initialization code to modify the contents of the masked subsystem (that is, it lets the code add or delete blocks and set the parameters of those blocks). Otherwise, an error is generated when a masked library block tries to modify its contents in any way. To set this option at the MATLAB prompt, select the self-modifying block and enter the following command.

```
set_param(gcb, 'MaskSelfModifiable', 'on');
```

Then save the block.

Creating Self-Modifying Masks for Library Blocks

You can create masked library blocks that can modify their structural contents. These self-modifying masks allow you to:

- Modify the contents of a masked subsystem based on parameters in the Mask Parameters dialog box or when the subsystem is initially dragged from the library into a new model.
- Vary the number of ports on a multiport S-Function block that resides in a library.

Creating Self-Modifying Masks Using the Mask Editor

To create a self-modifying mask using the Mask Editor:

1. Unlock the library (see "Modifying a Library" on page 23-15).
2. Select the block in the library.

3 Select **Edit Mask** from the **Edit** menu or the block's context menu. The Mask Editor opens.

4 In the Mask Editor's **Initialization** pane, select the **Allow library block to modify its contents** option.

5 Enter the code that modifies the masked subsystem in the mask's **Initialization** pane.

Note Do not enter code that structurally modifies the masked subsystem in a dialog parameter callback (see "Mask Parameters Dialog Box Callback Code" on page 21-24). Doing so triggers an error when a user edits the parameter.

---

6 Click **Apply** to apply the change or **OK** to apply the change and dismiss the Mask Editor.

7 Lock the library.

Creating Self-Modifying Masks from the Command Line

To create a self-modifying mask from the command line:

1 Unlock the library using the following command:

```
set_param(gcs,'Lock','off')
```

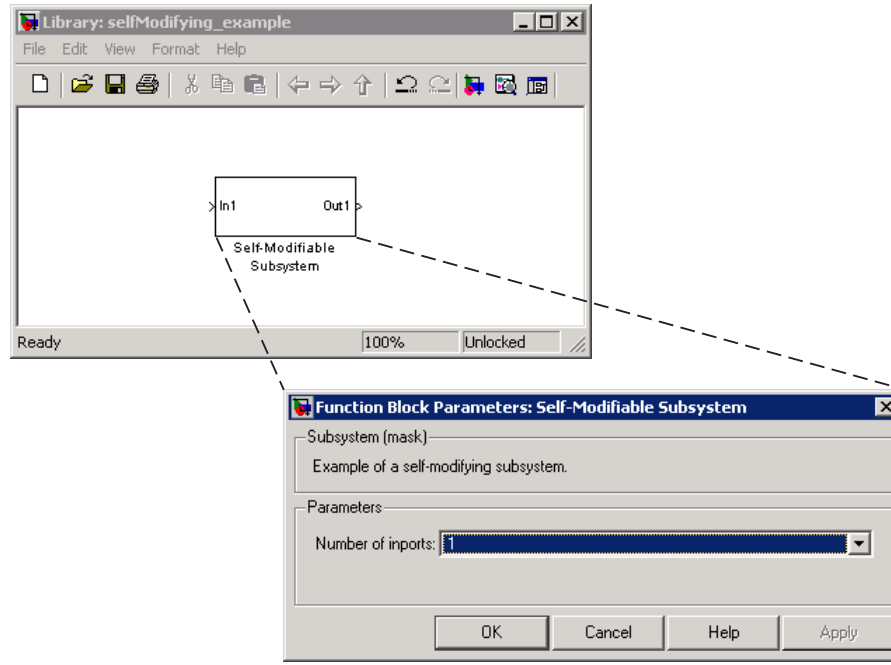
2 Specify that the block is self-modifying by using the following command:

```
set_param(block_name,'MaskSelfModifiable','on')
```

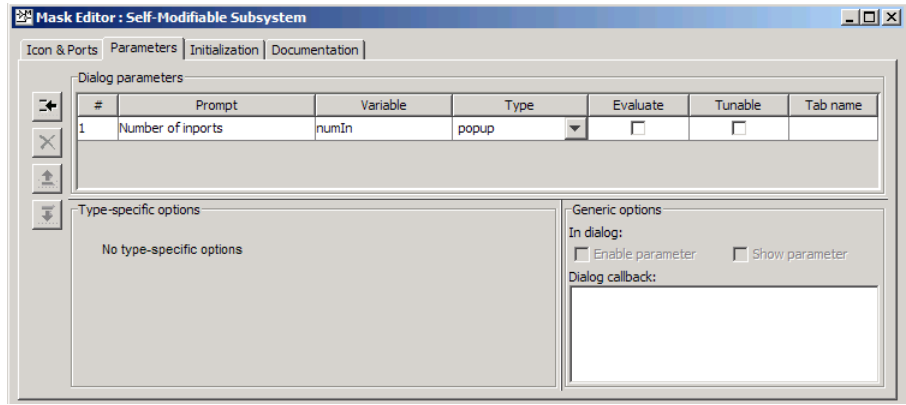
where `block_name` is the full path to the block in the library.

Self-Modifying Mask Example

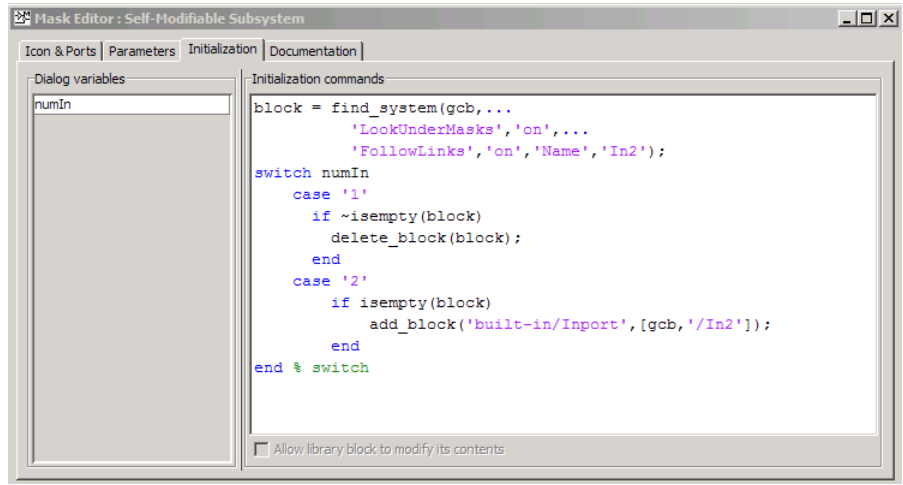
The library `selfModifying_example.mdl` contains a masked subsystem that modifies its number of input ports based on a selection made in the subsystem's Mask Parameters dialog box.



Select the subsystem then select **View Mask** from the **Edit** menu or the block's context menu. The Mask Editor opens. The Mask Editor **Parameters** pane defines one mask parameter variable `numIn` that stores the value for the **Number of inports** option. This Mask Parameters dialog box callback adds or removes Input ports inside the masked subsystem based on the selection made in the **Number of inports** list.



To allow the dialog box callback to function properly, the **Allow library block to modify its contents** option on the Mask Editor **Initialization** pane is selected. If this option were not selected, copies of the library block could not modify their structural contents and changing the selection in the **Number of inports** list would produce an error.



Understanding Mask Code Execution

In this section...

Partitioning MATLAB Code

You can specify MATLAB code for masked blocks in both the mask initialization code and in the block icon drawing code. The location of code affects model performance. In general, partition your code to reflect the functionality you need.

- Keep initialization code together in the **Initialization** pane (or in the `MaskInitialization` parameter).
- Keep icon drawing code, including variable definitions, together in the **Icon & Ports** pane (or in the `MaskDisplay` parameter).
- Keep Mask Parameters dialog box callback code in the **Parameters** pane (or in the `MaskCallback` parameter).

Drawing Commands Execution

Simulink executes the drawing commands in the **Drawing Commands** pane in the sequence in which the commands appear whenever the block has to be drawn or redrawn.

- If the drawing commands are dependent on the mask workspace and the mask workspace changes (that is, mask parameter values change), then the drawing commands execute.
- Rotation and other changes that affect the appearance of the block cause the icon to be redrawn.

Initialization Command Execution

When you open a model, initialization commands execute for all masked blocks that are visible and whose display depends on initialization code.

When you load a model into memory without displaying the model graphically, no initialization commands initially run for any masked blocks. See "Loading a Model" on page 1-7 and `load_system` for information about loading a model without displaying it.

Initialization commands for all masked blocks in a model run when you:

- Update the diagram
- Start simulation
- Start code generation

Initialization commands for an individual masked block run when you:

- Change any of the parameters that define the mask, such as `MaskDisplay` and `MaskInitialization`, by using the Mask Editor or `set_param`
- Rotate or flip the masked block, if the icon depends on initialization commands
- Cause the icon to be drawn or redrawn, and the icon display commands depend on initialization code.
- Change the value of a mask parameter by using the block dialog box or `set_param`
- Copy the masked block within the same model or between different models

Mask Parameters Dialog Box Callback Code Execution

Simulink executes the callback commands when you:

- Open the Mask Parameters dialog box. Callback commands execute top down, starting with the top mask dialog box parameter.

- Modify a parameter value in the Mask Parameters dialog box and then change the cursor's focus (that is, you press the **Tab** key or click into another field in the dialog box).

  Note When you modify the parameter value by using the `set_param` command, the callback commands do not execute.

- Modify the parameter value, either in the Mask Parameters dialog box or via a call to `set_param`, and then apply the change by clicking **Apply** or **OK**. Mask initialization commands execute after the callback commands. (See "Initialization Pane".)
- Hover over the masked block to see the data tip for the block, when the data tip contains parameter names and values. The callback executes again when the block data tip disappears.

  Note The callback commands do not execute if the Mask Parameters dialog box is open when the block data tip appears.

- Update a diagram (for example, by pressing **Ctrl-D** or by selecting the **Edit > Update diagram** menu item).

Debugging Masks That Use MATLAB Code

You can use MATLAB tools to debug mask initialization commands and dialog callbacks in the Mask Editor or the MATLAB Editor/Debugger.

You can debug initialization commands and parameter callbacks entered directly into the Mask Editor in these ways:

- Remove the terminating semicolon from a command to echo its results to the MATLAB Command Window.
- Place a `keyboard` commands in the code to stop execution and give control to the keyboard.

You can debug initialization commands and parameter callbacks written in files using the MATLAB Editor/Debugger in the same way that you would with any other MATLAB program file. When debugging initialization commands, you can view the contents of the mask workspace. When debugging parameter callbacks, you can access only base workspace of the block. If you need the value of a mask parameter, use the `get_param` command.

You *cannot* debug icon drawing commands using the MATLAB Editor/Debugger. Use the syntax examples provided in the Mask Editor's **Icon** pane to help solve errors in the icon drawing commands.

22

Creating Custom Blocks

When to Create Custom Blocks

Custom blocks allow you to expand the modeling functionality provided by the Simulink product. By creating a custom block, you can:

- Model behaviors for which the Simulink product does not provide a built-in solution.
- Build more advanced systems.
- Encapsulate systems into a library block that can be copied into multiple models.
- Provide custom graphical user interfaces or analysis routines.

Types of Custom Blocks

In this section...

MATLAB Function Blocks

MATLAB function blocks allow you to use functions to define custom functionality. These blocks serve as a good starting point for creating a custom block if:

- You have an existing MATLAB function that models the custom functionality.
- You find it easier to model custom functionality via a MATLAB function than via a block diagram.
- The custom functionality does not include continuous or discrete dynamic states.

You can create a custom block from a MATLAB function using one of the following types of MATLAB function blocks.

- The Fcn block allows you to use a MATLAB expression to define a single-input, single-output (SISO) block.
- The MATLAB Fcn block allows you to use a MATLAB function to define a SISO block.
- The Embedded MATLAB Function block allows you to define a custom block with multiple inputs and outputs that can be deployed to embedded processors.

Each of these blocks has advantages in particular modeling applications. For example, you can generate code from models containing Embedded MATLAB function blocks while you cannot generate code for models containing a Fcn block.

Subsystem Blocks

Subsystem blocks allow you to build a Simulink diagram to define custom functionality. These blocks serve as a good starting point for creating a custom block if:

- You have an existing Simulink diagram that models custom functionality.
- You find it easier to model custom functionality via a graphical representation than via hand-written code.
- The custom functionality is a function of continuous or discrete system states.
- The custom functionality can be modeled using existing Simulink blocks.

Once you have a Simulink subsystem that models the desired behavior, you can convert it into a custom block by:

1. Masking the block to hide the block's contents and provide a custom block dialog.
2. Placing the block in a library to prohibit modifications and allow for easily updating copies of the block.

See Chapter 23, "Working with Block Libraries" and Chapter 21, "Working with Block Masks" in Using Simulink for more information.

S-Function Blocks

S-function blocks allow you to write MATLAB, C, or C++ code to define custom functionality. These blocks serve as a good starting point for creating a custom block if:

- You have existing MATLAB, C, or C++ code that models custom functionality.
- You need to model continuous or discrete dynamic states or other system behaviors that require access to the S-function API.
- The custom functionality cannot be modeled using existing Simulink blocks.

You can create a custom block from an S-function using one of the following types of S-function blocks.

- The Level-2 MATLAB S-Function block allows you to write your S-function in including MATLAB. (See "Writing S-Functions in MATLAB"). You can debug a MATLAB S-function during a simulation using the MATLAB debugger.
- The S-Function block allows you to write your S-function in C or C++, or to incorporate existing code into your model via a C MEX wrapper. (See "Writing S-Functions in C".)
- The S-Function Builder block assists you in creating a new C MEX S-function or a wrapper function to incorporate legacy C or C++ code. (See "Building S-Functions Automatically".)
- The Legacy Code Tool transforms existing C or C++ functions into C MEX S-functions. (See "Integrating Existing C Functions into Simulink Models with the Legacy Code Tool".)

The S-function target in the Real-Time Workshop product automatically generates a C MEX S-function from a graphical subsystem. If you want to build your custom block in a Simulink subsystem, but implement the final version of the block in an S-function, you can use the S-function target to convert the subsystem to an S-function. See "Creating Component Object Libraries and Enhancing Simulation Performance" in the Real-Time Workshop User's Guide for details and limitations on using the S-function target.

Comparing MATLAB S-Functions to Embedded MATLAB Functions

MATLAB S-functions and Embedded MATLAB functions have some fundamental differences.

- The Real-Time Workshop product can generate code for both MATLAB S-functions and Embedded MATLAB functions. However, MATLAB S-functions require a Target Language Compiler (TLC) file for code generation. Embedded MATLAB functions do not require a TLC-file.
- MATLAB S-functions can use any MATLAB function. Embedded MATLAB functions support only a subset of the MATLAB functions. See "Embedded

MATLAB Function Library Reference" in the Embedded MATLAB documentation for a list of supported functions.

- MATLAB S-functions can model discrete and continuous state dynamics. Embedded MATLAB functions cannot model state dynamics.

Using S-Function Blocks to Incorporate Legacy Code

Each S-function block allows you to incorporate legacy code into your model, as follows.

- A MATLAB S-function accesses legacy code through its TLC-file. Therefore, the legacy code is available only in the generated code, not during simulation.
- A C MEX S-functions directly calls legacy C or C++ code.
- The S-Function Builder generates a wrapper function that calls the legacy C or C++ code.
- The Legacy Code Tool generates a C MEX S-function to call the legacy C or C++ code, which is optimized for embedded systems. See "Integrating Existing C Functions into Simulink Models with the Legacy Code Tool" for more information.

See "Integration Options" in the Real-Time Workshop User's Guide for more information.

See "Example Using S-Functions to Incorporate Legacy C Code" in "Writing S-Functions" for an example.

Comparison of Custom Block Functionality

In this section...

Custom Block Considerations

When creating a custom block, you may want to consider the following.

- Does the custom block need multiple input and output ports?
- Does the block need to model continuous or discrete state behavior?
- Will the block's inputs and outputs have various data attributes, such as data types or complexity?
- How important is the affect of the custom block on the speed of updating the Simulink diagram or simulating the Simulink model?
- Do you need to generate code for a model containing the custom block?

The following two tables provide an overview of how each custom block type addresses the previous questions. More detailed information for each consideration follows these two tables.

Modeling Requirements

Custom Block Type	Supports Multiple Inputs and Outputs	Models State Dynamics	Supports Various Data Attributes
Subsystem	Yes, including bus signals.	Yes.	Yes, including all data types, numeric types, and dimensions supported by the Simulink software. Also supports frame-based signals.
Fcn	No. Must have a single vector input and scalar output.	No.	Supports only real scalar signals with a data type of double or single.

Modeling Requirements (Continued)

Custom Block Type	Supports Multiple Inputs and Outputs	Models State Dynamics	Supports Various Data Attributes
MATLAB Fcn	No. Must have a single vector input and output.	No.	Supports only n-D, real, or complex signals with a data type of double.
Embedded MATLAB Function	Yes, including bus signals.	No.	Yes, including all data types, numeric types, and dimensions supported by the Simulink software. Also supports frame-based signals.
Level-2 MATLAB S-function	Yes.	Yes, including limited access to other S-function APIs.	Yes, including all data types, numeric types, and dimensions supported by the Simulink software. Also supports frame-based signals.
C MEX S-function	Yes, including bus signals if using the Legacy Code Tool to generate the S-function.	Yes, including full access to all S-function APIs.	Yes, including all data types, numeric types, and dimensions supported by the Simulink software. Also supports frame-based signals.

Speed and Code Generation Requirements

Custom Block Type	Speed of Updating the Diagram	Simulation Overhead	Code Generation Support
Subsystem	Proportional to the complexity of the subsystem. For library blocks, can be slower the first time the library is loaded.	Proportional to the complexity of the subsystem. Library blocks introduce no additional overhead.	Natively supported.

Speed and Code Generation Requirements (Continued)

Custom Block Type	Speed of Updating the Diagram	Simulation Overhead	Code Generation Support
Fcn	Very fast.	Minimal, but these blocks also provide limited functionality.	Natively supported.
MATLAB Fcn	Fast.	High and incurred when calling out to the MATLAB interpreter. These calls add overhead that should be avoided if simulation speed is a concern.	Not supported.
Embedded MATLAB Function	Can be slower if code must be generated to update the diagram.	Minimal if the MATLAB interpreter is not called. Simulation speed is equivalent to C MEX S-functions when the MATLAB interpreter is not called.	Natively supported, with exceptions. See "Code Generation" on page 22-16 for more information.
Level-2 MATLAB S-function	Can be slower if the S-function overrides methods executed when updating the diagram.	Higher than for MATLAB Fcn blocks because the MATLAB interpreter is called for every S-function method used. Very flexible, but very costly.	MATLAB S-functions initialized as a `SimViewingDevice` do not generate code. Otherwise, MATLAB S-functions require a TLC-file for code generation.
C MEX S-function	Can be slower if the S-function overrides methods executed when updating the diagram.	Minimal, but proportional to the complexity of the algorithm and the efficiency of the code.	Might require a TLC-file.

Modeling Requirements

Multiple Input and Output Ports

The following types of custom blocks support multiple input and output ports.

Custom Block Type	Multiple Input and Output Port Support
Subsystem	Supports multiple input and output ports, including bus signals. In addition, you can modify the number of input and output ports based on user-defined parameters. See "Self-Modifying Linked Subsystems" on page 23-5 for more information.
Fcn, MATLAB Fcn	Supports only a single input and a single output port. You must use a Mux block to combine the inputs and a Demux block to separate the outputs if you need to pass multiple signals into or out of these blocks.
Embedded MATLAB Function	Supports multiple input and output ports, including bus signals. See "Working with Structures and Bus Signals" on page 24-100 for more information.
S-function (MATLAB or C MEX)	Supports multiple input and output ports. In addition, you can modify the number of input and output ports based on user-defined parameters. S-functions generated using the Legacy Code Tool also accept Simulink bus signals. See "Integrating Existing C Functions into Simulink Models with the Legacy Code Tool" for more information.

State Behavior and the S-Function API

Simulink blocks communicate with the Simulink engine through the S-function API, a set of methods that fully specifies the behavior of blocks. Each custom block type accesses a different sets of the S-function APIs, as follows.

Custom Block Type	S-Function API Support
Subsystem	Communicates directly with the engine. You can model state behaviors using appropriate blocks from the Continuous and Discrete Simulink block libraries.
Fcn, MATLAB Fcn, Embedded MATLAB Function	All create an `mdlOutput` method to calculate the value of the outputs given the value of the inputs. You cannot access any other S-function API methods using one of these blocks and, therefore, cannot model state behavior.
MATLAB S-function	Accesses a larger subset of the S-function APIs, including the methods needed to model continuous and discrete states. For a list of supported methods, see "Level-2 MATLAB S-Function Callback Methods" in "Writing S-Functions".
C MEX S-function	Accesses the complete set of S-function APIs.

Data Attribute Support

All custom block types support real scalar inputs and outputs with a data type of double.

Custom Block Type	Data Attribute Support
Subsystem	Supports any data type supported by the Simulink software, including fixed-point types. Also supports complex, 2-D, n-D, and frame-based signals.
Fcn	Supports only double or single data types. In addition, the input and output cannot be complex and the output must be a scalar signal. Does not support frame-based signals.
MATLAB Fcn	Supports 2-D, n-D, and complex signals, but the signal must have a data type of double. Does not support frame-based signals.

Custom Block Type	Data Attribute Support
Embedded MATLAB Function	Supports any data type supported by the Simulink software, including fixed-point types. Also supports complex, 2-D, n-D, and frame-based signals.
S-function (MATLAB or C MEX)	Supports any data type supported by the Simulink software, including fixed-point types. Also supports complex, 2-D, n-D, and frame-based signals.

Speed and Code Generation Requirements

Updating the Simulink Diagram

The Simulink software updates the diagram before every simulation and whenever requested by the user. Every block introduces some overhead into the "update diagram" process.

Custom Block Type	Speed of Updating the Diagram
Subsystem	The speed is proportional to the complexity of the algorithm implemented in the subsystem. If the subsystem is contained in a library, some cost is incurred when the Simulink software loads any unloaded libraries the first time the diagram is updated or readied for simulation. If all referenced library blocks remain unchanged, the Simulink software does not subsequently reload the library and compiling the model becomes faster than if the model did not use libraries.
Fcn, MATLAB Fcn	Does not incur greater update cost than other Simulink blocks.
Embedded MATLAB Function	Performs simulation through code generation, so these blocks might take a significant amount of time when first updated. However, because code generation is incremental, if the block and the signals connected to it have not changed, the Simulink software does not repeatedly update the block.
S-function (MATLAB or C MEX)	Incurs greater costs than other Simulink blocks only if it overrides methods executed when updating the diagram. If these methods become complex, they can contribute significantly to the time it takes to update the diagram. For a list of methods executed when updating the diagram, see the process view in "How the Simulink Engine Interacts with C S-Functions". When updating the diagram, the Simulink software invokes all relevant methods in the model initialization phase up to, but not including, `mdlStart`.

Simulation Overhead

For most applications, any of the custom block types provide acceptable simulation performance. Use the Simulink profiler to obtain an indication of the actual performance. See "Capturing Performance Data" on page 17-29 for more information.

You can break simulation performance into two categories. The interface cost is the time it takes to move data from the Simulink engine into the block. The algorithm cost is the time needed to perform the algorithm that the block implements.

Custom Block Type	Simulation Overhead
Subsystem	If included in a library, introduces no interface or algorithm costs beyond what would normally be incurred if the block existed as a regular subsystem in the model.
Fcn	Has the least simulation overhead. The block is tightly integrated with the Simulink engine and implements a rudimentary expression language that is efficiently interpreted.
MATLAB Fcn	Has a higher interface cost than most blocks and the same algorithm cost as a MATLAB function. When block data (such as inputs and outputs) is accessed or returned from a MATLAB Fcn block, the Simulink engine packages this data into MATLAB arrays. This packaging takes additional time and causes a temporary increase in memory during communication. If you pass large amounts of data across this interface, such as, frames or arrays, this overhead can be substantial. Once the data has been converted, the MATLAB interpreter executes the algorithm. As a result, the algorithm cost is the same as for MATLAB function. Efficient code can be competitive with C code if the MATLAB software is able to optimize it, or if the code uses the highly optimized MATLAB library functions.

Custom Block Type	Simulation Overhead
Embedded MATLAB Function	Performs simulation through code generation and so incurs the same interface cost as standard blocks. The algorithm cost of this block is harder to analyze because of the block's implementation. On average, an Embedded MATLAB function and a MATLAB function run at about the same speed. To further reduce the algorithm cost, you can disable debugging for all the Embedded MATLAB Function blocks in your model. If the Embedded MATLAB function uses simulation-only capabilities to call out to the MATLAB interpreter, it incurs all the costs that a MATLAB S-function or MATLAB Fcn block incur. Calling out to the MATLAB interpreter from an Embedded MATLAB function produces a warning to prevent you from doing so unintentionally.
MATLAB S-function	Incurs the same algorithm costs as the MATLAB Fcn block, but with a slightly higher interface cost. Because MATLAB S-functions can handle multiple inputs and outputs, the packaging is more complicated than for the MATLAB Fcn block. In addition, the Simulink engine calls the MATLAB interpreter for each block method you implement whereas for the MATLAB Fcn block, it calls the MATLAB interpreter only for the `mdlOutput` method.
C MEX S-function	Simulates via the compiled code and so incurs the same interface cost as standard blocks. The algorithm cost depends on the complexity of the S-function.

Code Generation

Not all custom block types support code generation.

Custom Block Type	Code Generation Support
Subsystem	Supports code generation.
Fcn	Supports code generation.
MATLAB Fcn	Does not support code generation.
Embedded MATLAB Function	Supports code generation. However, if your Embedded MATLAB Function block calls out to the MATLAB interpreter, it will build with the Real-Time Workshop product only if the calls to the MATLAB interpreter do not affect the block's outputs. Under this condition, the Real-Time Workshop product omits these calls from the generated C code. This feature allows you to leave visualization code in place, even when generating embedded code.
MATLAB S-function	Generates code only if you implement the algorithm using a Target Language Compiler (TLC) function. In accelerated and external mode simulations, you can choose to execute the S-function in interpretive mode by calling back to the MATLAB interpreter without implementing the algorithm in TLC. If the MATLAB S-function is a `SimViewingDevice`, the Real-Time Workshop product automatically omits the block during code generation.
C MEX S-function	Supports code generation. For noninlined S-functions, the Real-Time Workshop product uses the C MEX function during code generation. However, you must write a TLC-file for the S-function if you need to either inline the S-function or create a wrapper for hand-written code. See "Integrating External Code With Generated C and C++ Code" in the Real-Time Workshop User's Guide for more information.

Expanding Custom Block Functionality

You can expand the functionality of any custom block using callbacks and Handle Graphics.

Block callbacks perform user-defined actions at specific points in the simulation. For example, the callback can load data into the MATLAB workspace before the simulation or generate a graph of simulation data at the end of the simulation. You can assign block callbacks to any of the custom block types. For a list of available callbacks and more information on how to use them, see "Creating Block Callback Functions" on page 3-58.

GUIDE, the MATLAB graphical user interface development environment, provides tools for easily creating custom user interfaces. See *MATLAB Creating Graphical User Interfaces* for more information on using GUIDE.

Tutorial: Creating a Custom Block

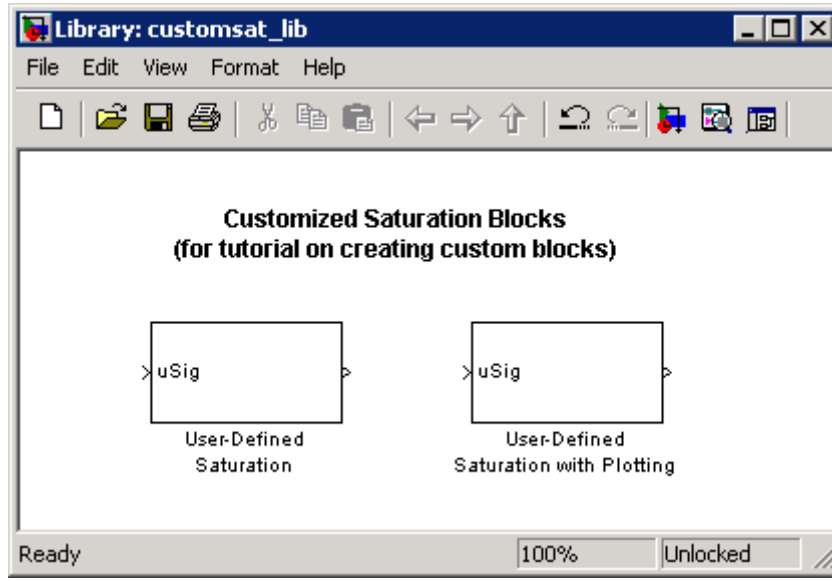
In this section...

How to Design a Custom Block

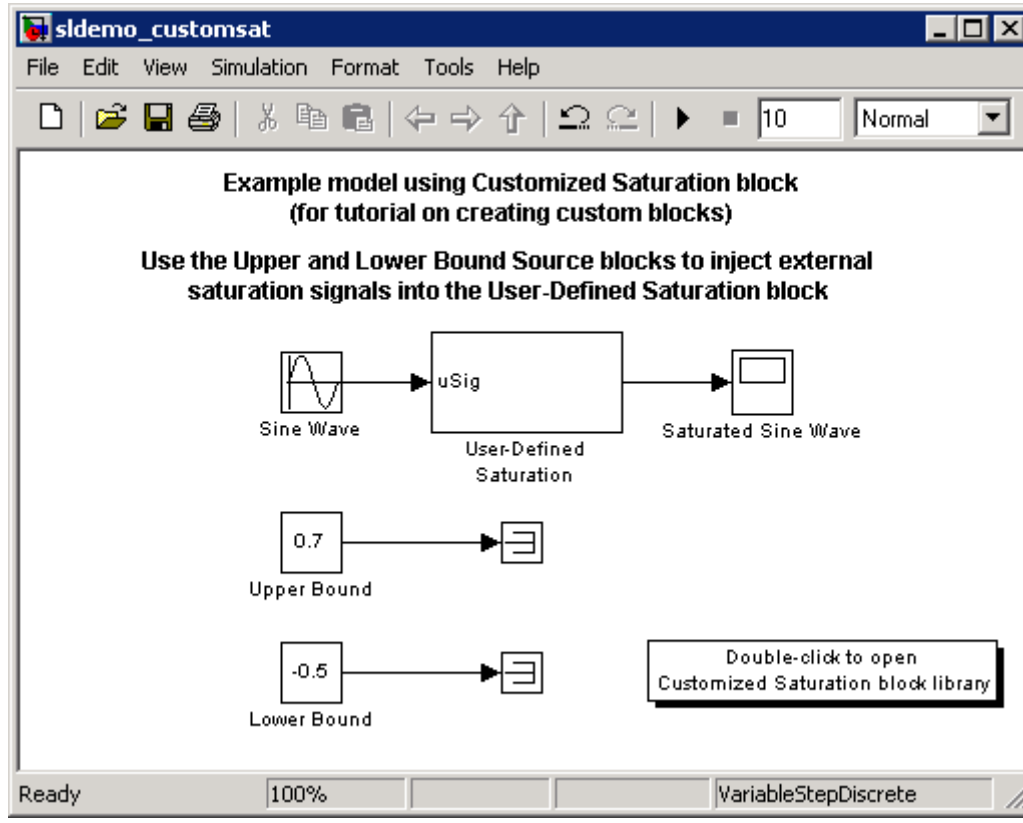
In general, you use the following process to design a custom block:

1. "Defining Custom Block Behavior" on page 22-20
2. "Deciding on a Custom Block Type" on page 22-21
3. "Placing Custom Blocks in a Library" on page 22-26
4. "Adding a Graphical User Interface to a Custom Block" on page 22-28

Suppose you want to create a customized saturation block that limits the upper and lower bounds of a signal based on either a block parameter or the value of an input signal. In a second version of the block, you want the option to plot the saturation limits after the simulation is finished. The following tutorial steps you through designing these blocks. The library `customsat_lib.mdl` contains the two versions of the customized saturation block.



The example model `sldemo_customsat.mdl` uses the basic version of the block.



Defining Custom Block Behavior

Begin by defining the features and limitations of your custom block. In this example, the block supports the following features:

- Turning on and off the upper or lower saturation limit.
- Setting the upper and/or lower limits via a block parameters.
- Setting the upper and/or lower limits using an input signal.

It also has the following restrictions:

- The input signal under saturation must be a scalar.

- The input signal and saturation limits must all have a data type of double.
- Code generation is not required.

Deciding on a Custom Block Type

Based on the custom block's features, the implementation needs to support the following:

- Multiple input ports
- A relatively simple algorithm
- No continuous or discrete system states

Therefore, this tutorial implements the custom block using a Level-2 MATLAB S-function. MATLAB S-functions support multiple inputs and, because the algorithm is simple, do not have significant overhead when updating the diagram or simulating the model. See "Comparison of Custom Block Functionality" on page 22-7 for a description of the different functionality provided by MATLAB S-functions as compared to other types of custom blocks.

Parameterizing the MATLAB S-Function

Begin by defining the S-function parameters. This example requires four parameters:

- The first parameter indicates how the upper saturation limit is set. The limit can be off, set via a block parameter, or set via an input signal.
- The second parameter is the value of the upper saturation limit. This value is used only if the upper saturation limit is set via a block parameter. In the event this parameter is used, you should be able to change the parameter's value during the simulation, i.e., the parameter is tunable.
- The third parameter indicates how the lower saturation limit is set. The limit can be off, set via a block parameter, or set via an input signal.
- The fourth parameter is the value of the lower saturation limit. This value is used only if the lower saturation limit is set via a block parameter. As with the upper saturation limit, this parameter is tunable when in use.

The first and third S-function parameters represent modes that must be translated into values the S-function can recognize. Therefore, define the following values for the upper and lower saturation limit modes:

- `1` indicates that the saturation limit is off.
- `2` indicates that the saturation limit is set via a block parameter.
- `3` indicates that the saturation limit is set via an input signal.

Writing the MATLAB S-Function

Once the S-function parameters and functionality are defined, write the S-function. The template `msfuntmpl.m` provides a starting point for writing a Level-2 MATLAB S-function. You can find a completed version of the custom saturation block in the file `custom_sat.m`. Save this file to your working folder before continuing with this tutorial.

This S-function modifies the S-function template as follows:

- The `setup` function initializes the number of input ports based on the values entered for the upper and lower saturation limit modes. If the limits are set via input signals, the method adds input ports to the block. The `setup` method then indicates there are four S-function parameters and sets the parameter tunability. Finally, the method registers the S-function methods used during simulation.

```
function setup(block)

% The Simulink engine passes an instance of the Simulink.MSFcnRunTimeBlock
% class to the setup method in the input argument "block". This is known as
% the S-function block's run-time object.

% Register original number of input ports based on the S-function
% parameter values

try % Wrap in a try/catch, in case no S-function parameters are entered
    lowMode    = block.DialogPrm(1).Data;
    upMode     = block.DialogPrm(3).Data;
    numInPorts = 1 + isequal(lowMode,3) + isequal(upMode,3);
catch
```

```
    numInPorts=1;
end % try/catch
block.NumInputPorts = numInPorts;
block.NumOutputPorts = 1;

% Setup port properties to be inherited or dynamic
block.SetPreCompInpPortInfoToDynamic;
block.SetPreCompOutPortInfoToDynamic;

% Override input port properties
block.InputPort(1).DatatypeID  = 0;  % double
block.InputPort(1).Complexity  = 'Real';

% Override output port properties
block.OutputPort(1).DatatypeID  = 0; % double
block.OutputPort(1).Complexity  = 'Real';

% Register parameters. In order:
% -- If the upper bound is off (1) or on and set via a block parameter (2)
%    or input signal (3)
% -- The upper limit value. Should be empty if the upper limit is off or
%    set via an input signal
% -- If the lower bound is off (1) or on and set via a block parameter (2)
%    or input signal (3)
% -- The lower limit value. Should be empty if the lower limit is off or
%    set via an input signal
block.NumDialogPrms     = 4;
block.DialogPrmsTunable = {'Nontunable','Tunable','Nontunable', ...
    'Tunable'};

% Register continuous sample times [0 offset]
block.SampleTimes = [0 0];

%% -----------------------------------------------------------------
%% Options
%% -----------------------------------------------------------------
% Specify if Accelerator should use TLC or call back into
% MATLAB script
block.SetAccelRunOnTLC(false);
```

```
%% ------------------------------------------------------------------
%% Register methods called during update diagram/compilation
%% ------------------------------------------------------------------

block.RegBlockMethod('CheckParameters',      @CheckPrms);
block.RegBlockMethod('ProcessParameters',    @ProcessPrms);
block.RegBlockMethod('PostPropagationSetup', @DoPostPropSetup);
block.RegBlockMethod('Outputs',              @Outputs);
block.RegBlockMethod('Terminate',            @Terminate);
%end setup function
```

- The `CheckParameters` method verifies the values entered into the Level-2 MATLAB S-Function block.

```
function CheckPrms(block)

lowMode = block.DialogPrm(1).Data;
lowVal  = block.DialogPrm(2).Data;
upMode  = block.DialogPrm(3).Data;
upVal   = block.DialogPrm(4).Data;

% The first and third dialog parameters must have values of 1-3
if ~any(upMode == [1 2 3]);
    error('The first dialog parameter must be a value of 1, 2, or 3');
end

if ~any(lowMode == [1 2 3]);
    error('The first dialog parameter must be a value of 1, 2, or 3');
end

% If the upper or lower bound is specified via a dialog, make sure there
% is a specified bound. Also, check that the value is of type double
if isequal(upMode,2),
    if isempty(upVal),
        error('Enter a value for the upper saturation limit.');
    end
    if ~strcmp(class(upVal), 'double')
        error('The upper saturation limit must be of type double.');
    end
end
```

```
if isequal(lowMode,2),
    if isempty(lowVal),
        error('Enter a value for the lower saturation limit.');
    end
    if ~strcmp(class(lowVal), 'double')
        error('The lower saturation limit must be of type double.');
    end
end

% If a lower and upper limit are specified, make sure the specified
% limits are compatible.
if isequal(upMode,2) && isequal(lowMode,2),
    if lowVal >= upVal,
        error('The lower bound must be less than the upper bound.');
    end
end

%end CheckPrms function
```

- The `ProcessParameters` and `PostPropagationSetup` methods handle the S-function parameter tuning.

```
function ProcessPrms(block)

%% Update run time parameters
block.AutoUpdateRuntimePrms;

%end ProcessPrms function


function DoPostPropSetup(block)

%% Register all tunable parameters as runtime parameters.
block.AutoRegRuntimePrms;

%end DoPostPropSetup function
```

- The `Outputs` method calculates the block's output based on the S-function parameter settings and any input signals.

```
function Outputs(block)

lowMode    = block.DialogPrm(1).Data;
upMode     = block.DialogPrm(3).Data;
sigVal     = block.InputPort(1).Data;
lowPortNum = 2; % Initialize potential input number for lower saturation limit

% Check upper saturation limit
if isequal(upMode,2), % Set via a block parameter
    upVal = block.RuntimePrm(2).Data;
elseif isequal(upMode,3), % Set via an input port
    upVal = block.InputPort(2).Data;
    lowPortNum = 3; % Move lower boundary down one port number
else
    upVal = inf;
end

% Check lower saturation limit
if isequal(lowMode,2), % Set via a block parameter
    lowVal = block.RuntimePrm(1).Data;
elseif isequal(lowMode,3), % Set via an input port
    lowVal = block.InputPort(lowPortNum).Data;
else
    lowVal = -inf;
end

% Assign new value to signal
if sigVal > upVal,
    sigVal = upVal;
elseif sigVal < lowVal,
    sigVal=lowVal;
end

block.OutputPort(1).Data = sigVal;

%end Outputs function
```

Placing Custom Blocks in a Library

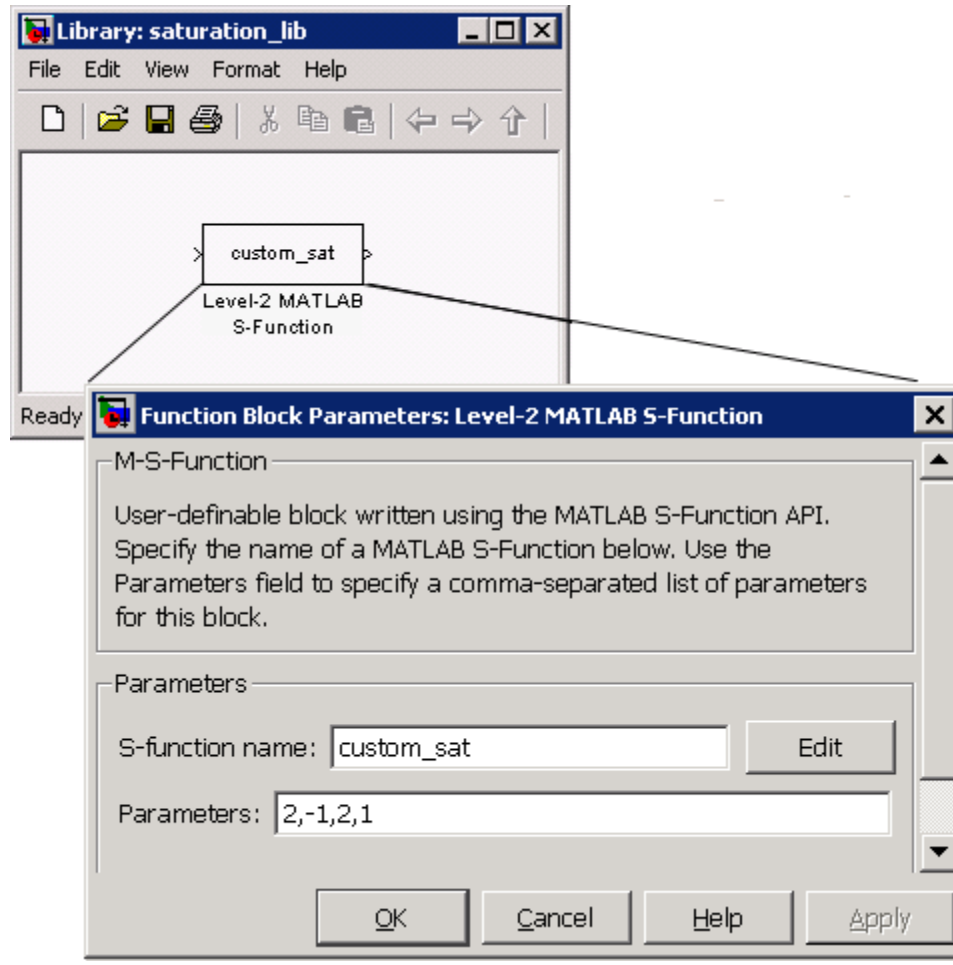
Libraries allow you to share your custom blocks with other users, easily update the functionality of copies of the custom block, and collect blocks for

a particular project into a single location. This example places the custom saturation block into a library as follows:

1. Open a new Simulink library (see "Creating a Library" on page 23-14).
2. Add a new Level-2 MATLAB S-Function block from the Simulink User-Defined Functions library into your new library.
3. Double-click the block to open its Block Parameters dialog box. Enter the name of the S-function `custom_sat` into the **S-function name** field.
4. Enter the following default values into the **Parameters** field.

   ```
   2,-1,2,1
   ```

5. On the Block Parameters dialog box, click **OK**.
6. Save the library to your working folder as `saturation_lib.mdl`. The following figure shows the resulting custom saturation block library.



At this point, you have created a custom saturation block that can be shared with other users. You can make the block easier to use by adding a customized graphical user interface.

Adding a Graphical User Interface to a Custom Block

You can create a simple block dialog for the custom saturation block using the provided masking capabilities. Masking the block also allows you to add port labels to indicate which port corresponds to the input signal and the saturation limits.

To mask the block:

1. Right-click the custom saturation block in `saturation_lib.mdl` and from the context menu, select **Mask MATLAB S-Function**. The Mask Editor opens.

2. On the **Icon & Ports** pane and in the **Icons Drawing commands** box, enter the following.

   ```
   port_label('input',1,'uSig')
   ```

   This command labels the default port as the input signal under saturation.

3. On the **Parameters** pane, add four parameters corresponding to the four S-function parameters. From top to bottom, set up each parameter's properties as follows.

Prompt	Variable	Type	Tunable	Popups	Action for Dialog Callback
Upper boundary:	`upMode`	`popup`	No	No limit | Enter limit as parameter | Limit using input signal	`'upperbound_callback'`
Upper limit:	`upVal`	`edit`	Yes	N/A	`'upperparam_callback'`
Lower boundary:	`lowMode`	`popup`	No	No limit | Enter limit as parameter | Limit using input signal	`'lowerbound_callback'`
Lower limit:	`lowVal`	`edit`	Yes	N/A	`'lowerparam_callback'`

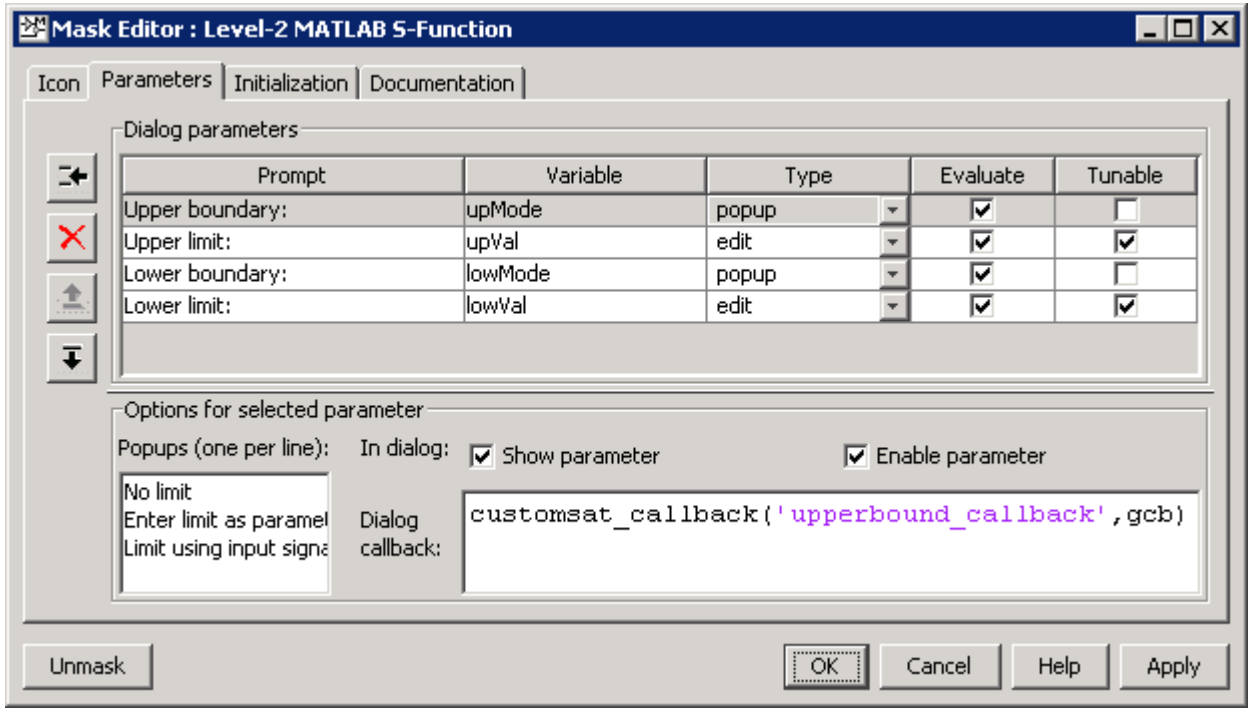
The dialog callback is invoked using the `action` string in the following command:

```
customsat_callback(action,gcb)
```

The MATLAB script `customsat_callback.m` contains the mask parameter callbacks. If you are stepping through this tutorial, open this file and save it to your working folder. This MATLAB script described in detail later, has two input arguments. The first input argument is a string indicating

which mask parameter invoked the callback. The second input argument is the handle to the associated Level-2 MATLAB S-Function block.

The following figure shows the final **Parameters** pane in the Mask Editor.



4 On the Mask Editor's **Initialization** pane, select **Allow library block to modify its contents**. This setting allows the S-function to change the number of ports on the block.

5 On the **Documentation** pane:

- Enter `Customized Saturation` into the **Mask type** field.
- Enter the following into the **Mask description** field.

```
Limit the input signal to an upper and lower saturation value
set either through a block parameter or input signal.
```

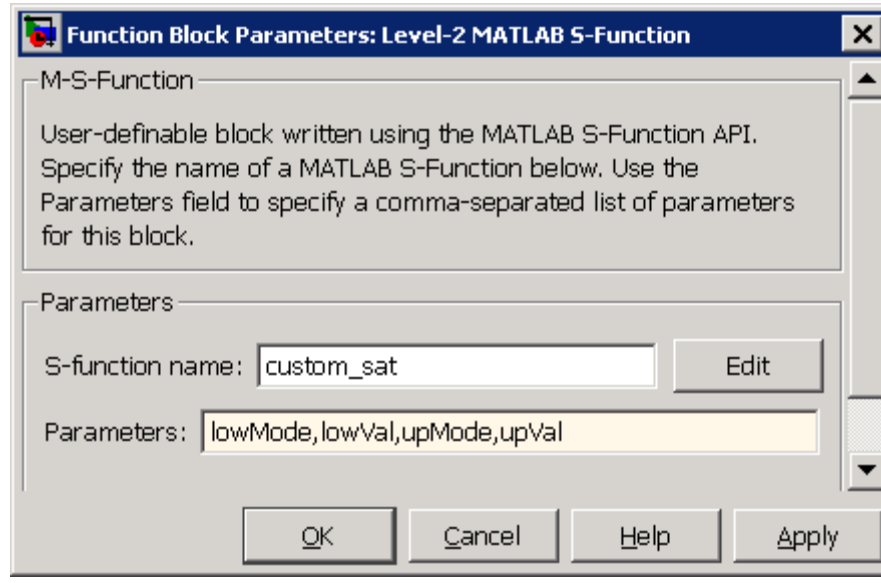
6 On the Mask Editor, click **OK** to complete the mask parameters dialog.

7 To map the S-function parameters to the mask parameters, right-click the Level-2 MATLAB S-Function block and select **Look Under Mask**. The Level-2 MATLAB S-Function Block Parameters dialog box opens.

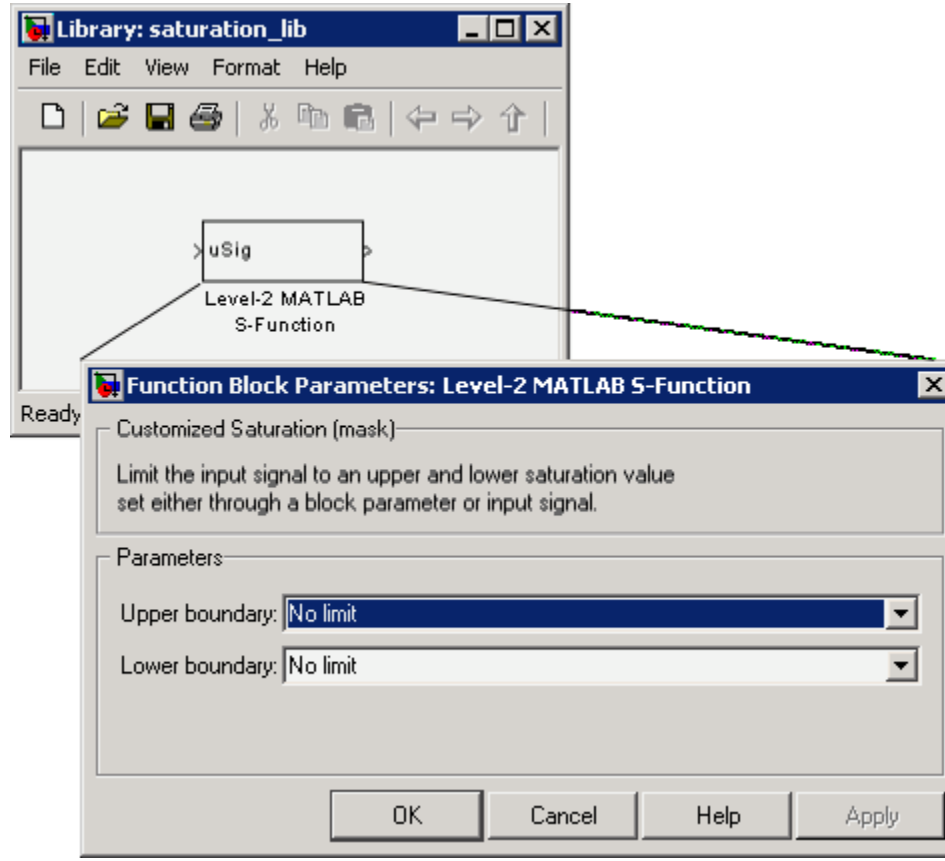
8 Change the entry in the **Parameters** field as follows.

```
lowMode,lowVal,upMode,upVal
```

The following figure shows the new Block Parameters dialog.



9 On the Level-2 MATLAB S-Function Block Parameters dialog box, click **OK** . Double-clicking the new version of the customized saturation block opens the mask parameter dialog box shown in the following figure.



To create a more complicated graphical user interface, place a Handle Graphics user interface on top of the masked block. The block's `OpenFcn` would invoke the Handle Graphics user interface, which uses calls to `set_param` to modify the S-function block's parameters based on settings in the user interface.

Writing the Mask Callback

The function `customsat_callback.m` contains the mask callback code for the custom saturation block's mask parameter dialog box. This function invokes subfunctions corresponding to each mask parameter through a call to `feval`.

The following subfunction controls the visibility of the upper saturation limit's field based on the selection for the upper saturation limit's mode. The callback begins by obtaining values for all mask parameters using a call to `get_param` with the property name `MaskValues`. If the callback needed the value of only one mask parameter, it could call `get_param` with the specific mask parameter name, for example, `get_param(block,'upMode')`. Because this example needs two of the mask parameter values, it uses the `MaskValues` property to reduce the calls to `get_param`.

The callback then obtains the visibilities of the mask parameters using a call to `get_param` with the property name `MaskVisbilities`. This call returns a cell array of strings indicating the visibility of each mask parameter. The callback alters the values for the mask visibilities based on the selection for the upper saturation limit's mode and then updates the port label string.

The callback finally uses the `set_param` command to update the block's `MaskDisplay` property to label the block's input ports.

```
function customsat_callback(action,block)
% CUSTOMSAT_CALLBACK contains callbacks for custom saturation block

%   Copyright 2003-2007 The MathWorks, Inc.

%% Use function handle to call appropriate callback
feval(action,block)

%% Upper bound callback
function upperbound_callback(block)

vals = get_param(block,'MaskValues');
vis = get_param(block,'MaskVisibilities');
portStr = {'port_label(''input'',1,''uSig'')'};
switch vals{1}
    case 'No limit'
        set_param(block,'MaskVisibilities',[vis(1);{'off'};vis(3:4)]);
```

```
    case 'Enter limit as parameter'
        set_param(block,'MaskVisibilities',[vis(1);{'on'};vis(3:4)]);
    case 'Limit using input signal'
        set_param(block,'MaskVisibilities',[vis(1);{'off'};vis(3:4)]);
        portStr = [portStr;{'port_label(''input'',2,''up'')'}];
end
if strcmp(vals{3},'Limit using input signal'),
    portStr = [portStr;{['port_label(''input'',',num2str(length(portStr)+1), ...
        ',''low'')']}];
end
set_param(block,'MaskDisplay',char(portStr));
```

The final call to `set_param` invokes the `setup` function in the MATLAB S-function `custom_sat.m`. Therefore, the `setup` function can be modified to set the number of input ports based on the mask parameter values instead of on the S-function parameter values. This change to the `setup` function keeps the number of ports on the Level-2 MATLAB S-Function block consistent with the values shown in the mask parameter dialog box.

The modified MATLAB S-function `custom_sat_final.m` contains the following new `setup` function. If you are stepping through this tutorial, open the file and save it to your working folder.

```
%% Function: setup ===================================================
function setup(block)

% Register original number of ports based on settings in Mask Dialog
ud = getPortVisibility(block);
numInPorts = 1 + isequal(ud(1),3) + isequal(ud(2),3);

block.NumInputPorts = numInPorts;
block.NumOutputPorts = 1;

% Setup port properties to be inherited or dynamic
block.SetPreCompInpPortInfoToDynamic;
block.SetPreCompOutPortInfoToDynamic;

% Override input port properties
block.InputPort(1).DatatypeID  = 0;  % double
block.InputPort(1).Complexity  = 'Real';
```

```
% Override output port properties
block.OutputPort(1).DatatypeID  = 0; % double
block.OutputPort(1).Complexity  = 'Real';

% Register parameters. In order:
% -- If the upper bound is off (1) or on and set via a block parameter (2)
%    or input signal (3)
% -- The upper limit value. Should be empty if the upper limit is off or
%    set via an input signal
% -- If the lower bound is off (1) or on and set via a block parameter (2)
%    or input signal (3)
% -- The lower limit value. Should be empty if the lower limit is off or
%    set via an input signal
block.NumDialogPrms     = 4;
block.DialogPrmsTunable = {'Nontunable','Tunable','Nontunable','Tunable'};

% Register continuous sample times [0 offset]
block.SampleTimes = [0 0];

%% -----------------------------------------------------------------
%% Options
%% -----------------------------------------------------------------
% Specify if Accelerator should use TLC or call back into
% MATLAB script
block.SetAccelRunOnTLC(false);

%% -----------------------------------------------------------------
%% Register methods called during update diagram/compilation
%% -----------------------------------------------------------------

block.RegBlockMethod('CheckParameters',      @CheckPrms);
block.RegBlockMethod('ProcessParameters',    @ProcessPrms);
block.RegBlockMethod('PostPropagationSetup', @DoPostPropSetup);
block.RegBlockMethod('Outputs',              @Outputs);
block.RegBlockMethod('Terminate',            @Terminate);
%endfunction
```

The `getPortVisibility` subfunction in `custom_sat_final.m` uses the saturation limit modes to construct a flag that is passed back to the `setup`

function. The `setup` function uses this flag to determine the necessary number of input ports.

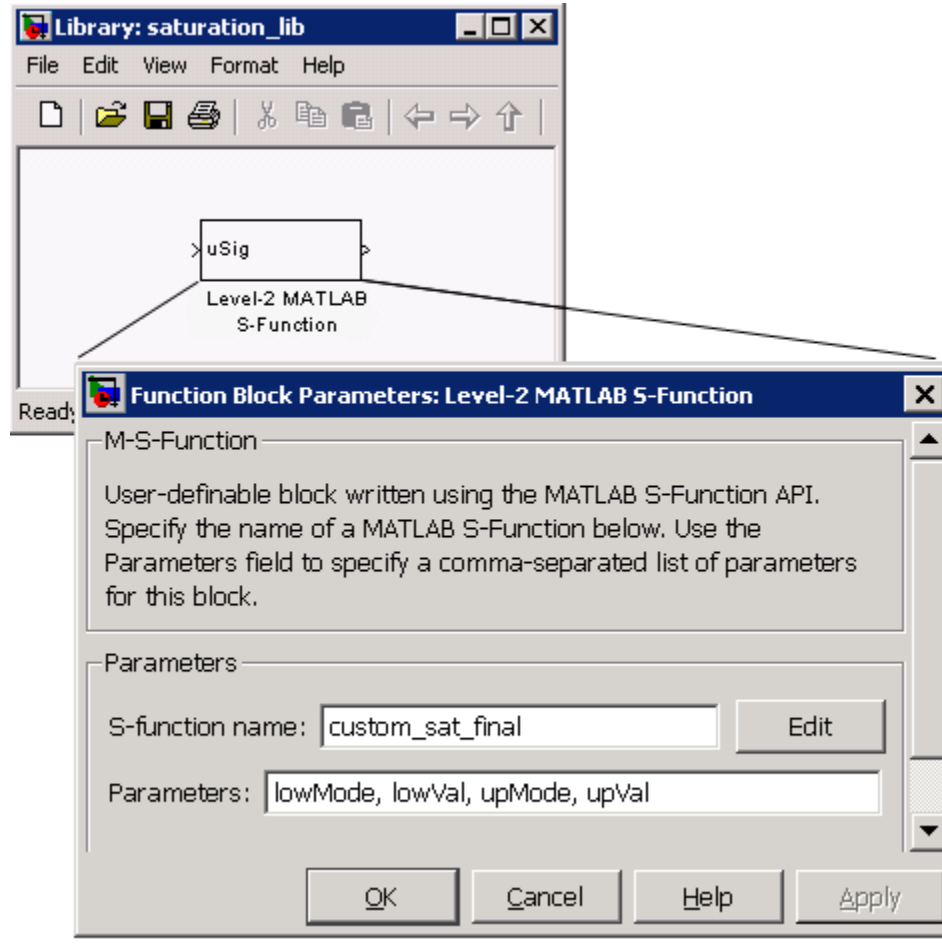
```
%% Function: Get Port Visibilities =======================================
function ud = getPortVisibility(block)

ud = [0 0];

vals = get_param(block.BlockHandle,'MaskValues');
switch vals{1}
    case 'No limit'
        ud(2) = 1;
    case 'Enter limit as parameter'
        ud(2) = 2;
    case 'Limit using input signal'
        ud(2) = 3;
end

switch vals{3}
    case 'No limit'
        ud(1) = 1;
    case 'Enter limit as parameter'
        ud(1) = 2;
    case 'Limit using input signal'
        ud(1) = 3;
end
```

Updating the Library

Update the library `saturation_lib.mdl` so that it calls `custom_sat_final.m`.

1. Right-click the Level-2 MATLAB S-Function block in `saturation_lib.mdl` and select **Look Under Mask**. The Level-2 MATLAB S-Function Block Parameters dialog box opens.

2. Enter `custom_sat_final` in the **S-function name** field, as shown in the following figure.

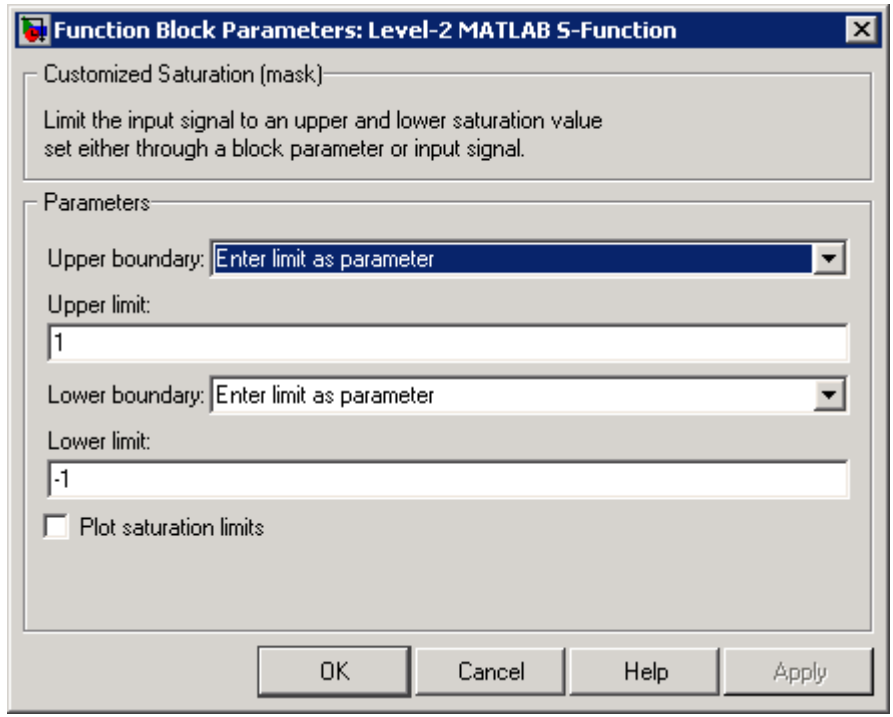


3 Click **OK** on the Block Parameters dialog box.

Adding Block Functionality Using Block Callbacks

The User-Defined Saturation with Plotting block in `customsat_lib.mdl` uses block callbacks to add functionality to the original custom saturation block. This block provides an option to plot the saturation limits when the simulation ends. The following steps show how to modify the original custom saturation block to create this new block.

1 Add a check box to the mask parameter dialog box to toggle the plotting option on and off, as shown in the following figure.



To add this check box:

a Right-click the Level-2 MATLAB S-Function block in `saturation_lib.mdl` and select **Edit Mask**.

b On the Mask Editor's **Parameters** pane, add a fifth mask parameter with the following properties.

Property	Value
Prompt	Plot saturation limits
Variable	`plotcheck`
Type	`checkbox`

Property	Value
Tunable	No
Dialog callback	`customsat_callback('plotsaturation',gcb);`

c On the Mask Editor, click **OK**.

2 Write a callback for the new check box. The callback initializes a structure to store the saturation limit values during simulation in the Level-2 MATLAB S-Function block's `UserData`. The MATLAB script `customsat_plotcallback.m` contains this new callback, as well as modified versions of the previous callbacks to handle the new mask parameter. If you are following through this example, open `customsat_plotcallback.m` and copy its subfunctions over the previous subfunctions in `customsat_callback.m`.

```
%% Plotting checkbox callback
function plotsaturation(block)

% Reinitialize the block's userdata
vals = get_param(block,'MaskValues');
ud = struct('time',[],'upBound',[],'upVal',[],'lowBound',[],'lowVal',[]);

if strcmp(vals{1},'No limit'),
    ud.upBound = 'off';
else
    ud.upBound = 'on';
end

if strcmp(vals{3},'No limit'),
    ud.lowBound = 'off';
else
    ud.lowBound = 'on';
end

set_param(gcb,'UserData',ud);
```

3 Update the MATLAB S-function `Outputs` method to store the saturation limits, if applicable, as done in the new MATLAB S-function `custom_sat_plot.m`. If you are following through this example, copy the

`Outputs` method in `custom_sat_plot.m` over the original `Outputs` method in `custom_sat_final.m`

```
%% Function: Outputs ================================================
function Outputs(block)

lowMode    = block.DialogPrm(1).Data;
upMode     = block.DialogPrm(3).Data;
sigVal     = block.InputPort(1).Data;
vals = get_param(block.BlockHandle,'MaskValues');
plotFlag = vals{5};
lowPortNum = 2;

% Check upper saturation limit
if isequal(upMode,2)
    upVal = block.RuntimePrm(2).Data;
elseif isequal(upMode,3)
    upVal = block.InputPort(2).Data;
    lowPortNum = 3; % Move lower boundary down one port number
else
    upVal = inf;
end

% Check lower saturation limit
if isequal(lowMode,2),
    lowVal = block.RuntimePrm(1).Data;
elseif isequal(lowMode,3)
    lowVal = block.InputPort(lowPortNum).Data;
else
    lowVal = -inf;
end

% Use userdata to store limits, if plotFlag is on
if strcmp(plotFlag,'on');
    ud = get_param(block.BlockHandle,'UserData');
    ud.lowVal = [ud.lowVal;lowVal];
    ud.upVal = [ud.upVal;upVal];
    ud.time = [ud.time;block.CurrentTime];
    set_param(block.BlockHandle,'UserData',ud)
end
```

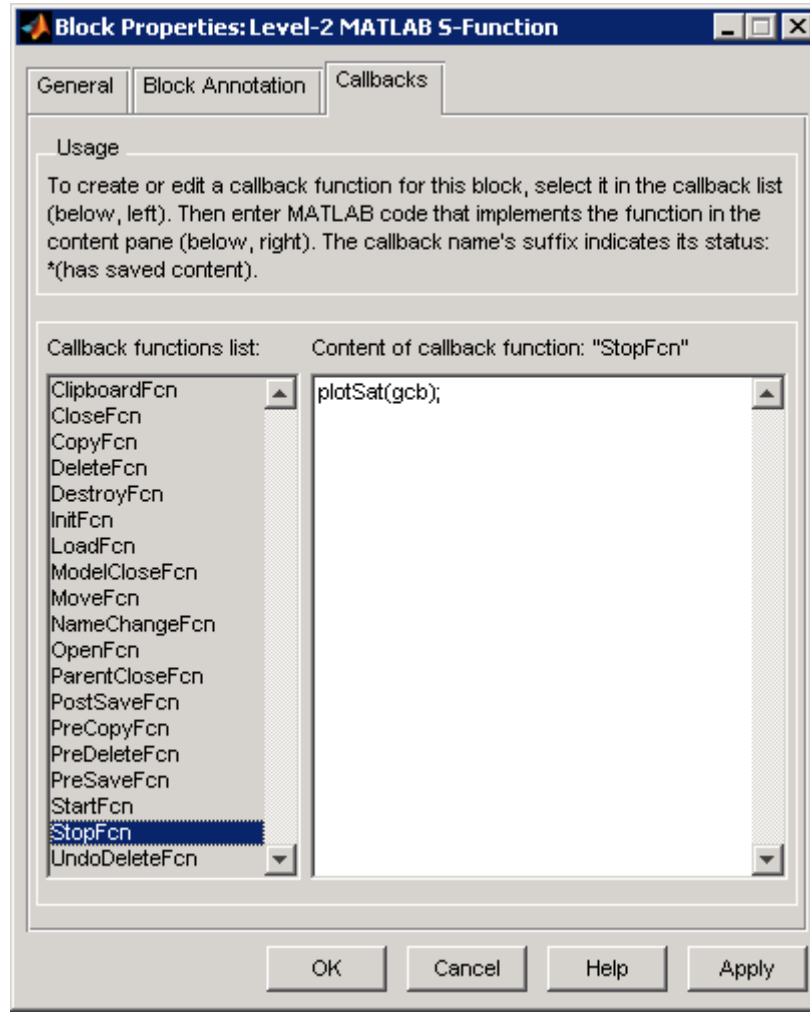
```
% Assign new value to signal
if sigVal > upVal,
    sigVal = upVal;
elseif sigVal < lowVal,
    sigVal=lowVal;
end

block.OutputPort(1).Data = sigVal;

%endfunction
```

4 Write the function `plotsat.m` to plot the saturation limits. This function takes the handle to the Level-2 MATLAB S-Function block and uses this handle to retrieve the block's `UserData`. If you are following through this tutorial, save `plotsat.m` to your working folder.

```
function plotSat(block)

% PLOTSAT contains the plotting routine for custom_sat_plot
%   This routine is called by the S-function block's StopFcn.

ud = get_param(block,'UserData');
fig=[];
if ~isempty(ud.time)
    if strcmp(ud.upBound,'on')
        fig = figure;
        plot(ud.time,ud.upVal,'r');
        hold on
    end
    if strcmp(ud.lowBound,'on')
        if isempty(fig),
            fig = figure;
        end
        plot(ud.time,ud.lowVal,'b');
    end
    if ~isempty(fig)
        title('Upper bound in red. Lower bound in blue.')
    end
```

```
    % Reinitialize userdata
    ud.upVal=[];
    ud.lowVal=[];
    ud.time = [];
    set_param(block,'UserData',ud);
end
```

5 Right-click the Level-2 MATLAB S-Function block and select **Block Properties**. The Block Properties dialog box opens. On the **Callbacks** pane, modify the `StopFcn` to call the plotting callback as shown in the following figure, then click **OK**.


Block Properties: Level-2 MATLAB S-Function
General
Block Annotation
Callbacks
Usage
To create or edit a callback function for this block, select it in the callback list (below, left). Then enter MATLAB code that implements the function in the content pane (below, right). The callback name's suffix indicates its status: *(has saved content).
Callback functions list:
Content of callback function: "StopFcn"
ClipboardFcn
CloseFcn
CopyFcn
DeleteFcn
DestroyFcn
InitFcn
LoadFcn
ModelCloseFcn
MoveFcn
NameChangeFcn
OpenFcn
ParentCloseFcn
PostSaveFcn
PreCopyFcn
PreDeleteFcn
PreSaveFcn
StartFcn
StopFcn
UndoDeleteFcn
plotSat(gcb);
OK
Cancel
Help
Apply

Custom Block Examples

In this section...

Creating Custom Blocks from Masked Library Blocks

The Additional Math and Discrete Simulink library is a group of custom blocks created by extending the functionality of built-in Simulink blocks. The Additional Discrete library contains a number of masked blocks that extend the functionality of the standard Unit Delay block. See Chapter 23, "Working with Block Libraries" for more general information on Simulink libraries.

Creating Custom Blocks from MATLAB Functions

The Simulink product provides a number of demonstrations that show how to incorporate MATLAB functions into a custom block.

- The Single Hydraulic Cylinder Simulation, `sldemo_hydcyl.mdl`, uses a Fcn block to model the control valve flow. In addition, the Control Valve Flow block is a library link to one of a number of custom blocks in the library `hydlib.mdl`.
- The Radar Tracking Model, `sldemo_radar.mdl`, uses a MATLAB Fcn block to model an extended Kalman filter. The MATLAB function `aero_extkalman.m` implements the Kalman filter found inside the Radar Kalman Filter subsystem. In this example, the MATLAB function requires three inputs, which are bundled together using a Mux block in the Simulink model.
- The Spiral Galaxy Formation demonstration, `sldemo_eml_galaxy.mdl`, uses several Embedded MATLAB Function blocks to construct two galaxy and calculate the effects of gravity as these two galaxies nearly collide. The demo also uses Embedded MATLAB Function blocks to plot the simulation results using a subset of MATLAB functions not supported for code generation. However, because these Embedded MATLAB Function

blocks have no outputs, the Real-Time Workshop product optimizes them away during code generation.

Creating Custom Blocks from S-Functions

The Simulink model `sfundemos.mdl` contains various examples of MATLAB and C MEX S-functions. For more information on writing MATLAB S-functions, see "Writing S-Functions in MATLAB". For more information on writing C MEX S-functions, see "Writing S-Functions in C". For a list of available S-function demos, see "S-Function Examples" in Writing S-Functions.

23

Working with Block Libraries

About Block Libraries

A *block library* is a collection of blocks that serve as prototypes for cloning blocks to Simulink models. Simulink provides a Library Browser that you can use to display block libraries, search for blocks by name, and clone library blocks into models. All installed libraries appear in the Library Browser when you open it. See “Populating a Model” on page 3-4for information about how to use the Simulink Library Browser.

Simulink comes with two built-in block libraries: the Simulink block library and the Real-Time Workshop block library. The latter is included with Simulink to support sharing models that contain Real-Time Workshop blocks. Many additional MathWorks products and associated block libraries are available. See the MathWorks Web site for product information. You cannot change a built-in block library in any way.

When you clone a block from a library into a model, Simulink does not copy the library block itself. Instead, Simulink places a *reference block* in the model, and connects the reference block to the library block using a *library link*. The library block is then the *prototype block*, and the prototype representation in the model (via the reference block) is a *block instance*. The appearance and behavior of a linked block are the same as if you had actually copied it to the model. For most purposes, you can ignore the underlying and link and reference block structure and just think of a block cloned from a library as a *block instance*.

Working with Reference Blocks

In this section...

About Reference Blocks

A *reference block* is an instance of a block type in a model that contains a link to a library block that serves as the block type's prototype. The link consists of the path of the library block that serves as the instance's prototype. The link allows the reference block to update whenever the corresponding prototype in the library changes ("Updating a Reference Block" on page 23-4). This ensures that your model always uses the latest version of the block.

Note The data tip for a reference block shows the name of the library block it references (see "Block Data Tips" on page 18-2).

You can change the values of a reference block's parameters but you cannot mask the block or edit its mask. Also, you cannot set callback parameters for a reference block. If the reference block's prototype is a subsystem, you can make nonstructural changes to the contents of the referenced subsystem (see "Modifying Reference Blocks" on page 23-4).

Creating a Reference Block

To create a reference block in a model or another library:

1 Open your model.

2 Open the Simulink Library Browser (see "About the Library Browser" on page 3-4).

3 Use the Library Browser to find the library block that serves as a prototype of the block you want to create (see "Browsing Block Libraries" on page 3-5 and "Searching Block Libraries" on page 3-5).

4 Drag the library block from the Library Browser's **Library** pane and drop it into your model.

Updating a Reference Block

Simulink updates out-of-date reference blocks in a model or library at these times:

- When the model or library is loaded
- When you select **Update Diagram** from the **Edit** menu or run the simulation
- When you use the `find_system` command
- When you query the `LinkStatus` parameter of a block, using the `get_param` command (see "Determining Link Status" on page 23-10)

Note Querying the `StaticLinkStatus` parameter of a block does not update any out-of-date reference blocks.

Modifying Reference Blocks

You cannot make structural changes to reference blocks, such as adding or deleting lines or blocks to the block diagram of a masked subsystem. If you want to make such changes, you must disable the reference block's link to its library prototype (see "Disabling Links to Library Blocks" on page 23-7).

You can, however, change the values of any masked subsystem reference block parameter that does not alter the block's structure, e.g., by adding or deleting lines, blocks, or ports. An example of a nonstructural change is a change to the value of a mathematical block parameter, such as the Gain parameter of the Gain block. A link to a library block from a reference block whose parameter values differ from those of the corresponding library block is

called a *parameterized link*. When saving a model containing a parameterized link, Simulink saves the changes to the local copy of the subsystem together with the path to the library copy in the model's model (`.mdl`) file. When you reopen the system, Simulink copies the library subsystem into the loaded model and applies the saved changes.

Tip To determine whether a reference block's parameter values differ from those of its library prototype, open the reference block's block diagram in an editor window. The title bar of the editor window displaying the subsystem displays "parameterized link" if the reference block parameter values differ from the library block's parameter values.

Self-Modifying Linked Subsystems

Simulink allows linked subsystems to change their own structural contents without disabling the link. This allows you to create masked subsystems that modify their structural contents based on mask parameter dialog box values.

Finding a Reference Block's Library Block Prototype

To find the source library and block linked to a reference block, select the reference block. Then choose **Go To Library Link** from the **Link Options** submenu of the model window's **Edit** or context menu. If the library is open, Simulink selects and highlights the library block and makes the source library the active window. If the library is not open, Simulink opens it and selects the library block.

Getting Information About Library Blocks Referenced by a Model

Use the `libinfo` command to get information about reference blocks in a system.

Working with Library Links

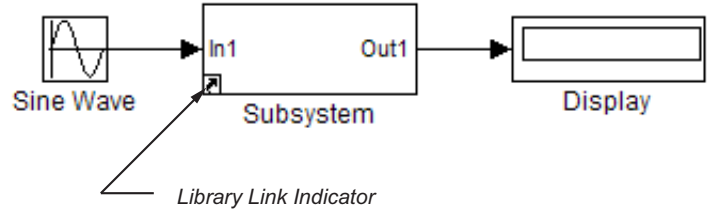
In this section...

Displaying Library Links

A model can have a block linked to a library block, or it can have a local instance of a block that is not linked. To enable the display of library links:

1. In the Model Editor window, and from the **Format** menu, select **Library Link Display.**
2. From the submenu, select either **User** (displays only links to user libraries) or **All** (displays all links).

   The library link indicator is an arrow in the bottom left corner of each block.



The color of the link arrow indicates the status of the link.

Color	Status
Black	Active link
Grey	Inactive link
Red	Active and modified (parameterized link)

Disabling Links to Library Blocks

To make a structural change to a linked subsystem block, you need to disable the link between the block and the library block that serves as its prototype.

Note When you use the Model Editor to make a structural change (such as editing the diagram) to a local copy of a subsystem block with an active library link, Simulink offers to disable the library link for you. If you accept, Simulink disables the link and allows you to make changes to the subsystem block.

Do not use `set_param` to make a structural change to an active link; the result of this type change is undefined.

To disable a link:

1. In the Model Editor window, select a subsystem block.
2. From the **Edit** menu, select **Link Options**, and then select **Disable link**.

   The model breaks the library link and grays out the library link indicator. When a library block is disabled and it is within another library block (a child of a parent library block), the model also disables the parent block containing the child block.

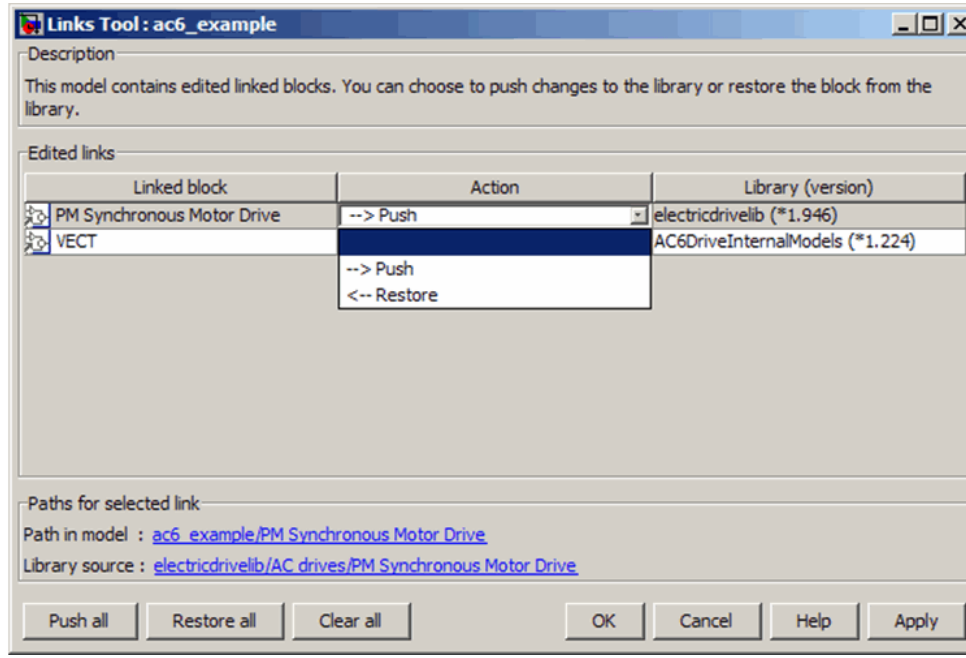
Restoring Disabled or Parameterized Links

After you make structural changes to a linked subsystem block, you need to restore the link to its library block and resolve any differences between the two blocks. The Links Tool helps you with this task.

1 In the Model Editor window, select a linked subsystem block with a disabled library link.

2 From the **Edit** menu, select **Link Options**, and then select **Resolve link**.

The Links Tool window opens.



The table in the Edited links panel has the following columns:

- **Linked block** — List of linked blocks. The list of edited links includes library links with structural changes, parameterized library links, and library links that were actively chosen to be resolved.
- **Action** — Select an action to perform on the linked block or library.
- **Library** — List of library names and version numbers.

3 From the **Linked block** list, select a block name.

The Links Tool updates the **Paths for selected link** panel with links to the linked block in the model and in the library.

4 From the **Action** list, choose one of two actions.

Action Choice	Simulink Action
`Push`	Updates the library version with the changes you made in the model version of that subsystem.
`Restore`	Replaces the version of the subsystem in the model with the version in the library.

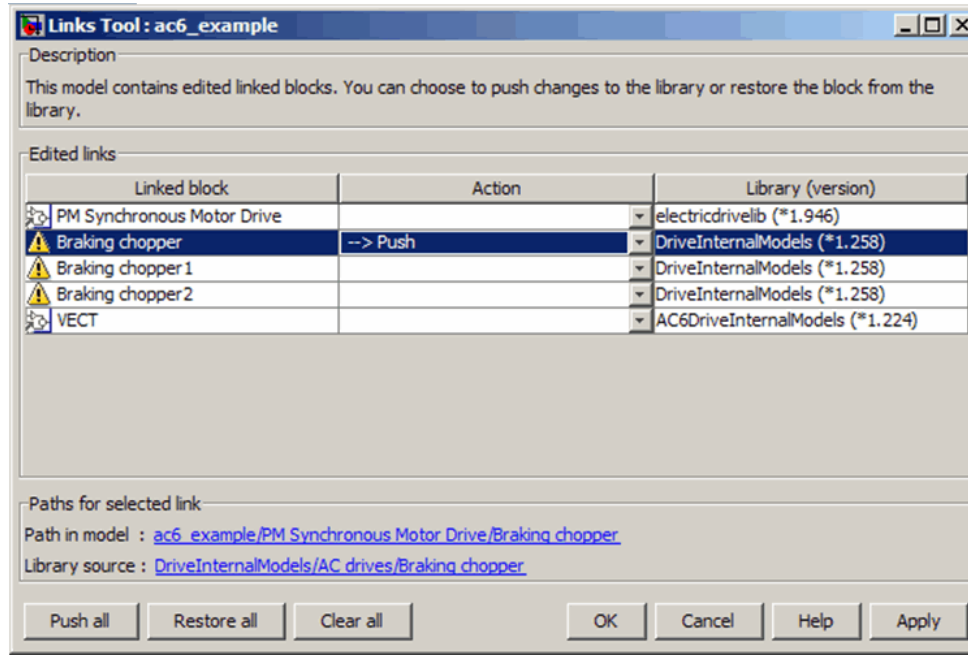
Choosing the **Push all**, **Restore all** or **Clear all** button selects an action for all linked blocks.

5 Click **OK** or **Apply**.

Simulink restores the library links to the selected subsystems in the model. The subsystem versions in the library and the model now match. If the link for a child that was structurally changed is restored, and there were no structural changes with its parent, the parent link is also restored.

Changes pushed to the library are not saved until you actively save the library.

If a linked block name has a cautionary icon  before it, the model has other instances of this block linked from the same library block, and they have different changes. Choose one of the instances (In this case, Braking chopper, Braking chopper 1, or Braking chopper 2) to push changes to the library block and restore links to the other blocks , or choose to restore all of them with the library version.



Determining Link Status

All blocks have a `LinkStatus` parameter and a `StaticLinkStatus` parameter that indicate whether the block is a reference block. The parameters can have these values.

Note Using `get_param` to query a block's `LinkStatus` also resolves any out-of-date block references. It is, therefore, useful to update library links in a model programmatically. Conversely, querying the `StaticLinkStatus` property does not resolve any out-of-date references. Query the `StaticLinkStatus` property when the call to `get_param` is in the callback of a child block querying the link status of its parent.

Status	Description
`none`	Block is not a reference block.
`resolved`	Resolved link.
`Unresolved`	Unresolved link.
`Implicit`	Block resides in library block and is itself not a link to a library block. For example, suppose that A is a link to a subsystem in a library that contains a Gain block. Further, suppose that you open A and select the Gain block. Then, `get_param(gcb, 'LinkStatus')` returns `implicit`.
`Inactive`	Link disabled.
`Restore`	Restores an inactive or disabled link to a library block and discards any changes made to the local copy of the library block. For example, `set_param(gcb, 'LinkStatus', 'restore')` replaces the selected block with a link to a library block of the same type, discarding any changes in the local copy of the library block. The function `get_param` never return `Restore`. It is only used with `set_param`.
`Propagate`	Restores an inactive or disabled link to a library block and pushes any changes made to the local copy to the library. The function `get_param` never return `Propagate`. It is only used with `set_param`.

Breaking a Link to a Library Block

You can break the link between a reference block and its library block to cause the reference block to become a simple copy of the library block, unlinked to the library block. Changes to the library block no longer affect the block. Breaking links to library blocks may enable you to transport a model as a standalone model, without the libraries.

To break the link between a reference block and its library block, first disable the link. Then select the block and choose **Break Link** from the **Link Options** menu. You can also break the link between a reference block and its

library block from the command line by changing the value of the `LinkStatus` parameter to `'none'` using this command:

```
set_param('refblock', 'LinkStatus', 'none')
```

You can also break links to library blocks when saving the model, by supplying arguments to the `save_system` command. See save_system in the Simulink reference documentation.

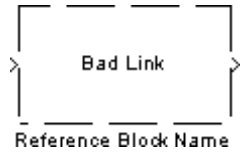
Note Breaking library links in a model does not guarantee that you can run the model standalone, especially if the model includes blocks from third-party libraries or optional Simulink blocksets. It is possible that a library block invokes functions supplied with the library and hence can run only if the library is installed on the system running the model. Further, breaking a link can cause a model to fail when you install a new version of the library on a system. For example, suppose a block invokes a function that is supplied with the library. Now suppose that a new version of the library eliminates the function. Running a model with an unlinked copy of the block results in invocation of a now nonexistent function, causing the simulation to fail. To avoid such problems, you should generally avoid breaking links to third-party libraries and optional Simulink blocksets.

Fixing Unresolved Library Links

If Simulink is unable to find either the library block or the source library on your MATLAB path when it attempts to update the reference block, the link becomes *unresolved*. Simulink issues an error message and displays these blocks using red dashed lines. The error message is

```
Failed to find block "source-block-name"
in library "source-library-name"
referenced by block
"reference-block-path".
```

The unresolved reference block appears like this (colored red).



To fix a bad link, you must do one of the following:

- Delete the unlinked reference block and copy the library block back into your model.
- Add the folder that contains the required library to the MATLAB path and select **Update Diagram** from the **Edit** menu.
- Double-click the unlinked reference block to open its dialog box (see the Bad Link block reference page). On the dialog box that appears, correct the pathname in the **Source block** field and click **OK**.

Creating Block Libraries

In this section...

Creating a Library

You can create your own block library and add it to the Simulink Library Browser (see "Adding Libraries to the Library Browser" on page 23-24).

Tip If your library contains many blocks, consider grouping the blocks into a hierarchy of sublibraries (see "Creating a Sublibrary" on page 23-15).

To create a library:

1. Select **Library** from the **New** submenu of the **File** menu.

   Simulink creates a model (`*.mdl`) file for storing the new library and displays the file in a new model editor window.

   Tip You can also use the `new_system` command to create the library and the `open_system` command to open the new library.

   ---

2. Drag blocks from models or other libraries into the new library.

Note If you want to be able to create links in models to a block in the library, you must provide a mask (see Chapter 21, "Working with Block Masks") for the block. You can also provide a mask for a subsystem in a library but you do not need to do so in order to create links to it in models.

3 Save the library's model file under a new name.

Creating a Sublibrary

Creating a sublibrary entails inserting a reference in the model (`.mdl`) file of one library to the model file of another library. The referenced file is called a *sublibrary* of the parent (i.e., referencing) library. The sublibrary is said to be included by reference in the parent library.

To include a library in another library as a sublibrary:

1 Open the parent library.

2 Unlock the parent library (see "Modifying a Library" on page 23-15).

3 Add a Subsystem block to the parent library.

4 Delete the subsystem's default input and output ports.

5 Create a mask for the subsystem that displays text or an image that conveys the sublibrary's purpose.

6 Set the subsystem's OpenFcn parameter to the name of the sublibrary's model file.

7 Save the parent library.

Modifying a Library

When you open a library, it is automatically locked and you cannot modify its contents. To unlock the library, select **Unlock Library** from the **Edit** menu. Closing the library window locks the library.

Locking Libraries

To lock a block library, save and close the library or set its Lock parameter to `'on'` at the MATLAB command line, using the `set_param` command. Locking a library prevents a user from inadvertently modifying a library, for example, by moving a block in the library or adding or deleting a block from the library. If you attempt to modify a locked library, Simulink displays a dialog box that allows you to unlock the library and make the change. You must then relock the library from the MATLAB command line to prevent further changes.

Making Backward-Compatible Changes to Libraries

Simulink provides the following features to facilitate making changes to library blocks without invalidating models that use the library blocks.

Forwarding Tables

Library forwarding tables enable Simulink to update models to reflect changes in the names or locations of the library blocks that they reference. For example, suppose that you rename a block in a library. You can use a forwarding table for that library to enable Simulink to update models that reference the block under its old name to reference it under its new name.

Simulink allows you to associate a forwarding table with any library. The forwarding table for a library specifies the old locations and new locations of blocks that have moved within the library or to another library. You associate a forwarding table with a library by setting its ForwardingTable parameter to a cell array of two-element cell arrays, each of which specifies the old and new path of a block that has moved. For example, the following command creates a forwarding table and assigns it to a library named Lib1.

```
set_param('Lib1', 'ForwardingTable', {{'Lib1/A', 'Lib2/A'}
{'Lib1/B', 'Lib1/C'}});
```

The forwarding table specifies that block A has moved from Lib1 to Lib2. and that block B is now named C. Suppose that you open a model that contains links to Lib1/A and Lib1/B. Simulink updates the link to Lib1/A to refer to Lib2/A and the link to Lib1/B to refer to Lib1/C. The changes become permanent when you subsequently save the model.

Creating Aliases for Mask Parameters

Simulink lets you create aliases, i.e., alternate names, for a mask's parameters. A model can then refer to the mask parameter by either its name or its alias. This allows you to change the name of a mask parameter in a library block without having to recreate links to the block in existing models (see "Example: Using Mask Parameter Aliases to Create Backward-Compatible Parameter Name Changes" on page 23-17).

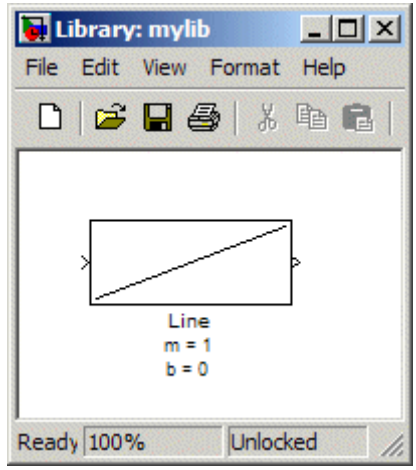
To create aliases for a masked block's mask parameters, use the `set_param` command to set the block's MaskVarAliases parameter to a cell array that specifies the names of the aliases in the same order as the mask names appear in the block's MaskVariables parameter.

Example: Using Mask Parameter Aliases to Create Backward-Compatible Parameter Name Changes. The following example illustrates the use of mask parameter aliases to create backward-compatible parameter name changes.

1. Create a library named `mylib`.
2. Create the masked subsystem described in in `mylib`.
3. Name the masked subsystem Line.
4. Set the masked subsystem's annotation property (see "Block Annotation Pane" on page 18-17) to display the value of its `m` and `b` parameters, i.e., to

   ```
   m = %<m>
   b = %<b>
   ```

   The library appears as follows:



5 Save `mylib`.

6 Create a model named `mymdl`.

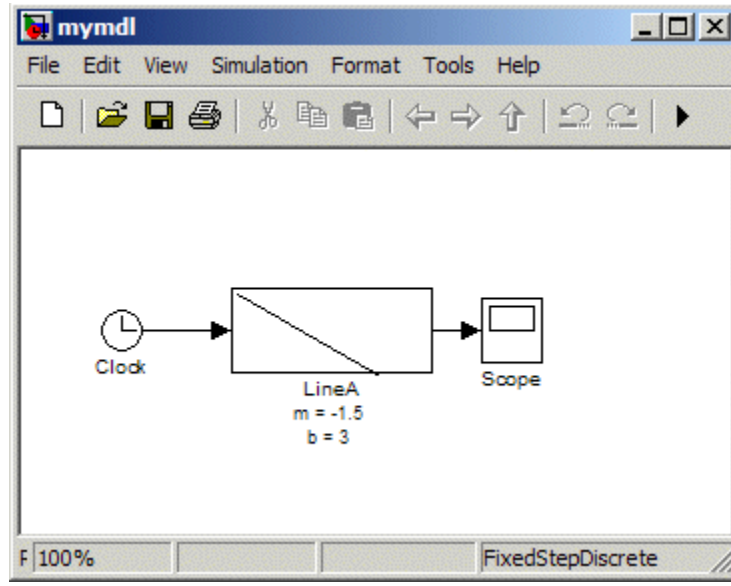
7 Create an instance of the Line block in `mymdl`.

8 Rename the instance LineA.

9 Change the value of LineA's `m` parameter to `-1.5`.

10 Change the value of LineA's `b` parameter to `3`.

11 Set LineA's annotation property to display the values of its `m` and `b` parameters.



12 Configure `mymdl` to use a fixed-step, discrete solver with a step size of `0.1` second.

13 Save `mymdl`.

14 Simulate `mymdl`.

Note that the model simulates without error.

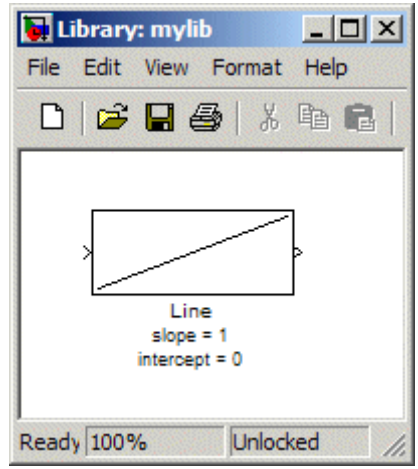
15 Close `mymdl`.

16 Unlock `mylib`.

17 Rename the `m` parameter of the Line block in `mylib` to `slope`.

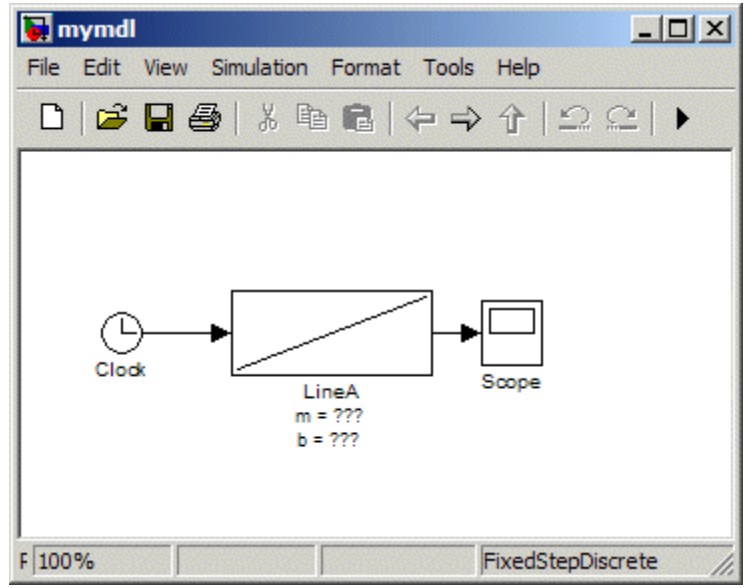
18 Rename Line's `b` parameter to `intercept`.

19 Change Line's mask icon and annotation properties to reflect the parameter name changes.



20 Save `mylib`.

21 Reopen `mymdl`.



Note that LineA's icon has reverted to the appearance of its library master (i.e., `mylib/Line`) and that its annotation displays question marks for the values of `m` and `b`. These changes reflect the parameter name changes in the library block . In particular, Simulink cannot find any parameters named `m` and `b` in the library block and hence does not know what to do with the instance values for those parameters. As a result, LineA reverts to the default values for the slope and intercept parameters, thereby inadvertently changing the behavior of the model. The following steps show how to use parameter aliases to avoid this inadvertent change of behavior.

22 Close `mymdl`.

23 Unlock `mylib`.

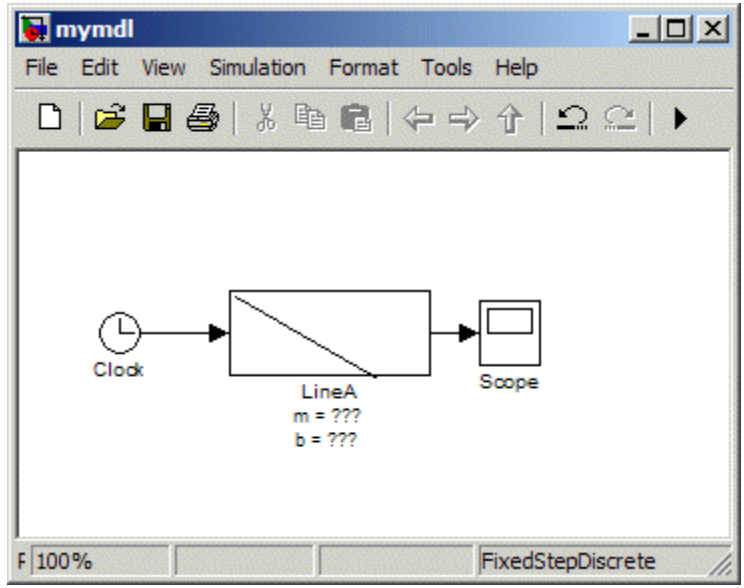
24 Select the Line block in `mylib`.

25 Execute the following command at the MATLAB command line.

```
set_param(gcb, 'MaskVarAliases',{'m', 'b'})
```

This specifies that `m` and `b` are aliases for the Line block's `slope` and `intercept` parameters.

26 Reopen `mymdl`.



Note that LineA's appearance now reflects the value of the slope parameter under its original name, i.e., `m`. This is because when Simulink opened the model, it found that `m` is an alias for slope and assigned the value of `m` stored in the model file to LineA's slope parameter.

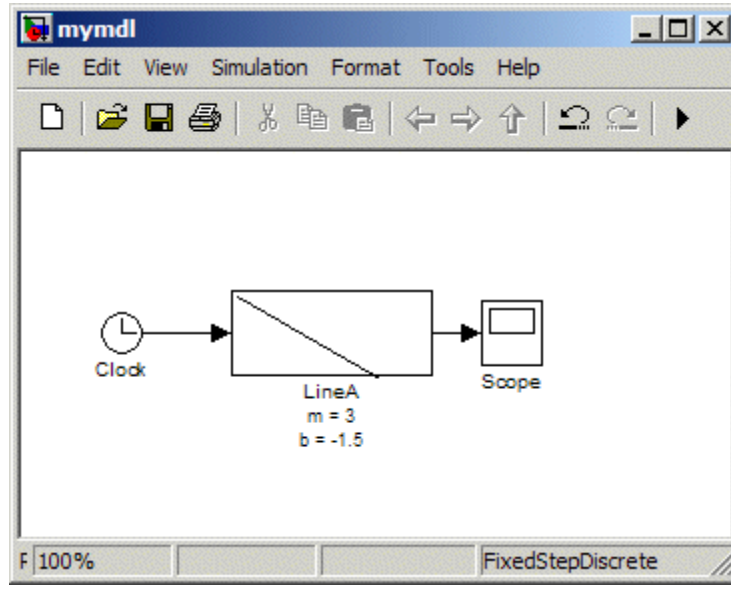
27 Change LineA's block annotation property to reflect LineA's parameter name changes, i.e., replace

```
m = %<m>
b = %<b>
```

with

```
m = %<slope>
b = %<intercept>
```

LineA now appears as follows.



Note that LineA's annotation shows that, thanks to parameter aliasing, Simulink has correctly applied the parameter values stored for LineA in `mymdl`'s model file to the block's renamed parameters.

Adding Libraries to the Library Browser

In this section...

How to Display a Library in the Library Browser

1. Create a folder in the MATLAB path for the top-level library and its sublibraries.

   You must store each top-level library that you want to appear in the Library Browser in its own folder on the MATLAB path. Two top-level libraries cannot exist in the same folder.

2. Create or copy the top-level library and its sublibraries into the folder you created in the MATLAB path.

3. In the folder for the top-level library, include a `slblocks.m` file.

   The approach you use to create the `slblocks.m` file depends on your requirements for describing the library:

   - If a minimal `slblocks.m` file meets your needs, then create a new `slblocks.m` file, based on the example below
   - If you want to describe the library more fully, consider copying an existing slblocks.m file to use as a template, editing the copy to describe your library (see below).

Example of a Minimal slblocks.m File

To display a library in the Library Browser, at a minimum you must include these lines (adjusted to describe your library; comments are not required) in the `slblock.m` file.

```
function blkStruct = slblocks
  % Specify that the product should appear in the library browser
```

```
% and be cached in its repository
Browser.Library = 'mylib';
Browser.Name    = 'My Library';
blkStruct.Browser = Browser;
```

Adding More Descriptive Information in slblocks.m

You can review other descriptive information you may wish to include in your `slblocks.m` file by examining the comments in the Simulink library `slblocks.m` file: *`matlabroot`*`/toolbox/simulink/blocks/slblocks.m`.

24

Using the Embedded MATLAB Function Block

Introduction to Embedded MATLAB Function Blocks

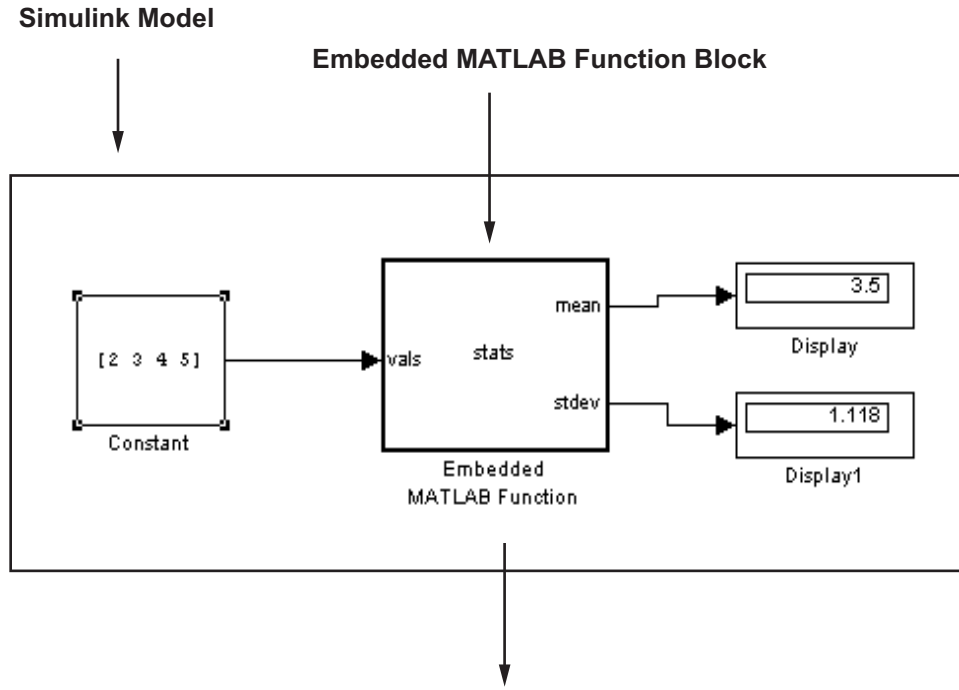
In this section...

What Is an Embedded MATLAB Function Block?

The Embedded MATLAB Function block allows you to add MATLAB functions to Simulink models for deployment to embedded processors. This capability is useful for coding algorithms that are better stated in the textual language of the MATLAB software than in the graphical language of the Simulink product. This block works with a subset of the MATLAB language called the Embedded MATLAB subset, which provides optimizations for generating efficient, production-quality C code for embedded applications. For more information, see "Working with the Embedded MATLAB Subset" in the MATLAB documentation. For more information on fixed-point support in MATLAB, refer to "Working with the Fixed-Point Embedded MATLAB Subset" in the Fixed-Point Toolbox™ documentation.

Example: Calculating Statistical Mean and Standard Deviation

Here is an example of a Simulink model that contains an Embedded MATLAB Function block:




```
function [mean,stdev] = stats(vals)
%#eml

% calculates a statistical mean and a standard
% deviation for the values in vals.

eml.extrinsic('plot');

len = length(vals);
mean = avg(vals,len);
stdev = sqrt(sum(((vals-avg(vals,len)).^2))/len);
plot(vals,'-+');

function mean = avg(array,size)
mean = sum(array)/size;
```

You will build this model in "Creating an Example Embedded MATLAB Function" on page 24-8.

Defining Local Variables. Note in this Embedded MATLAB function that you can declare local variables implicitly through assignment, just as you would in MATLAB functions. The variable takes its type and size from the context in which it is assigned. For example, the following code line declares `x` to be a scalar variable of type double.

```
x = 1.54;
```

Once you define a variable, you cannot redefine it to any other type or size in the function body. For example, you cannot declare `x` and reassign it:

```
x = 2.65; % OK: x is a scalar double
x = [x 2*x]; % Error: x cannot be changed to a vector
```

See "Creating Local Complex Variables By Assignment" in the Embedded MATLAB documentation for detailed descriptions and examples.

Declaring Extrinsic Functions. Note in this example, that you can declare functions to be extrinsic by using `eml.extrinsic`. This ensures that the Embedded MATLAB software does not attempt to compile this function. Instead, the function will execute in the MATLAB workspace during simulation of the model. For example, the following code declares the `plot` function to be extrinsic:

```
eml.extrinsic('plot');
```

See "Calling Embedded MATLAB Library Functions" in the Embedded MATLAB documentation for more information.

Calling Functions in Embedded MATLAB Function Blocks

In addition to supporting a rich subset of the MATLAB language, Embedded MATLAB Function blocks can call any of the following types of functions:

- **Subfunctions**

Subfunctions are defined in the body of the Embedded MATLAB block. In the preceding example, `avg` is a subfunction. See "Calling Subfunctions" in the Embedded MATLAB documentation.

- **Embedded MATLAB run-time library functions**

  Embedded MATLAB run-time library functions are a subset of the functions that you call in MATLAB. When you build your model with Real-Time Workshop, these functions generate C code that conforms to the memory and variable type requirements of embedded environments. In the preceding example, `length`, `sqrt`, and `sum` are Embedded MATLAB run-time library functions. See "Calling Embedded MATLAB Library Functions" in the Embedded MATLAB documentation.

- **MATLAB functions**

  Function calls that cannot be resolved as subfunctions or Embedded MATLAB run-time library functions are extrinsic functions and are resolved in the MATLAB workspace. These functions do not generate code; they execute only in the MATLAB workspace during simulation of the model. The Embedded MATLAB subset attempts to compile all MATLAB functions unless you explicitly declare them to be extrinsic by using `eml.extrinsic`. See "Calling MATLAB Functions" in the Embedded MATLAB documentation.

Why Use Embedded MATLAB Function Blocks?

Embedded MATLAB Function blocks provide the following capabilities:

- **Allow you to build MATLAB functions into embeddable applications** — Embedded MATLAB Function blocks support a subset of MATLAB commands that generate efficient C code (see "Embedded MATLAB Function Library Reference" in the Embedded MATLAB documentation). With this support, you can use Real-Time Workshop to generate embeddable C code from Embedded MATLAB Function blocks that implements a variety of sophisticated mathematical applications. In this way, you can build executables that harness MATLAB functionality, but run outside the MATLAB environment.
- **Inherit properties from Simulink input and output signals** — By default, both the size and type of input and output signals to an Embedded MATLAB Function block are inherited from Simulink signals. You can also choose to specify the size and type of inputs and outputs explicitly in the

Model Explorer or Ports and Data Manager (see “Ports and Data Manager” on page 24-41).

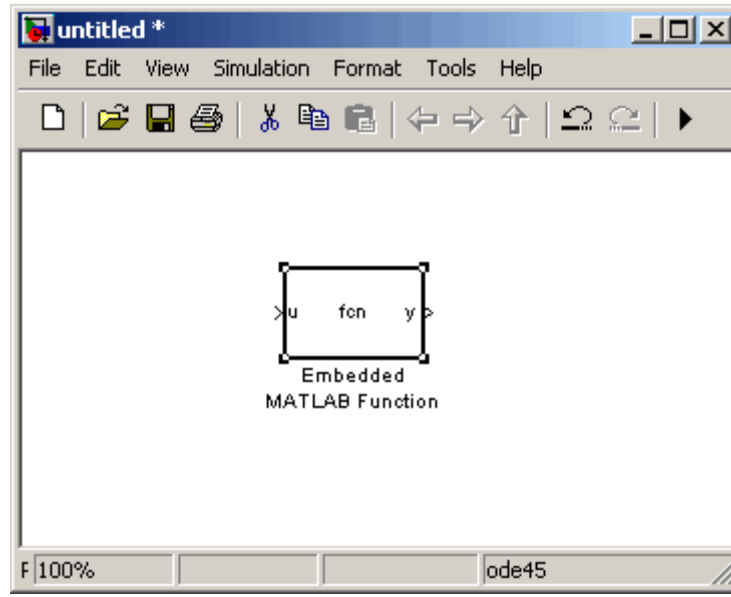
Creating an Example Embedded MATLAB Function

In this section...

Adding an Embedded MATLAB Function Block to a Model

Start by creating an empty model and filling it with an Embedded MATLAB Function block, and other blocks necessary to complete the model.

1 Create a new model with the Simulink product and add an Embedded MATLAB Function block to it from the User-Defined Function library.



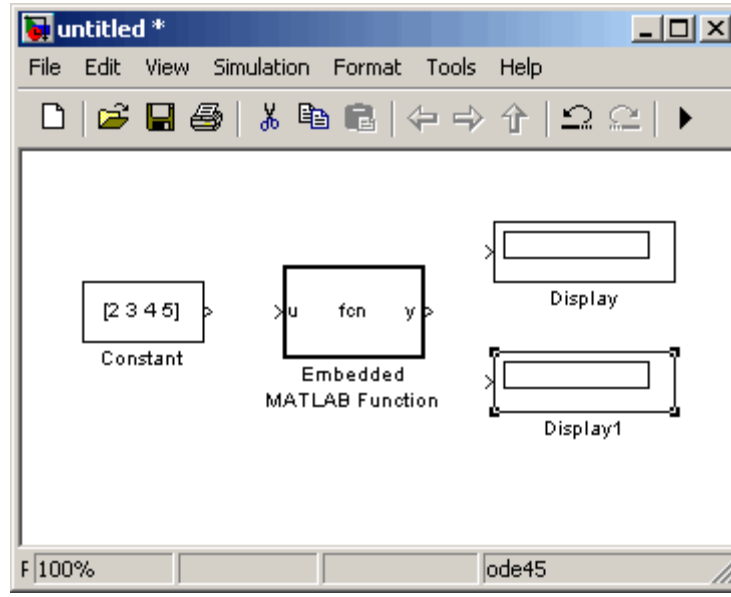
An Embedded MATLAB Function block has two names. The name in the middle of the block is the name of the function you build for the Embedded MATLAB Function block. Its name defaults to `fcn`. The name at the bottom of the block is the name of the block itself. Its name defaults to `Embedded MATLAB Function`.

The default Embedded MATLAB Function block has an input port and an output port. The input port is associated with the input argument `u`, and the output port is associated with the output argument `y`.

2 Add the following Source and Sink blocks to the model:

- From the Sources library, add a Constant block to the left of the Embedded MATLAB Function block and set its value to the vector `[2 3 4 5]`.
- From the Sinks library, add two Display blocks to the right of the Embedded MATLAB Function block.

The model should now have the following appearance:



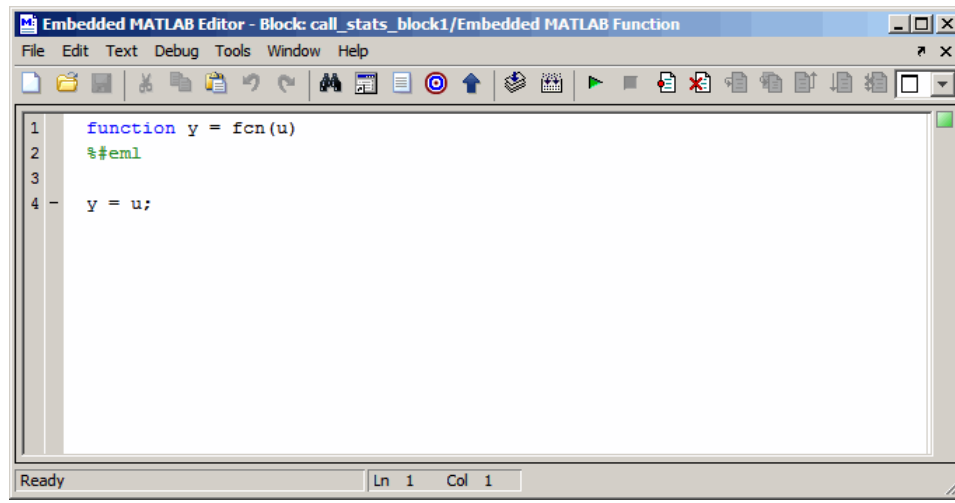
3 In the window displayed by the Simulink product, select **File > Save As** and save the model as `call_stats_block1`.

Programming the Embedded MATLAB Function

The following exercise shows you how to program the block to calculate the mean and standard deviation for a vector of values:

1 Open the `call_stats_block1` model that you saved at the end of "Adding an Embedded MATLAB Function Block to a Model" on page 24-8. Double-click the Embedded MATLAB Function block `fcn` to open it for editing.

The Embedded MATLAB Editor appears.



The Embedded MATLAB Editor window is titled with the syntax <*model name*>/<*Embedded MATLAB Function block name*> in its header. In this example, the model name is `call_stats_block1`, and the block name is `Embedded MATLAB Function`, the name that appears at the bottom of the Embedded MATLAB Function block.

Inside the Embedded MATLAB Editor is an edit window for editing the function that specifies the Embedded MATLAB Function block. A function header with the function name `fcn` is at the top of the edit window. The

header specifies an argument to the function, `u`, and a return value, `y`. The `%#eml` compilation directive appears after the function header. The directive declares the function to be Embedded MATLAB compliant. To learn more, see "Adding the Compilation Directive %#eml" in the Embedded MATLAB documentation.

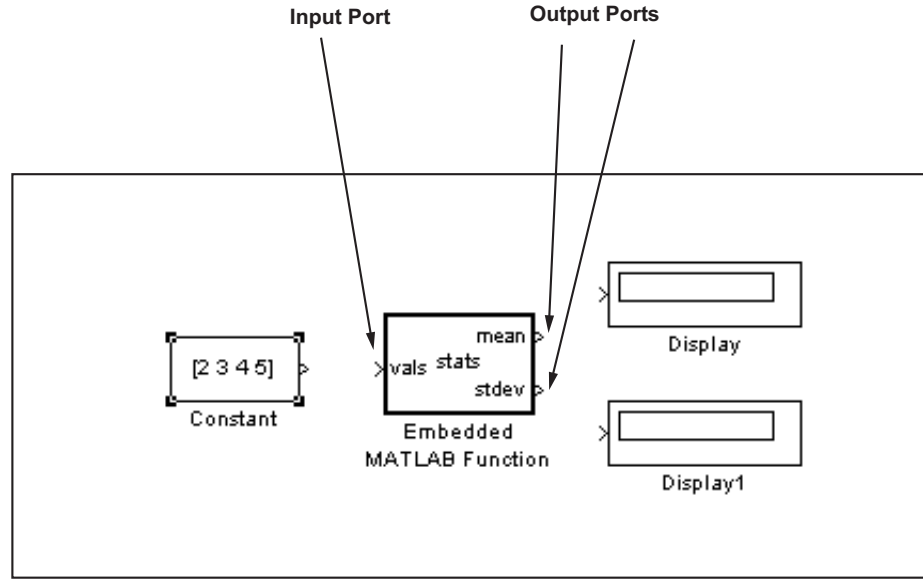
2 Edit the function header line with the return values, function name, and argument:

```
function [mean,stdev] = stats(vals)
```

The Embedded MATLAB function `stats` calculates a statistical mean and standard deviation for the values in the vector `vals`. The function header declares `vals` as an argument to the `stats` function, with `mean` and `stdev` as return values.

3 In the Embedded MATLAB Editor, select **File > Save As** and save the model as `call_stats_block2`.

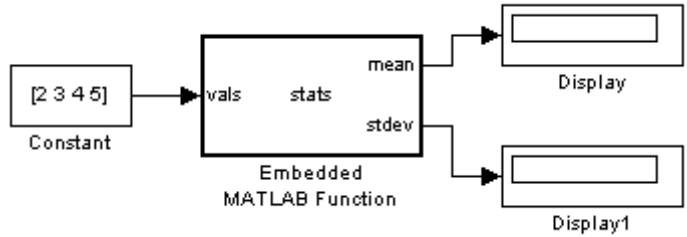
Saving the model updates the model window, which now looks like this:



Changing the function header of the Embedded MATLAB Function block makes the following changes to the Embedded MATLAB Function block in the Simulink model:

- The function name in the middle of the block changes to `stats`.
- The argument `vals` appears as an input port to the block.
- The return values `mean` and `stdev` appear as output ports to the block.

4 Complete the connections to the Embedded MATLAB Function block as shown.



5 In the Embedded MATLAB Editor, enter a line space after the function header and add the following comment lines:

```
% calculates a statistical mean and a standard
% deviation for the values in vals.
```

You specify comments with a leading percent (`%`) character, just as you do in MATLAB.

6 Enter a line space after the comments and replace the default function line `y = u;` with the following:

```
len = length(vals);
```

The function `length` is an example of a built-in function supported by the run-time function library for Embedded MATLAB Function blocks. This `length` works just like the MATLAB function `length`. It returns the vector length of its argument `vals`. However, when you simulate this model, C code is generated for this function in the simulation application. Callable

functions supported for Embedded MATLAB Function blocks are listed in the "Embedded MATLAB Function Library Reference".

The variable `len` is a local variable that is automatically typed as a scalar `double` because the Embedded MATLAB run-time library function, `length`, returns a scalar of type `double`. You can change the declaration of `len` to have a different type and size as described in "Working with Variables" in the Embedded MATLAB documentation.

By default, implicitly declared local variables like `len` are temporary. They come into existence only when the function is called and cease to exist when the function is exited. To make implicitly declared variables persist between function calls, see "Declaring Persistent Variables" in the Embedded MATLAB documentation.

7 Enter the following lines to calculate the value of `mean` and `stdev`:

```
mean = avg(vals,len);
stdev = sqrt(sum(((vals-avg(vals,len)).^2))/len);
```

`stats` stores the mean and standard deviation values in the variables `mean` and `stdev`, which it outputs to the Display blocks in the model. The line that calculates `mean` calls a subfunction, `avg`, that you have not defined yet. The line that calculates `stdev` calls the Embedded MATLAB run-time library functions `sqrt` and `sum`.

8 Enter the following line to plot the input values in `vals`.

```
plot(vals,'-+');
```

This line calls the function `plot` to plot the input values sent to `stats` against their vector indices. Because the Embedded MATLAB run-time library has no `plot` function, you need to declare the `plot` function to be extrinsic. An extrinsic function is a function that is executed by MATLAB software during simulation.

9 To declare the `plot` function to be extrinsic, add the declaration:

```
eml.extrinsic('plot');
```

after the comments at the top of the Embedded MATLAB function.

See “Calling MATLAB Functions” in the Embedded MATLAB documentation for more details on using this mechanism to call MATLAB functions from Embedded MATLAB functions.

10 At the bottom of the Embedded MATLAB function, enter a line space followed by the following lines for the subfunction `avg`, which is called in an earlier line.

```
function mean = avg(array,size)
mean = sum(array)/size;
```

These two lines define the subfunction `avg`. You are free to use subfunctions in Embedded MATLAB function code with single or multiple return values, just as you do in MATLAB functions.

Your Embedded MATLAB function should now look like this:

```
function [mean,stdev] = stats(vals)
%#eml

% calculates a statistical mean and a standard
% deviation for the values in vals.

eml.extrinsic('plot');

len = length(vals);
mean = avg(vals,len);
stdev = sqrt(sum(((vals-avg(vals,len)).^2))/len);
plot(vals,'-+');

function mean = avg(array,size)
mean = sum(array)/size;
```

11 Save the model as `call_stats_block2`.

Building the Function and Checking for Errors

After programming an Embedded MATLAB Function block in a Simulink model, you can build the function and test for errors. This section describes the steps:

1. Set up your compiler.
2. Build the function.
3. Locate and fix errors.

Setting Up Your Compiler

Before building your Embedded MATLAB Function block, you must set up your C compiler by running the `mex -setup` command, as described in the documentation for `mex` in the MATLAB Function Reference. You must run this command even if you use the default C compiler that comes with the MATLAB product for Microsoft Windows platforms. You can also use `mex` to choose and configure a different C compiler, as described in "Building MEX-Files" in the MATLAB External Interfaces documentation.

Supported Compilers for Simulation Builds. To view a list of compilers for building models containing Embedded MATLAB Function blocks for simulation:

1. Navigate to the Supported and Compatible Compilers Web page.
2. Select your platform.
3. In the table for Simulink and related products, find the compilers checked in the column titled Simulink (Embedded MATLAB).

Supported Compilers for Code Generation. To generate code for models that contain Embedded MATLAB Function blocks, you can use any of the C compilers supported by Simulink software for code generation with Real-Time Workshop. For a list of these compilers:

1. Navigate to the Supported and Compatible Compilers Web page.
2. Select your platform.
3. In the table for Simulink and related products, find the compilers checked in the column titled Real-Time Workshop.

How to Build the Embedded MATLAB Function

To build the function that calculates the mean and standard deviation:

- Open the `call_stats_block2` model that you saved at the end of "Programming the Embedded MATLAB Function" on page 24-10.
- Double-click its Embedded MATLAB Function block `stats` to open it for editing.
- In the Embedded MATLAB Editor, click the **Build** icon  to compile and build the example model.

  If no errors occur, the **Diagnostics Manager** window displays the following message:

  ```
  Parsing successful for machine:model_name
  ```

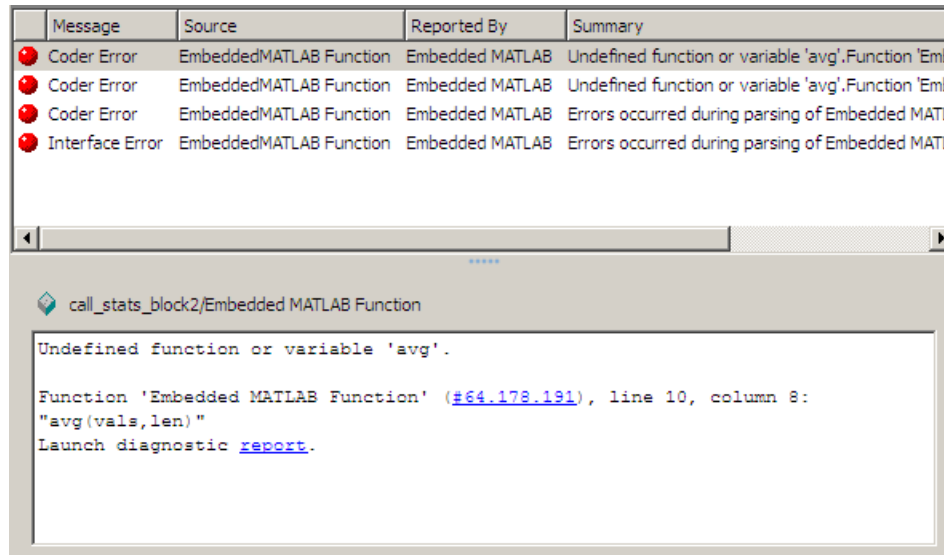
  Otherwise, the **Diagnostics Manager** helps you locate errors, as described in "How to Locate and Fix Errors" on page 24-16.

How to Locate and Fix Errors

If errors occur during the build process, the **Diagnostics Manager** window lists the errors with links to the offending code.

The following exercise shows how to locate and fix an error in an Embedded MATLAB Function block:

1. In the `stats` function, change the subfunction `avg` to a fictitious subfunction `aug` and then compile to see the following messages in the **Diagnostics Manager** window:

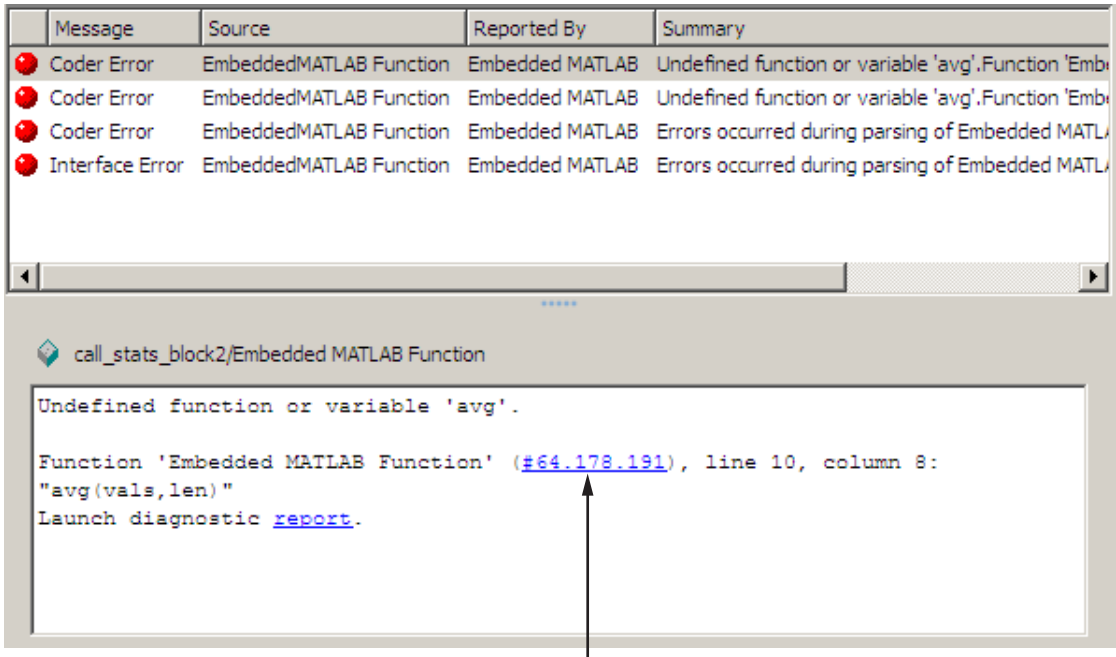


Each detected error appears with a red button.

2 Click the first error line to display its diagnostic message in the bottom error window.

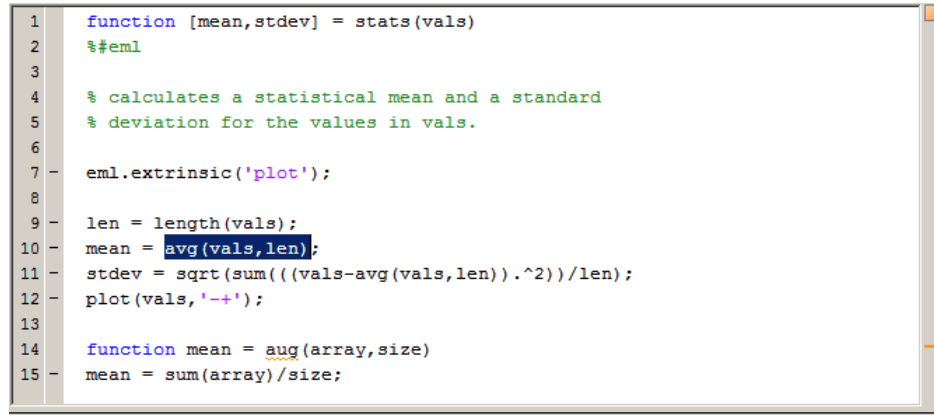
The message also links to a report about compile-time type information for variables and expressions in your Embedded MATLAB functions. This information helps you diagnose error messages and understand type propagation rules. For more information about the compilation report, see “Working with Compilation Reports” on page 24-66.

3 In the diagnostic message for the selected error, click the blue link after the function name to display the offending code:



Click to display the offending code in the Embedded MATLAB Editor

The offending line appears highlighted in the Embedded MATLAB Editor:



4 Correct the error by changing `aug` back to `avg` and recompile.

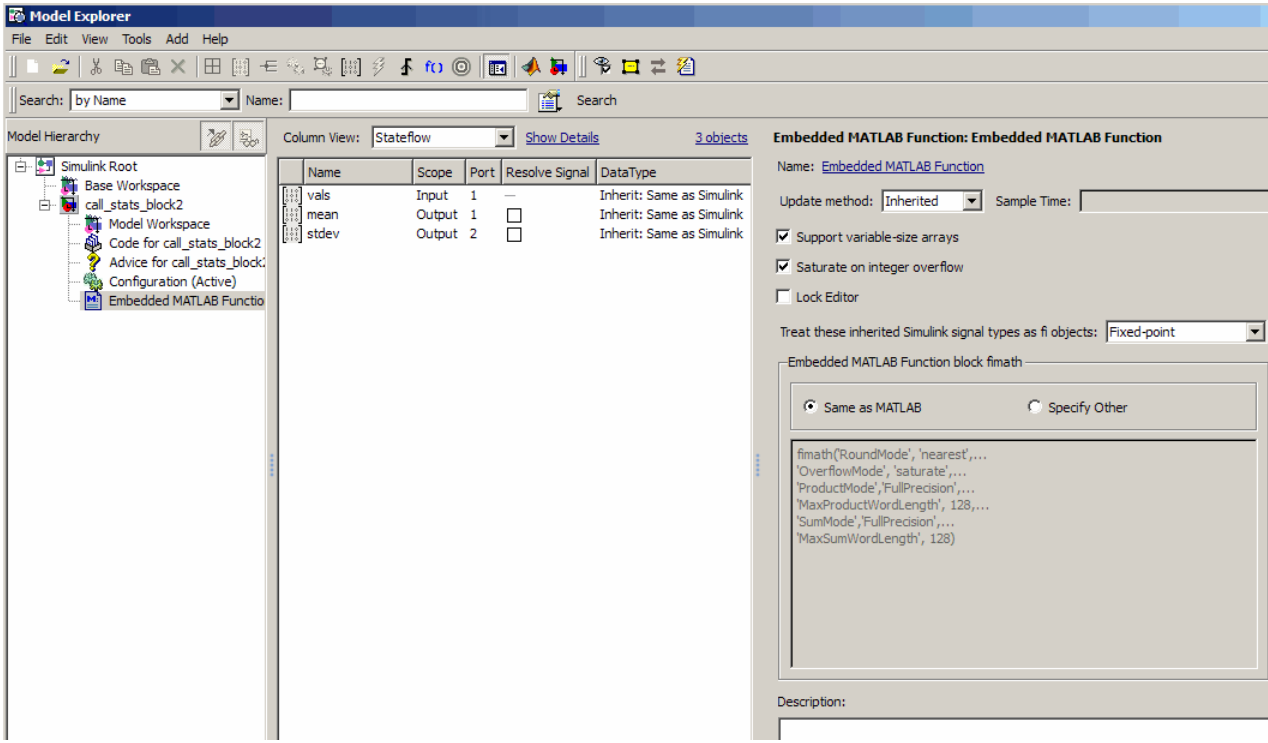
Defining Inputs and Outputs

In the `stats` function header for the Embedded MATLAB Function block you defined in "Programming the Embedded MATLAB Function" on page 24-10, the function argument `vals` is an input, and `mean` and `stdev` are outputs. By default, function inputs and outputs inherit their data type and size from the signals attached to their ports. In this topic, you examine input and output data for the Embedded MATLAB Function block to verify that it inherits the correct type and size.

1 Open the `call_stats_block2` model that you saved at the end of "Programming the Embedded MATLAB Function" on page 24-10. Double-click the Embedded MATLAB Function block `stats` to open it for editing.

2 In the Embedded MATLAB Editor, select **Tools > Model Explorer**.

The Model Explorer window opens:

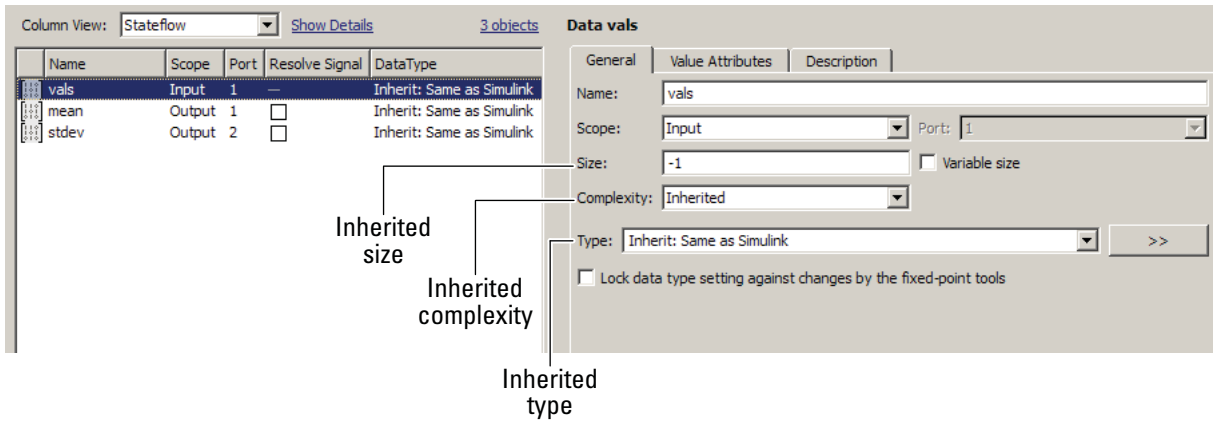


You can use the Model Explorer to define arguments for Embedded MATLAB Function blocks. Notice that the Embedded MATLAB Function block `Embedded MATLAB` is highlighted in the left **Model Hierarchy** pane.

The **Contents** pane displays the argument `vals` and the return values `mean` and `stdev` that you have already created for the Embedded MATLAB Function block. Notice that `vals` is assigned a **Scope** of `Input`, which is short for **Input from Simulink**. `mean` and `stdev` are assigned the **Scope** of `Output`, which is short for **Output to Simulink**.

You can also use the Ports and Data Manager to define arguments for Embedded MATLAB Function blocks (see “Ports and Data Manager” on page 24-41).

3 In the **Contents** pane of the Model Explorer window, click anywhere in the row for `vals` to highlight it:



The right pane displays the **Data** properties dialog box for `vals`. By default, the type, size, and complexity of input and output arguments are inherited from the signals attached to each input or output port. Inheritance is specified by setting **Size** to `-1`, **Complexity** to `Inherited`, and **Type** to `Inherit: Same as Simulink`.

The actual inherited values for size and type are set during compilation of the model, and are reported in the **Compiled Type** and **Compiled Size** columns of the **Contents** pane.

You can specify the type of an input or output argument by selecting a type in the **Type** field of the **Data** properties dialog box, for example, `double`. You can also specify the size of an input or output argument by entering an expression in the **Size** field of the **Data** properties dialog box for the argument. For example, you can enter `[2 3]` in the **Size** field to size `vals` as a 2-by-3 matrix. See "Typing Function Arguments" on page 24-81 and "Sizing Function Arguments" on page 24-93 for more information on the expressions that you can enter for type and size.

Note The default first index for any arrays that you add to an Embedded MATLAB Function block function is `1`, just as it would be in MATLAB.

Debugging an Embedded MATLAB Function Block

In this section...

How Debugging Affects Simulation Speed

Debugging an Embedded MATLAB function slows simulation speed. If your model has many Embedded MATLAB Function blocks and debugging is enabled, the simulation speed is much slower than when debugging is disabled. For maximum simulation speed, disable debugging as described in "Enabling and Disabling Debugging" on page 24-22.

Enabling and Disabling Debugging

There are two levels of debugging available when using Embedded MATLAB Function blocks, model level debugging and block level debugging.

Debugging is enabled for all Embedded MATLAB functions by default, except for Embedded MATLAB functions in Stateflow. Debugging for Embedded MATLAB functions in Stateflow is controlled in the **Simulation Target** pane in the **Configuration Parameters** dialog.

Disable debugging for an entire model by clearing the **Enable debugging/animation** check box in the **Simulation Target** pane in the **Configuration Parameters** dialog. Disable debugging for an individual Embedded MATLAB Function block by clicking **Enable Debugging** in the Embedded MATLAB Editor Debug menu. If **Enable Debugging** is unavailable, then the **Simulation Target** pane in the **Configuration Parameters** dialog is controlling debugging.

Debugging the Function in Simulation

In "Creating an Example Embedded MATLAB Function" on page 24-8, you created an example model with an Embedded MATLAB Function block. You use this block to specify an Embedded MATLAB function `stats` that calculates the mean and standard deviation for a set of input values. In this section, you debug `stats` in the example model.

You can debug your Embedded MATLAB Function block just like you can debug a function in MATLAB. In simulation, you test your Embedded MATLAB functions for run-time errors with tools similar to the MATLAB debugging tools. See "Watching with the Command Line Debugger" on page 24-31 and "Debugging Tools" on page 24-33 for more information.

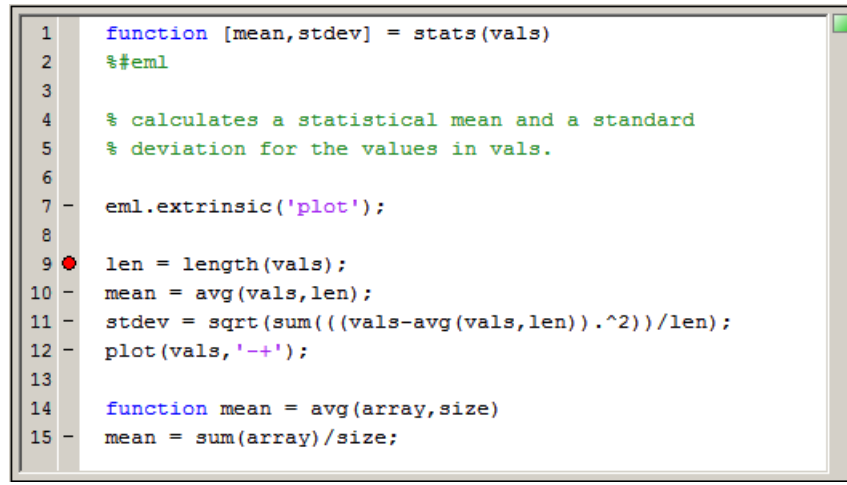
When you start simulation of your model, the Simulink software checks to see if the Embedded MATLAB Function block has been built since creation, or since a change has been made to the block. If not, it performs the build described in "Building the Function and Checking for Errors" on page 24-14. If no diagnostic errors are found, the simulation of your model begins.

Use the following procedure to debug the `stats` Embedded MATLAB function during simulation of the model:

1. Open the `call_stats_block2` model that you saved at the end of "Programming the Embedded MATLAB Function" on page 24-10. Double-click its Embedded MATLAB Function block `stats` to open it for editing in the Embedded MATLAB Editor.

2 In the Embedded MATLAB Editor, click the dash (-) character in the left margin of the line:

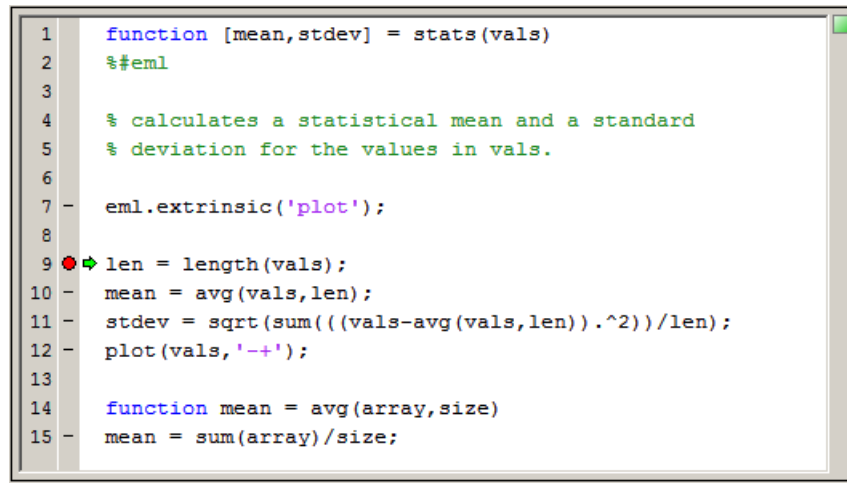
```
len = length(vals);
```



A small red ball appears in the margin of this line, indicating that you have set a breakpoint.

3 Begin simulating the model:

If you get any errors or warnings, make corrections before you try to simulate again. Otherwise, simulation pauses when execution reaches the breakpoint you set. This is indicated by a small green arrow in the left margin, as shown.

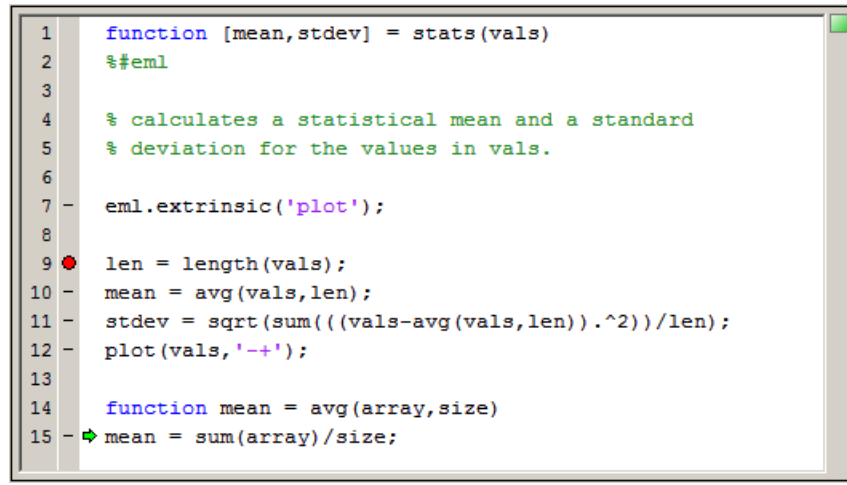


4 Click the **Step** icon  to advance execution:

The execution arrow advances to the next line of `stats`. Notice that this line calls the subfunction `avg`. If you click **Step** here, execution advances to the next line, past the execution of the subfunction `avg`. To track execution of the lines in the subfunction `avg`, you need to click the **Step In** icon.

5 Click the **Step In** icon  .

Execution advances to enter the subfunction `avg`:

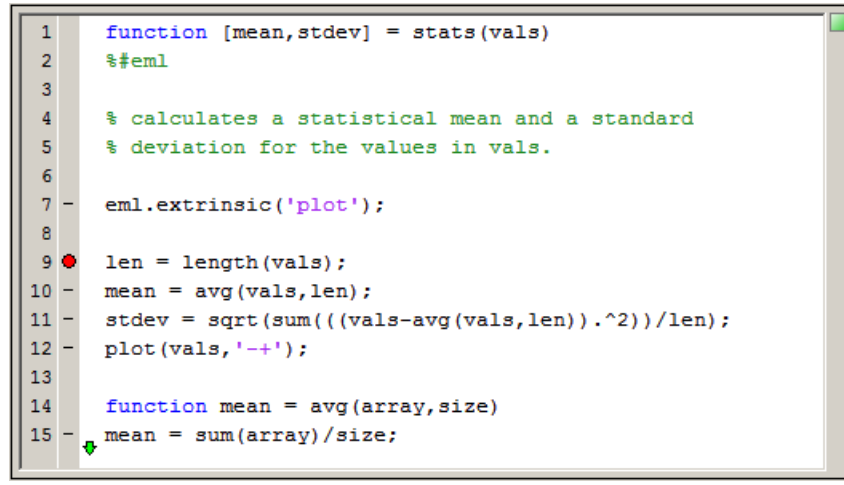


```
1   function [mean,stdev] = stats(vals)
2   %#eml
3
4   % calculates a statistical mean and a standard
5   % deviation for the values in vals.
6
7   eml.extrinsic('plot');
8
9   len = length(vals);
10  mean = avg(vals,len);
11  stdev = sqrt(sum(((vals-avg(vals,len)).^2))/len);
12  plot(vals,'-+');
13
14  function mean = avg(array,size)
15  mean = sum(array)/size;
```

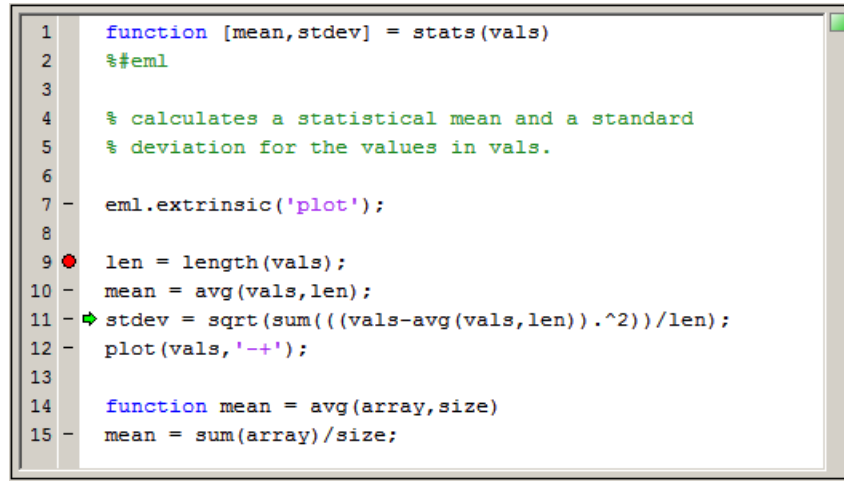
Once you are in a subfunction, you can use the **Step** or **Step In** icons to advance execution. If the subfunction calls another subfunction, use the **Step In** icon to enter it. If you want to execute the remaining lines of the subfunction, click the **Step Out** icon  .

6 Click the **Step** icon to execute the only line in the subfunction `avg`.

The subfunction `avg` finishes its execution, and you see a green arrow pointing down under its last line as shown.



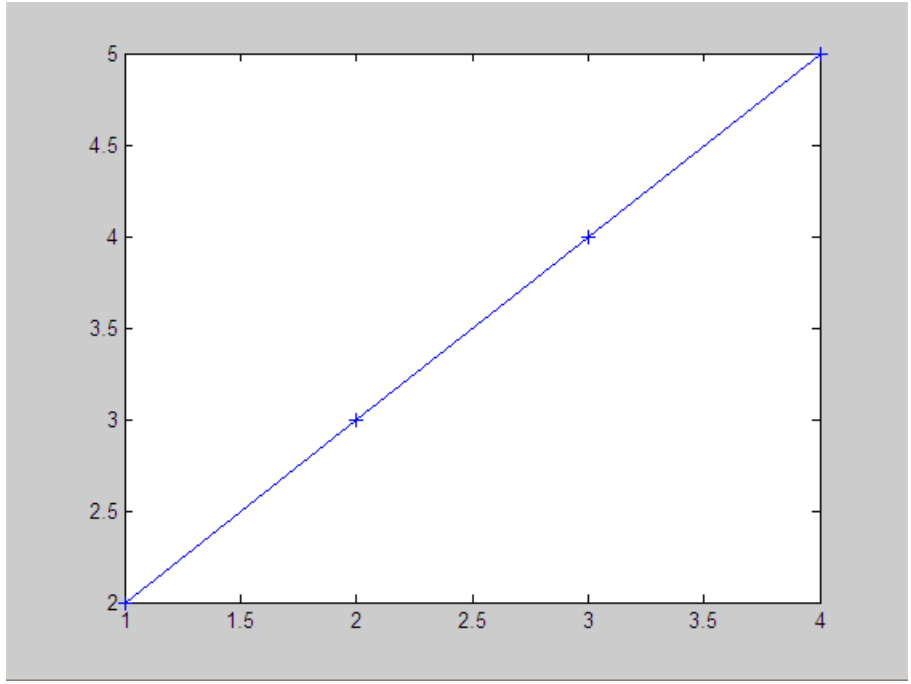
7 Click the **Step** icon to return to the function `stats`.



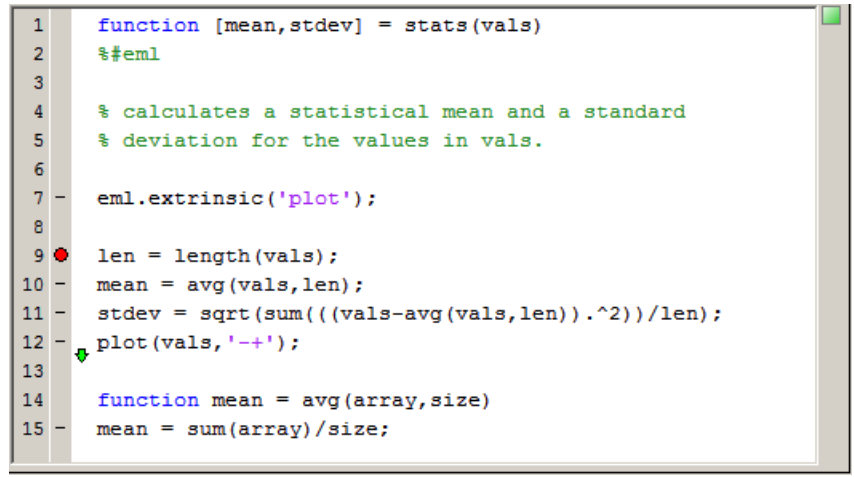
Execution advances to the line after the call to the subfunction `avg`.

8 Click **Step** twice to calculate the `stdev` and to execute the `plot` function.

The plot function executes in MATLAB, and you see the following plot.



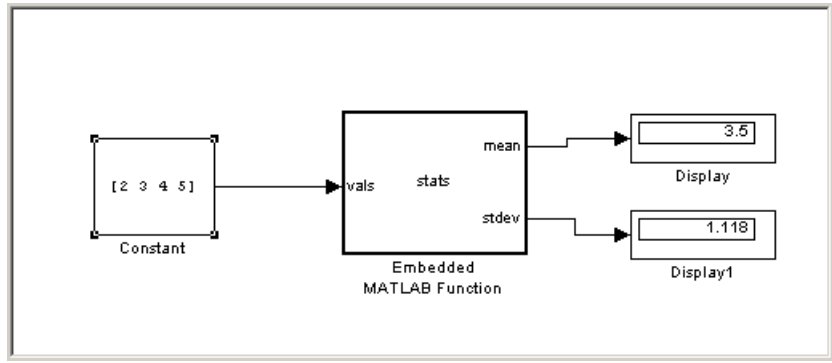
In the Embedded MATLAB Editor, a green arrow points down under the last line of code, indicating the completion of the function `stats`.



9 Click the **Continue Debugging** icon  to continue execution of the model.

At any point in a function, you can advance through the execution of the remaining lines of the function with the **Continue Debugging** icon. If you are at the end of the function, clicking the **Step** icon accomplishes the same thing.

The computed values of `mean` and `stdev` now appear in the Display blocks.



10 In the Embedded MATLAB Editor, click the **Exit Debug Mode** icon  to stop simulation.

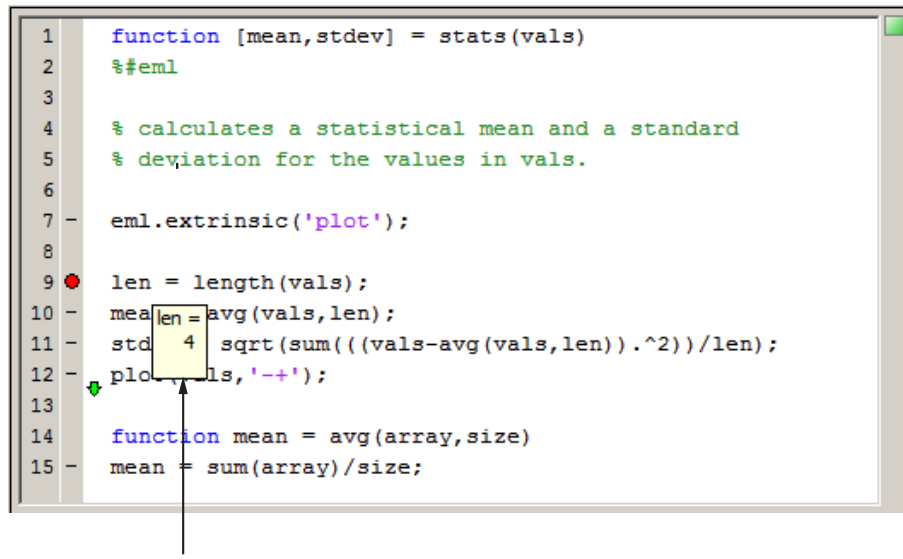
Watching Function Variables During Simulation

While you are simulating the function of an Embedded MATLAB Function block, you can use several tools to keep track of variable values in the function. These tools are described in the topics that follow.

Watching with the Interactive Display

To display the value of a variable in the function of an Embedded MATLAB Function block during simulation, in the Embedded MATLAB Editor, place the mouse cursor over the variable text and observe the pop-up display.

For example, to watch the variable `len` during simulation, place the mouse cursor over the text `len` in the code. The value of `len` appears adjacent to the cursor, as shown:



Display of value for variable len

You can display the value for any variable in the Embedded MATLAB function in this way, no matter where it appears in the function.

Watching with the Command Line Debugger

You can report the values for an Embedded MATLAB function variable with the Command Line Debugger utility in the MATLAB window during simulation. When you reach a breakpoint, the Command Line Debugger prompt, `debug>>`, appears. At this prompt, you can see the value of a variable defined for the Embedded MATLAB Function block by entering its name:

```
debug>> stdev

 1.1180

debug>>
```

The Command Line Debugger also provides the following commands during simulation:

Command	Description
`ctrl-c`	Quit debugging and terminate simulation.
`dbcont`	Continue execution to next breakpoint.
`dbquit`	Quit debugging and terminate simulation.
`dbstep [in|out]`	Advance to next program step after a breakpoint is encountered. Step over or step into/out of an Embedded MATLAB subfunction.
`help`	Display help for command line debugging.
`print <var>`	Display the value of the variable `var` in the current scope. If `var` is a vector or matrix, you can also index into `var`. For example, `var(1,2)`.
`save`	Saves all variables in the current scope to the specified file. Follows the syntax of the MATLAB `save` command. To retrieve variables to the MATLAB base workspace, use `load` command after simulation has been ended.
`<var>`	Equivalent to "print <var>" if variable is in the current scope.
`who`	Display the variables in the current scope.
`whos`	Display the size and class (type) of all variables in the current scope.

You can issue any other MATLAB command at the `debug>>` prompt, but the results are executed in the workspace of the Embedded MATLAB Function block. To issue a command in the MATLAB base workspace at the `debug>>` prompt, use the `evalin` command with the first argument `'base'` followed by the second argument command string, for example, `evalin('base','whos')`. To return to the MATLAB base workspace, use the `dbquit` command.

Watching with MATLAB

You can display the execution result of an Embedded MATLAB function line by omitting the terminating semicolon. If you do, execution results for the line are echoed to the MATLAB window during simulation.

Display Size Limits

The Embedded MATLAB Editor does not display the contents of matrices that have more than two dimensions or more than 200 elements. For matrices that exceed these limits, the Embedded MATLAB Editor displays the shape and base type only.

Checking for Data Range Violations

When you enable debugging, Embedded MATLAB Function blocks automatically check input and output data for data range violations when the values enter or leave the blocks.

Specifying a Range

To specify a range for input and output data, follow these steps:

1. In the Model Explorer, select the input or output of interest in the Embedded MATLAB Function block.

   The data properties dialog box opens in the Dialog pane of the Model Explorer.

2. In the data properties dialog box, select the General tab and enter a limit range, as described in "Setting General Properties" on page 24-51.

Debugging Tools

Use the following tools during an Embedded MATLAB function debugging session:

Tool Button	Description	Shortcut Key
 **Build**	Check for errors and build a simulation application (if no errors are found) for the model containing this Embedded MATLAB function. Alternatively, from the **Tools** menu, select **Build**.	**Ctrl+B**
 **Start Simulation**	Start simulation of the model containing the Embedded MATLAB function.	**F5**
 **Stop Simulation**	Stop simulation of the model containing the Embedded MATLAB function. Alternatively, from the **Debug** menu, select **Exit debug mode** if execution is paused at a breakpoint.	**Shift+F5**
 **Set/Clear Breakpoint**	Set a new breakpoint or clear an existing breakpoint for the selected Embedded MATLAB code line. The presence of the text cursor or highlighted text selects the line. A **Breakpoint Indicator** appears in the breakpoints column for the selected line. Alternatively, click the hyphen character (-) in the breakpoints column for the line. A breakpoint indicator appears in place of the hyphen. Click the breakpoint indicator to clear the breakpoint.	**F12**
 **Clear All Breakpoints**	Clear all existing breakpoints in the Embedded MATLAB function.	**None**

Tool Button	Description	Shortcut Key
 **Step**	Step through the execution of the next Embedded MATLAB code line. This tool steps past function calls and does not enter called functions for line-by-line execution. You can use this tool only after execution has stopped at a breakpoint. Alternatively, from the **Debug** menu, select **Step**.	**F10**
 **Step In**	Step through the execution of the next Embedded MATLAB code line. If the line calls a subfunction, step into the first line of the subfunction. You can use this tool only after execution has stopped at a breakpoint. Alternatively, from the **Debug** menu, select **Step In**.	**F11**
 **Step Out**	Step out of line-by-line execution of the current function or subfunction. If in a subfunction, the debugger continues to the line following the call to this subfunction. You can use this tool only after execution has stopped at a breakpoint. Alternatively, from the **Debug** menu, select **Step Out**.	**Shift+F11**
 **Continue Debugging**	Continue debugging after a pause, such as stopping at a breakpoint. You can use this tool only after execution has stopped at a breakpoint. Alternatively, from the **Debug** menu, select **Continue**.	**F5**
 **Exit Debug Mode**	Exit debug mode. You can use this tool only after execution has stopped at a breakpoint. Alternatively, from the **Debug** menu, select **Exit Debug Mode**.	**Shift+F5**

Embedded MATLAB Function Editor

In this section...

Customizing the Embedded MATLAB Editor

Use the toolbar icons to customize the appearance of the Embedded MATLAB Editor in the same manner as the MATLAB editor. See "Arranging the Desktop" in the MATLAB documentation.

Embedded MATLAB Editor Tools

The following tools are specific to Embedded MATLAB:

Tool Button	Description
 **Edit Data/Ports**	Opens the Ports and Data Manager dialog to add or modify arguments for the current Embedded MATLAB Function block (see "Ports and Data Manager" on page 24-41). You can also open this dialog by selecting **Edit Data/Ports** from the **Tools** menu. To define and modify input and output arguments for any Embedded MATLAB Function block in the model hierarchy, use the Model Explorer, which you can open from the **Tools** menu.

Tool Button	Description
 **Open Compilation Report**	Opens the compilation report for the Embedded MATLAB Function block. For more information, see "Working with Compilation Reports" on page 24-66.
 **Simulation Target**	Opens the **Simulation Target** pane in the **Configuration Parameters** dialog to enable debugging or include custom code. See "Enabling and Disabling Debugging" on page 24-22 for more information on debugging, and "Including C/C++ Functions in Simulation Targets" in the Embedded MATLAB documentation for more information on including custom code.
 **Go To Diagram**	Displays the Embedded MATLAB function in its native diagram without closing the Embedded MATLAB Editor.
 **Update Ports**	Updates the ports of the Embedded MATLAB Function block with the latest changes made to the function argument and return values without closing the Embedded MATLAB Editor.

See "Defining Inputs and Outputs" on page 24-19 for an example of defining an input argument for an Embedded MATLAB Function block.

Editing and Debugging Embedded MATLAB Code

Commenting Out a Block of Code

To comment out a block of code in the Embedded MATLAB editor:

1. Highlight the text that you would like to comment out.
2. Hold the mouse over the highlighted text and then right-click and select **Comment** from the context menu. (Alternatively, select **Comment** from the **Text** menu).

Note To uncomment a block of code, follow the same steps, but select **Uncomment** instead of **Comment**.

For more information, refer to "Adding Comments" in the MATLAB Desktop Tools and Development Environment documentation.

Manual Indenting

To indent a block of code manually:

1. Highlight the text that you would like to indent.
2. Hold the mouse over the highlighted text and then right-click and select one of the following options from the context menu:
   - **Smart Indent** to indent lines that start with keyword functions or that follow lines containing certain keyword functions. (Alternatively, select **Smart Indent** from the **Text** menu).
   - **Decrease Indent** to move selected lines further to the left. (Alternatively, select **Decrease Indent** from the **Text** menu).
   - **Increase Indent** to move selected lines further to the right. (Alternatively, select **Increase Indent** from the **Text** menu).

For more information, refer to "Indenting" in the MATLAB Desktop Tools and Development Environment documentation.

Opening a Selection

You can open a subfunction, function, file, or variable from within a file in the Embedded MATLAB Function Editor.

To open a selection:

1. Position the cursor in the name of the item you would like to open.
2. Right-click and select **Open Selection** from the context menu.

The Editor chooses the appropriate tool to open the selection. For more information, refer to "Evaluating or Opening a Selection" in the MATLAB Desktop Tools and Development Environment documentation.

Note If you open an Embedded MATLAB Function block input or output parameter, the Ports and Data Manager opens with the selected parameter highlighted. You can use the Ports and Data Manager to modify parameter attributes. For more information, refer to "Ports and Data Manager" on page 24-41.

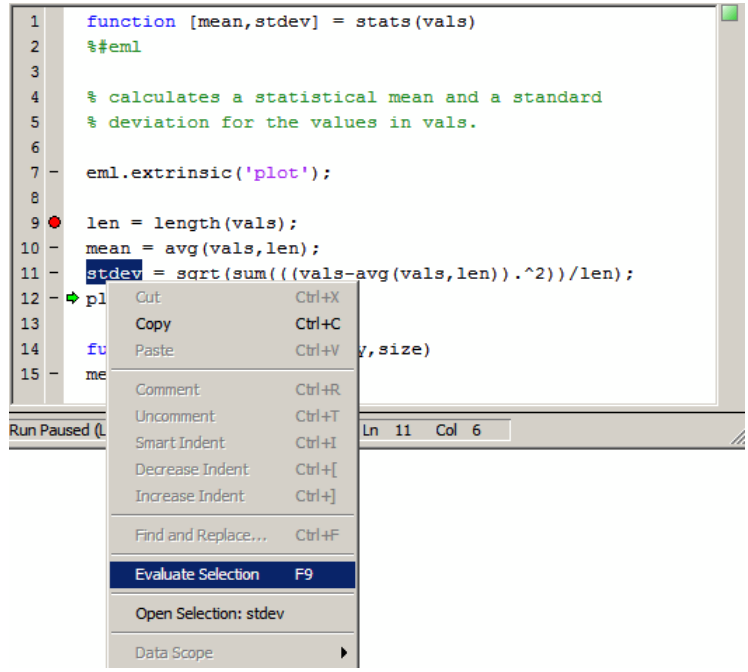
Evaluating a Selection

You can use the **Evaluate a Selection** menu option to report the value for an Embedded MATLAB function variable or equation in the MATLAB window during simulation.

To evaluate a selection:

1. Highlight the variable or equation that you would like to evaluate.

2 Hold the mouse over the highlighted text and then right-click and select **Evaluate Selection** from the context menu. (Alternatively, select **Evaluate Selection** from the **Text** menu).



When you reach a breakpoint, the MATLAB command Window displays the value of the variable or equation at the Command Line Debugger prompt.

```
debug>> stdev

 1.1180

debug>>
```

Note You cannot evaluate a selection while MATLAB is busy, for example, running a MATLAB file.

Setting Data Scope

To set the data scope of an Embedded MATLAB Function block input parameter:

1. Highlight the input parameter that you would like to modify.
2. Hold the mouse over the highlighted text and then right-click and select **Data Scope** from the context menu.
3. Select:
   - **Input** if your input data is provided by the Simulink model via an input port to the Embedded MATLAB Function block.
   - **Parameter** if your input is a variable of the same name in the MATLAB or model workspace or in the workspace of a masked subsystem containing this block.

For more information, refer to "Setting General Properties" on page 24-51 in the Ports and Data Manager documentation.

Ports and Data Manager

The Ports and Data Manager provides a convenient method for defining objects and modifying their properties in an Embedded MATLAB Function block that is open and has focus.

The Ports and Data Manager provides the same data definition capabilities as the Model Explorer, but supports only individual Embedded MATLAB Function blocks. To modify objects and properties for blocks across the model hierarchy, use the "The Model Explorer: Overview" on page 8-2.

Ports and Data Manager Dialog

The Ports and Data Manager dialog allows you to add and define data arguments, input triggers, and function call outputs for Embedded MATLAB Function blocks. Using this dialog, you can also modify properties for the Embedded MATLAB Function block and the objects it contains.

The dialog consists of two panes:

- The **Contents** pane lists the objects that have been defined for the Embedded MATLAB Function block.
- The **Dialog** pane displays fields for modifying the properties of the selected object.

Properties vary according to the scope and type of the object. Therefore, the Ports and Data Manager properties dialogs are dynamic, displaying only the property fields that are relevant for the object you add or modify.

When you first open the dialog, it displays the properties of the Embedded MATLAB Function block.

Opening the Ports and Data Manager

To open the Ports and Data Manger from the Embedded MATLAB Editor, select **Tools > Edit Data/Ports** or click the **Edit Data/Ports** icon  .

The Ports and Data Manager appears for the Embedded MATLAB Function block that is open and has focus.

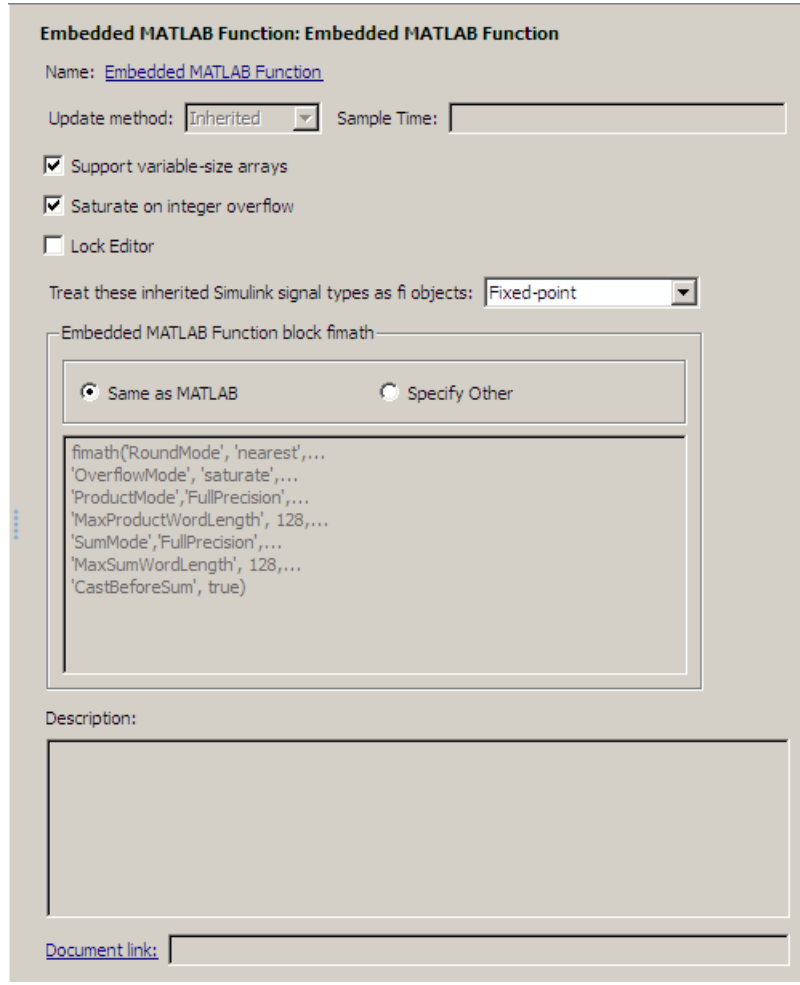
Ports and Data Manager Tools

The following tools are specific to the Ports and Data Manager:

Tool Button	Description
 **Goto Block Editor**	Displays the Embedded MATLAB function in the Embedded MATLAB Editor.
 **Show Block Dialog**	Displays the default Embedded MATLAB function properties (see “Setting Embedded MATLAB Function Block Properties” on page 24-43). Use this button to return to the settings used by the block after viewing data associated with the block arguments.

Setting Embedded MATLAB Function Block Properties

The **Dialog** pane for an Embedded MATLAB Function block looks like this:



This section describes each property of an Embedded MATLAB Function block.

Name. Name of the Embedded MATLAB Function block, following the same naming conventions as for Simulink blocks (see "Manipulating Block Names" on page 18-27).

Update method. Method for activating the Embedded MATLAB Function block. You can choose from the following update methods:

Update Method	Description
Inherited (default)	Input from the Simulink model activates the Embedded MATLAB Function block. If you define an input trigger, the Embedded MATLAB Function block executes in response to a Simulink signal or function-call event on the trigger port. If you do not define an input trigger, the Embedded MATLAB Function block implicitly inherits triggers from the model. These implicit events are the sample times (discrete or continuous) of the signals that provide inputs to the chart. If you define data inputs, the Embedded MATLAB Function block samples at the rate of the fastest data input. If you do not define data inputs, the Embedded MATLAB Function block samples as defined by its parent subsystem's execution behavior.
Discrete	The Embedded MATLAB Function block is sampled at the rate you specify as the block's **Sample Time** property. An implicit event is generated at regular time intervals corresponding to the specified rate. The sample time is in the same units as the Simulink simulation time. Note that other blocks in the model can have different sample times.
Continuous	The Simulink software wakes up (samples) the Embedded MATLAB Function block at each step in the simulation, as well as at intermediate time points that can be requested by the solver. This method is consistent with the continuous method.

Saturate on integer overflow. Option that determines how the Embedded MATLAB Function block handles overflow conditions during integer operations:

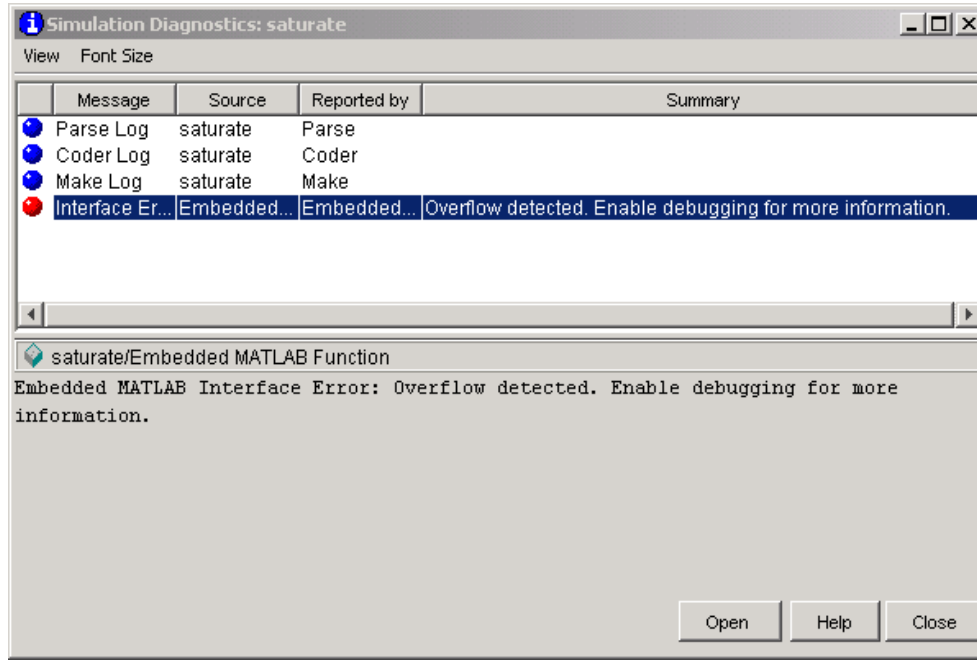
Setting	Action When Overflow Occurs
Enabled (default)	Saturates an integer by setting it to the maximum positive or negative value allowed by the word size. Matches MATLAB behavior.
Disabled	In simulation mode, generates a run-time error. For Real-Time Workshop code generation, the behavior depends on your C language compiler.

Note The **Saturate on integer overflow** option is relevant only for integer arithmetic. It has no effect on fixed-point or double-precision arithmetic.

When you enable **Saturate on integer overflow**, the Embedded MATLAB Function block adds additional checks in the generated code to detect integer overflow or underflow. Therefore, it is more efficient to disable this option if you are sure that integer overflow and underflow will not occur in your Embedded MATLAB function code.

Even when you disable this option, the code for a simulation target checks for integer overflow and underflow. If either condition occurs, simulation stops and an error is generated. If you enabled debugging for the Embedded MATLAB Function block, the debugger displays the error and lets you examine the data.

If you have not enabled debugging for the Embedded MATLAB Function block, the block generates a run-time error, as in this example:



It is important to note that the code for a Real-Time Workshop target does *not* check for integer overflow or underflow and, therefore, may produce unpredictable results when **Saturate on integer overflow** is disabled. In this situation, it is recommended that you simulate first to test for overflow and underflow before generating the Real-Time Workshop target.

Lock Editor. Option for locking the Embedded MATLAB Editor. When enabled, this option prevents users from making changes to the Embedded MATLAB Function block.

Treat these inherited Simulink signal types as fi objects. Parameter that applies to Embedded MATLAB Function blocks in models that use fixed-point or integer data types. You can control how the Embedded MATLAB Function block handles Simulink input signals using the **Treat these inherited Simulink signal types as fi objects** parameter.

Property	Description
Treat these inherited Simulink signal types as fi objects	Determines whether to treat inherited fixed-point and integer signals as Fixed-Point Toolbox `fi` objects. • When you select `Fixed-point`, the Embedded MATLAB Function block treats all fixed-point inputs as Fixed-Point Toolbox `fi` objects. • When you select `Fixed-Point & Integer`, the Embedded MATLAB Function block treats all fixed-point and integer inputs as Fixed-Point Toolbox `fi` objects.

Embedded MATLAB Function block fimath. Setting that defines `fimath` properties for the Embedded MATLAB Function block. The block associates the `fimath` properties you specify with the following objects:

- All fixed-point and integer input signals to the Embedded MATLAB Function block that you choose to treat as `fi` objects.
- All `fi` and `fimath` objects constructed in the Embedded MATLAB Function block.

You can select one of the following options for the **Embedded MATLAB Function block fimath**.

Setting	Description
Same as MATLAB	When you select this option, the block uses the same `fimath` properties as the current global fimath. The edit box appears dimmed and displays the current global fimath in read-only form. For more information on the global fimath, see "Working with the Global fimath" in the Fixed-Point Toolbox documentation.

Setting	Description
Specify other	When you select this option, you can specify your own `fimath` object in the edit box. You can do so in one of two ways: • Constructing the `fimath` object inside the edit box. • Constructing the `fimath` object in the MATLAB or model workspace and then entering its variable name in the edit box. If you use this option and plan to share your model with others, make sure you define the variable in the model workspace. See "Sharing Models with Fixed-Point Embedded MATLAB Function Blocks" in the Fixed-Point Toolbox documentation for more information. For more information on `fimath` objects, see "Working with fimath Objects" in the Fixed-Point Toolbox documentation.

Description. Description of the Embedded MATLAB Function block.

Document link. Link to documentation for the Embedded MATLAB Function block. To document an Embedded MATLAB Function block, set the **Document link** property to a Web URL address or MATLAB expression that displays documentation in a suitable format (for example, an HTML file or text in the MATLAB Command Window). The Embedded MATLAB Function block evaluates the expression when you click the blue **Document link** text.

Adding Data to an Embedded MATLAB Function Block

You can define input and output data arguments for an Embedded MATLAB Function block directly in the script, or by using the Ports and Data Manager or Model Explorer. You can use the Ports and Data Manager to add data arguments to an Embedded MATLAB Function block that is open and has focus. You can also modify the properties of data arguments in the block.

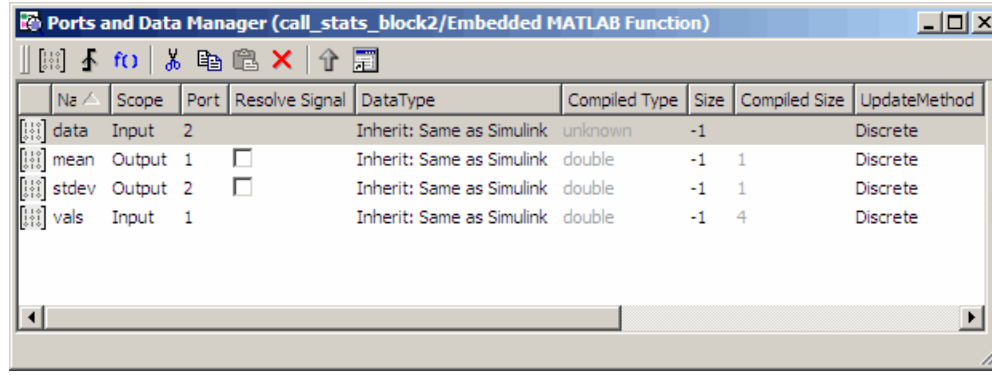
You can define data arguments for Embedded MATLAB Function blocks in the following methods:

Method	For Defining	Reference
Define data directly in the Embedded MATLAB function script	Input and output data	See "Defining Inputs and Outputs" on page 24-19.
Use the Ports and Data Manager	Input, output, and parameter data in the Embedded MATLAB Function block that is open and has focus	See "Defining Data in the Ports and Data Manager" on page 24-49.
Use the Model Explorer	Input, output, and parameter data in Embedded MATLAB Function blocks at all levels of the model hierarchy	See "Defining Data in the Model Explorer" on page 24-50

Defining Data in the Ports and Data Manager. To add a data argument and modify its properties, follow these steps:

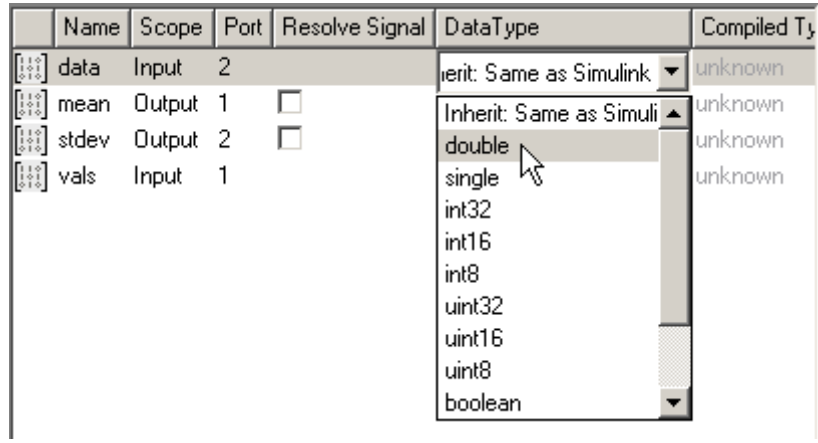
1 In the Ports and Data Manager, click the **Add Data** icon  .

The Ports and Data Manager adds a default definition of the data to the Embedded MATLAB Function block and displays the new data argument.



2 Select the row containing the new data argument.

3 Select the data property you want to modify, and specify a new value, as in this example:



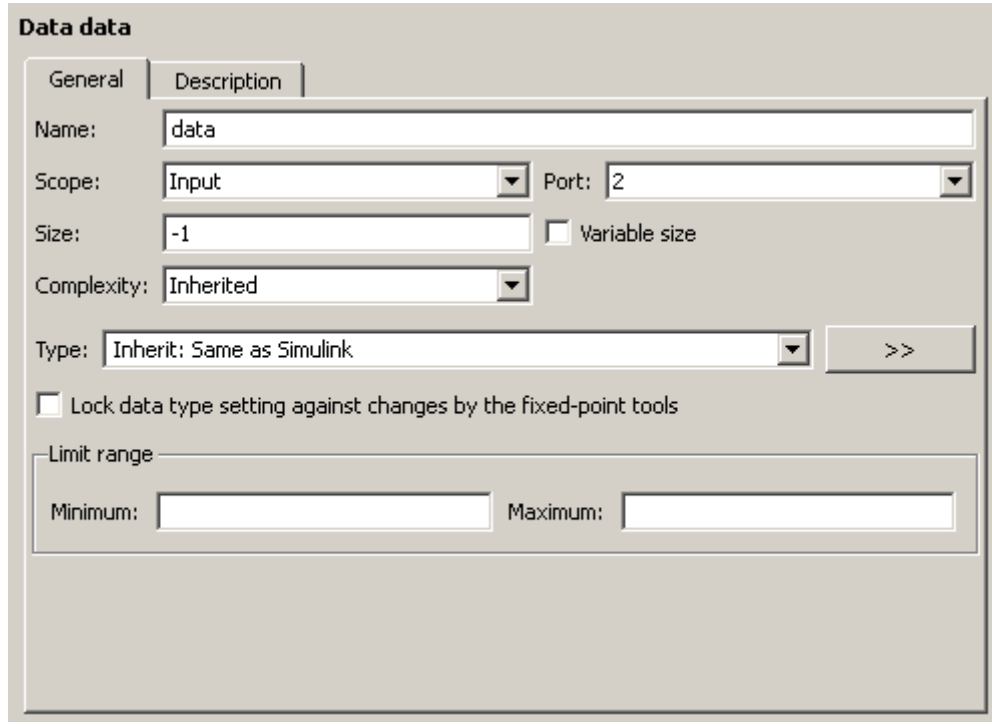
4 Repeat step 3 to specify values for other data properties.

5 Return to the `Embedded MATLAB Function` block properties at any time by clicking the **Show Block Dialog** icon .

Defining Data in the Model Explorer. The Data properties dialog in the Model Explorer allows you to set and modify the properties of data arguments in Embedded MATLAB Function blocks. Properties vary according to the scope and type of the data object. Therefore, the Data properties dialog is dynamic, displaying only the property fields that are relevant for the data argument you are defining.

Open the Data properties dialog by selecting a data argument in the Contents pane.

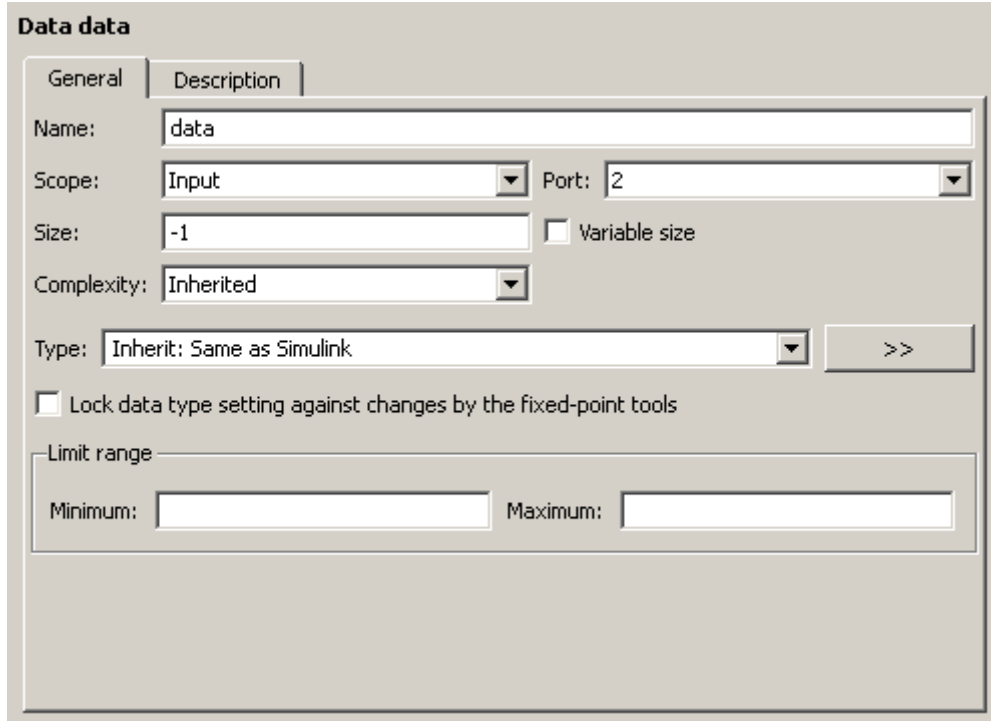
The Data properties dialog provides a set of tabbed panes, as in this example:



Each tab lets you define different features of your data argument:

- The **General** tab lets you define the scope, size, complexity, type, and limit range of the data argument. See "Setting General Properties" on page 24-51.
- The **Description** tab lets you save values to the base workspace, enter a description, and link to documentation about the data argument. See "Setting Description Properties" on page 24-56.

Setting General Properties. The General tab of the Data properties dialog looks like this:



Note If you cannot see the Data Type Assistant, click the Show data type assistant button >>.

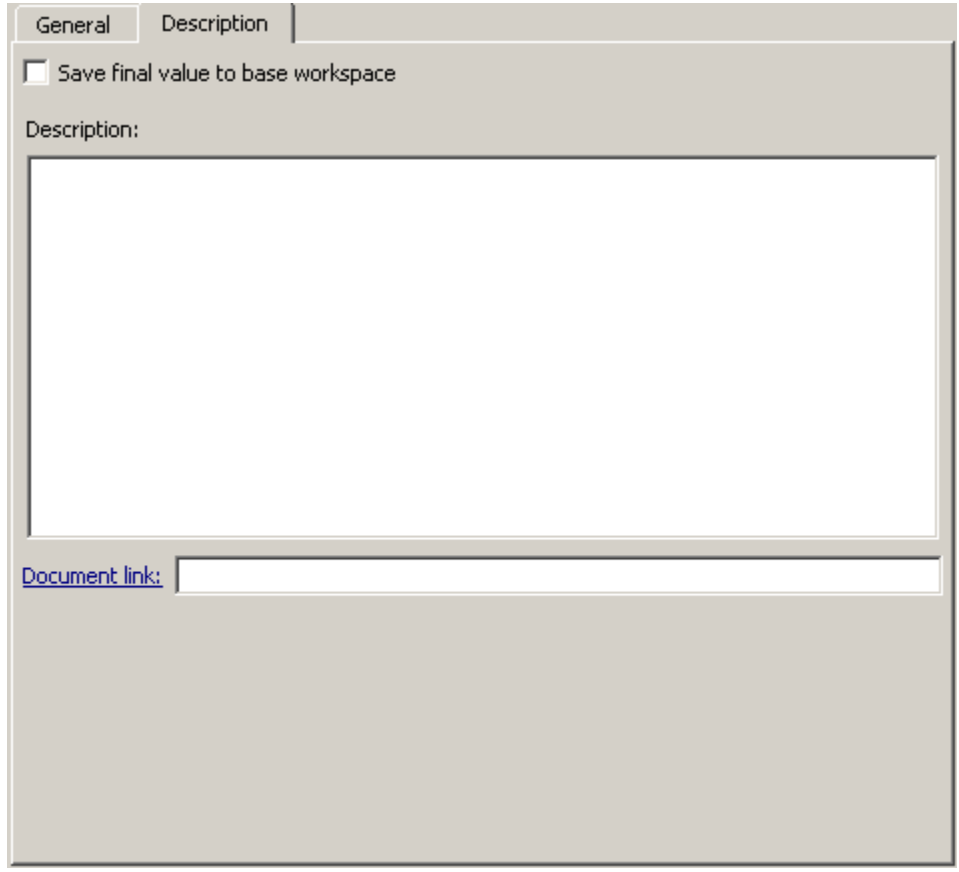
You can set the following properties in the General tab:

Property	Description
Name	Name of the data argument, following the same naming conventions used in MATLAB (see "Naming Variables" in the MATLAB documentation.
Scope	Where data resides in memory, relative to its parent. Scope determines the range of functionality of the data argument. You can set scope to one of the following values: • `Parameter`— Specifies that the source for this data is a variable of the same name in the MATLAB or model workspace or in the workspace of a masked subsystem containing this block. If a variable of the same name exists in more than one of the workspaces visible to the block, the variable closest to the block in the workspace hierarchy is used (see "Using Model Workspaces" on page 3-67). • `Input`— Data provided by the model via an input port to the Embedded MATLAB Function block. • `Output`— Data provided by the Embedded MATLAB Function block via an output port to the model. • `Data Store Memory`— Data provided by a Data Store Memory block in the model. For more information, see "Defining Inputs and Outputs" on page 24-19 and "Parameter Arguments in Embedded MATLAB Functions" on page 24-97.
Port	Index of the port associated with the data argument. This property applies only to input and output data.
Tunable	Indicates whether the parameter used as the source of this data item is tunable (see "Tunable Parameters" on page 2-9). This property applies only to parameter data. You must clear this option if you want to use the parameter where Embedded MATLAB requires a constant expression, such as `zeros` (see entry for `zeros` in "Embedded MATLAB Function Library — Alphabetical List" in the Embedded MATLAB documentation).

Property	Description
Data must resolve to Simulink signal object	Specifies that the data argument must resolve to a Simulink signal object. This property applies only to output data. See "Resolving Symbols" on page 3-75 for more information.
Size	Size of the data argument. Size can be a scalar value or a MATLAB vector of values. Size defaults to –1, which means that it is inherited, as described in "Inheriting Argument Sizes from Simulink" on page 24-93. This property does not apply to Data Store Memory data. For more details, see "Sizing Function Arguments" on page 24-93.
Variable Size	Indicates whether the size of this data item is variable (see "Using Variable-Size Data in Embedded MATLAB Function Blocks" on page 24-113). This property does not apply to Data Store Memory data.
Complexity	Indicates real or complex data arguments. You can set complexity to one of the following values: • `Off`— Data argument is a real number • `On`— Data argument is a complex number • `Inherited`— Data argument inherits complexity based on its scope. Input and output data inherit complexity from the Simulink signals connected to them; parameter data inherits complexity from the parameter to which it is bound.
Sampling mode	Specifies how an output signal propagates through a model. This property applies only to data with scope equal to `Output`. You can set sampling mode to one of the following values: • `Sample based`: Propagate the signal sample by sample (default) • `Frame based`: Propagate the signal in batches of samples

Property	Description
Type	Type of data object. You can specify the data type by: • Selecting a built-in type from the **Type** drop down list. • Entering an expression in the **Type** field that evaluates to a data type (see "Working with Data Types" on page 25-2 in the Simulink® User's Guide on page 1). • Using the Data Type Assistant to specify a data **Mode**, then specifying the data type based on that mode. **Note** Click the Show data type assistant button  to display the Data Type Assistant. For more information, see "Specifying Argument Types" on page 24-81.
Lock data type setting against changes by the fixed-point tools	Specify whether you want to prevent replacement of the current data type with a type chosen by the Fixed-Point Tool or Fixed-Point Advisor. The default setting allows replacement. See Scaling in the Simulink Fixed Point documentation for instructions on autoscaling fixed-point data.
Limit range properties	Specify the range of acceptable values for input or output data. The Embedded MATLAB Function block uses this range to validate the input or output as it enters or leaves the block. You can enter an expression or parameter that evaluates to a numeric scalar value. • **Minimum** — The smallest value allowed for the data item during simulation. The default value is `-inf`. • **Maximum** — The largest value allowed for the data item during simulation. The default value is `inf`.

Setting Description Properties. The **Description** tab of the Data properties dialog looks like this:



You can set the following properties on the Description tab:

Property	Description
Save final value to base workspace	The Embedded MATLAB Function block assigns the value of the data argument to a variable of the same name in the MATLAB base workspace at the end of simulation.
Description	Description of the data argument.
Document link	Link to documentation for the data argument. You can enter a Web URL address or a MATLAB command that displays documentation in a suitable format, such as an HTML file or text in the MATLAB Command Window. When you click the blue text, **Document link**, displayed at the bottom of the **Data** properties dialog, the Embedded MATLAB Function block evaluates the link and displays the documentation.

Adding Input Triggers to an Embedded MATLAB Function Block

An input trigger is an event on the input port that causes the Embedded MATLAB Function block to execute. See "Triggered Subsystems" on page 6-14 in the Simulink documentation.

You can define the following types of triggers in Embedded MATLAB function blocks:

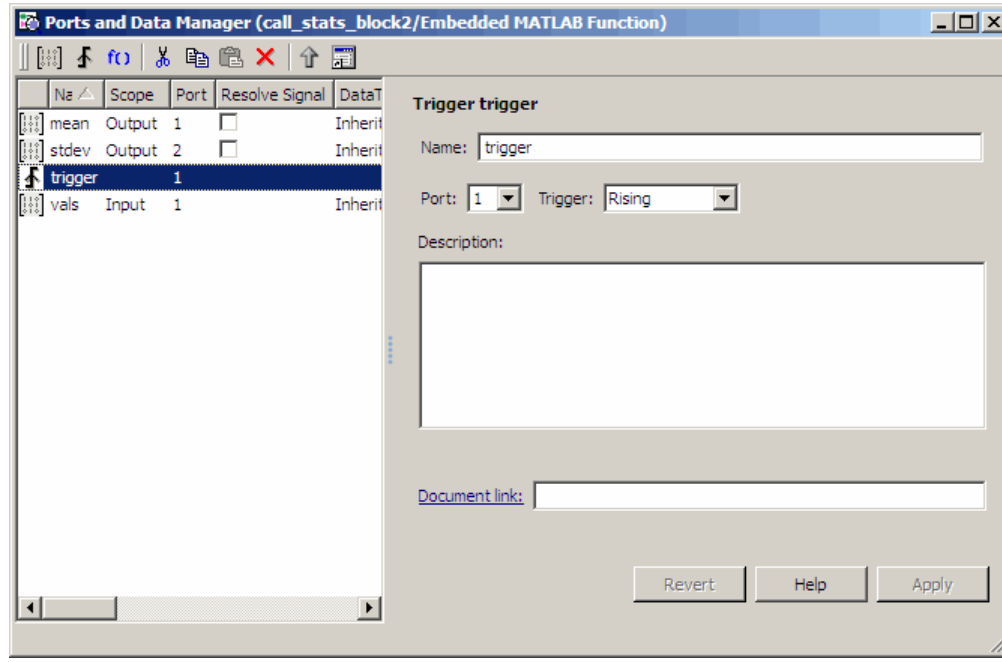
- Rising
- Falling
- Either (rising or falling)
- Function call

For a description of each trigger type, see "Setting Input Trigger Properties" on page 24-60.

Use the Ports and Data Manager to add input triggers to an Embedded MATLAB Function block that is open and has focus. To add an input trigger and modify its properties, follow these steps:

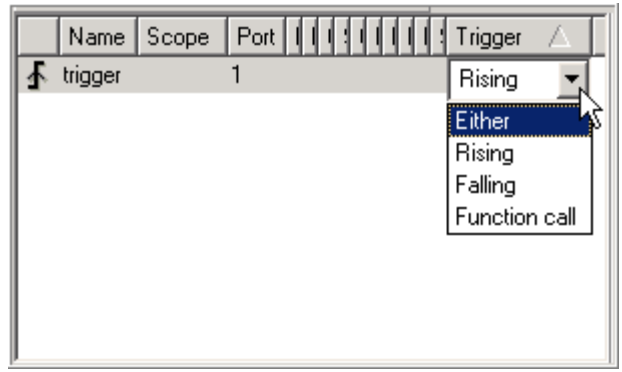
1 In the Ports and Data Manager, click the **Add Input Trigger** icon  .

The Ports and Data Manager adds a default definition of the new input trigger to the Embedded MATLAB Function block and displays the Trigger properties dialog.



2 Modify properties for the new input trigger, using one of the following methods:

- In the Contents pane, select the row that contains the input trigger you want to modify and then edit the property of interest, as in this example:



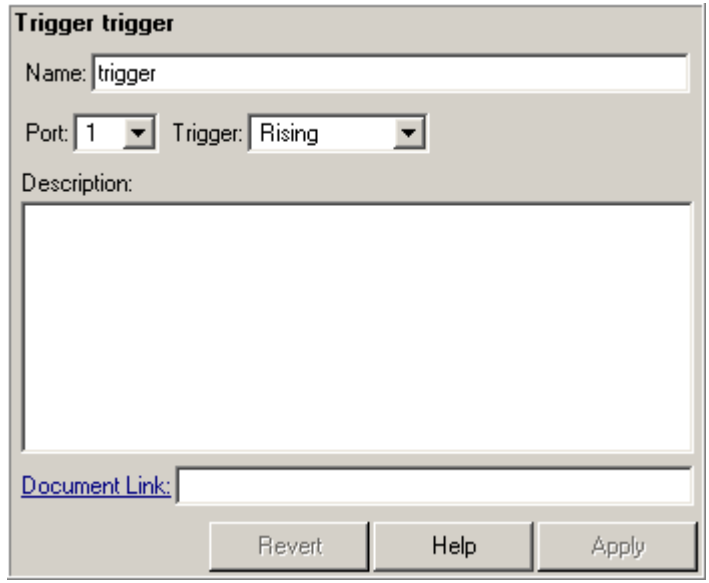
- Modify fields in the Trigger properties dialog, as described in "The Trigger Properties Dialog" on page 24-59.
- Return to the `Embedded MATLAB Function` block properties at any time by clicking the **Show Block Dialog** icon  .

The Trigger Properties Dialog. The Trigger properties dialog in the Ports and Data Manager allows you to set and modify the properties of input triggers in Embedded MATLAB Function blocks.

You can open the Trigger properties dialog using one of these methods:

- Select an input trigger in the Contents pane of the Ports and Data Manager to open the Trigger properties dialog in the Dialog pane.
- Right-click an input trigger in the Contents pane and select **Properties** from the submenu to open the Trigger properties dialog outside the Ports and Data Manager.

The Trigger properties dialog looks like this:



Setting Input Trigger Properties. You can set the following properties in the Trigger properties dialog:

Property	Description
Name	Name of the input trigger, following the same naming conventions used in MATLAB (see "Naming Variables" in the MATLAB documentation.
Port	Index of the port associated with the input trigger. The default value is 1.

Property	Description
Trigger	Type of event that triggers execution of the Embedded MATLAB Function block. You can select one of the following types of triggers: • `Rising` (default) — Triggers execution of the Embedded MATLAB Function block when the control signal rises from a negative or zero value to a positive value (or zero if the initial value is negative). • `Falling`— Triggers execution of the Embedded MATLAB Function block when the control signal falls from a positive or zero value to a negative value (or zero if the initial value is positive). • `Either`— Triggers execution of the Embedded MATLAB Function block when the control signal is either rising or falling. • `Function call`— Triggers execution of the Embedded MATLAB Function block from a block that outputs function-call events, or from an S-function
Description	Description of the input trigger.
Document link	Link to documentation for the input trigger. You can enter a Web URL address or a MATLAB command that displays documentation in a suitable format, such as an HTML file or text in the MATLAB Command Window. When you click the blue text that reads **Document link** displayed at the bottom of the **Trigger** properties dialog, the Embedded MATLAB Function block evaluates the link and displays the documentation.

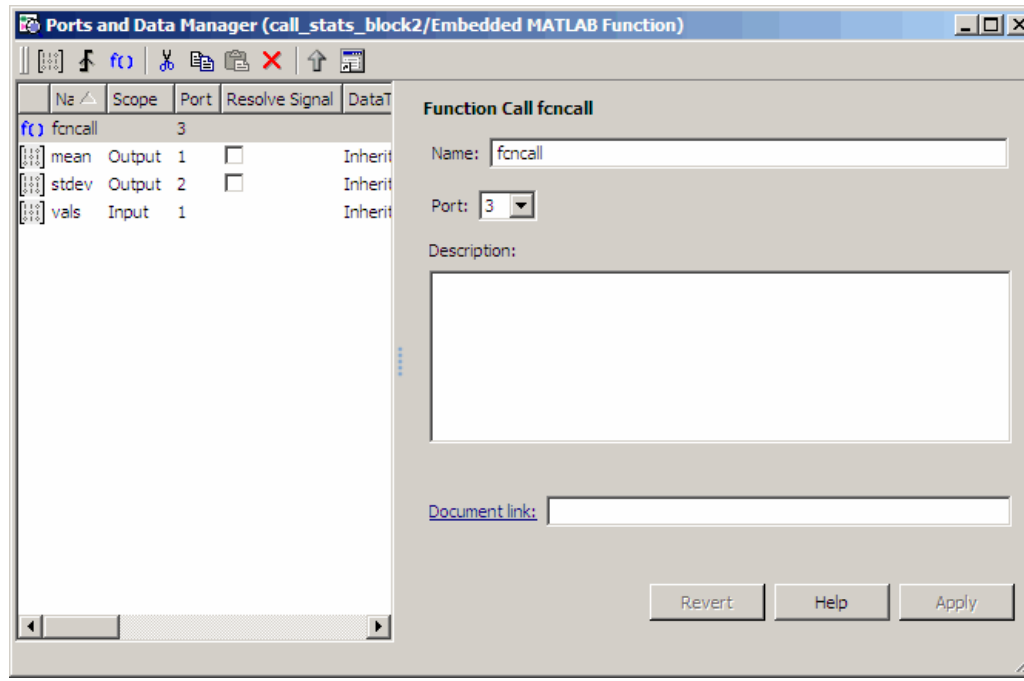
Adding Function Call Outputs to an Embedded MATLAB Function Block

A function call output is an event on the output port of an Embedded MATLAB Function block that causes a function-call subsystem in the Simulink model to execute. A function-call subsystem is a subsystem that another block can invoke directly during a simulation. See “Function-Call Subsystems” on page 6-23 in the Simulink documentation.

Use the Ports and Data Manager to add and modify function call outputs to an Embedded MATLAB Function block that is open and has focus. To add a function call output and modify its properties, follow these steps:

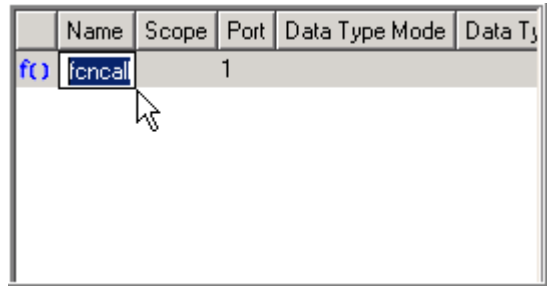
1 In the Ports and Data Manager, click the **Add Function Call Output** icon  .

The Ports and Data Manager adds a default definition of the new function call output to the Embedded MATLAB Function block and displays the Function Call properties dialog.



2 Modify properties for the new function call output, using one of the following methods:

- In the Contents pane, select the row that contains the function call output you want to modify and then edit the property of interest, as in this example:

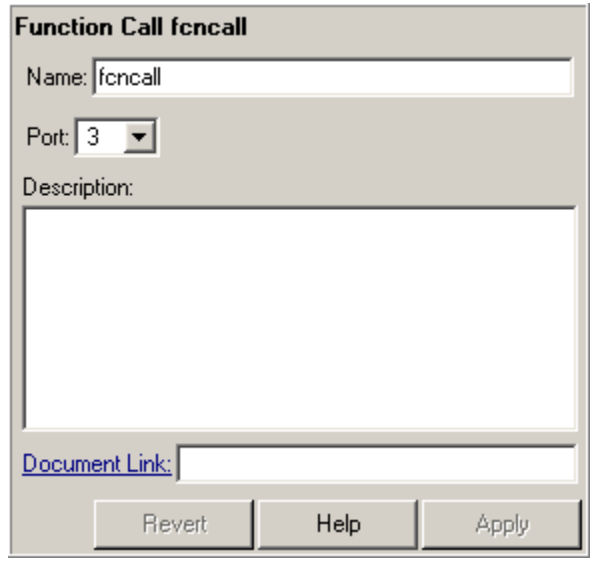


- Modify fields in the Function Call properties dialog, as described in "The Function Call Properties Dialog" on page 24-63.
- Return to the `Embedded MATLAB Function` block properties at any time by clicking the **Show Block Dialog** icon  .

The Function Call Properties Dialog. The Function Call properties dialog in the Ports and Data Manager allows you to edit the properties of function call outputs in Embedded MATLAB Function blocks.

You can open the Function Call properties dialog in the Dialog pane by selecting a function call output in the Contents pane of the Ports and Data Manager.

The Function Call properties dialog looks like this:



Setting Function Call Output Properties. You can set the following properties in the Function Call properties dialog:

Property	Description
Name	Name of the function call output, following the same naming conventions used in MATLAB (see “Naming Variables” in the MATLAB documentation.
Port	Index of the port associated with the function call output. Function call output ports are numbered sequentially after input and output ports.

Property	Description
Description	Description of the function call output.
Document link	Link to documentation for the function call output. You can enter a Web URL address or a MATLAB command that displays documentation in a suitable format, such as an HTML file or text in the MATLAB Command Window. When you click **Document link** displayed at the bottom of the **Function Call** properties dialog, the Embedded MATLAB Function block evaluates the link and displays the documentation.

Working with Compilation Reports

In this section...

About Compilation Reports

Whenever you build a Simulink model that contains Embedded MATLAB Function blocks, Simulink automatically generates a compilation report in HTML format for each Embedded MATLAB Function block in your model. The report helps you debug your Embedded MATLAB functions and verify compliance with the Embedded MATLAB subset. The report provides links to your Embedded MATLAB functions and compile-time type information for the variables and expressions in these functions. If your model fails to build, this information simplifies finding sources of error messages and aids understanding of type propagation rules.

Note There is one compilation report for each Stateflow chart, regardless of the number of Embedded MATLAB functions it contains.

Location of Compilation Reports

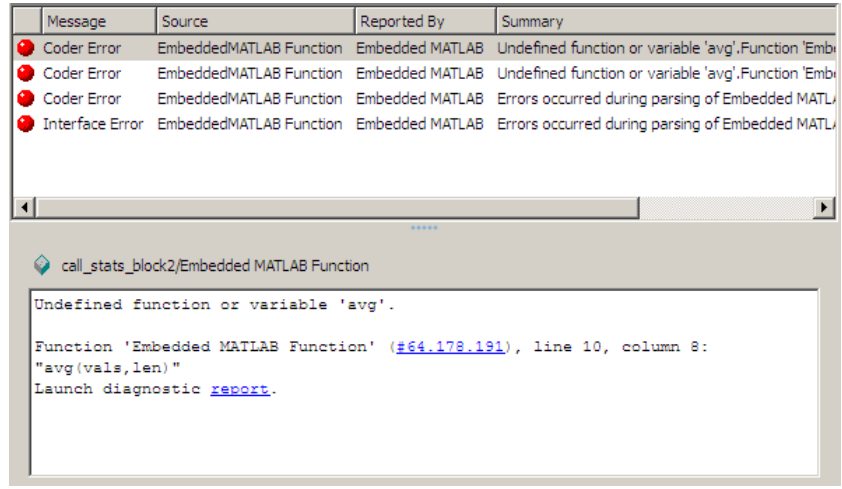
Embedded MATLAB provides a compilation report for each Embedded MATLAB Function block in the model `model_name` at the following location:

```
slprj/_sfprj/
model_name/_self/
sfun/html/
```

Opening Compilation Reports

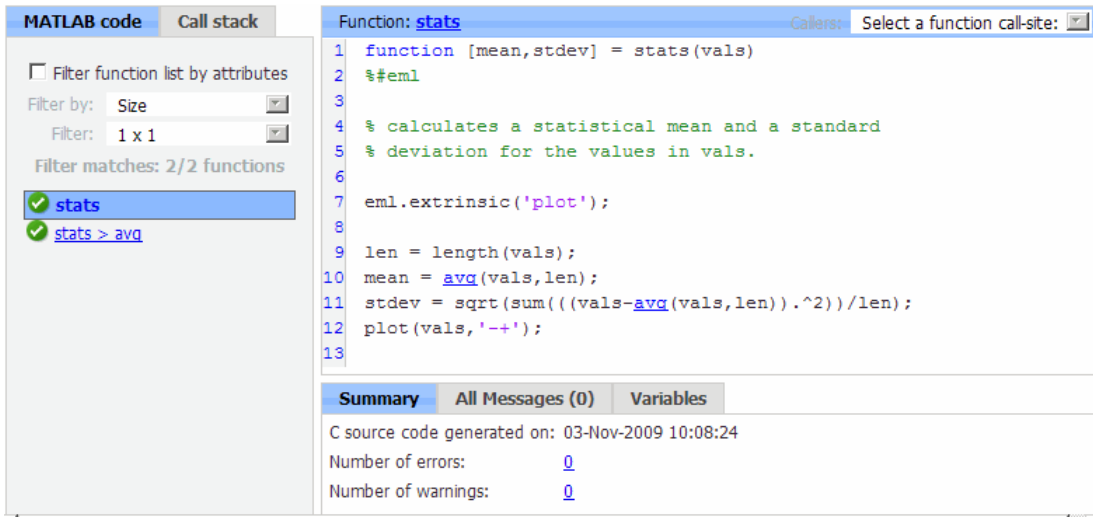
Open the compilation report using one of the following methods:

- Click the `Open compilation report`  in the Embedded MATLAB Editor.
- Select **Tools > Open Compilation Report** from the Embedded MATLAB Editor toolbar.
- Click the **`report`** link in the **Diagnostics Manager** window if compilation errors occur.



Description of Compilation Reports

When you build the Embedded MATLAB function, Embedded MATLAB generates an HTML report. The following example shows a successful compilation:



The report provides the following information, as applicable:

- MATLAB code information, including a list of all functions and their compilation status
- Call stack information, providing information on the nesting of function calls
- Summary of compilation results, including type of target and number of warnings or errors
- List of all error and warning messages
- List of all variables in your Embedded MATLAB function

Viewing Your Embedded MATLAB Function Code

To view your Embedded MATLAB function code, click the **MATLAB code** tab. The compilation report displays the MATLAB code for the function highlighted in the list on this tab.

The **MATLAB code** tab provides:

- A list of the Embedded MATLAB functions that have been compiled. The report displays icons next to each function name to indicate whether compilation was successful:
  -  Errors in function.
  -  Warnings in function.
  -  Successful compilation, no errors or warnings.
- A filter control, **Filter function list by attributes**, that you can use to sort your functions by:
  - Size
  - Complexity
  - Class

Viewing Subfunctions

The compilation report annotates the subfunction with the name of the parent function in the list of functions on the **MATLAB code** tab.

For example, if the MATLAB function `fcn1` contains the subfunction `subfcn` and `fcn2` contains the subfunction `subfcn2`, the report displays:

```
fcn1 > subfcn1
fcn2 > subfcn2
```

Viewing Specializations

If your Embedded MATLAB function calls the same function with different types of inputs, the compilation report numbers each of these **specializations** in the list of functions on the **MATLAB code** tab.

For example, if the function `fcn` calls the function `subfcn` with different types of inputs:

```
function y = fcn(u) %#eml
```

```
% Specializations
y = y + subfcn(single(u));
y = y + subfcn(double(u));
```

The compilation report numbers the specializations in the list of functions.

```
fcn > subfcn > 1
fcn > subfcn > 2
```

Viewing Call Stack Information

The compilation report provides call stack information:

- On the **Call stack** tab.
- In the list of **Callers**.

  If a function is called from more than one function, this list provides details of each call site. Otherwise, the list is disabled.

Viewing Call Stack Information on the Call Stack Tab

To view call stack information, click the **Call stack** tab. The call stack lists the functions in the order that the top-level function calls them. It also lists the subfunctions that each function calls.

Viewing Function Call Sites in the Callers List

If a function is called from more than one function, this list provides details of each call site. To navigate between call sites, select a call site from the **Callers** list. If the function is not called more than once, this list is disabled.

Viewing the Compilation Summary Information

To view a summary of the compilation results, including type of target and number of errors or warnings, click the **Summary** tab.

Viewing Error and Warning Messages

The compilation report provides information about errors and warnings. If errors occur during simulation of a Simulink model, simulation stops. If warnings occur, but no errors, simulation of the model continues.

The compilation report provides information about warnings and errors by:

- Listing all errors and warnings in the **All Messages** tab. The report lists these messages in chronological order.
- Highlighting all errors and warnings in the MATLAB code pane

Viewing Errors and Warnings in the All Messages Tab

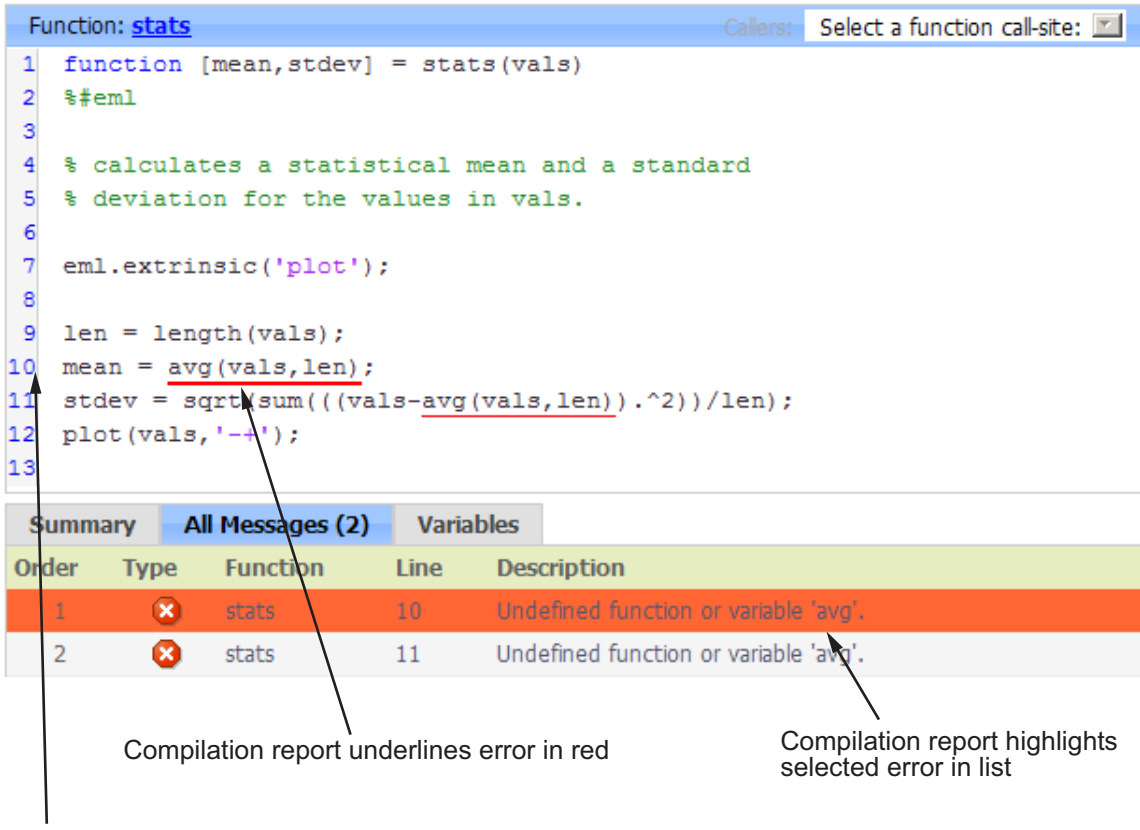
If errors or warnings occurred during compilation, click the **All Messages** tab to view a complete list of these messages. The report lists the messages in the order that the compiler detects them. It is best practice to address the first message in the list, because often subsequent errors and warnings are related to the first message. The compilation report marks messages as follows:

 Error

 Warning

To locate the offending line of code for an error or warning in the list, click the message in the list. The compilation report highlights errors in the list and MATLAB code in red and warnings in orange. Click the blue line number next to the offending line of code in the MATLAB code pane to go to the error in the source file.

Note You can only fix errors in the source file.



Viewing Error and Warning Information in Your MATLAB Code

If errors or warnings occurred during compilation, the compilation report underlines them in your MATLAB code. The report underlines errors in red and warnings in orange. To learn more about a particular error or warning, place your pointer over the underlined text.

Viewing Variables in Your MATLAB Code

The compilation report provides compile-time type information for the variables and expressions in your MATLAB code, including name, type,

size, complexity, and class. The report also provides type information for fixed-point data types including word length and fraction length. You can use this type information to find sources of error messages and to understand type propagation rules.

You can view information about the variables in your MATLAB code by:

- Viewing the list in the **Variables** tab
- Placing your pointer over the variable name in your MATLAB code

Viewing Variables in the Variables Tab

To view a list of all the variables in your MATLAB function, click the **Variables** tab. The compilation report displays a complete list of variables in the order they appear in the function selected in the **MATLAB code** tab. Clicking a variable in the list highlights all instances of that variable, and scrolls the MATLAB code pane so that the first instance is in view.

The report provides the following information about each variable, as applicable. The report only displays a column if at least one variable in the code has information in that column. For example, if the code does not contain any fixed-point data types, the report does not display the `DT mode`, `WL` or `FL` columns.

- Order
- Name
- Type
- Size
- Complexity
- Class
- DataTypeMode (DT mode) — for fixed-point data types only. For more information, see "DataTypeMode" in the Fixed-Point Toolbox documentation.
- Signed — sign information for built-in data types, signedness information for fixed-point data types
- Word length (WL) — for fixed-point data types only

- Fraction length (FL) — for fixed-point data types only

Note For more information on viewing fixed-point data types, see "Working with Fixed-Point Compilation Reports" in the Fixed-Point Toolbox documentation.

Sorting Variables in the Variables Tab. By default, the report lists the variables in the order they appear in the selected function.

You can sort the variables by clicking the column headings in the **Variables** tab. To sort the variables by multiple columns, hold down the `Shift` key when clicking the column headings.

To restore the list to the original order, click the **Order** column heading.

Viewing Structures in the Variables Tab. You can expand structures listed in the **Variables** tab to display the field properties.

Summary | All Messages (0) | Variables

Order	Variable	Type	Size	Complex	Class
1	s	Output	1 x 1	-	struct
1.1	*s.a*	Field	1 x 1	No	double
1.2	*s.b*	Field	1 x 1	No	double
2	a	Input	1 x 1	No	double
3	b	Input	1 x 1	No	double

If you sort the variables by type, size, complexity or class, a structure and its fields might not appear sequentially in the list. To restore the list to the original order, click the **Order** column heading.

Viewing Information About Variable-Size Arrays in the Variables Tab. For variable-size arrays, the size field includes information on the computed maximum size of the array. The size of each array dimension that varies is prefixed with a colon **:**.

In the following report, variable *A* is variable-size. Its maximum computed size is 1×100.

Summary | All Messages (0) | Variables

Order	Variable	Type	Size	Complex	Class
1	B	Output	1 x :100	No	double
2	A	Input	1 x :100	No	double
3	tol	Input	1 x 1	No	double
4	k	Local	1 x 1	No	double
5	i	Local	1 x 1	No	double

If Embedded MATLAB technology cannot compute the maximum size of a variable-sized array, the compilation report displays the size as `:?`.

Summary | All Messages (1) | Variables

Order	Type	Function	Line	Description
1	⊗	emldemo_uniquetol	10	Computed maximum size is not bounded. Static memory allocation requires all sizes to be bounded. The computed size is [1 x :?]. This error may be reported due to a limitation of the underlying analysis.

If you declare a variable-size array and then subsequently fix the dimensions of this array in the code, the compilation report appends `*` to the size of the variable. In the generated C code, this variable appears as a variable-size array, but the size of its dimensions do not change during execution.

Summary | All Messages (0) | Variables | Target Build Log

Order	Variable	Type	Size	Complex	Class
1	y	Output	1 x 10 *	No	double

For more information on how to use the size information for variable-sized arrays, see “Working with Variable-Size Data” in the Embedded MATLAB documentation.

Viewing Renamed Variables in the Variables Tab. If your Embedded MATLAB function reuses a variable with different size, type, or complexity, whenever possible, Embedded MATLAB creates separate uniquely named variables in the generated code. (For more information, see "Reusing the Same Variable with Different Properties" in the Embedded MATLAB documentation.) The compilation report numbers the renamed variables in the list in the **Variables** tab. When you place your pointer over a renamed variable, the compilation report highlights only the instances of this variable that share the same data type, size, and complexity.

For example, suppose your code uses the variable `t` in a for-loop to hold a scalar double, and reuses it outside the for-loop to hold a `5x5` matrix. The compilation report displays two variables, `t>1` and `t>2` in the list in the **Variables** tab.

```
6  if all(all(u))
7      % First time t is used to hold a scalar double value
8      t = mean(mean(u)) / numel(u);
9      u = u - t;
10 end
```

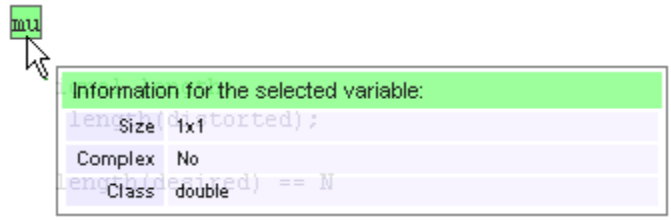
Summary | All Messages (0) | Variables

Order	Variable	Type	Size	Complex	Class
1	u	Input	5 x 5	No	double
2	t > 1	Local	5 x 5	No	double
3	t > 2	Local	1 x 1	No	double

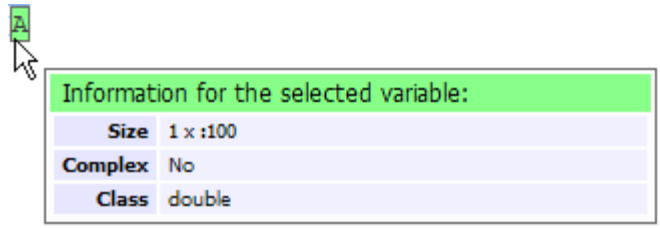
Viewing Information About Variables and Expressions in Your Embedded MATLAB Function Code

To view information about a particular variable or expression in your Embedded MATLAB function code, place your pointer over the variable name or expression in the MATLAB code pane. The compilation report highlights variables and expressions in different colors:

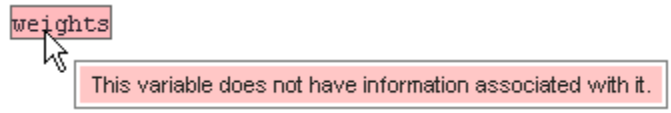
Green, when the variable has data type information at this location in the code.



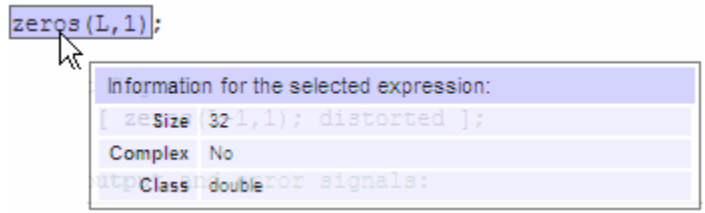
For variable-sized arrays, the size field includes information on the computed maximum size of the array. The size of each array dimension that varies is prefixed with a colon `:`. Here the array `A` is variable-sized with a maximum computed size of `1 x 100`.



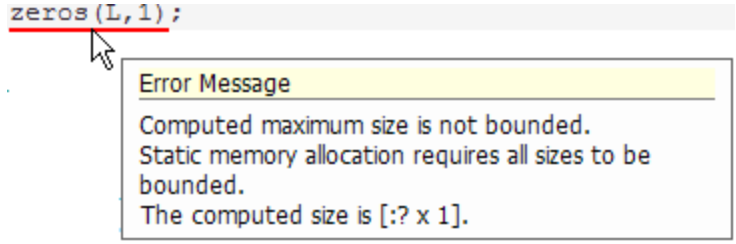
Pink, when the variable has no data type information.



Purple, information about expressions. You can also view information about expressions in your MATLAB code. Place your pointer over an expression in the MATLAB code pane. The compilation report highlights expressions in purple and provides more detailed information.



Red, when there is error information for an expression. If the Embedded MATLAB software cannot compute the maximum size of a variable-sized array, the compilation report underlines the variable name and provides error information.



Keyboard Shortcuts for the Compilation Report

You can use the following keyboard shortcuts to navigate between the different panes in the compilation report. Once you have selected a pane, use the `Tab` key to advance through data in that pane.

To select ...	Use...
MATLAB Code Tab	Ctrl+m
Call Stack Tab	Ctrl+k
MATLAB Code Pane	Ctrl+w
Summary Tab	Ctrl+s
All Messages Tab	Ctrl+a
Variables Tab	Ctrl+v

Embedded MATLAB Compilation Report Limitations

The compilation report displays information about the variables and expressions in your Embedded MATLAB code with the following limitations:

varargin and varargout

The report does not support `varargin` and `varargout` arrays.

Loop Unrolling

The report does not display the correct information for unrolled loops.

Dead Code

The report does not display information about any dead code.

Structures

The report does not provide complete information about structures.

- In the **MATLAB code** pane, the report does not provide information about all structure fields in the `struct()` constructor.
- In the **MATLAB code** pane, if a structure has a nonscalar field, and an expression accesses an element of this field, the report does not provide information for the field.

Column Headings on Variables Tab

If you scroll down through the list of variables, the report does not display the column headings on the **Variables** tab.

Multiline Matrices

In the **MATLAB code** pane, the report does not support selection of multiline matrices. It only supports selection of individual lines at a time. For example, if you place your pointer over the following matrix, you cannot select the entire matrix.

```
out1 = [1 2 3;
```

```
        4 5 6];
```

The report does support selection of single line matrices.

```
out1 = [1 2 3; 4 5 6];
```

Typing Function Arguments

In this section...

About Function Arguments

You create function arguments for an Embedded MATLAB Function block by entering them in its function header in the Embedded MATLAB Editor. When you define arguments, the Simulink software creates corresponding ports on the Embedded MATLAB Function block that you can attach to signals. You can select a *data type mode* for each argument that you define for an Embedded MATLAB Function block. Each data type mode presents its own set of options for selecting a *data type*.

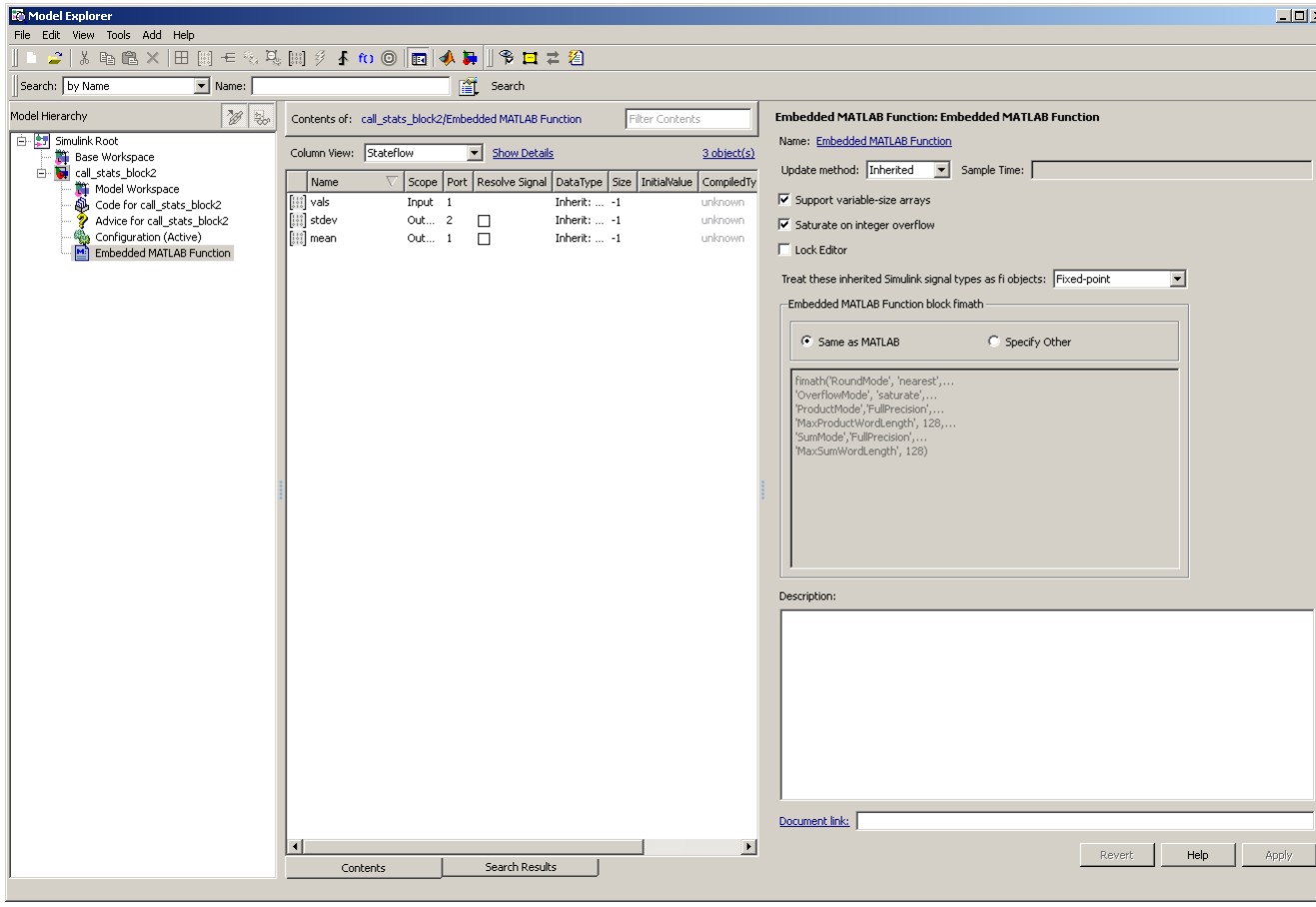
By default, the data type mode for Embedded MATLAB function arguments is **Inherited**. This means that the function argument inherits its data type from the incoming or outgoing signal. To override the default type, you first choose a data type mode and then select a data type based on the mode. The following procedure describes how to use the Model Explorer to set data types for function arguments. You can also use the Ports and Data Manager tool (see "Ports and Data Manager" on page 24-41).

Specifying Argument Types

To specify the type of an Embedded MATLAB function argument:

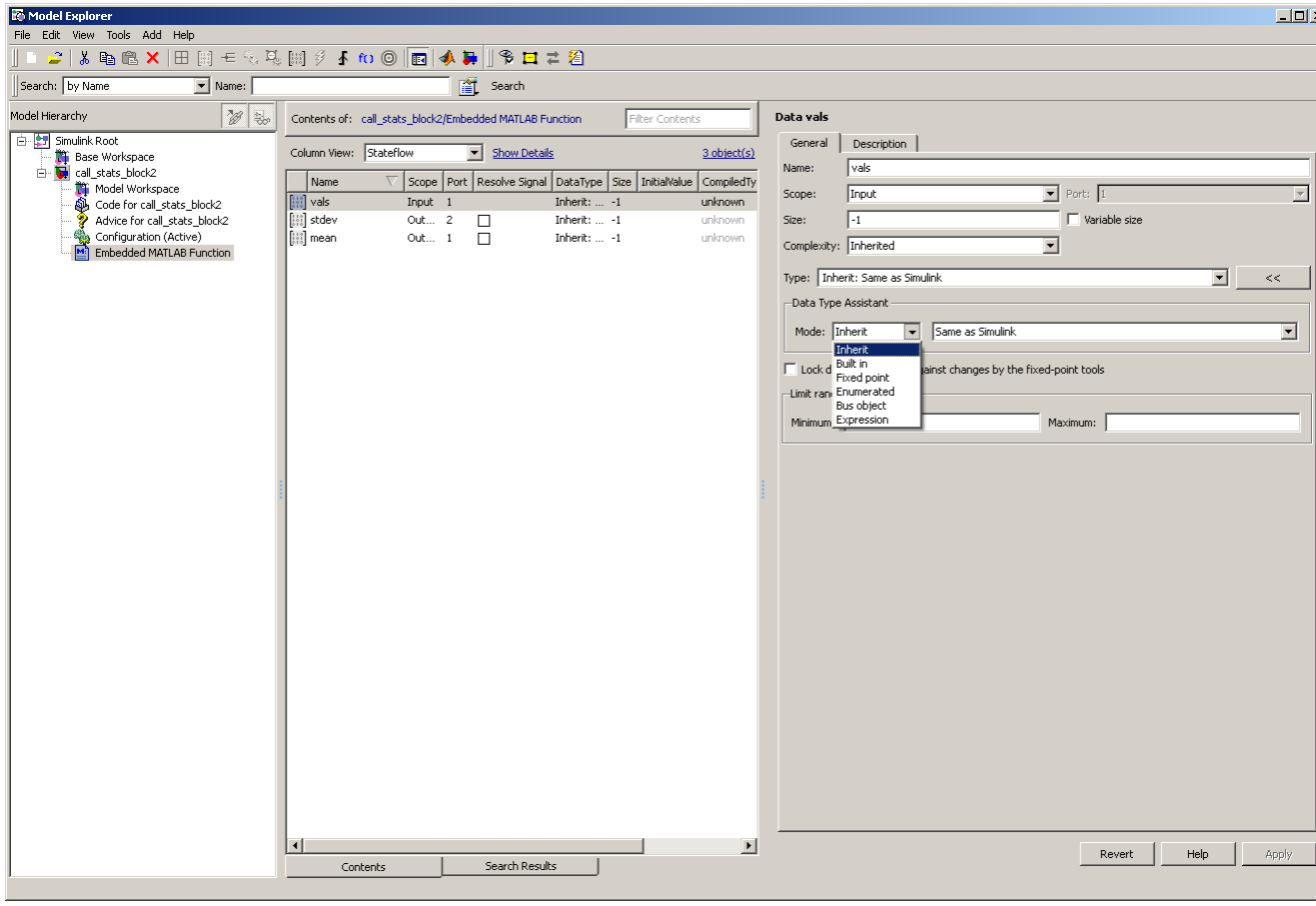
1 From the Embedded MATLAB Editor, select **Tools > Model Explorer**.

Model Explorer appears with the Embedded MATLAB Function block highlighted in the **Model Hierarchy** pane.



2 In the **Contents** pane (in the middle), click the row containing the argument of interest.

3 In the **Data** properties dialog (on the right), click the Show data type assistant button >> to display the Data Type Assistant. Then, choose an option from the **Mode** drop-down menu, as shown:



The **Data** properties dialog changes dynamically to display additional fields for specifying the data type associated with the mode.

4 Based on the mode you select, specify a desired data type:

Mode	What to Specify
`Inherit` (default)	You cannot specify a value. The data type is inherited from previously-defined data, based on the scope you selected for the Embedded MATLAB function argument: • If scope is **Input**, data type is inherited from the input signal on the designated port. • If scope is **Output**, data type is inherited from the output signal on the designated port. • If scope is **Parameter**, data type is inherited from the associated parameter, which can be defined in the Simulink masked subsystem or the MATLAB workspace. See "Inheriting Argument Data Types" on page 24-84.
`Built in`	In the **Data type** field, select from the drop-down list of supported data types, as described in "Built-In Data Types for Arguments" on page 24-86.
`Fixed point`	Specify the fixed-point data properties as described in "Specifying Simulink® Fixed Point Data Properties" on page 24-87.
`Expression`	Enter an expression that evaluates to a data type, as described in "Specifying Argument Types with Expressions" on page 24-86.
`Bus Object`	In the **Bus object** field, enter the name of a `Simulink.Bus` object to define the properties of an Embedded MATLAB structure. You must define the bus object in the base workspace. See "Working with Structures and Bus Signals" on page 24-100. **Note** You can click the **Edit** button to create or modify `Simulink.Bus` objects using the Simulink Bus Editor (see "Using the Bus Editor" on page 30-14 in the Simulink User's Guide).

Inheriting Argument Data Types

Embedded MATLAB function arguments can inherit their data types, including fixed point types, from the signals to which they are connected.

Select the argument of interest in the Contents pane of the Model Explorer or Ports and Data Manager, and set data type mode using one of these methods:

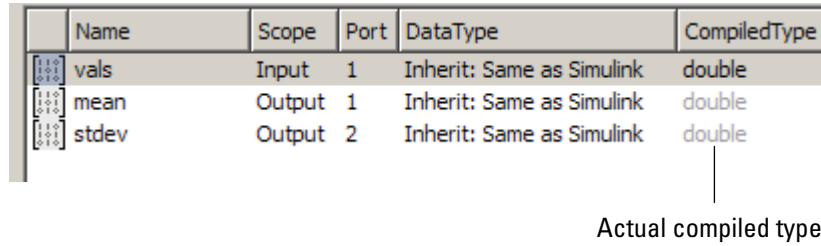
- In the **Data** properties dialog, select `Inherit:  Same as Simulink` from the **Type** drop-down menu.
- In the Contents pane, set the **Data Type** column to **Inherit: Same as Simulink**.

See "Built-In Data Types for Arguments" on page 24-86 for a list of supported data types.

Note An argument can also inherit its complexity (whether its value is a real or complex number) from the signal that is connected to it. To inherit complexity, set the **Complexity** field on the **Data** properties dialog to **Inherited**.

Once you build the model, the **Compiled Type** column of the Model Explorer or Ports and Data Manager gives the actual type used in the compiled simulation application.

In the following figure, an Embedded MATLAB Function block argument inherits its data type from an input signal of type `double`:



The inherited type of output data is inferred from diagram actions that store values in the specified output. In the preceding example, the variables `mean` and `stdev` are computed from operations with double operands, which yield results of type `double`. If the expected type matches the inferred type, inheritance is successful. In all other cases, a mismatch occurs during build time.

Note Library Embedded MATLAB Function blocks can have inherited data types, sizes, and complexities like ordinary Embedded MATLAB Function blocks. However, all instances of the library block in a given model must have inputs with the same properties.

Built-In Data Types for Arguments

When you select **Built-in** for **Data type mode**, the **Data** properties dialog displays a **Data type** field that provides a drop-down list of supported data types. You can also choose a data type from the **Data Type** column in the **Contents** pane of the Model Explorer or Ports and Data Manager. The supported data types are:

Data Type	Description
`double`	64-bit double-precision floating point
`single`	32-bit single-precision floating point
`int32`	32-bit signed integer
`int16`	16-bit signed integer
`int8`	8-bit signed integer
`uint32`	32-bit unsigned integer
`uint16`	16-bit unsigned integer
`uint8`	8-bit unsigned integer
`boolean`	Boolean (1 = `true`; 0 = `false`)

Specifying Argument Types with Expressions

You can specify the types of Embedded MATLAB function arguments as expressions in the Model Explorer or Ports and Data Manager. Follow these steps:

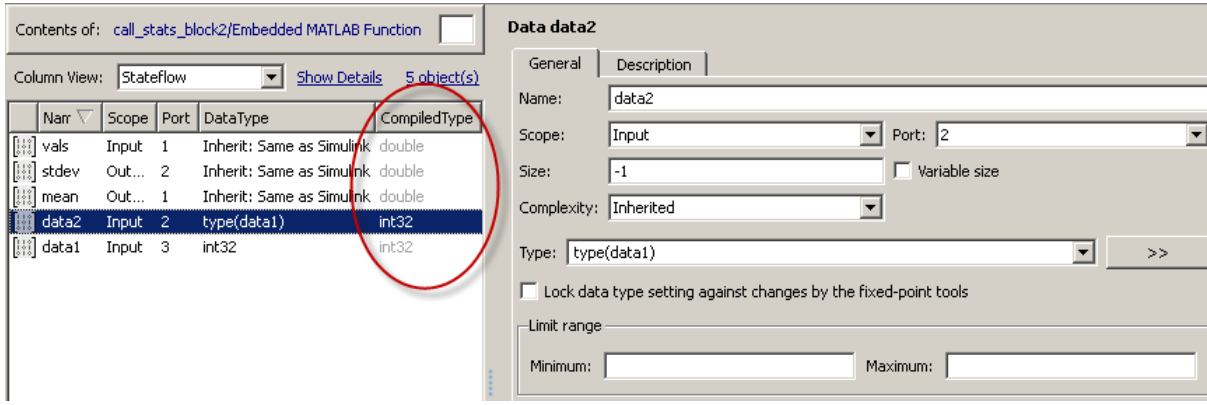
1. Select `<data type expression>` from the **Type** drop-down menu of the Data properties dialog.

2 In the **Type** field, replace "*<data type expression>*" with an expression that evaluates to a data type. The following expressions are allowed:

- Alias type from the MATLAB workspace, as described in "Creating a Data Type Alias" in the Simulink reference documentation.
- `fixdt` function to create a `Simulink.NumericType` object describing a fixed-point or floating-point data type
- `type` operator, to base the type on previously defined data

  In the following figure, the data type of input argument `data1` is **int32**. The data type of input argument `data2` is based on `data1` using the expression `type(data1)`.

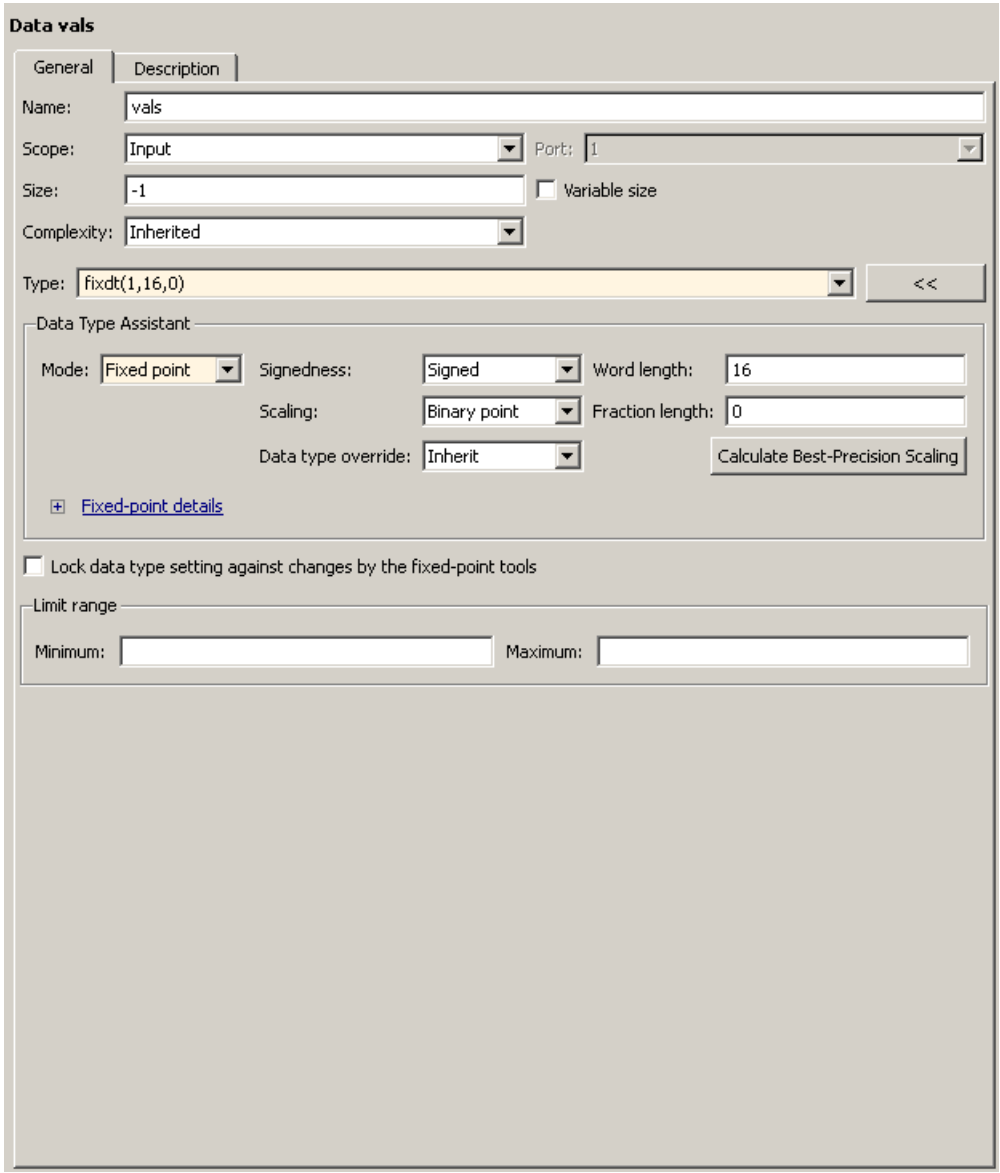
  When the model is compiled, the actual type of `data2` appears in the Compiled Type column in the **Contents** pane:



Specifying Simulink Fixed Point Data Properties

Embedded MATLAB Function blocks can represent signals and parameter values as fixed-point numbers. To simulate models that use fixed-point data in Embedded MATLAB Function blocks, you must install the Simulink Fixed Point product on your system (see "Product Overview" in the Simulink Fixed Point documentation).

When you select the `Fixed point` data type Mode, the Data Type Assistant displays fields for additional information about your fixed-point data, as in this example:

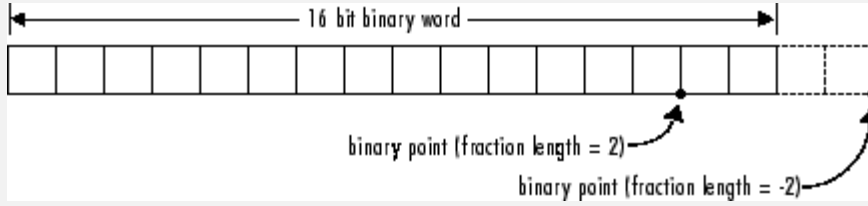


You can set the following fixed-point properties:

Signedness. Select whether you want the fixed-point data to be `Signed` or `Unsigned`. Signed data can represent positive and negative quantities. Unsigned data represents positive values only. The default is `Signed`.

Word length. Specify the size (in bits) of the word that will hold the quantized integer. Large word sizes represent large quantities with greater precision than small word sizes. Word length can be any integer between 0 and 128 bits. The default is 16.

Scaling. Specify the method for scaling your fixed point data to avoid overflow conditions and minimize quantization errors. You can select the following scaling modes:

Scaling Mode	Description
`Binary point` (default)	If you select this mode, the Data Type Assistant displays the **Fraction Length** field, specifying the binary point location. Binary points can be positive or negative integers. A positive integer moves the binary point left of the rightmost bit by that amount. For example, an entry of 2 sets the binary point in front of the second bit from the right. A negative integer moves the binary point further right of the rightmost bit by that amount, as in this example:  The default is 0.
`Slope and bias`	If you select this mode, the Data Type Assistant displays fields for entering the **Slope** and **Bias**. • Slope can be any *positive* real number. The default is 1.0. • Bias can be any real number. The default value is 0.0.

Scaling Mode	Description
	You can enter slope and bias as expressions that contain parameters defined in the MATLAB workspace.

Note You should use binary-point scaling whenever possible to simplify the implementation of fixed-point data in generated code. Operations with fixed-point data using binary-point scaling are performed with simple bit shifts and eliminate the expensive code implementations required for separate slope and bias values.

Data type override. Specify whether the data type override setting is `Inherit` (default) or `Off`.

Calculate Best-Precision Scaling. The Simulink software can automatically calculate "best-precision" values for both `Binary point` and `Slope and bias` scaling, based on the Limit range properties you specify on the **Value Attributes** tab.

To automatically calculate best precision scaling values:

1. Select the **Value Attributes** tab.
2. Specify **Minimum**, **Maximum**, or both Limit range properties.
3. Select the **General** tab.
4. Click **Calculate Best-Precision Scaling**.

The Simulink software calculates the scaling values, then displays them in either the **Fraction Length**, or **Slope** and **Bias** fields.

Note The Limit range properties do not apply to `Constant` or `Parameter` scopes. Therefore, the Simulink software cannot calculate best-precision scaling for these scopes.

Fixed-point Details. You can view the following Fixed-point details:

Fixed-point Detail	Description
Representable maximum	The maximum number that can be represented by the chosen data type, sign, word length and fraction length (or data type, sign, slope and bias).
Maximum	The maximum value specified on the Value Attributes tab.
Minimum	The minimum value specified on the Value Attributes tab.
Representable minimum	The minimum number that can be represented by the chosen data type, sign, word length and fraction length (or data type, sign, slope and bias).
Precision	The precision for the given word length and fraction length (or slope and bias).

Lock data type setting against changes by the fixed-point tools. Specify whether you want to prevent replacement of the current data type with a type chosen by the Fixed-Point Tool or Fixed-Point Advisor. The default setting allows replacement. See "Scaling" in the Simulink Fixed Point documentation for instructions on autoscaling fixed-point data.

Using Data Type Override with the Embedded MATLAB Function Block

If you set the Data Type Override mode to `Double` or `Single` in Simulink, the Embedded MATLAB function block sets the type of all inherited input signals and parameters to `fi double` or `fi single` objects respectively (see

"Using the Embedded MATLAB Function Block with Data Type Override" in the Fixed-Point Toolbox User's Guide for more information). You must check the data types of your inherited input signals and parameters and use the Ports and Data Manager (see "Ports and Data Manager" on page 24-41) to set explicit types for any inputs that should not be fixed-point. Some operations, such as `sin`, are not applicable to fixed-point objects.

Note If you do not set the correct input types explicitly, you may encounter compilation problems after setting Data Type Override.

How Do I Set Data Type Override?

To set Data Type Override, follow these steps:

1. From the Simulink Tools menu, select **Fixed-Point > Fixed-Point Tool**.

   The Fixed-Point Tool appears.

2. Set the value of the **Data type override** parameter to `Double` or `Single`.

Sizing Function Arguments

In this section...

Specifying Argument Size

To examine or specify the size of an argument, follow these steps:

1. From the Embedded MATLAB Editor, select **Model Explorer** or **Tools > Edit Data/Ports**.
2. In the **Contents** pane, click the row that contains the data argument.
3. Enter the size of the argument in one of two places:
   - Size field of the Data properties dialog, located in the **Dialog** pane
   - Size column in the row that contains the data argument, located in the **Contents** pane

---

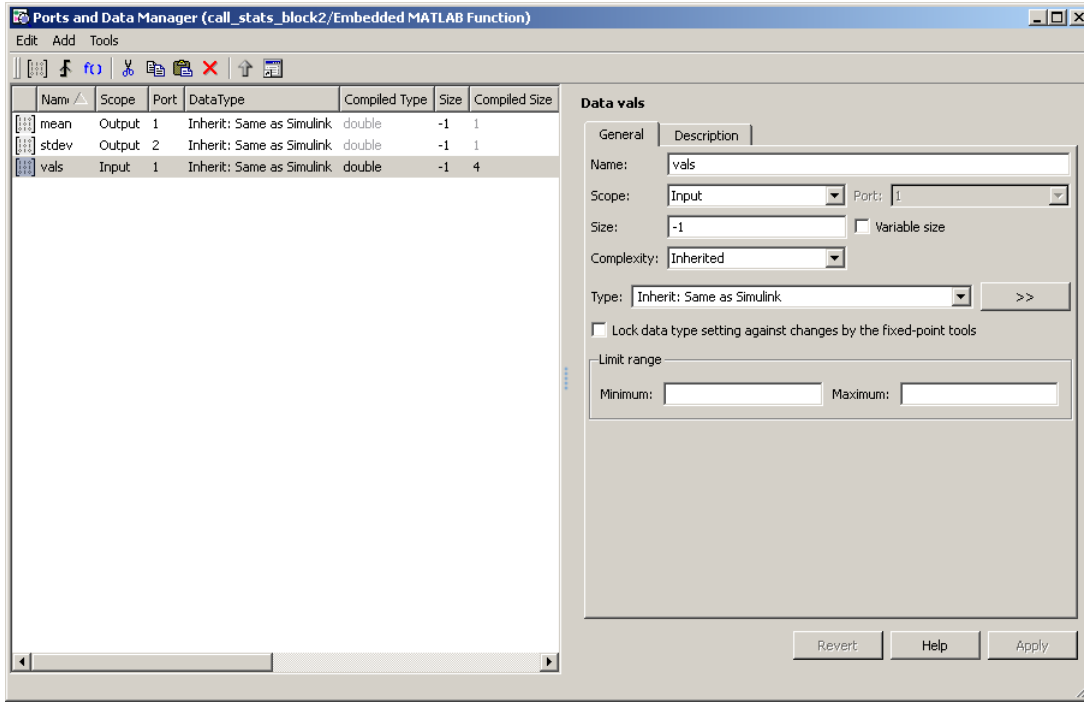
Note The default value is `-1`, indicating that size is inherited, as described in "Inheriting Argument Sizes from Simulink" on page 24-93.

Inheriting Argument Sizes from Simulink

Size defaults to `-1`, which means that the data argument inherits its size from Simulink based on its scope:

For Scope	Inherits Size
`Input`	From the Simulink input signal connected to the argument.
`Output`	From the Simulink output signal connected to the argument.
`Parameter`	From the Simulink or MATLAB parameter to which it is bound. See “Parameter Arguments in Embedded MATLAB Functions” on page 24-97.

After you compile the model, the **Compiled Size** column in the **Contents** pane displays the actual size used in the compiled simulation application. Here the compiled size for `vals` is `4`.



The size of an output argument is the size of the value that is assigned to it. If the expected size in the Simulink model does not match, a mismatch error occurs during compilation of the model.

Note No arguments with inherited sizes are allowed for Embedded MATLAB Function blocks in a library.

Specifying Argument Sizes with Expressions

The size of a data argument can be a scalar value or a MATLAB vector of values.

To specify size as a scalar, set the **Size** field to 1 or leave it blank. To specify **Size** as a vector, enter an array of up to two dimensions in `[row column]` format where

- The number of dimensions equals the length of the vector.
- The size of each dimension corresponds to the value of each element of the vector.

For example, a value of `[2 4]` defines a 2-by-4 matrix. To define a row vector of size 5, set the **Size** field to `[1 5]`. To define a column vector of size 6, set the **Size** field to `[6 1]` or just `6`. You can enter a MATLAB expression for each `[row column]` element in the **Size** field. Each expression can use one or more of the following elements:

- Numeric constants
- Arithmetic operators, restricted to `+`, `-`, `*`, and `/`
- Parameters defined in the MATLAB Workspace or the parent Simulink masked subsystem
- Calls to the MATLAB functions `min`, `max`, and `size`

The following examples are valid expressions for **Size**:

```
k+1
size(x)
min(size(y),k)
```

In these examples, `k`, `x`, and `y` are variables of scope `Parameter`.

Once you build the model, the **Compiled Size** column in the **Contents** pane displays the actual size used in the compiled simulation application.

Parameter Arguments in Embedded MATLAB Functions

Parameter arguments for Embedded MATLAB Function blocks do not take their values from signals in the Simulink model. Instead, their values come from parameters defined in a parent Simulink masked subsystem or variables defined in the MATLAB base workspace. Using parameters allows you to pass read-only constants in the Simulink model to the Embedded MATLAB Function block.

Use the following procedure to add a parameter argument to a function for an Embedded MATLAB Function block.

1. In the Embedded MATLAB Editor, add an argument to the function header of the Embedded MATLAB Function block.

   The name of the argument must be identical to the name of the masked subsystem parameter or MATLAB variable that you want to pass to the Embedded MATLAB Function block. For information on declaring parameters for masked subsystems, see "Simulink Mask Editor".

2. Bring focus to the Embedded MATLAB Function block.

   The new argument appears as an input port in the Simulink diagram.

3. In the Embedded MATLAB Editor, select **Model Explorer** or **Tools > Edit Data/Ports**.

4. In the **Contents** pane, click the row that contains the new argument.

5. Set **Scope** to `Parameter`.

6. Examine the Embedded MATLAB Function block.

   The input port no longer appears for the parameter argument.

Note Parameter arguments appear as arguments in the function header of the Embedded MATLAB Function block to maintain MATLAB consistency. This lets you test functions in an Embedded MATLAB Function block by copying and pasting them to MATLAB.

Resolving Signal Objects for Output Data

In this section...

Implicit Signal Resolution

Embedded MATLAB Function blocks participate in signal resolution with Simulink signal objects. By default, output data from Embedded MATLAB Function blocks become associated with Simulink signal objects of the same name during a process called *implicit signal resolution*, as described in Simulink.Signal in the Reference documentation.

By default, implicit signal resolution generates a warning when you update the chart in the Simulink model. The following sections show you how to manage implicit signal resolution at various levels of the model hierarchy. See "Resolving Symbols" on page 3-75 and "Explicit and Implicit Symbol Resolution" on page 3-78 for more information.

Eliminating Warnings for Implicit Signal Resolution in the Model

To enable implicit signal resolution for all signals in a model, but eliminate the attendant warnings, follow these steps:

1 In the Simulink Model Editor, select **Simulation > Configuration Parameters**.

The Configuration Parameters dialog appears.

2 In the left pane of the Configuration Parameters dialog, under Diagnostics, select **Data Validity**.

   Data Validity configuration parameters appear in the right pane.

3 In the Signal resolution field, select **Explicit and implicit**.

Disabling Implicit Signal Resolution for an Embedded MATLAB Function Block

To disable implicit signal resolution for an Embedded MATLAB Function block in your model, follow these steps:

1 Right-click the Embedded MATLAB Function block and select **Subsystem Parameters** in the context menu.

   The Block Parameters dialog opens.

2 In the Permit hierarchical resolution field, select **ExplicitOnly** or **None**, and click **OK**.

Forcing Explicit Signal Resolution for an Output Data Signal

To force signal resolution for an output signal in an Embedded MATLAB Function block, follow these steps:

1 In the Simulink model, right-click the signal line connected to the output that you want to resolve and select **Signal Properties** from the context menu.

2 In the Signal Properties dialog, enter a name for the signal that corresponds to the signal object.

3 Select the **Signal name must resolve to Simulink signal object** check box and click **OK**.

Working with Structures and Bus Signals

In this section...

About Structures in Embedded MATLAB Function Blocks

Embedded MATLAB Function blocks support MATLAB structures (see "Structures" in the MATLAB getting started guide). In Embedded MATLAB Function blocks, you can define structure data as inputs or outputs that interact with bus signals. Embedded MATLAB Function blocks also support arrays of buses (for more information, see "Combining Buses into an Array of Buses" on page 30-67). You can also define structures inside Embedded MATLAB functions that are not part of Embedded MATLAB Function blocks (see "Working with Structures" in the Embedded MATLAB documentation).

The following table summarizes how to create different types of structures in Embedded MATLAB Function blocks:

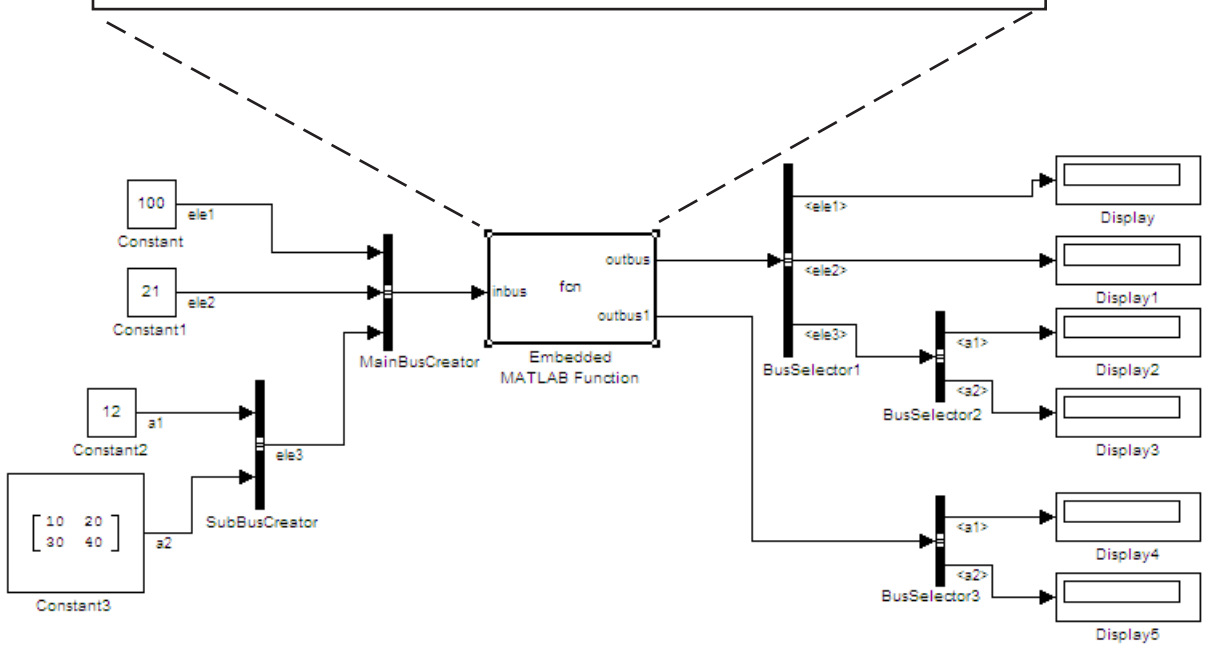
Scope	How to Create	Details
Input	Create structure data with scope of `Input`.	You can create structure data as inputs or outputs in the top-level Embedded MATLAB function for interfacing to other environments. See "Workflow for Creating Structures in Embedded MATLAB Function Blocks" on page 24-105.
Output	Create structure data with scope of `Output`.	
Local	Create a local variable implicitly in an Embedded MATLAB function.	See "Defining Local Structure Variables" in the Embedded MATLAB documentation.
Persistent	Declare a variable to be persistent in an Embedded MATLAB function.	See "Making Structures Persistent" in the Embedded MATLAB documentation.
Parameter	Create structure data with scope of `Parameter`	See "Working with Structure Parameters in Embedded MATLAB Function Blocks" on page 24-109.

Structures in Embedded MATLAB Function blocks can contain fields of any type and size, including muxed signals, buses and arrays of structures, as described in "Elements of Structures in the Embedded MATLAB Subset" in the Embedded MATLAB documentation.

Example of Structures in an Embedded MATLAB Function Block

The following example shows how to use structures in an Embedded MATLAB Function block:

```
function [outbus, outbus1] = fcn(inbus)
%#eml

substruct.a1 = inbus.ele3.a1;
substruct.a2 = int8([1 2;3 4]);

mystruct = struct('ele1',20.5, 'ele2', single(100), 'ele3', substruct);

outbus = mystruct;
outbus.ele3.a2 = 2*(substruct.a2);

outbus1 = inbus.ele3;
```



In this model, an Embedded MATLAB Function block receives a bus signal using the structure `inbus` at input port 1 and outputs two bus signals from the structures `outbus` at output port 1 and `outbus1` at output port 2. The input signal comes from the Bus Creator block `MainBusCreator`, which bundles signals `ele1`, `ele2`, and `ele3`. The signal `ele3` is the output of another Bus Creator block `SubBusCreator`, which bundles the signals `a1` and

`a2`. The structure `outbus` connects to a Bus Selector block `BusSelector1`; the structure `outbus1` connects to another Bus Selector block `BusSelector3`.

Like other outputs in the Embedded MATLAB subset, structure outputs must be initialized. The Embedded MATLAB function in this example implicitly defines a local structure variable `mystruct` using the `struct` function, and uses this local structure variable to initialize the value of the first output `outbus`. It initializes the second output `outbus1` to the value of field `ele3` of structure `inbus`.

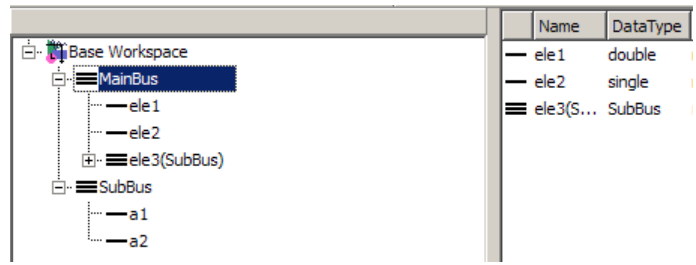
Structure Definitions in Example

Here are the definitions of the structures in the Embedded MATLAB Function block in the example, as they appear in the Ports and Data Manager:

Name	Scope	Port	Resolve Signal	DataType	Compiled Type
inbus	Input	1		Inherit: Same as Simulink	MainBus
outbus	Output	1	☐	Bus: MainBus	MainBus
outbus1	Output	2	☐	Bus: SubBus	SubBus

Bus Objects Define Structure Inputs and Outputs

Each structure input and output must be defined by a `Simulink.Bus` object in the base workspace (see "Workflow for Creating Structures in Embedded MATLAB Function Blocks" on page 24-105). This means that the structure shares the same properties as the bus object, including number, name, type, and sequence of fields. In this example, the following bus objects define the structure inputs and outputs:



The Simulink.Bus object MainBus defines structure input inbus and structure output outbus. The Simulink.Bus object SubBus defines structure output outbus1. Based on these definitions, inbus and outbus have the same properties as MainBus and, therefore, reference their fields by the same names as the fields in MainBus, using dot notation (see "Indexing Substructures and Fields" on page 24-107). Similarly, outbus1 references its fields by the same names as the fields in SubBus. Here are the field references for each structure in this example:

Structure	First Field	Second Field	Third Field
inbus	inbus.ele1	inbus.ele2	inbus.ele3
outbus	outbus.ele1	outbus.ele2	outbus.ele3
outbus1	outbus1.a1	outbus1.a2	—

To learn how to define structures in Embedded MATLAB Function blocks, see "Workflow for Creating Structures in Embedded MATLAB Function Blocks" on page 24-105.

How Structure Inputs and Outputs Interface with Bus Signals

Buses in a Simulink model appear inside the Embedded MATLAB Function block as structures; structure outputs from the Embedded MATLAB Function block appear as buses in Simulink models. When you create structure inputs, the Embedded MATLAB Function block determines the type, size, and complexity of the structure from the input signal. When you create structure outputs, you must define their type, size, and complexity in the Embedded MATLAB function.

You connect structure inputs and outputs from Embedded MATLAB Function blocks to any bus signal, including:

- Blocks that output bus signals — such as Bus Creator blocks
- Blocks that accept bus signals as input — such as Bus Selector and Gain blocks
- S-Function blocks

- Other Embedded MATLAB Function blocks

Working with Virtual and Nonvirtual Buses

Embedded MATLAB Function blocks supports nonvirtual buses only (see "Virtual and Nonvirtual Buses" on page 30-48 in the Simulink User's Guide). When models that contain Embedded MATLAB function inputs and outputs are built, hidden converter blocks are used to convert bus signals for use with Embedded MATLAB, as follows:

- Converts incoming virtual bus signals to nonvirtual buses for Embedded MATLAB structure inputs
- Converts outgoing nonvirtual bus signals from Embedded MATLAB to virtual bus signals

Rules for Defining Structures in Embedded MATLAB Function Blocks

Follow these rules when defining structures in Embedded MATLAB Function blocks:

- For each structure input or output in an Embedded MATLAB Function block, you must define a `Simulink.Bus` object in the base workspace to specify its type. For more information, see Simulink.Bus.
- Embedded MATLAB Function blocks support nonvirtual buses only (see "Working with Virtual and Nonvirtual Buses" on page 24-105).

Workflow for Creating Structures in Embedded MATLAB Function Blocks

Here is the workflow for creating a structure in Embedded MATLAB:

1. Decide on the type (or scope) of the structure (see "About Structures in Embedded MATLAB Function Blocks" on page 24-100).
2. Based on the scope, follow these guidelines for creating the structure:

For Structure Scope:	Follow These Steps:
Input	**1** Create a `Simulink.Bus` object in the base workspace to define the structure input. **2** Add data to the Embedded MATLAB Function block, as described in "Adding Data to an Embedded MATLAB Function Block" on page 24-48. The data should have the following properties • **Scope** = `Input` • **Type** = `Bus: <object name>` For `<object name>`, enter the name of the `Simulink.Bus` object that defines the structure input See "Rules for Defining Structures in Embedded MATLAB Function Blocks" on page 24-105.
Output	**1** Create a `Simulink.Bus` object in the base workspace to define the structure output. **2** Add data to the Embedded MATLAB Function block with the following properties: • **Scope** = `Output` • **Type** = `Bus: <object name>` For `<object name>`, enter the name of the `Simulink.Bus` object that defines the structure output **3** Define and initialize the output structure implicitly as a variable in the Embedded MATLAB function, as described in "Defining Outputs as Structures" in the Embedded MATLAB documentation. **4** Make sure the number, type, and size of fields in the output structure variable definition match the properties of the `Simulink.Bus` object.
Local	Define the structure implicitly as a local variable in the Embedded MATLAB function, as described in "Defining Local Structure Variables" in the Embedded MATLAB documentation. By default, local variables in Embedded MATLAB are temporary.

For Structure Scope:	Follow These Steps:
Persistent	Define the structure implicitly as a persistent variable in the Embedded MATLAB function, as described in "Making Structures Persistent" in the Embedded MATLAB documentation.
Parameter	**1** Create a structure variable in the base workspace. **2** Add data to the Embedded MATLAB Function block with the following properties: • **Name** = same name as the structure variable you created in step 1. • **Scope** = `Parameter` See "Working with Structure Parameters in Embedded MATLAB Function Blocks" on page 24-109.

Indexing Substructures and Fields

As in MATLAB, you index substructures and fields of Embedded MATLAB structures by using dot notation. Unlike MATLAB, you must reference field values individually (see "Limitations with Structures" in the Embedded MATLAB documentation).

For example, in the model described in "Example of Structures in an Embedded MATLAB Function Block" on page 24-101, the Embedded MATLAB function uses dot notation to index fields and substructures:

```
function [outbus, outbus1] = fcn(inbus)

substruct.a1 = inbus.ele3.a1;
substruct.a2 = int8([1 2;3 4]);

mystruct = struct('ele1',20.5,'ele2',single(100),
                  'ele3',substruct);

outbus = mystruct;
outbus.ele3.a2 = 2*(substruct.a2);

outbus1 = inbus.ele3;
```

The following table shows how Embedded MATLAB resolves symbols in dot notation for indexing elements of the structures in this example:

Dot Notation	Symbol Resolution
`substruct.a1`	Field `a1` of local structure `substruct`
`inbus.ele3.a1`	Value of field `a1` of field `ele3`, a substructure of structure input`inbus`
`inbus.ele3.a2(1,1)`	Value in row 1, column 1 of field `a2` of field `ele3`, a substructure of structure input `inbus`

Assigning Values to Structures and Fields

You can assign values to any Embedded MATLAB structure, substructure, or field. Here are the guidelines:

Operation	Conditions
Assign one structure to another structure	You must define each structure with the same number, type, and size of fields, either as `Simulink.Bus` objects in the base workspace or locally as implicit structure declarations (see "Workflow for Creating Structures in Embedded MATLAB Function Blocks" on page 24-105).
Assign one structure to a substructure of a different structure and vice versa	You must define the structure with the same number, type, and size of fields as the substructure, either as `Simulink.Bus` objects in the base workspace or locally as implicit structure declarations.
Assign an element of one structure to an element of another structure	The elements must have the same type and size.

For example, the following table presents valid and invalid structure assignments based on the specifications for the model described in "Example of Structures in an Embedded MATLAB Function Block" on page 24-101:

Assignment	Valid or Invalid?	Rationale
`outbus = mystruct;`	Valid	Both `outbus` and `mystruct` have the same number, type, and size of fields. The structure `outbus` is defined by the `Simulink.Bus` object `MainBus` and `mystruct` is defined locally to match the field properties of `MainBus`.
`outbus = inbus;`	Valid	Both `outbus` and `inbus` are defined by the same `Simulink.Bus` object, `MainBus`.
`outbus1 = inbus.ele3;`	Valid	Both `outbus1` and `inbus.ele3` have the same type and size because each is defined by the `Simulink.Bus` object `SubBus`.
`outbus1 = inbus;`	Invalid	The structure `outbus1` is defined by a different `Simulink.Bus` object than the structure `inbus`.

Working with Structure Parameters in Embedded MATLAB Function Blocks

You can define structure parameters in Embedded MATLAB Function blocks.

Defining Structure Parameters

To define structure parameters in Embedded MATLAB Function blocks, follow these steps:

1. Define and initialize a structure variable

   A common method is to create a structure in the base workspace. For other methods, see Chapter 19, "Working with Block Parameters".

2. In the Ports and Data Manager or Model Explorer, add data in the Embedded MATLAB Function block with the following properties:

Property	What to Specify
Name	Enter same name as the structure variable you defined in the base workspace
Scope	Select `Parameter`
Tunable	Leave checked if you want to change (tune) the value of the parameter during simulation; otherwise, clear to make the parameter non-tunable and preserve the initial value during simulation
Type	Select `Inherit: Same as Simulink`

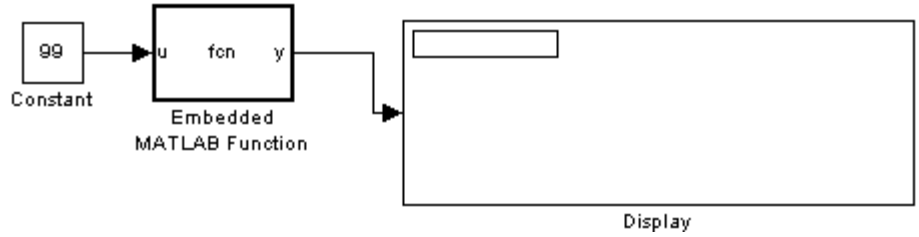
3 Click **Apply**.

FIMATH Properties of Non-Tunable Structure Parameters

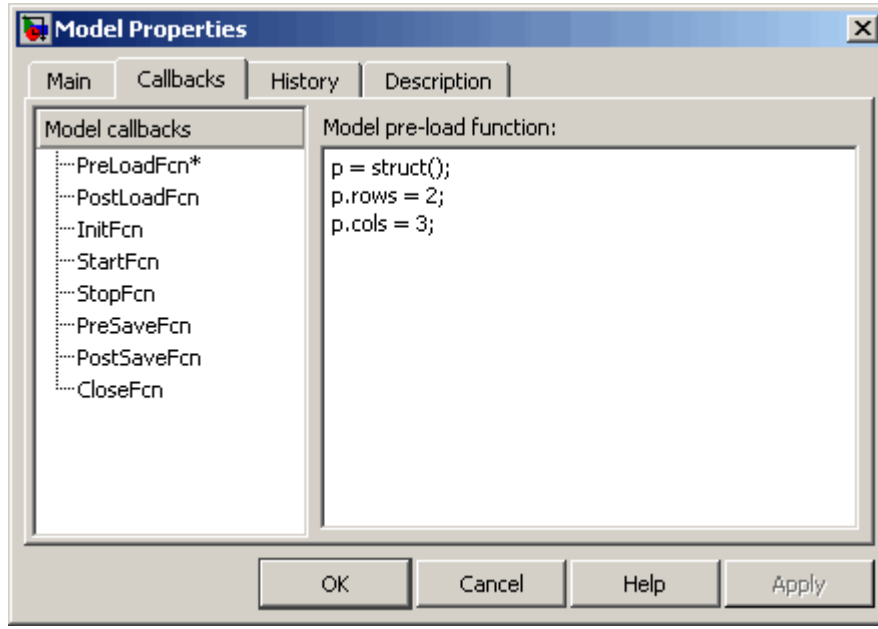
FIMATH properties for non-tunable structure parameters containing fixed-point values are based on the initial values of the structure. They do *not* come from the FIMATH properties specified for fixed-point input signals to the parent Embedded MATLAB Function block. (These FIMATH properties appear in the properties dialog box for Embedded MATLAB Function blocks.)

Example: Using a Non-Tunable Structure Parameter to Initialize a Matrix

The following simple example uses a non-tunable structure parameter input to initialize a matrix output. The model looks like this:



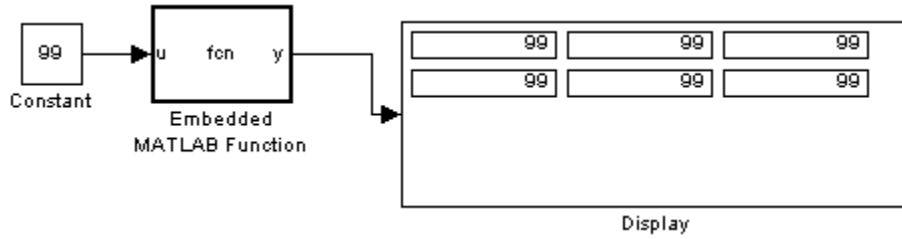
This model defines a structure variable `p` in its pre-load callback function, as follows:



The structure `p` has two fields, `rows` and `cols`, which specify the dimensions of a matrix. The Embedded MATLAB Function block uses a constant input `u` to initialize the matrix output `y`. Here is the code:

```
function y = fcn(u, p)
y = zeros(p.rows,p.cols) + u;
```

Running the model initializes each element of the 2-by-3 matrix `y` to 99, the value of `u`:



Limitations of Structures and Buses in Embedded MATLAB Function Blocks

- Structures in Embedded MATLAB Function blocks support a subset of the operations available for MATLAB structures (see "Limitations with Structures" in the Embedded MATLAB documentation).
- You cannot use variable-size data with arrays of buses (see "Array of Buses Limitations" on page 30-71).

Using Variable-Size Data in Embedded MATLAB Function Blocks

In this section...

What Is Variable-Size Data?

Variable-size data is data whose size may change at run time. By contrast, fixed-size data is data whose size is known and locked at compile time, and therefore cannot change at run time.

How Embedded MATLAB Function Blocks Implement Variable-Size Data

You can define variable-size arrays and matrices as inputs, outputs, and local data in Embedded MATLAB Function blocks. However, the block must be able to determine the upper bounds of variable-size data at compile time.

For more information about working with variable-size data in the Embedded MATLAB subset, see "Working with Variable-Size Data" in the Embedded MATLAB user guide documentation. For more information about using variable-size data in Simulink, see Chapter 31, "Working with Variable-Size Signals" in the Simulink user guide documentation.

Enabling Support for Variable-Size Data

Support for variable-size data is enabled by default for Embedded MATLAB Function blocks. To modify this property for individual blocks:

1 In the Embedded MATLAB Editor, select **Tools > Edit Data/Ports**

   The Ports and Data Manager dialog box opens.

2 Select or clear the check box **Support variable-size arrays**.

Declaring Variable-Size Inputs and Outputs

1 In the Embedded MATLAB Editor, select **Tools > Edit Data/Ports**

   The Ports and Data Manager dialog box opens.

2 Click the Add Data icon:

3 Select the **Variable size** check box.

4 Set **Scope** as either `Input` or `Output`.

5 Enter size:

For:	What to Specify
Input	Enter `-1` to inherit size from Simulink or specify the explicit size and upper bound. For example, enter `[2 4]` to specify a 2-D matrix where the upper bounds are 2 for the first dimension and 4 for the second.
Output	Specify the explicit size and upper bound.

Declaring Variable-Size Data Locally

Use the function `eml.varsize` to declare variable-size data locally, as described in "Declaring Variable-Size Data in Embedded MATLAB Code" in the Embedded MATLAB user guide documentation.

Simple Example: Defining and Using Variable-Size Data in Embedded MATLAB Function Blocks

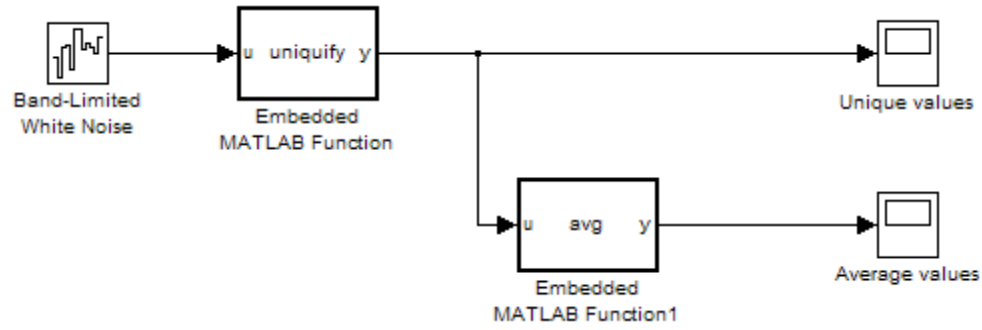
About the Example

The following example appears throughout this section to illustrate how Embedded MATLAB Function blocks exchange variable-size data with other Simulink blocks. The model uses a variable-size vector to store the values of a white noise signal. The size of the vector may vary at run time as the signal values get pruned by functions that:

- Filter out signal values that are not unique within a specified tolerance of each other
- Average every two signal values and output only the resulting means

Simulink Model

The model that generates and filters the white noise signal looks like this:

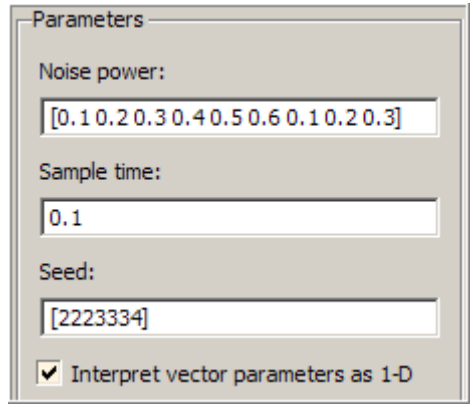


The model contains the following blocks:

Simulink Block	Description
Band-Limited White Noise	Generates a set of normally distributed random values as the source of the white noise signal.
Embedded MATLAB Function `uniquify`	Filters out signal values that are not unique to within a specified tolerance of each other.
Embedded MATLAB Function `avg`	Outputs the average of a specified number of unique signal values.
Unique values	Scope that displays the unique signal values output from the `uniquify` function.
Average values	Scope that displays the average signal values output from the `avg` function.

Source Signal

The band-limited white noise signal has these properties:



The size of the noise power value defines the size of the matrix that holds the signal values — in this case, a 1-by-9 vector of double values.

Embedded MATLAB Function Block: uniquify

This block filters out signal values that are not within a tolerance of 0.2 of each other. Here is the code:

```
function y = uniquify(u) %#eml
y = uniquetol(u,0.2);
```

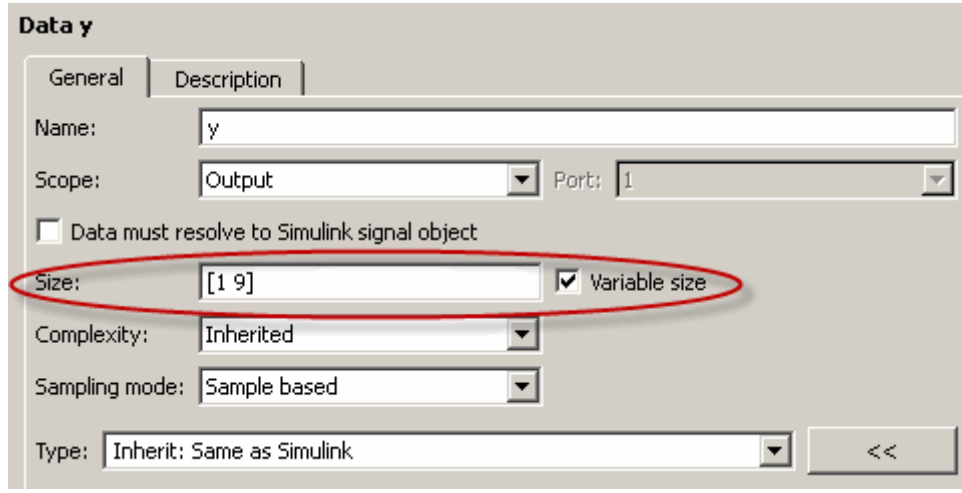
The `uniquify` function calls an external Embedded MATLAB function `uniquetol` to filter the signal values. `uniquify` passes the 1-by-9 vector of white noise signal values as the first argument and the tolerance value as the second argument. Here is the code for `uniquetol`:

```
function B = uniquetol(A,tol) %#eml

A = sort(A);
eml.varsize('B',[1 100]);
B = A(1);
k = 1;
for i = 2:length(A)
    if abs(A(k) - A(i)) > tol
        B = [B A(i)];
        k = i;
    end
end
```

`uniquetol` returns the filtered values of `A` in an output vector `B` so that `abs(B(i) - B(j)) > tol` for all `i` and `j`. Every time Simulink samples the Band-Limited White Noise block, it generates a different set of random values for `A`. As a result, `uniquetol` may produce a different number of output signals in `B` each time it is called. To allow `B` to accommodate a variable number of elements, `uniquetol` declares it as variable-size data with an explicit upper bound:

```
eml.varsize('B',[1 100]);
```

In this statement, `eml.varsize` declares `B` as a vector whose first dimension is fixed at 1 and whose second dimension can grow to a maximum size of 100. Accordingly, output `y` of the `uniquify` block must also be variable sized so it can pass the values returned from `uniquetol` to the **Unique values** scope. Here are the properties of `y`:



For variable-size outputs, you must specify an explicit size and upper bound.

Embedded MATLAB Function Block: avg

This block averages signal values filtered by the `uniquify` block as follows:

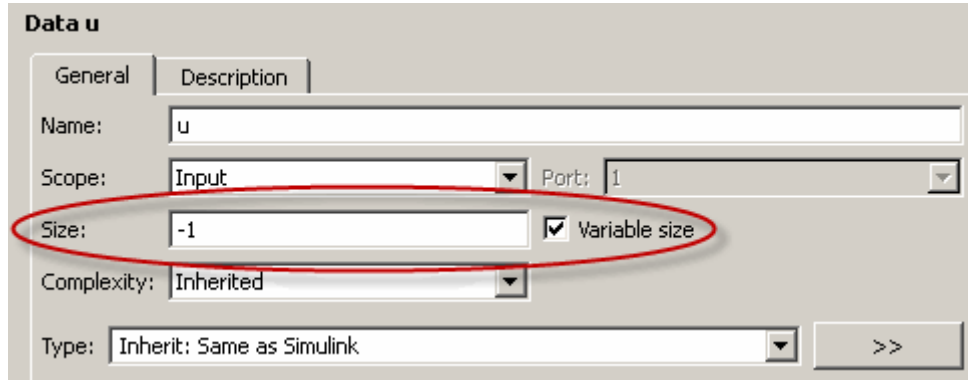
If number of signal values...	The Embedded MATLAB Function block...
> 1 and divisible by 2	Averages every consecutive pair of values
> 1 but *not* divisible by 2	Drops the first (smallest) value and average the remaining consecutive pairs
= 1	Returns the value unchanged

The `avg` function outputs the results to the **Average values** scope. Here is the code:

```
function y = avg(u) %#eml

if numel(u) == 1
    y = u;
```

```
else
    k = numel(u)/2;
    if k ~= floor(k)
        u = u(2:numel(u));
    end
    y = nway(u,2);
end
```

Both input `u` and output `y` of `avg` are declared as variable-size vectors because the number of elements varies depending on how the `uniquify` function block filters the signal values. Input `u` inherits its size from the output of `uniquify`:



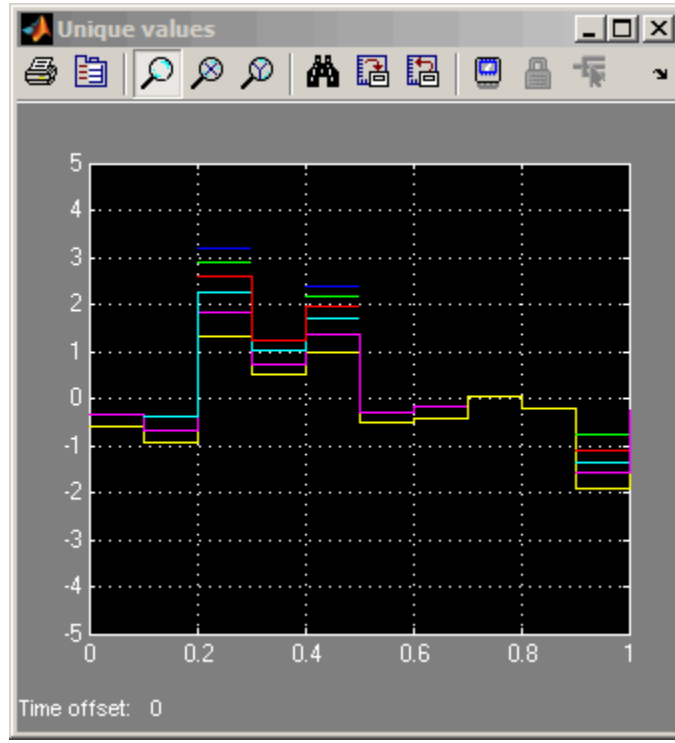
The `avg` function calls an external Embedded MATLAB function `nway` to calculate the average of every two consecutive signal values. Here is the code for `nway`:

```
function B = nway(A,n) %#eml

assert(n>=1 && n<=numel(A));

B = zeros(1,numel(A)/n);
k = 1;
for i = 1 : numel(A)/n
     B(i) = mean(A(k + (0:n-1)));
     k = k + n;
end
```

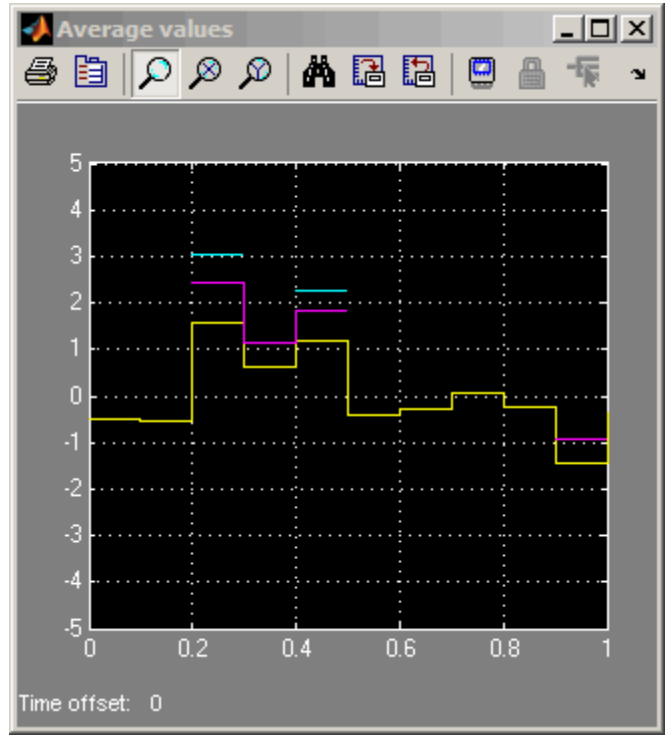
Variable-Size Results

Simulating the model produces the following results:

- The `uniquify` block outputs a variable number of signal values each time it executes:



- The `avg` block outputs a variable number of signal values each time it executes — approximately half the number of the unique values:


Average values
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
0.2
0.4
0.6
0.8
1
Time offset: 0

Using Enumerated Data in Embedded MATLAB Function Blocks

In this section...

Enumerated Data in Embedded MATLAB Function Blocks

Enumerated data is data that has a finite set of values. An enumerated data type is a user-defined type whose values belong to a predefined set of symbols, also called *enumerated values*. Each enumerated value consists of a name and an underlying numeric value.

Like other Simulink blocks, Embedded MATLAB Function blocks support an integer-based enumerated type derived from the class `Simulink.IntEnumType`. The instances of the class represent the values that comprise the enumerated type. The allowable values for an enumerated type must be 32-bit integers, but do not need to be consecutive.

For example, the following MATLAB script defines an integer-based enumerated data type named `PrimaryColors`:

```
classdef(Enumeration) PrimaryColors < Simulink.IntEnumType
    enumeration
        Red(1),
        Blue(4),
        Yellow(8)
    end
end
```

`PrimaryColors` is restricted to three enumerated values:

Enumerated Value	Enumerated Name	Underlying Numeric Value
`Red(1)`	`Red`	1
`Blue(4)`	`Blue`	4
`Yellow(8)`	`Yellow`	8

You can exchange enumerated data between Embedded MATLAB Function blocks and other Simulink blocks in a model as long as the enumerated type definition is based on the `Simulink.IntEnumType` class.

For comprehensive information about enumerated data support in Simulink, see “Enumerations” on page 25-6 in the Simulink documentation.

When to Use Enumerated Data

You can use enumerated types to represent program states and to control program logic, especially when you need to restrict data to a finite set of values and refer to these values by name. Even though you can sometimes achieve these goals by using integers or strings, enumerated types offer the following advantages:

- Provide more readable code than integers
- Allow more robust error checking than integers or strings

For example, if you mistype the name of an element in the enumerated type, Embedded MATLAB alerts you that the element does not belong to the set of allowable values.

- Produce more efficient code than strings

  For example, comparisons of enumerated values execute faster than comparisons of strings.

Simple Example: Defining and Using Enumerated Types in Embedded MATLAB Function Blocks

About the Example

The following example appears throughout this section to illustrate how Embedded MATLAB Function blocks exchange enumerated data with other Simulink blocks. This simple model uses enumerated data to represent the modes of a device that controls the colors of an LED display. The Embedded MATLAB Function block receives an enumerated data input representing the mode and, in turn, outputs enumerated data representing the color to be displayed by the LED.

This example uses two enumerated types: `myMode` to represent the set of allowable modes and `myLED` to represent the set of allowable colors. Both type definitions inherit from the built-in type `Simulink.IntEnumType` and must reside on the MATLAB path.

See Also.

- "Using Enumerated Data in Embedded MATLAB Function Blocks" on page 24-128

- "How to Define Enumerated Data Types for Embedded MATLAB Function Blocks" on page 24-129
- "How to Instantiate Enumerated Data in Embedded MATLAB Function Blocks" on page 24-132

Class Definition: myMode

Here is the class definition of the `myMode` enumerated data type:

```
classdef(Enumeration) myMode < Simulink.IntEnumType
  enumeration
    OFF(0)
    ON(1)
  end
end
```

This definition must reside on the MATLAB path in a MATLAB file with the same name as the class, `myMode.m`.

Class Definition: myLED

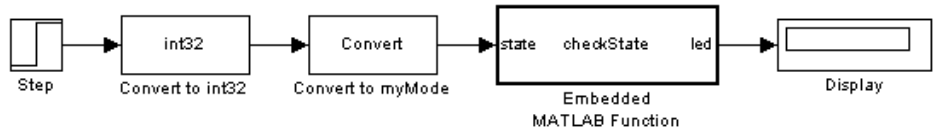
Here is the class definition of the `myLED` enumerated data type:

```
classdef(Enumeration) myLED < Simulink.IntEnumType
    enumeration
        GREEN(1),
        RED(8),
    end
end
```

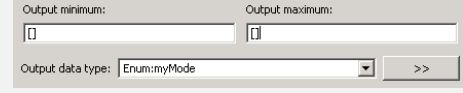
This definition must reside on the MATLAB path in a file called `myLED.m`. The set of allowable values do not need to be consecutive integers.

Simulink Model

The model that controls the LED display looks like this:



The model contains the following blocks:

Simulink Block	Description
Step	Provides source of the on/off signal. Outputs an initial value of 0 (off) and at 10 seconds steps up to a value of 1 (on).
Data Type Conversion from `double` to `int32`	Converts the `Step` signal of type `double` to type `int32`.
Data Type Conversion from `int32` to enumerated type `myMode`	Converts the value of type `int32` to the enumerated type `myMode`. In the Data Conversion block, you specify the enumerated data type using the prefix `Enum:` followed by the type name. You cannot set a minimum or maximum value for a signal of an enumerated type; leave these fields at the default value `[]`. For this example, the Data Conversion block parameters have these settings:  For more information about specifying enumerated types in Simulink models, see “Specifying an Enumerated Data Type” on page 25-26.

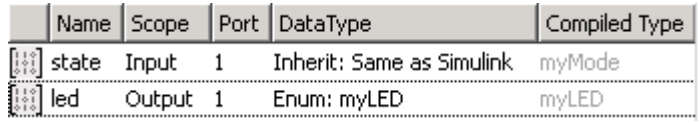
Simulink Block	Description
Embedded MATLAB Function	Evaluates enumerated data input `state` to determine the color to output as enumerated data `led`. See "Embedded MATLAB Function Block: checkState" on page 24-127.
Display	Displays the enumerated value of output `led`.

Embedded MATLAB Function Block: checkState

The function `checkState` in the Embedded MATLAB Function block uses enumerated data to activate an LED display, based on the state of a device. It lights a green LED display to indicate the ON state and lights a red LED display to indicate the OFF state.

```
function led = checkState(state)
%#eml
if state == myMode.ON
    led = myLED.GREEN;
else
    led = myLED.RED;
end
```

The input `state` inherits its enumerated type `myMode` from the Simulink step signal; the enumerated type of output `led` is explicitly declared as `myLED`:

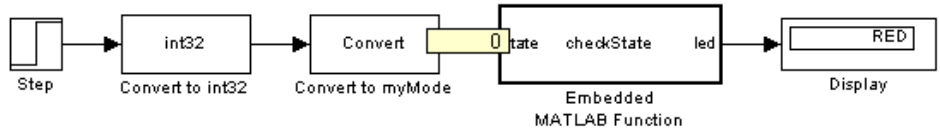


Explicit enumerated type declarations must include the prefix `Enum:`. For more information, see .

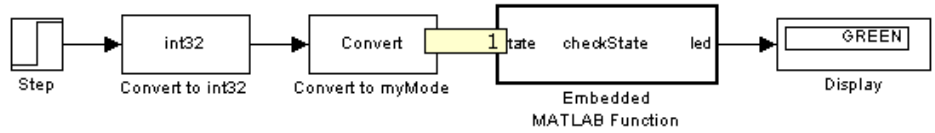
How the Model Displays Enumerated Data

Wherever possible, Simulink displays the name of an enumerated value, not its underlying integer. For instance, Display blocks display the name of

enumerated values. In this example, when the model simulates for less than 10 seconds, the step signal is 0, resulting in a red LED display to signify the off state:



Similarly, if the model simulates for 10 seconds or more, the step signal is 1, resulting in a green LED display to signify the on state:



Simulink scope blocks work differently. For more information, see "Enumerations and Scopes" on page 26-26.

Using Enumerated Data in Embedded MATLAB Function Blocks

Here is the basic workflow for using enumerated data in Embedded MATLAB function blocks:

Step	Action	How?
1	Define an enumerated data type that inherits from `Simulink.IntEnumType`.	See "How to Define Enumerated Data Types for Embedded MATLAB Function Blocks" on page 24-129.
2	Add the enumerated data to your Embedded MATLAB Function block.	See "How to Add Enumerated Data to Embedded MATLAB Function Blocks" on page 24-129.

Step	Action	How?
3	Instantiate the enumerated type in your Embedded MATLAB Function block.	See "How to Instantiate Enumerated Data in Embedded MATLAB Function Blocks" on page 24-132.
4	Simulate and/or generate code.	See "Enumerated Data Type Considerations" in the Real-Time Workshop documentation.

How to Define Enumerated Data Types for Embedded MATLAB Function Blocks

You define enumerated data types for Embedded MATLAB Function blocks in the same way as for other Simulink blocks. The basic workflow is:

1. Create a class definition file.
2. Define enumerated values in an `enumeration` section.
3. Optionally override default methods in a `methods` section.
4. Save the MATLAB file on the MATLAB path.

For complete descriptions of each procedure, see "Specifying an Enumerated Data Type" on page 25-26 .

How to Add Enumerated Data to Embedded MATLAB Function Blocks

You can add inputs, outputs, and parameters as enumerated data, according to these guidelines:

For:	Do This:
Inputs	Inherit from the enumerated type of the connected Simulink signal or specify the enumerated type explicitly.
Outputs	Always specify the enumerated type explicitly.
Parameters	For tunable parameters, specify the enumerated type explicitly. For non-tunable parameters, derive properties from an enumerated parameter in a parent Simulink masked subsystem or enumerated variable defined in the MATLAB base workspace.

To add enumerated data to an Embedded MATLAB Function block:

1. In the Embedded MATLAB Editor, select **Tools > Edit Data/Ports**.

   The Ports and Data Manager dialog box appears with the **General** pane selected.

2. In the **Name** field, enter a name for the enumerated data.

   For parameters, the name must match the enumerated masked parameter or workspace variable name.

3. In the **Type** field, specify an enumerated type.

   To specify an explicit enumerated type:

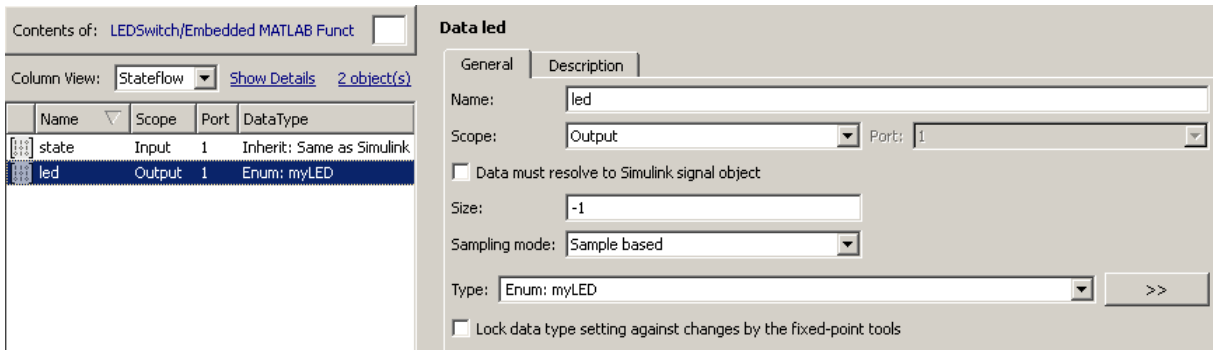
   a. Select `Enum:<class name>` from the drop-down menu in the **Type** field.

   b. Replace `<class name>` with the name of an enumerated data type that you defined in a MATLAB file on the MATLAB path.

      For example, you can enter `Enum:myLED` in the **Type** field. (See "How to Define Enumerated Data Types for Embedded MATLAB Function Blocks" on page 24-129.)

Note The **Complexity** field disappears when you select `Enum:<class name>` because enumerated data types do not support complex values.

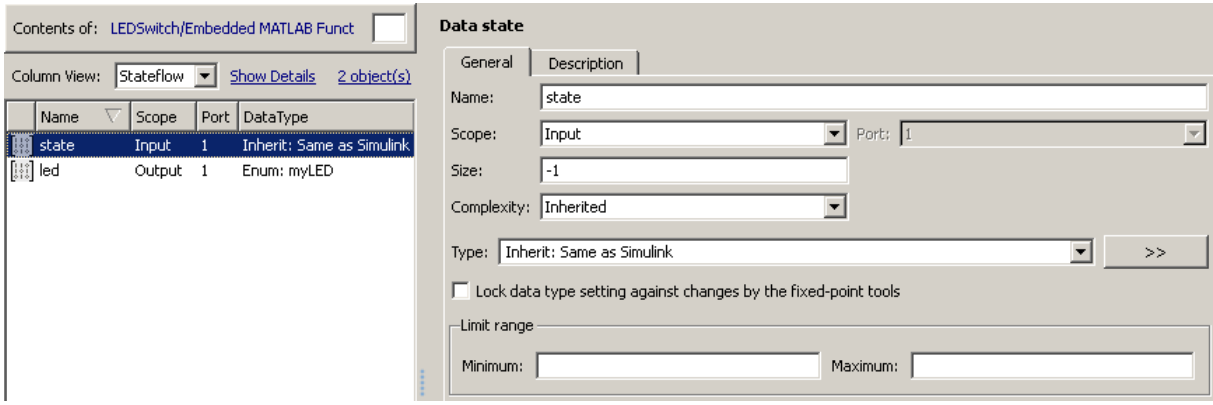
For example, the following output `led` has an explicit enumerated type, `myLED`:



To inherit the enumerated type from a connected Simulink signal (for inputs only):

a Select `Inherit:Same as Simulink` from the drop-down menu in the **Type** field.

   For example, the following input `state` inherits its enumerated type `myMode` from a Simulink signal:



4 Click **Apply**.

How to Instantiate Enumerated Data in Embedded MATLAB Function Blocks

To instantiate an enumerated type in an Embedded MATLAB Function block, use dot notation to specify *`ClassName.EnumName`*. For example, the following Embedded MATLAB function `checkState` instantiates the enumerated types `myMode` and `myLED` from "Simple Example: Defining and Using Enumerated Types in Embedded MATLAB Function Blocks" on page 24-124. The dot notation appears highlighted in the code.

```
function led = checkState(state)
%#eml

if state == myMode.ON
    led = myLED.GREEN;
else
    led = myLED.RED;
end
```

Operations on Enumerated Data

Simulink software prevents enumerated values from being used as numeric values in mathematical computation (see "Enumerated Values in Computation" on page 26-19) .

The Embedded MATLAB subset supports the following enumerated data operations:

- Assignment (=)
- Relational operations (==, ~=, <, >, <=, >=,)
- Cast
- Indexing

For more information, see “Operations on Enumerated Data in the Embedded MATLAB Subset”.

Limitations of Enumerated Types

Enumerated types in Embedded MATLAB Function blocks are subject to the limitations imposed by the Embedded MATLAB subset. See “Limitations of Enumerated Types in the Embedded MATLAB Subset”.

Using Global Data with the Embedded MATLAB Function Block

In this section...

When Do You Need to Use Global Data?

You might need to use global data with an Embedded MATLAB Function block if:

- You have multiple MATLAB functions that use global variables and you want to call these functions from Embedded MATLAB Function blocks.
- You have an existing model that uses a large amount of global data and you are adding an Embedded MATLAB Function block to this model, and you want to avoid cluttering your model with additional inputs and outputs.
- You want to scope the visibility of data to parts of the model.

Using Global Data with the Embedded MATLAB Function Block

In Simulink, you store global data using data store memory. You implement data store memory using either Data Store Memory blocks or `Simulink.Signal` objects. (For more information, see "About Data Stores" on page 28-2 in the Simulink documentation.) How you store global data depends on how many global variables you are using and the scope of these

variables. For more information, see “Choosing How to Store Global Data” on page 24-135.

How MATLAB Globals Relate to Data Store Memory

In MATLAB functions in Simulink, global declarations are not mapped to the MATLAB global workspace. Instead, you register global data with the Embedded MATLAB Function block to map the data to data store memory. This difference allows global data in Embedded MATLAB functions to inter-operate with the Simulink solver and to provide diagnostics if they are misused.

A global variable resolves hierarchically to the closest data store memory with the same name in the model. The same global variable occurring in two different Embedded MATLAB Function blocks might resolve to different data store memory depending on the hierarchy of your model. You can use this ability to scope the visibility of data to a subsystem.

How to Use Globals with the Embedded MATLAB Function Block

To use global data in your Embedded MATLAB Function block, or in any code that this block calls, you must:

1. Declare a global variable in your Embedded MATLAB Function block, or in any code that is called by the Embedded MATLAB Function block.
2. Register a Data Store Memory block or `Simulink.Signal` object that has the same name as the global variable with the Embedded MATLAB Function block.

For more information, see “How to Use Data Store Memory Blocks” on page 24-137 and “How to Use Simulink.Signal Objects” on page 24-139.

Choosing How to Store Global Data

The following table summarizes whether to use Data Store Memory blocks or `Simulink.Signal` objects.

If you want to...	Use...	For more information
Use a small number of global variables in a single model that does not use model reference.	Data Store Memory blocks. **Note** Using Data Store Memory blocks scopes the data to the model.	"How to Use Data Store Memory Blocks" on page 24-137
Use a large number of global variables in a single model that does not use model reference.	`Simulink.Signal` objects defined in the model workspace. `Simulink.Signal` objects offer these advantages: • You do not have to add numerous Data Store Memory blocks to your model. • You can load the `Simulink.Signal` objects in from a MAT-file.	"How to Use Simulink.Signal Objects" on page 24-139
Share data between multiple models (including referenced models).	`Simulink.Signal` objects defined in the base workspace **Note** If you use Data Store Memory blocks as well as `Simulink.Signal`, note that using Data Store Memory blocks scopes the data to the model.	"How to Use Simulink.Signal Objects" on page 24-139

How to Use Data Store Memory Blocks

1. Add an Embedded MATLAB Function block to your model.
2. Double-click the Embedded MATLAB Function block to open the Embedded MATLAB Editor.
3. Declare a global variable in the Embedded MATLAB Function block code, or in any MATLAB file that the Embedded MATLAB Function block code calls. For example:

   ```
   global A;
   ```

4. Add a Data Store Memory block to your model and set the following:
   a. Set the **Data store name** to match the name of the global variable in your Embedded MATLAB Function block code.
   b. Set **Data type** to an explicit data type.

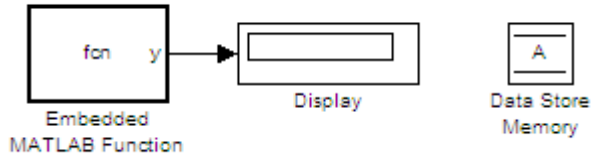
      The data type cannot be `auto`.
   c. Set **Signal type** to `real`.

      The signal type cannot be `complex` or `auto`.
   d. Specify an **Initial value**.

      The initial value of the Data Store Memory block cannot be unspecified.
5. Register the variable to the Embedded MATLAB Function block.
   a. In the Ports and Data Manager, add data with the same name as the global variable.
   b. Set the **Scope** of the data to `Data Store Memory`.

For more information on using the Ports and Data Manager, see "Ports and Data Manager" on page 24-41.

Example: Using Data Store Memory with the Embedded MATLAB Function Block



This simple model demonstrates how an Embedded MATLAB Function block uses the global data stored in Data Store Memory block `A`.

1

2 Double-click the Embedded MATLAB Function block to open the Embedded MATLAB Editor.

The Embedded MATLAB Function block modifies the value of global data `A` each time it executes.

```
function y = fcn
%#eml
global A;
A = A+1;
y = A;
```

3 From the menu in the Embedded MATLAB Editor, select **Tools > Edit Data/Ports**.

The Ports and Data Manager opens.

4 Select the data `A` in the left pane.

The Ports and Data Manager displays the data attributes in the right pane. Note that `A` has a scope of `Data Store Memory`.

5 In the model, double-click the Data Store Memory block `A`.

The Block Parameters dialog box opens. Note that `A` has an initial value of `25`.

6 Simulate the model.

The Embedded MATLAB Function block reads the initial value of global data stored in `A` and updates the value of `A` each time it executes.

How to Use Simulink.Signal Objects

1 Create a `Simulink.Signal` object in the model workspace.

Tip Create a `Simulink.Signal` object in the base workspace to use the global data with multiple models.

---

a In the Model Explorer, navigate to ***`model_name`*** **> Model Workspace** in the **Model Hierarchy** pane.

b Select **Add > Simulink Signal**.

c Ensure that these settings apply to the `Simulink.Signal` object:

i Set **Data type** to an explicit data type.

The data type cannot be `auto`.

ii Set **Dimensions** to be fully specified.

The signal dimensions cannot be `-1` or inherited.

iii Set **Complexity** to `real`.

iv Set **Sample mode** to `Sample based`.

v Specify an **Initial value**.

The initial value of the signal cannot be unspecified.

2 Register the `Simulink.Signal` object to the Embedded MATLAB Function block.

a In the Ports and Data Manager, add data with the same name as the `Simulink.Signal` object you created in the model (or base) workspace.

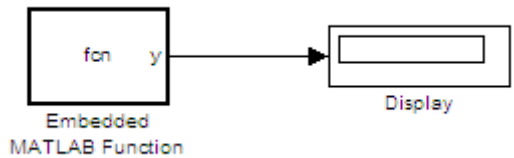
b Set the **Scope** of the data to `Data Store Memory`.

3 Declare a global variable with the same name in the code for your Embedded MATLAB Function block.

```
global Sig;
```

For more information on using the Ports and Data Manager, see "Ports and Data Manager" on page 24-41.

Example: Using a Simulink.Signal Object with an Embedded MATLAB Function Block



1

2 Double-click the Embedded MATLAB Function block to open the Embedded MATLAB Editor.

The Embedded MATLAB Function block modifies the value of global data `A` each time it executes.

```
function y = fcn
%#eml
global A;
A = A+1;
y = A;
```

3 From the Embedded MATLAB Editor menu, select **Tools > Edit Data/Ports**.

The Ports and Data Manager opens.

4 Select the data `A` in the left pane.

The Ports and Data Manager displays the data attributes in the right pane. Note that `A` has a scope of `Data Store Memory`.

5. From the model menu, select **View > Model Explorer**.

   The Model Explorer opens.

6. In the left pane, select the model workspace for the `simulink_signal_local` model.

   The **Contents** pane displays the data in the model workspace.

7. Click the Simulink.Signal object `A`.

   The right pane displays the attributes for `A`.

Attribute	Value
Data type	`double`
Complexity	`real`
Dimensions	`1`
Sample mode	`Sample based`
Initial value	`5`

8. Simulate the model.

   The Embedded MATLAB Function block reads the initial value of global data stored in `A` and updates the value of `A` each time it executes.

Using Data Store Diagnostics to Detect Memory Access Issues

You can configure your model to provide run-time and compile-time diagnostics for avoiding problems with data stores. Diagnostics are available in the Configuration Parameters dialog box and the parameters dialog box for the Data Store Memory block. These diagnostics are available for Data Store Memory blocks only, not for `Simulink.Signal` objects. For more information on using data store diagnostics, see “Using Data Store Diagnostics” on page 28-25 in the Simulink documentation.

Note If you pass data store memory arrays to functions, optimizations such as `A=foo(A)` might result in Embedded MATLAB marking the entire contents of the array as read or written even though only some elements were accessed.

Limitations of Using Shared Data in Embedded MATLAB Function Blocks

There is no Data Store Memory support for:

- Buses
- Structures
- Variable-sized data

Working with Frame-Based Signals

In this section...

About Frame-Based Signals

Embedded MATLAB Function blocks can input and output frame-based signals in Simulink models. A frame of data is a collection of sequential samples from a single channel or multiple channels. To generate frame-based signals, you must install Signal Processing Blockset. For more information about using frame-based signals, see "What is Frame-Based Processing?" in the Signal Processing Blockset documentation.

Embedded MATLAB Function blocks automatically convert incoming frame-based signals as follows:

- Converts single-channel frame-based signals to MATLAB column vectors
- Converts multichannel frame-based signals to two-dimensional MATLAB matrices

An M-by-N frame-based signal represents M consecutive samples from each of N independent channels. N-Dimensional signals are not supported for frames.

To convert matrix or vector data to a frame-based output, Embedded MATLAB provides a data property called **Sampling mode** that lets you specify whether your output is a frame-based or sample-based signal for downstream processing.

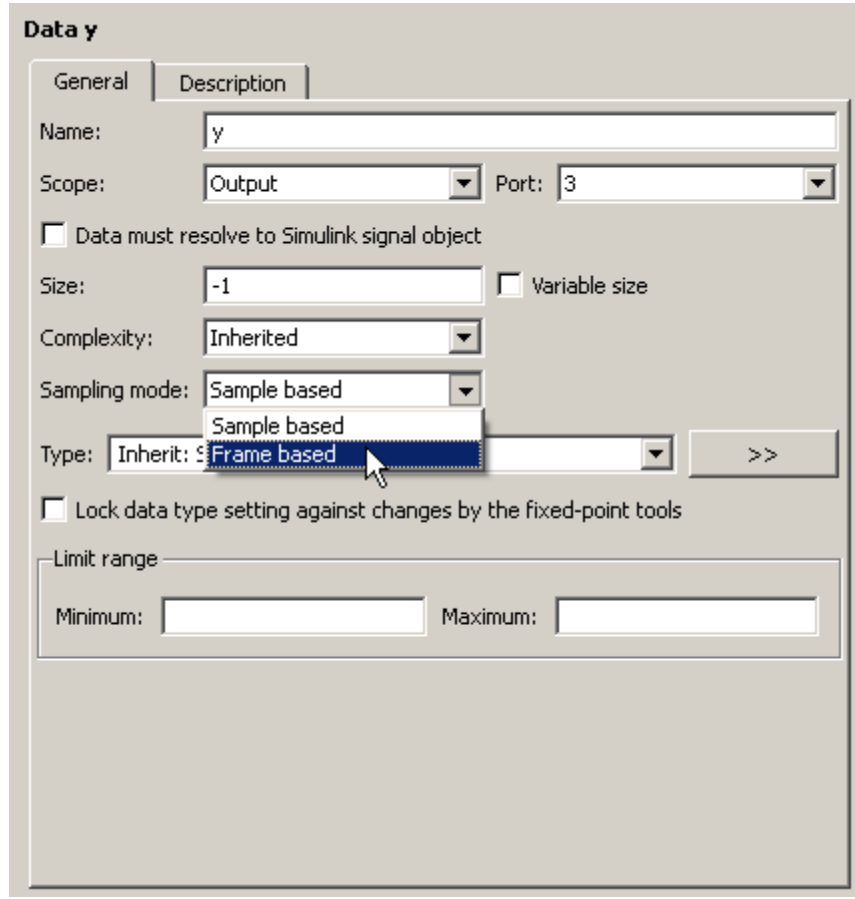
Supported Types for Frame-Based Data

Embedded MATLAB Function blocks accept frame-based signals of any data type *except* bus objects. For a list of supported types, see "Supported Variable Types" in the Embedded MATLAB documentation.

Adding Frame-Based Data in Embedded MATLAB Function Blocks

To add frame-based data to an Embedded MATLAB Function block, follow these steps:

1. Add an input or output, as described in "Adding Data to an Embedded MATLAB Function Block" on page 24-48.
2. If your data is an output, set **Sampling mode** to `Frame based`.



Note If your data is an input, **Sampling mode** is not an option.

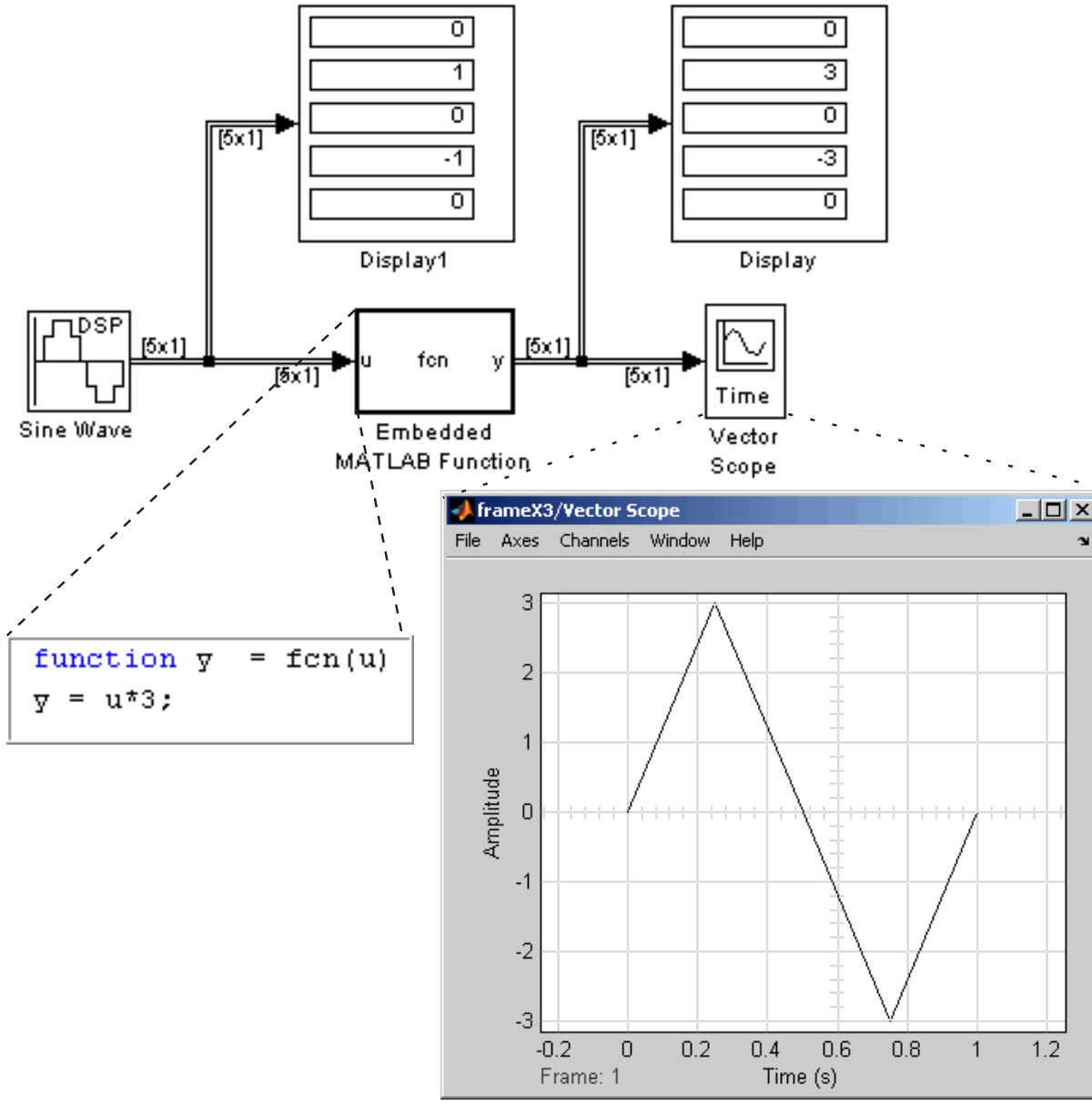
Note For more information on how to set data properties, see "Defining Data in the Model Explorer" on page 24-50.

Examples of Frame-Based Signals in Embedded MATLAB Function Blocks

This topic presents examples of how to work with frame-based signals in Embedded MATLAB Function blocks.

Multiplying a Frame-Based Signal by a Constant Value

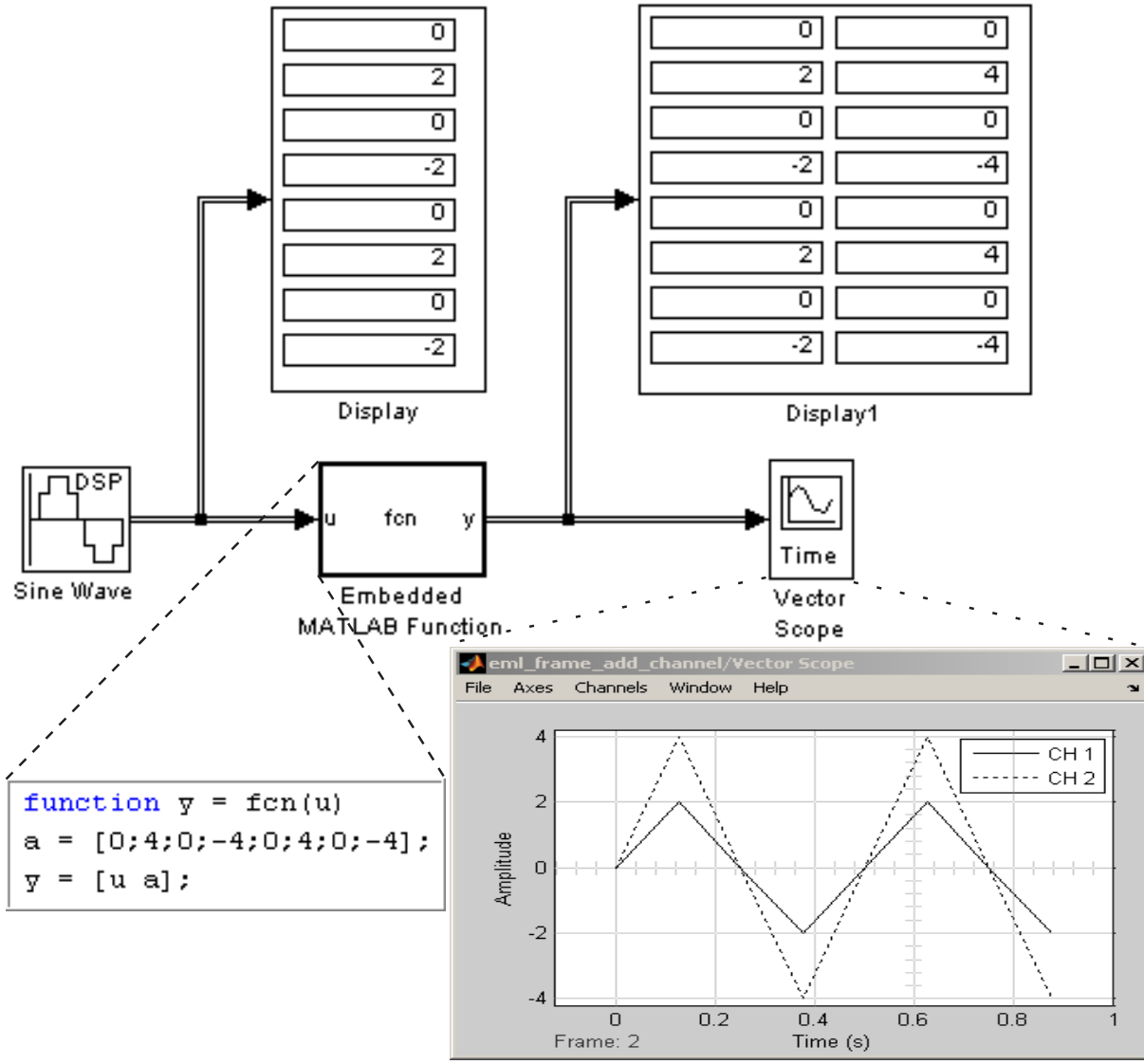
In the following example, an Embedded MATLAB Function block multiplies all the signal values in a frame-based single-channel input by a constant value and outputs the result as a frame. The input signal is a sine wave that contains 5 samples per frame. Here is the model:


0
1
0
-1
0
Display1
0
3
0
-3
0
Display
[5x1]
[5x1]
[5x1]
[5x1]
[5x1]
DSP
Sine Wave
u
fcn
y
Embedded
MATLAB Function
Time
Vector
Scope
function y = fcn(u)
y = u*3;
frameX3/Vector Scope
File Axes Channels Window Help
Amplitude
3
2
1
0
-1
-2
-3
-0.2 0 0.2 0.4 0.6 0.8 1 1.2
Frame: 1
Time (s)

In the Embedded MATLAB Function block, input `u` and output `y` inherit size, complexity, and data type from the input sine wave signal, a 5-by-1 vector of signed, generalized fixed-point values. For `y` to output a frame of data, you must explicitly set **Sampling mode** to `Frame based` (see "Adding Frame-Based Data in Embedded MATLAB Function Blocks" on page 24-144). When you simulate this model, the Embedded MATLAB Function block multiplies each input signal by 3 and outputs the result as a frame.

Adding a Channel to a Frame-Based Signal

In the following example, an Embedded MATLAB Function block adds a channel to a frame-based single-channel input and outputs the multichannel result. The input signal is a sine wave that contains 8 samples per frame. Here is the model:



In the Embedded MATLAB Function block, input `u` and output `y` inherit size, complexity, and data type from the input sine wave signal, an 8-by-1 vector of signed, generalized fixed-point values. For `y` to output a frame of data, you must explicitly set **Sampling mode** to `Frame based`(see "Adding

Frame-Based Data in Embedded MATLAB Function Blocks" on page 24-144). Local variable a defines a second column on the matrix which will be output as a frame and interpreted as a second channel by downstream blocks. When you simulate this model, the Embedded MATLAB Function block outputs the new multichannel signal.

Creating Custom Block Libraries with Embedded MATLAB Function Blocks

In this section...

When to Use Embedded MATLAB Block Libraries

In Simulink, you can create your own block libraries as a way to reuse the functionality of blocks or subsystems in one or more models. If you want to reuse a set of MATLAB algorithms in Simulink models, you can encapsulate your MATLAB code in an Embedded MATLAB Function block library.

As with other Simulink block libraries, you can specialize each instance of Embedded MATLAB Function library blocks in your model to use different data types, sample times, and other properties. Library instances that inherit the same properties can reuse generated code (see "Code Reuse with Library Blocks" on page 24-164).

For more information about Simulink block libraries, see Chapter 23, "Working with Block Libraries"

How to Create Custom Embedded MATLAB Block Libraries

Here is a basic workflow for creating custom block libraries with Embedded MATLAB Function blocks. To work through these steps with an example,

see "Example: Creating a Custom Signal Processing Filter Block Library" on page 24-152.

1. Add polymorphic MATLAB code to Embedded MATLAB Function blocks in a Simulink model.

   Polymorphic code is code that can process data with different properties, such as type, size, and complexity.

2. Configure the blocks to inherit the properties you want to specialize.

   For a list of properties you can specialize, see "Properties You Can Specialize Across Instances of Library Blocks" on page 24-169.

3. Optionally, customize your library code using masking.

4. Add instances of Embedded MATLAB Function library blocks to a Simulink model.

Example: Creating a Custom Signal Processing Filter Block Library

What You Will Learn

This simple example takes you through the workflow described in "How to Create Custom Embedded MATLAB Block Libraries" on page 24-151 to show you how to:

- Create a library of signal processing filter algorithms using Embedded MATLAB Function blocks
- Customize one of the library blocks using mask parameters
- Convert one of the filter algorithms to source-protected P-code that you can call from an Embedded MATLAB Function library block

About the Filter Algorithms

The MATLAB filter algorithms are:

my_fft. Performs a discrete Fourier transform on an input signal. The input can be a vector, matrix, or multidimensional array whose length is a power of 2.

my_conv. Convolves two input vector signals. Outputs a subsection of the convolution with a size specified by a mask parameter, `Shape`.

my_sobel. Convolves a 2D input matrix with a Sobel edge detection filter.

Step 1: Add the Filter Algorithms to Embedded MATLAB Function Library Blocks

1. In Simulink, create a library model by selecting **File > New > Library**
2. Drag three Embedded MATLAB Function blocks into the model from the User-Defined Functions section of the Simulink Library Browser and name them:
   - `my_fft_filter`
   - `my_conv_filter`
   - `my_sobel_filter`
3. Save the library model as `my_filter_lib`.
4. Open the Embedded MATLAB Function block named `my_fft_filter`, replace the template code with the following code, and save the block:

```
function y = my_fft(x)
```

```
y = fft(x);
```

5 Replace the template code in `my_conv_filter` block with the following code and save the block:

```
function c = my_conv(a, b)

c = conv(a, b);
```

6 Replace the template code in `my_sobel_filter` block with the following code and save the block:

```
function y = my_sobel(u)

%% "my_sobel_filter" is a MATLAB function
%%  on the Embedded MATLAB path.
y = my_sobel_filter(u);
```

The `my_sobel` function acts as a wrapper that calls a MATLAB function, `my_sobel_filter`, on the Embedded MATLAB path. `my_sobel_filter` implements the algorithm that convolves a 2D input matrix with a Sobel edge detection filter. By calling the function rather than inlining the code directly in the Embedded MATLAB Function block, you can reuse the algorithm both as MATLAB code and in a Simulink model. You will create `my_sobel_filter` next.

7 In the same folder where you created `my_filter_lib`, create a new MATLAB function `my_sobel_filter` with the following code:

```
function y = my_sobel_filter(u)

% Sobel edge detection filter
h = [1     2     1;...
     0     0     0;...
    -1    -2    -1];

y = abs(conv2(u, h));
```

Save the file as `my_sobel_filter.m`.

Step 2: Configure Blocks to Inherit Properties You Want to Specialize

In this example, the data in the signal processing filter algorithms must inherit size, type, and complexity from the Simulink model. By default, data in Embedded MATLAB Function blocks inherit these properties. To explicitly configure data to inherit properties:

1. Open an Embedded MATLAB Function block and select **Tools > Edit Data/Ports**.

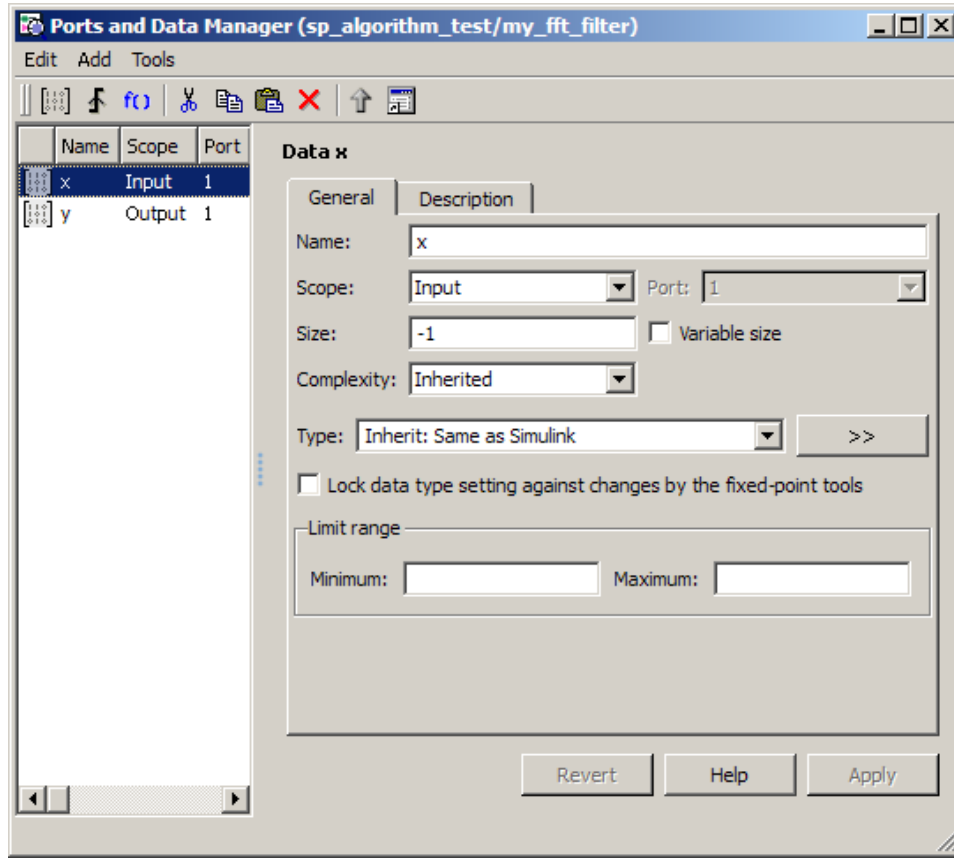
   The Ports and Data Manager opens.

2. In the left pane of the Ports and Data Manager, select the data of interest.

3. In the right pane, configure the data to inherit properties from Simulink:

To Inherit	What to Specify
Size	Enter `-1` in Size field
Complexity	Select **Inherited** from the Complexity menu
Type	Select **Inherit: Same as Simulink** from the Type menu

For example, if you open the Embedded MATLAB Function block my_fft_filter and look at the properties of input `x` in the Ports and Data Manager, you see that size, type, and complexity are inherited by default:



Note If your design has specific requirements or constraints, you can enter values for any of these properties, rather than inherit them from Simulink. For example, if your algorithm is not supposed to work with complex inputs, set **Complexity** to **Off**.

See Also.

- “Ports and Data Manager” on page 24-41
- “Inheriting Argument Data Types” on page 24-84

Step 3: Customize Your Library Using Masking

In this exercise you will modify the convolution filter `my_conv` to use a custom parameter `shape` that specifies what subsection of the convolution to output. To customize this algorithm for your library, place the `my_conv_filter` block under a masked subsystem and define `shape` as a mask parameter.

1. Convert the block to a masked subsystem:
   a. Click the my_conv_filter block and select **Edit > Create Subsystem**.

      The my_conv_filter block changes to a subsystem block.
   b. Change the name of the subsystem to my_conv_filter.
   c. Right-click the my_conv_filter subsystem and select **Mask Subsystem** from the context menu.

      The Mask Editor appears with the Icon & Ports pane open.
   d. In the Icons & Ports pane, add the following icon drawing commands:

      ```
      disp('my_conv');
      port_label('output', 1, 'c');
      port_label('input', 1, 'a');
      port_label('input', 2, 'b');
      ```

   e. Select the Parameters tab and add a dialog parameter by selecting the Add icon:

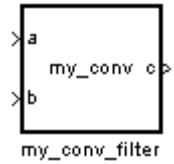
   f. Assign the following properties to the new dialog parameter:

Property	What to Specify
Prompt	Type `Shape`
Variable	Type `shape`

Property	What to Specify
Type	• Select **popup** • Enter type-specific options, each on a separate line: – `full` – `same` – `valid` • Check **Enable parameter** • Check **Show parameter**
Evaluate	Check the box
Tunable	Clear the box **Note** In this example, the `shape` parameter is not tunable. If in your own application you want to change the value of a mask parameter during simulation, check this box.
Tab name	Leave blank

a Click **OK**.

Your subsystem should now look like this:



2 Set subsystem properties for code reuse:

a Right-click the my_conv_filter subsystem and select **Subsystem Parameters** from the context menu.

The subsystem parameters dialog box opens.

b Select the **Treat as atomic unit** check box.

The dialog box expands to display new fields.

c To generate a reusable function, in the **Real-Time Workshop system code** field, select **Reusable function** from the drop-down menu.

Note This is an optional step, required for this example. If you leave the default setting of **Auto**, the code generation software uses an internal rule to determine whether to inline the function or not.

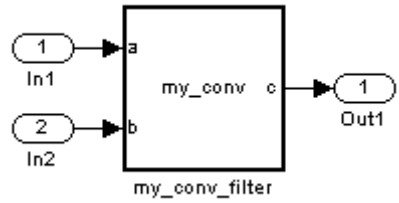
---

d Click **OK**.

3 Define the `shape` parameter in the Embedded MATLAB Function `my_conv`:

a Right-click the my_conv_filter subsystem and select **Look Under Mask** from the context menu.

The block diagram under the masked subsystem opens, containing the my_conv_filter block:



b Change the names of the port blocks to match the data names as follows:

Change:	To:
In1	a
In2	b
Out1	c

c Double-click the my_conv_filter block to open the Embedded MATLAB Editor.

d In the Embedded MATLAB Editor, select **Tools > Edit Data/Ports**.

The Ports and Data Manager opens.

e In the Ports and Data Manager, select **Add > Data**.

A new data element appears selected, along with its properties dialog.

f Enter the following properties:

Property	What To Specify
Name	Enter shape.
Scope	Select **Parameter**.
Tunable	Clear the box.

g Leave **Size**, **Complexity**, and **Type** as inherited (the defaults), as described in "Step 2: Configure Blocks to Inherit Properties You Want to Specialize" on page 24-155.

h Click **Apply**, close the Ports and Data Manager, and return to the Embedded MATLAB Editor.

4 Use the shape parameter to determine the size of the convolution to output:

a In the Embedded MATLAB Editor, modify the my_conv function to call conv with the right shape:

```
function c = my_conv(a, b, shape)
if shape == 1
    c = conv(a, b, 'full');
elseif shape == 2
    c = conv(a, b, 'same');
```

```
else
    c = conv(a, b, 'valid');
end
```

b Save your changes and close the Embedded MATLAB Editor.

See Also.

- Chapter 21, "Working with Block Masks"

Step 4: Add Instances of Embedded MATLAB Library Blocks to a Simulink Model

In this exercise, you will add specialized instances of the my_conv_filter library block to a simple test model.

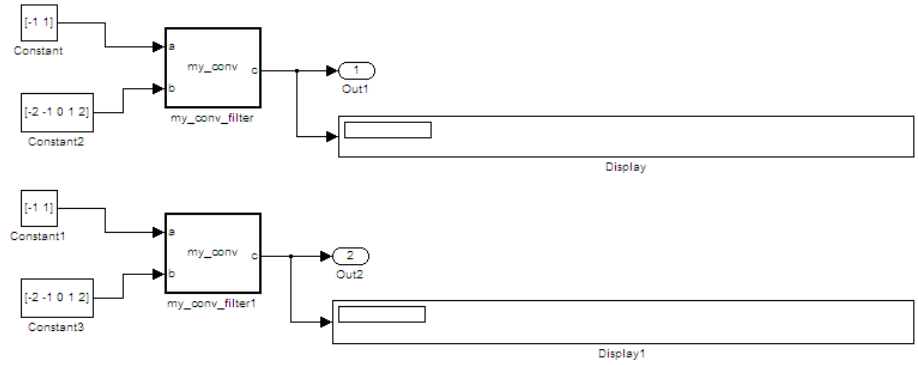
1 Open a new Simulink model.

For purposes of this exercise, set the following configuration parameters for simulation:

Pane	Section	What to Specify
`Solver`	`Solver options`	• Select **Fixed-Step** for `Type` • Select **discrete (no continuous states)** for `Solver` • Enter **1** for `Fixed-step size`
`Data Import/Export`	`Save options`	**Structure** for `Format`

2 Drag two instances of the my_conv_filter block from the `my_filter_lib` library into the model.

3 Add Constant, Outport, and Display blocks as follows:



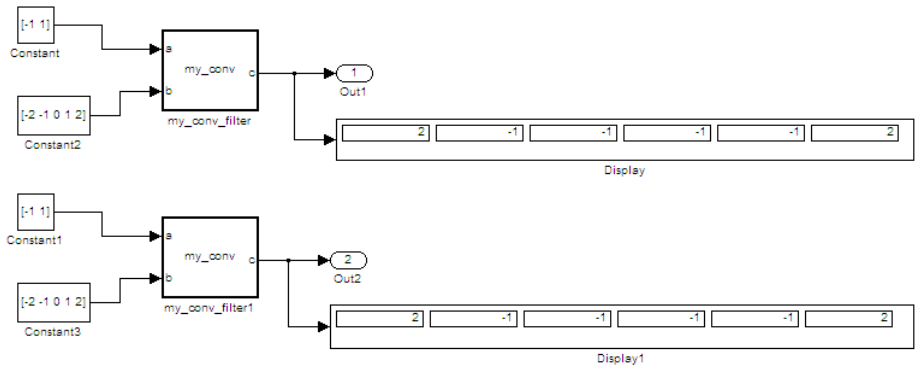
Both library instances share the same size, type, and complexity for inputs `a` and `b` respectively.

4 Double-click each library instance.

The `shape` parameter defaults to **full** for both instances.

5 Simulate the model.

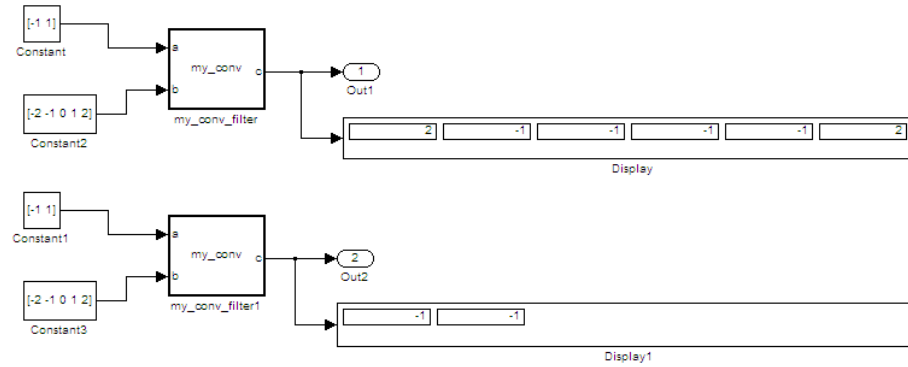
Each library instance outputs the same result, the full 2D convolution:



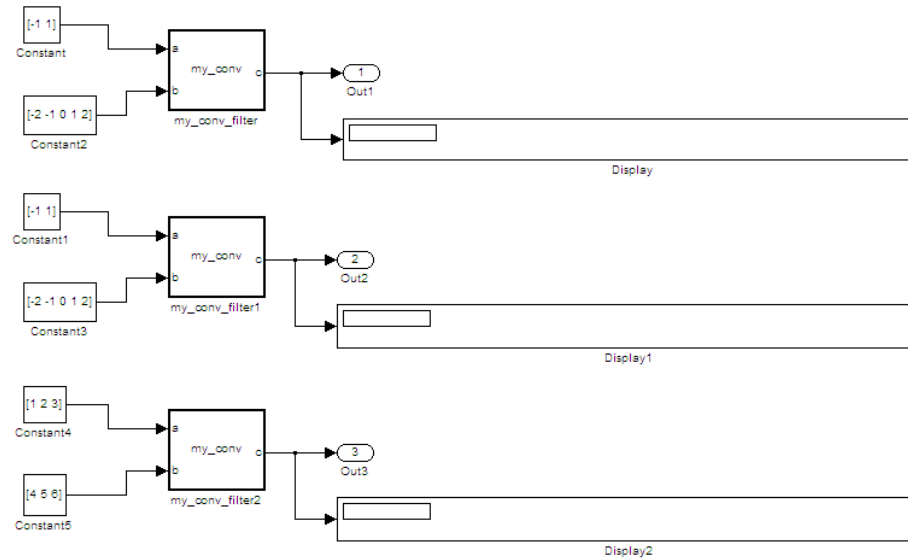
6 Specialize the second instance, my_conv_filter1 by setting the value of its `shape` parameter to **same**.

7 Now simulate the model again.

This time, the outputs have different sizes: my_conv_filter outputs the full 2D convolution, while my_conv_filter1 displays the central part of the convolution as a 1-by-2 vector, the same size as a:

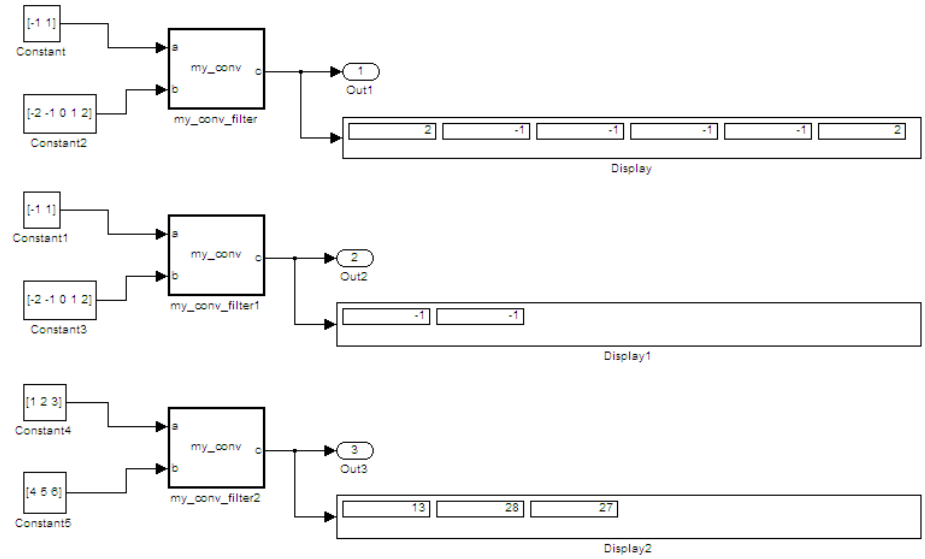


8 Now, add a third instance by copying my_conv_filter1. Specialize the new instance, my_conv_filter2, so that it does not inherit the same size inputs as the first two instances:



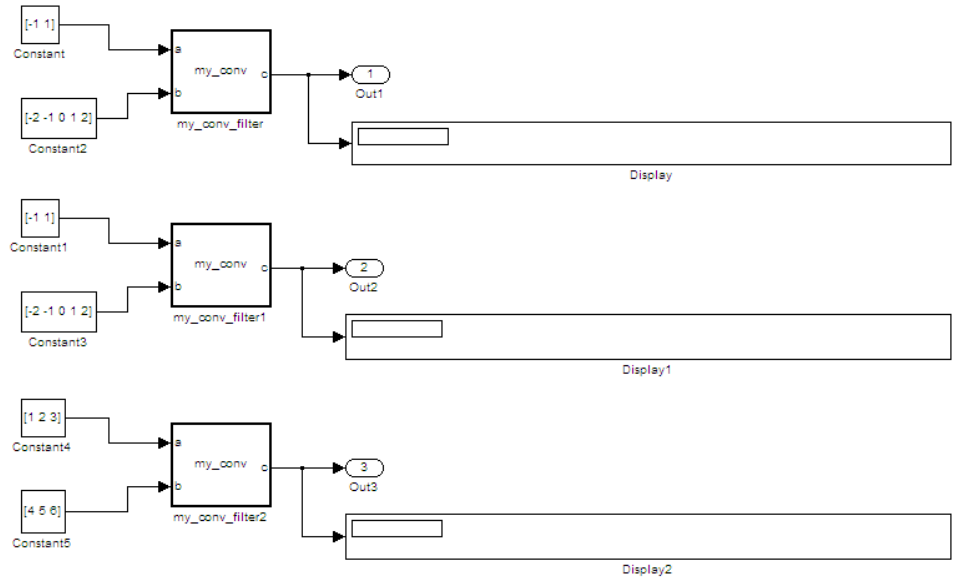
9 Simulate the model again.

This time, my_conv_filter1 and my_conv_filter2 each display the central part of the convolution, but the output sizes are different because each matches a different sized input a.



Code Reuse with Library Blocks

When instances of Embedded MATLAB Function library blocks inherit the same properties, they can reuse generated code, as illustrated by an example based on “Step 4: Add Instances of Embedded MATLAB Library Blocks to a Simulink Model” on page 24-161:



In this model, the library instances my_conv_filter and my_conv_filter1 inherit the same size, type, and complexity for each respective input. For each instance, input `a` is a 1-by-2 vector and input `b` is a 1-by-5 vector. By comparison, the inputs of my_conv_filter2 inherit different respective sizes; both are 1-by-3 vectors.

In addition, each library instance has a mask parameter called shape that determines what subsection of the convolution to output. Assume that the value of shape is the same for each instance.

To generate code for this example, follow these steps:

1. Enable code reuse for the library block:
   a. In the library, right-click on the Embedded MATLAB Function block my_conv_filter and select **Subsystem Parameters** from the context menu.
   b. In the Function Block Parameters dialog box, set these parameters:
      - Select the **Treat as atomic unit** check box.

- In the **Real-Time Workshop system code** field, select **Reusable function** from the drop-down menu.

2. Configure the model for code generation.

   For purposes of this exercise, set the following configuration parameters:

Pane	Section	What to Specify
`Real-Time Workshop`	`Target selection`	Enter **ert.tlc** for `System target file`
`Real-Time Workshop > Report`		Select **Create code generation report** check box.

3. Build the model.

   If you build this model, the generated C code reuses logic for the `my_conv_filter` and `my_conv_filter1` library instances because they inherit the same input properties:

```
/*
 * Output and update for atomic system:
 *     <Root>/my_conv_filter
 *     <Root>/my_conv_filter1
 */
void test_lib_special_my_conv_filter(const real_T rtu_a[2], const real_T rtu_b[5],
  rtB_my_conv_filter_test_lib_spe *localB)
{
  int32_T jp;
  int32_T jA;
  int32_T jA_0;
  real_T s;
  int32_T jC;

  /* Embedded MATLAB: '<S1>/my_conv_filter' */
  /* Embedded MATLAB Function 'my_conv_filter/my_conv_filter': '<S4>:1' */
  /* '<S4>:1:3' */
  for (jC = 0; jC < 6; jC++) {
```

```
    jp = jC + 2;
    if (5 < jp) {
      jA = jp - 5;
    } else {
      jA = 1;
    }

    if (2 < jC + 1) {
      jA_0 = 2;
    } else {
      jA_0 = jC + 1;
    }

    s = 0.0;
    while (jA <= jA_0) {
      s += rtu_b[(jp - jA) - 1] * rtu_a[jA - 1];
      jA++;
    }

    localB->c[jC] = s;
  }
}
}
```

However, a separate function is generated for my_conv_filter2:

```
/* Output and update for atomic system:  <Root>/my_conv_filter2  */
void test_lib_specia_my_conv_filter2(const real_T rtu_a[3], const real_T rtu_b[3],
  rtB_my_conv_filter_test_lib_s_p *localB)
{
  int32_T jp;
  int32_T jA;
  int32_T jA_0;
  real_T s;
  int32_T jC;

  /* Embedded MATLAB: '<S3>/my_conv_filter' */
  /* Embedded MATLAB Function 'my_conv_filter/my_conv_filter': '<S6>:1' */
  /* '<S6>:1:3' */
```

```
  for (jC = 0; jC < 5; jC++) {
    jp = jC + 2;
    if (3 < jp) {
      jA = jp - 3;
    } else {
      jA = 1;
    }

    if (3 < jC + 1) {
      jA_0 = 3;
    } else {
      jA_0 = jC + 1;
    }

    s = 0.0;
    while (jA <= jA_0) {
      s += rtu_b[(jp - jA) - 1] * rtu_a[jA - 1];
      jA++;
    }

    localB->c[jC] = s;
  }
}
```

Note Generating C code for this model requires a Real-Time Workshop or Real-Time Workshop Embedded Coder license.

Debugging Embedded MATLAB Function Library Blocks

You debug Embedded MATLAB Function library blocks the same way you debug any Embedded MATLAB Function block. However, when you add a

breakpoint in a library block, the breakpoint is shared by all instances. As you continue execution, the debugger stops at the breakpoint in each instance.

For more information, see "Debugging an Embedded MATLAB Function Block" on page 24-22

Properties You Can Specialize Across Instances of Library Blocks

You can specialize instances of Embedded MATLAB Function library blocks by allowing them to inherit any of the following properties from Simulink:

Property	Inherits by Default?	How to Specify Inheritance
Type	Yes	Set data type property to **Inherit: Same as Simulink**.
Size	Yes	Set data size property to **-1**.
Complexity	Yes	Set data complexity property to **Inherited**.
Limit range	No	Specify minimum and maximum values as Simulink parameters. For example, if minimum value = `aParam` and maximum value = `aParam` + 3, different instances of an Embedded MATLAB Function library block can resolve to different `aParam` parameters defined in their parent mask subsystems.
Sampling mode (input)	Yes	Embedded MATLAB Function block input ports always inherit sampling mode
Data type override mode for fixed-point data	Yes	Set data type override property to **Inherit**.
Sample time (block)	Yes	Set block sample time property to **-1**.

Using Traceability in Embedded MATLAB Function Blocks

In this section...

Extent of Traceability in Embedded MATLAB Function Blocks

Like other Simulink blocks, Embedded MATLAB Function blocks support bidirectional traceability, but extend navigation to lines of source code. That is, you can navigate between a line of generated code and its corresponding line of source code. In other Simulink blocks, you can navigate between a line of generated code and its corresponding object.

In addition, you can select to include the source code as comments in the generated code. When you select this option, the MATLAB source code appears immediately after the associated traceability tag. For more information, see "Including MATLAB Source Code as Comments in the Generated Code" on page 24-177.

For information about how traceability works in Simulink blocks, see "Tracing Generated Code" in the Real-Time Workshop User's Guide.

Traceability Requirements

To enable traceability comments in your code, you must have a license for Real-Time Workshop Embedded Coder software. These comments appear only in code that you generate for an Embedded Real-Time (`ERT`) target.

Note Traceability is not supported for MATLAB files that you call from an Embedded MATLAB Function block.

Basic Workflow for Using Traceability

The workflow for using traceability is described in "Generating Reports for Code Reviews and Traceability Analysis" in the Real-Time Workshop Embedded Coder User's Guide.

Here are the basic steps:

1. Open the Embedded MATLAB Function block in your Simulink model.
2. Define your system target file to be an Embedded Real-Time (`ERT`) target.

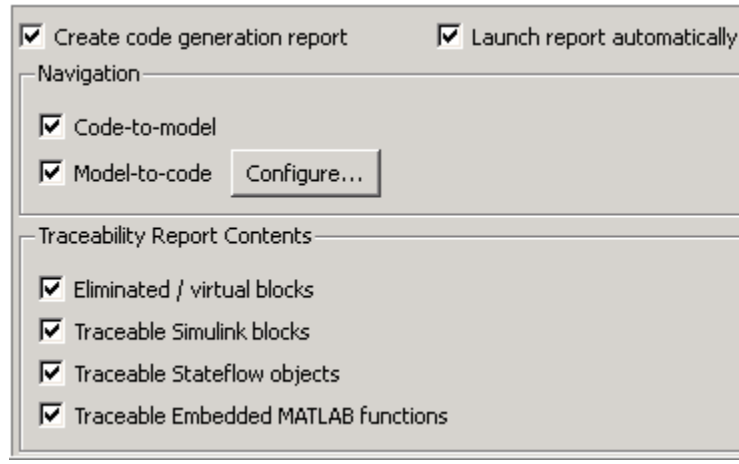
   How?

   a. In the model, open **Simulation > Configuration Parameters**.

   b. In the Real-Time Workshop pane, enter `ert.tlc` for the system target file.
3. Enable traceability options.

   How?

   In the Real-Time Workshop Report pane, enable options, as shown:



4 Generate the source code and header files for your model.

5 Trace a line of code:

To Trace:	Do This:
Line of source code to line of generated code	Right-click in a line in your source code and select **Real-Time Workshop > Navigate to Code** from the context menu
Line of generated code to line of source code	Click a hyperlink in the traceability comment in your generated code

To learn how to complete each step in this workflow, see "Tutorial: Using Traceability in an Embedded MATLAB Function Block" on page 24-172

Tutorial: Using Traceability in an Embedded MATLAB Function Block

This example shows how to trace between source code and generated code in an Embedded MATLAB Function block in the `eml_fire` demo model. Follow these steps:

1 Type `eml_fire` at the MATLAB prompt.

2. In the Simulink model window, double-click the `flame` block to open the Embedded MATLAB Editor.

3. In the Simulink model window, select **Simulation > Configuration Parameters**.

4. In the **Real-Time Workshop** pane, go to the **Target selection** section and enter `ert.tlc` for the system target file. Then click **Apply**.

   Note Traceability comments appear hyperlinked in generated code only for embedded real-time (`ert`) targets.

5. In the **Real-Time Workshop > Report** pane, select the **Create code generation report** option.

   This action automatically selects the **Launch report automatically** and **Code-to-model** options.

6. Select the **Model-to-code** option in the **Navigation** section. Then click **Apply**.

   This action automatically selects all options in the **Traceability Report Contents** section.

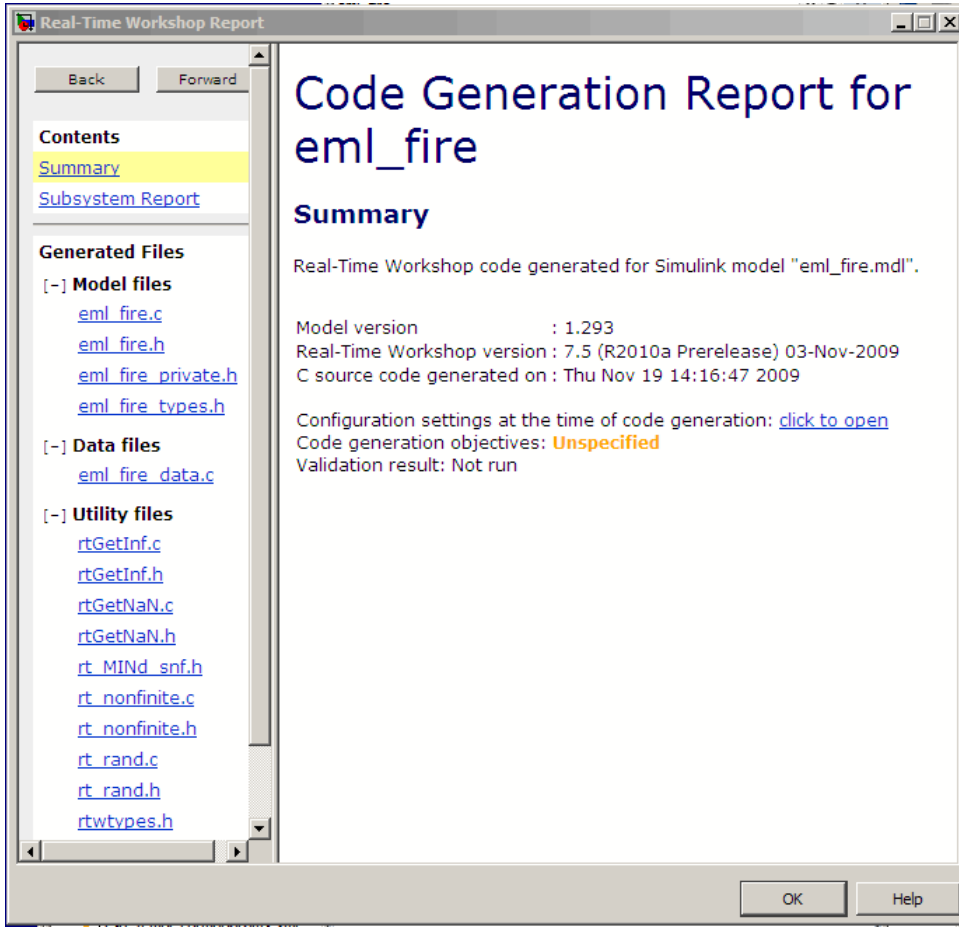
   Note For large models that contain over 1000 blocks, disable the **Model-to-code** option to speed up code generation.

7. Go to the **Real-Time Workshop > Interface** pane. In the **Software environment** section, select the **continuous time** option. Then click **Apply**.

   Note Because this demo model contains a block with a continuous sample time, you must perform this step before generating code.

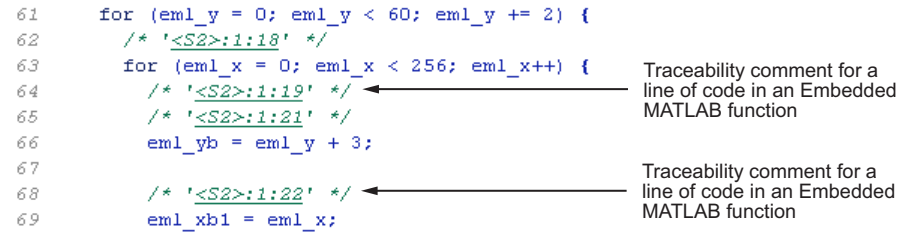
8. In the **Real-Time Workshop** pane, click **Build** in the lower right corner.

This action generates source code and header files for the `eml_fire` model that contains the `flame` block. After the code generation process is complete, the code generation report appears automatically.



9 Click the `eml_fire.c` hyperlink in the report.

10 Scroll down through the code to see the traceability comments.

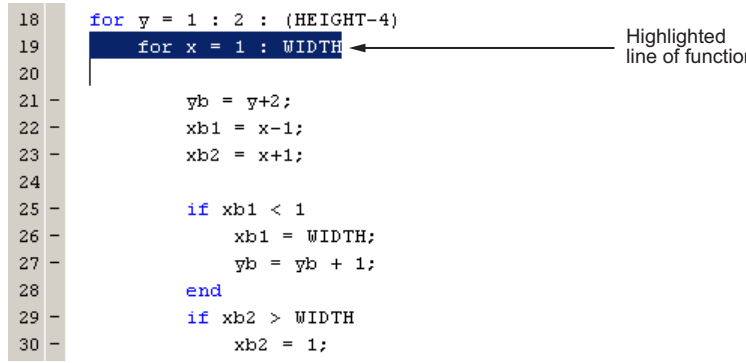


Note The line numbers shown above may differ from the numbers that appear in your code generation report.

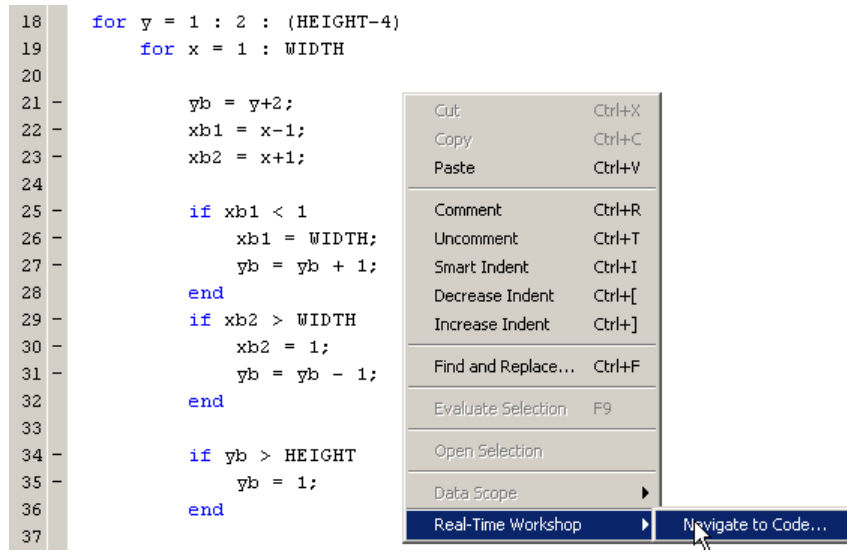
11 Click the `<S2>:1:19` hyperlink in this traceability comment:

```
/* '<S2>:1:19' */
```

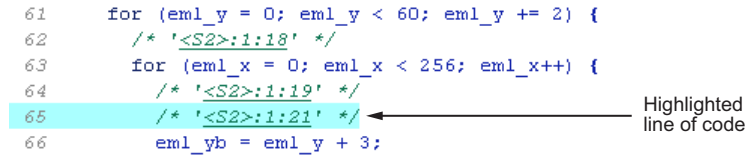
Line 19 of the Embedded MATLAB function appears highlighted in the Embedded MATLAB Editor.



12 You can also trace a line in an Embedded MATLAB function to a line of generated code. For example, right-click in line 21 of your function and select **Real-Time Workshop > Navigate to Code** from the context menu.



The code location for line 21 appears highlighted in `eml_fire.c`.



Including MATLAB Source Code as Comments in the Generated Code

If you have a Real-Time Workshop license, you can include MATLAB source code as comments in the code generated for an Embedded MATLAB Function block. Including this information in the generated code enables you to:

- Correlate the generated code with your source code.
- Understand how the generated code implements your algorithm.
- Evaluate the quality of the generated code.

When you select this option, the generated code includes:

- The source code as a comment immediately after the traceability tag. When you enable traceability and generate code for ERT targets (requires a Real-Time Workshop Embedded Coder license), the traceability tags are hyperlinks to the source code. For more information on traceability for the Embedded MATLAB Function block, see "Using Traceability in Embedded MATLAB Function Blocks" on page 24-170.

  For examples and information on the location of the comments in the generated code, see "Location of Comments in Generated Code" on page 24-178.

- The function help text in the function body in the generated code. The function help text is the first comment after the MATLAB function signature. It provides information about the capabilities of the function and how to use it.

Note With a Real-Time Workshop Embedded Coder license, you can also include the function help text in the function banner of the generated code. For more information, see "Including MATLAB Function Help Text in the Function Banner" on page 24-183.

How to Include MATLAB Code as Comments in the Generated Code

To include MATLAB source code as comments in the code generated for an Embedded MATLAB Function block:

1. In the model, select **Simulation > Configuration Parameters**.
2. In the **Comments** pane, select **MATLAB code as comments** and click **Apply**.

Location of Comments in Generated Code

The automatically generated comments containing the source code appear after the traceability tag in the generated code as follows.

Straight-Line Source Code

The comment containing the source code precedes the generated code that implements the source code statement. This comment appears after any comments that you add that precede the generated code. The comments are separated from the generated code because the statements are assigned to function outputs.

MATLAB Code.

```
function [x y] = straightline(r,theta)
%#eml
% Convert polar to Cartesian
x = r * cos(theta);
y = r * sin(theta);
```

Commented C Code.

```
static void slstraightline_output(int_T tid)
{
  /* Embedded MATLAB: '<Root>/EMLFcn' */
  /* Embedded MATLAB Function 'EMLFcn': '<S1>:1' */
  /*  Convert polar to Cartesian */
  /* '<S1>:1:4' x = r * cos(theta); */
  /* '<S1>:1:5' y = r * sin(theta); */
```

```
  /* Outport: '<Root>/x' incorporates:
   *  Inport: '<Root>/r'
   *  Inport: '<Root>/theta'
   */
  slstraightline_Y.x = slstraightline_U.r *
                       cos(slstraightline_U.theta);

  %/* Outport: '<Root>/y' incorporates:
   *  Inport: '<Root>/r'
   *  Inport: '<Root>/theta'
   */
  slstraightline_Y.y = slstraightline_U.r *
                       sin(slstraightline_U.theta);
}
```

If Statements

The comment for the `if` statement immediately precedes the code that implements the statement. This comment appears after any comments that you add that precede the generated code. The comments for the `elseif` and `else` clauses appear immediately after the code that implements the clause, and before the code generated for statements in the clause.

MATLAB Code.

```
function y = ifstmt(u,v)
%#eml
if u > v
    y = v + 10;
elseif u == v
    y = u * 2;
else
    y = v - 10;
end
```

Commented C Code.

```
static void slifstmt_output(int_T tid)
{
```

```
  /* Embedded MATLAB: '<Root>/EMLFcn' incorporates:
   *  Inport: '<Root>/u'
   *  Inport: '<Root>/v'
   *  Outport: '<Root>/y'
   */
  /* Embedded MATLAB Function 'EMLFcn': '<S1>:1' */
  /* '<S1>:1:3' if u > v */
  if (slifstmt_U.u > slifstmt_U.v) {
    /* '<S1>:1:4' y = v + 10; */
    slifstmt_Y.y = slifstmt_U.v + 10.0;
  } else if (slifstmt_U.u == slifstmt_U.v) {
    /* '<S1>:1:5' elseif u == v */
    /* '<S1>:1:6' y = u * 2; */
    slifstmt_Y.y = slifstmt_U.u * 2.0;
  } else {
    /* '<S1>:1:7' else */
    /* '<S1>:1:8' y = v - 10; */
    slifstmt_Y.y = slifstmt_U.v - 10.0;
  }
}
```

For Statements

The comment for the `for` statement header immediately precedes the generated code that implements the header. This comment appears after any comments that you add that precede the generated code.

MATLAB Code.

```
function y = forstmt(u)
%#eml
y = 0;
for i=1:u
    y = y + 1;
end
```

Commented C Code.

```
static void slforstmt_output(int_T tid)
{
```

```
  real_T eml_i;
  real_T rtb_y;

  /* Embedded MATLAB: '<Root>/EMLFcn' incorporates:
   *  Inport: '<Root>/u'
   */
  /* Embedded MATLAB Function 'EMLFcn': '<S1>:1' */
  /* '<S1>:1:3' y = 0; */
  rtb_y = 0.0;

   /* '<S1>:1:4' for i=1:u */
  for (eml_i = 1.0; eml_i <= slforstmt_U.u; eml_i++) {
    /* '<S1>:1:5' y = y + 1; */
    rtb_y++;
  }

  //* Outport: '<Root>/y' */
  slforstmt_Y.y = rtb_y;
}
```

While Statements

The comment for the `while` statement header immediately precedes the generated code that implements the statement header. This comment appears after any comments that you add that precede the generated code.

MATLAB Code.

```
function y = subfcn(y)
eml.inline('never');
while y < 100
    y = y + 1;
end
```

Commented C Code.

```
static void slwhilestmt_refp1_subfcn(real_T *eml_y)
{
```

```
  /* '<S1>:1:6' eml.inline('never'); */
  /* '<S1>:1:7' while y < 100 */
  while (*eml_y < 100.0) {
    /* '<S1>:1:8' y = y + 1; */
    (*eml_y)++;
  }
}
```

Switch Statements

The comment for the `switch` statement header immediately precedes the generated code that implements the statement header. This comment appears after any comments that you add that precede the generated code. The comments for the `case` and `otherwise` clauses appear immediately after the generated code that implements the clause, and before the code generated for statements in the clause.

MATLAB Code.

```
function y = switchstmt(u)
%#eml
y = 0;
switch u
    case 1
        y = y + 1;
    case 3
        y = y + 2;
    otherwise
        y = y - 1;
end
```

Commented C Code.

```
static void slswitchstmt_output(int_T tid)
{
  /* Embedded MATLAB: '<Root>/EMLFcn' incorporates:
   *  Inport: '<Root>/u'
   *  Outport: '<Root>/y'
   */
```

```
  /* Embedded MATLAB Function 'EMLFcn': '<S1>:1' */
  /* '<S1>:1:3' y = 0; */
  /* '<S1>:1:4' switch u */
  switch ((int32_T)slswitchstmt_U.u) {
   case 1:
    /* '<S1>:1:5' case 1 */
    /* '<S1>:1:6' y = y + 1; */
    slswitchstmt_Y.y = 1.0;
    break;

   case 3:
    /* '<S1>:1:7' case 3 */
    /* '<S1>:1:8' y = y + 2; */
    slswitchstmt_Y.y = 2.0;
    break;

   default:
    /* '<S1>:1:9' otherwise */
    /* '<S1>:1:10' y = y - 1; */
    slswitchstmt_Y.y = -1.0;
    break;
  }
}
```

Including MATLAB Function Help Text in the Function Banner

You can include the function help text in the function banner of the code generated for an Embedded MATLAB Function block. The function help text is the first comment after the MATLAB function signature. It provides information about the capabilities of the function and how to use it.

1. In the model, select **Simulation > Configuration Parameters**.
2. In the **Comments** pane, select **MATLAB function help text** and click **Apply**.

Note If the function is inlined, the function help text is also inlined. Therefore, the help text for inlined functions appears in the function body in the generated code even when this option is selected.

Limitations of MATLAB Source Code as Comments

The Embedded MATLAB Function block has the following limitations for including MATLAB source code as comments.

- You cannot include MATLAB source code as comments for:
  - MathWorks toolbox functions
  - P-code
  - Simulation targets
  - StateflowTruth Table blocks
- The appearance or location of comments can vary depending on the following conditions:
  - Comments might still appear in the generated code even if the implementation code is eliminated, for example, due to constant folding.
  - Comments might be eliminated from the generated code if a complete function or code block is eliminated.
  - For certain optimizations, the comments might be separated from the generated code.
  - The generated code always includes legally required comments from the MATLAB source code, even if you do not choose to include source code comments in the generated code.

Enhancing Readability of Generated Code for Embedded MATLAB Function Blocks

In this section...

Requirements for Using Readability Optimizations

To use readability optimizations in your code, you must have a Real-Time Workshop Embedded Coder license. These optimizations appear only in code that you generate for an embedded real-time (`ert`) target.

Note These optimizations do not apply to MATLAB files that you call from an Embedded MATLAB Function block.

For more information, see "Selecting and Configuring an Embedded Real-Time Target" and "Controlling Code Style" in the Real-Time Workshop Embedded Coder documentation.

Converting If-Elseif-Else Code to Switch-Case Statements

When you generate code for embedded real-time targets, you can choose to convert `if-elseif-else` decision logic to `switch-case` statements. This conversion can enhance readability of the code.

For example, when an Embedded MATLAB Function block contains a long list of conditions, the `switch-case` structure:

- Reduces the use of parentheses and braces
- Minimizes repetition in the generated code

How to Convert If-Elseif-Else Code to Switch-Case Statements

The following procedure describes how to convert generated code for the Embedded MATLAB Function block from `if-elseif-else` to `switch-case` statements.

Step	Task	Reference
1	Verify that your block follows the rules for conversion.	"Verifying the Contents of the Block" on page 24-190
2	Enable the conversion.	"Enabling the Conversion" on page 24-191
3	Generate code for your model.	"Generating Code for Your Model" on page 24-192

Rules for Conversion

For the conversion to occur, the following rules must hold. LHS and RHS refer to the left-hand side and right-hand side of a condition, respectively.

Construct	Rules to Follow
Embedded MATLAB Function block	Must have two or more *unique* conditions, in addition to a default. For more information, see "How the Conversion Handles Duplicate Conditions" on page 24-187.
Each condition	Must test equality only.
	Must use the same variable or expression for the LHS. **Note** You can reverse the LHS and RHS.

Construct	Rules to Follow
Each LHS	Must be a single variable or expression, not a compound statement.
	Cannot be a constant.
	Must have an integer or enumerated data type.
	Cannot have any side effects on simulation. For example, the LHS can read from but not write to global variables.
Each RHS	Must be a constant.
	Must have an integer or enumerated data type.

How the Conversion Handles Duplicate Conditions

If an Embedded MATLAB Function block has duplicate conditions, the conversion preserves only the first condition. The generated code discards all other instances of duplicate conditions.

After removal of duplicates, two or more unique conditions must exist. Otherwise, no conversion occurs and the generated code contains all instances of duplicate conditions.

The following examples show how the conversion handles duplicate conditions.

Example of Generated Code	Code After Conversion

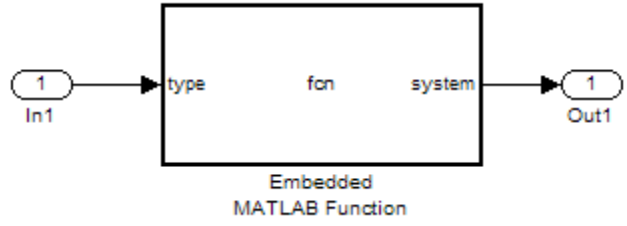
`if (x == 1) {`
`  block1`
`} else if (x == 2) {`
`  block2`
`} else if (x == 1) {  // duplicate`
`  block3`
`} else if (x == 3) {`
`  block4`
`} else if (x == 1) {  // duplicate`
`  block5`
`} else {`
	`switch (x) {`
	`  case 1:`
	`  block1; break;`
	`  case 2:`
	`  block2; break;`
	`  case 3:`
	`  block4; break;`
	`  default:`
	`  block6; break;`

Example of Generated Code	Code After Conversion
`    block6` `}`	`}`

`if (x == 1) {`
`    block1`
`} else if (x == 1) {  // duplicate`
`    block2`
`} else {`
`    block3`
`}`
	No change, because only one unique condition exists

Example of Converting Code for If-Elseif-Else Decision Logic to Switch-Case Statements

Suppose that you have the following model with an Embedded MATLAB Function block. Assume that the output data type is `double` and the input data type is `Controller`, an enumerated type that you define. (See "How to Define Enumerated Data Types for Embedded MATLAB Function Blocks" on page 24-129 for more information.)



The block contains the following code:

```
function system = fcn(type)
%#eml

if (type == Controller.P)
    system = 0;
elseif (type == Controller.I)
    system = 1;
elseif (type == Controller.PD)
    system = 2;
elseif (type == Controller.PI)
    system = 3;
elseif (type == Controller.PID)
    system = 4;
else
    system = 10;
end
```

The enumerated type definition in `Controller.m` is:

```
classdef(Enumeration) Controller < Simulink.IntEnumType
  enumeration
    P(0)
    I(1)
    PD(2)
    PI(3)
    PID(4)
    UNKNOWN(10)
  end
end
```

If you generate code for an embedded real-time target using default settings, you see something like this:

```
if (if_to_switch_eml_blocks_U.In1 == P) {
  /* '<S1>:1:4' */
  /* '<S1>:1:5' */
  if_to_switch_eml_blocks_Y.Out1 = 0.0;
} else if (if_to_switch_eml_blocks_U.In1 == I) {
  /* '<S1>:1:6' */
```

```
  /* '<S1>:1:7' */
  if_to_switch_eml_blocks_Y.Out1 = 1.0;
} else if (if_to_switch_eml_blocks_U.In1 == PD) {
  /* '<S1>:1:8' */
  /* '<S1>:1:9' */
  if_to_switch_eml_blocks_Y.Out1 = 2.0;
} else if (if_to_switch_eml_blocks_U.In1 == PI) {
  /* '<S1>:1:10' */
  /* '<S1>:1:11' */
  if_to_switch_eml_blocks_Y.Out1 = 3.0;
} else if (if_to_switch_eml_blocks_U.In1 == PID) {
  /* '<S1>:1:12' */
  /* '<S1>:1:13' */
  if_to_switch_eml_blocks_Y.Out1 = 4.0;
} else {
  /* '<S1>:1:15' */
  if_to_switch_eml_blocks_Y.Out1 = 10.0;
}
```

The LHS variable `if_to_switch_eml_blocks_U.In1` appears multiple times in the generated code.

Note By default, variables that appear in the block do not retain their names in the generated code. Modified identifiers guarantee that no naming conflicts occur.

Traceability comments appear between each set of `/*` and `*/` markers. To learn more about traceability, see "Using Traceability in Embedded MATLAB Function Blocks" on page 24-170.

Verifying the Contents of the Block

Check that the block follows all the rules in "Rules for Conversion" on page 24-186.

Construct	How the Construct Follows the Rules
Embedded MATLAB Function block	Five unique conditions exist, in addition to the default: • `(type == Controller.P)` • `(type == Controller.I)` • `(type == Controller.PD)` • `(type == Controller.PI)` • `(type == Controller.PID)`
Each condition	Each condition: • Tests equality • Uses the same input for the LHS
Each LHS	Each LHS: • Contains a single variable • Is the input to the block and therefore not a constant • Is of enumerated type `Controller`, which you define in `Controller.m` on the MATLAB path • Has no side effects on simulation
Each RHS	Each RHS: • Is an enumerated value and therefore a constant • Is of enumerated type `Controller`

Enabling the Conversion

1. Open the Configuration Parameters dialog box.
2. In the **Real-Time Workshop** pane, select `ert.tlc` for the **System target file**.

   This step specifies an embedded real-time target for your model.

3 In the **Real-Time Workshop > Code Style** pane, select the **Convert if-elseif-else patterns to switch-case statements** check box.

Tip This conversion works on a per-model basis. If you select this check box, the conversion applies to:

- All Embedded MATLAB Function blocks in a model
- Embedded MATLAB functions in all Stateflow charts of that model
- Flow graphs in all Stateflow charts of that model

For more information, see "Enhancing Readability of Generated Code for Flow Graphs" in the Stateflow documentation.

Generating Code for Your Model

In the **Real-Time Workshop** pane of the Configuration Parameters dialog box, click **Build** in the lower right corner.

The code for the Embedded MATLAB Function block uses `switch-case` statements instead of `if-elseif-else` code:

```
switch (if_to_switch_eml_blocks_U.In1) {
 case P:
  /* '<S1>:1:4' */
  /* '<S1>:1:5' */
  if_to_switch_eml_blocks_Y.Out1 = 0.0;
  break;

 case I:
  /* '<S1>:1:6' */
  /* '<S1>:1:7' */
  if_to_switch_eml_blocks_Y.Out1 = 1.0;
  break;

 case PD:
  /* '<S1>:1:8' */
  /* '<S1>:1:9' */
```

```
    if_to_switch_eml_blocks_Y.Out1 = 2.0;
    break;

   case PI:
    /* '<S1>:1:10' */
    /* '<S1>:1:11' */
    if_to_switch_eml_blocks_Y.Out1 = 3.0;
    break;

   case PID:
    /* '<S1>:1:12' */
    /* '<S1>:1:13' */
    if_to_switch_eml_blocks_Y.Out1 = 4.0;
    break;

   default:
    /* '<S1>:1:15' */
    if_to_switch_eml_blocks_Y.Out1 = 10.0;
    break;
  }
```

The `switch-case` statements provide the following benefits to enhance readability:

- The code reduces the use of parentheses and braces.
- The LHS variable `if_to_switch_eml_blocks_U.In1` appears only once, minimizing repetition in the code.

Speeding Up Simulation with the Basic Linear Algebra Subprograms (BLAS) Library

In this section...

How Embedded MATLAB Function Blocks Use the BLAS Library

The Basic Linear Algebra Subprograms (BLAS) Library is a library of external linear algebra routines optimized for fast computation of low-level matrix operations. By default, Embedded MATLAB Function blocks call BLAS library routines to speed simulation whenever possible, based on heuristics implemented in the Embedded MATLAB subset. These heuristics are described in "How Embedded MATLAB Functions Use the BLAS Library" in the Embedded MATLAB documentation.

When to Disable BLAS Library Support

Consider disabling BLAS library support for Embedded MATLAB Function blocks when:

- You want your simulation results to more closely agree with code generated by Real-Time Workshop for your Embedded MATLAB Function block.
- You are executing code on a 64-bit platform and the number of elements in a matrix exceeds 32 bits.

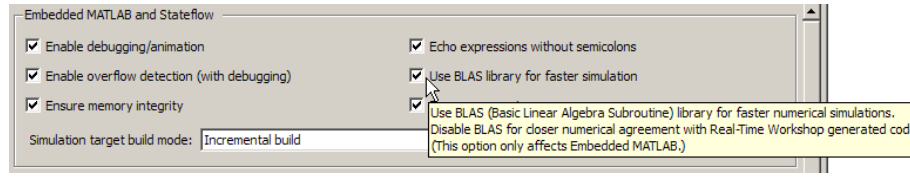
  In this case, Embedded MATLAB automatically truncates the matrix size to 32 bits.
- Your platform does not provide a robust implementation of BLAS routines.

How to Disable BLAS Library Support

Embedded MATLAB Function blocks enable BLAS library support by default, but you can disable this feature explicitly for all Embedded MATLAB Function blocks in your Simulink model. Follow these steps:

1. Open your Embedded MATLAB Function block.
2. In the Embedded MATLAB Editor, select **Tools > Open Simulation Target**.

   The Configuration Parameters dialog box opens with Simulation Target selected.
3. Under the **Embedded MATLAB and Stateflow** panel, clear the **Use BLAS library for faster simulation** check box and click **Apply**.



Supported Compilers

Embedded MATLAB function blocks use the BLAS library on all C compilers **except**:

- Watcom
- Intel
- Borland

The default MATLAB compiler, `lcc`, supports the BLAS library. To install a different C compiler, use the `mex -setup` command, as described in "Building MEX-Files" in the MATLAB External Interfaces documentation.

Controlling Run-Time Checks

In this section...

Types of Run-Time Checks

In simulation, the code generated for your Embedded MATLAB Function block includes the following run-time checks:

- Memory integrity checks

  These checks detect violations of memory integrity in code generated for Embedded MATLAB Function blocks and stop execution with a diagnostic message.

  Caution For safety, these checks are enabled by default. Without memory integrity checks, violations will result in unpredictable behavior.

- Responsiveness checks in code generated for Embedded MATLAB Function blocks

  These checks enable periodic checks for Ctrl+C breaks in code generated for Embedded MATLAB functions. Enabling responsiveness checks also enables graphics refreshing.

  Caution For safety, these checks are enabled by default. Without these checks, the only way to end a long-running execution might be to terminate MATLAB.

When to Disable Run-Time Checks

Generally, generating code with run-time checks enabled results in more lines of generated code and slower simulation than generating code with the checks disabled. Disabling run-time checks usually results in streamlined generated code and faster simulation, with these caveats:

Consider disabling...	Only if...
Memory integrity checks	You are sure that your code is safe and that all array bounds and dimension checking is unnecessary.
Responsiveness checks	You are sure that you will not need to stop execution of your application using Ctrl+C.

How to Disable Run-Time Checks

Embedded MATLAB Function blocks enable run-time checks by default, but you can disable them explicitly for all Embedded MATLAB Function blocks in your Simulink model. Follow these steps:

1. Open your Embedded MATLAB Function block.
2. In the Embedded MATLAB Editor, select **Tools > Open Simulation Target**.

   The Configuration Parameters dialog box opens with Simulation Target selected.
3. Under the **Embedded MATLAB and Stateflow** panel, clear the **Ensure memory integrity** or **Ensure responsiveness** check boxes, as applicable, and click **Apply**.

Tutorial: Integrating MATLAB Code with a Simulink Model for Filtering an Audio Signal

In this section...

Learning Objectives

In this tutorial, you will learn how to:

- Use the Embedded MATLAB Function block to add MATLAB functions to Simulink models for modeling, simulation, and deployment to embedded processors.

  This capability is useful for coding algorithms that are better stated in the textual language of MATLAB than in the graphical language of Simulink. For more information, see Chapter 24, "Using the Embedded MATLAB Function Block" in the Simulink® User's Guide on page 1.

- Use `eml.extrinsic` to call MATLAB code from an Embedded MATLAB Function block.

  This capability allows you to call existing MATLAB code from Simulink without first having to make this code compliant with the Embedded MATLAB subset, allowing for rapid prototyping.

- Check that existing MATLAB code is compliant with the Embedded MATLAB subset.

  You must make your code compliant before generating code.

- Convert a MATLAB algorithm from batch processing to streaming.

- Use persistent variables in Embedded MATLAB code.

You need to make the filter weights persistent so that the filter algorithm does not reset their values each time it runs.

Tutorial Prerequisites

What You Need to Know

To work through this tutorial, you should have basic familiarity with MATLAB software. You should also understand how to create a basic Simulink model and how to simulate that model. For more information, see "Simulink Software Basics" in the Simulink documentation.

Required Products

To complete this tutorial, you must install the following products:

- MATLAB
- Simulink
- Real-Time Workshop
- Signal Processing Blockset
- C compiler (a default C compiler is supplied with MATLAB)

  For a list of supported compilers, see .

For instructions on installing MathWorks products, refer to the installation documentation. If you have installed MATLAB and want to check which other MathWorks products are installed, enter `ver` in the MATLAB Command Window. For instructions on installing and setting up a C compiler, see "Setting Up the C Compiler" in the *Embedded MATLAB User's Guide*.

Example: The LMS Filter

Description

A least mean squares (LMS) filter is an adaptive filter that adjusts its transfer function according to an optimizing algorithm. You provide the filter with an example of the desired signal together with the input signal. The filter then calculates the filter weights, or coefficients, that produce the least mean squares of the error between the output signal and the desired signal.

This example uses an LMS filter to remove the noise in a music recording. There are two inputs. The first input is the distorted signal: the music recording plus the filtered noise. The second input is the desired signal: the unfiltered noise. The filter works to eliminate the difference between the output signal and the desired signal and outputs the difference, which, in this case, is the clean music recording. When you start the simulation, you hear both the noise and the music. Over time, the adaptive filter removes the noise so you hear only the music.

Algorithm

This example uses the least mean squares (LMS) algorithm to remove noise from an input signal. The LMS algorithm computes the filtered output, filter error, and filter weights given the distorted and desired signals.

At the start of the tutorial, the LMS algorithm uses a batch process to filter the audio input. This algorithm is suitable for MATLAB, where you are likely to load in the entire signal and process it all at once. However, a batch process is not suitable for processing a signal in real time. As you work through the tutorial, you refine the design of the filter to convert the algorithm from batch-based to stream-based processing.

The baseline function signature for the algorithm is:

```
function [ signal_out, err, weights ] = ...
    lms_01(signal_in, desired)
```

The filtering is performed in the following loop:

```
for n = 1:SignalLength
```

```
    % Compute the output sample using convolution:
    signal_out(n,ch) = weights' * signal_in(n:n+FilterLength-1,ch);
    % Update the filter coefficients:
    err(n,ch) = desired(n,ch) - signal_out(n,ch) ;
    weights = weights + mu*err(n,ch)*signal_in(n:n+FilterLength-1,ch);
  end
```

where `SignalLength` is the length of the input signal, `FilterLength` is the filter length, and `mu` is the adaptation step size.

What Is the Adaptation Step Size?

LMS algorithms have a step size that determines the amount of correction to apply as the filter adapts from one iteration to the next. Choosing the appropriate step size requires experience in adaptive filter design. A step size that is too small increases the time for the filter to converge. Filter convergence is the process where the error signal (the difference between the output signal and the desired signal) approaches an equilibrium state over time. A step size that is too large might cause the adapting filter to overshoot the equilibrium and become unstable. Generally, smaller step sizes improve the stability of the filter at the expense of the time it takes to adapt.

Filtering Process

The filtering process has three phases:

- Convolution

  The convolution for the filter is performed in:

  ```
  signal_out(n,ch) = weights' * signal_in(n:n+FilterLength-1,ch);
  ```

  ### What Is Convolution?

  Convolution is the mathematical foundation of filtering. In signal processing, convolving two vectors or matrices is equivalent to filtering one of the inputs by the other. In this implementation of the LMS filter, the convolution operation is the vector dot product between the filter weights and a subset of the distorted input signal.

- Calculation of error

The error is the difference between the desired signal and the output signal:

```
err(n,ch) = desired(n,ch) - signal_out(n,ch);
```

- Adaptation

  The new value of the filter weights is the old value of the filter weights plus a correction factor that is based on the error signal, the distorted signal, and the adaptation step size:

```
weights = weights + mu*err(n,ch)*signal_in(n:n+FilterLength-1,ch);
```

Reference

Haykin, Simon. *Adaptive Filter Theory*. Upper Saddle River, NJ: Prentice-Hall, Inc., 1996.

Files for the Tutorial

About the Tutorial Files

The tutorial uses the following files:

- Simulink model files for each step of the tutorial.
- MATLAB code files for each step of the example.

  Throughout this tutorial, you work with Simulink models that call MATLAB files that contain a simple least mean squares (LMS) filter algorithm.

Location of Files

The tutorial files are available in the following folder: `docroot\toolbox\eml\gs\examples\lms`. To run the tutorial, you must copy these files to a local folder. For instructions, see "Copying Files Locally" on page 24-204.

Names and Descriptions of Files

Type	Name	Description
MATLAB files	`lms_01.m`	Baseline MATLAB implementation of batch filter. Not Embedded MATLAB compliant.
	`lms_02.m`	Filter modified from batch to streaming.
	`lms_03.m`	Frame-based streaming filter with Reset and Adapt controls.
	`lms_04.m`	Embedded MATLAB compliant frame-based streaming filter with Reset and Adapt controls.
	`lms_05.m`	Disabled inlining for code generation.
	`lms_06.m`	Demonstrates use of `eml.nullcopy`.
Simulink model files	`acoustic_environment.mdl`	Simulink model that provides an overview of the acoustic environment.
	`noise_cancel_00.mdl`	Simulink model without an Embedded MATLAB Function block.
	`noise_cancel_01.mdl`	Complete `noise_cancel_00` model including an Embedded MATLAB Function block.
	`noise_cancel_02.mdl`	Simulink model for use with `lms_02.m`.
	`noise_cancel_03.mdl`	Simulink model for use with `lms_03.m`.
	`noise_cancel_04.mdl`	Simulink model for use with `lms_04.m`.
	`noise_cancel_05.mdl`	Simulink model for use with `lms_05.m`.
	`noise_cancel_06.mdl`	Simulink model for use with `lms_06.m`.
	`design_templates.mdl`	Simulink model containing Adapt and Reset controls.

Tutorial Steps

- "Copying Files Locally" on page 24-204

Copying Files Locally

Copy the tutorial files to a local folder:

1. Create a local *`solutions`* folder, for example, `c:\eml\lms\solutions`.

2. Change to the `docroot\toolbox\eml\gs\examples` folder. At the MATLAB command line, enter:

   ```
   cd([docroot '\toolbox\eml\gs\examples'])
   ```

3. Copy the contents of the `lms` subfolder to your *`solutions`* folder, specifying the full path name of the *`solutions`* folder:

   ```
   copyfile('lms', 'solutions')
   ```

   Your *`solutions`* folder now contains a complete set of solutions for the tutorial. If you do not want to perform the steps for each task, you can view the supplied solution to see how the code should look.

4. Create a local *`work`* folder, for example, `c:\eml\lms\work`.

5. Copy the following files from your *`solutions`* folder to your *`work`* folder.

   - `lms_01.m`

- `lms_02.m`
- `noise_cancel_00.mdl`
- `acoustic_environment.mdl`
- `design_templates.mdl`

Your *`work`* folder now contains all the files that you need to get started.

You are now ready to set up your C compiler.

Setting Up Your C Compiler

Before generating code for your Simulink model, you must set up your C compiler. For most platforms, MathWorks supplies a default compiler with MATLAB. If your installation does not include a default compiler, for a list of supported compilers for the current release of MATLAB, see and install a compiler that is suitable for your platform.

To install a compiler:

1. At the MATLAB command line, enter:

   ```
   mex -setup
   ```

2. Enter `y` to see the list of installed compilers.
3. Select a supported compiler.
4. Enter `y` to verify your choice.

Running the acoustic_environment Model

Run the `acoustic_environment` model supplied with the tutorial to understand the problem that you are trying to solve using the LMS filter. This model adds band-limited white noise to an audio signal and outputs the resulting signal to a speaker.

To simulate the model:

1. Open `acoustic_environment.mdl` in Simulink:

   a. Set your MATLAB current folder to the folder that contains your working files for this tutorial. At the MATLAB command line, enter:

      ```
      cd work
      ```

      where *`work`* is the full path name of the folder containing your files. See "Using the Current Folder Browser" in the MATLAB Desktop Tools and Development Environment documentation for more information.

   b. At the MATLAB command line, enter:

      ```
      acoustic_environment
      ```

      The model opens.

2. Ensure that your speakers are on.

3. To simulate the model, from the Simulink model window, select **Simulation > Start**.

   As Simulink runs the model, you hear the audio signal distorted by noise.

4. While the simulation is running, double-click the Manual Switch to select the audio source.

   Now you hear the desired audio input without any noise.

The goal of this tutorial is to use a MATLAB LMS filter algorithm to remove the noise from the noisy audio signal. You do this by adding an Embedded MATLAB Function block to the model and calling the MATLAB code from this block. To learn how, see "Adding an Embedded MATLAB Function Block to Your Model" on page 24-206.

Adding an Embedded MATLAB Function Block to Your Model

To modify the model and code yourself, work through the exercises in this section. Otherwise, open the supplied model `noise_cancel_01.mdl` in your *`solutions`* subfolder to see the modified model.

For the purposes of this tutorial, you add the Embedded MATLAB Function block to the `noise_cancel_00.mdl` model supplied with the tutorial. In

practice, you would have to develop your own test bench starting with an empty Simulink model.

To add an Embedded MATLAB Function block to the `noise_cancel_00` model:

1. Open `noise_cancel_00.mdl` in Simulink.

   ```
   noise_cancel_00
   ```

2. Add an Embedded MATLAB Function block to the model:
   a. At the MATLAB command line, type `simulink` to open the Simulink Library Browser.
   b. From the list of Simulink libraries, select the `User-Defined Functions` library.
   c. Click the Embedded MATLAB Function block and drag it into the `noise_cancel_00` model. Place the block just above the red text annotation `Place Embedded MATLAB Function Block here.`
   d. Delete the red text annotations from the model.
   e. Save the model in the current folder as `noise_cancel_01`.

Calling Your MATLAB Code As an Extrinsic Function for Rapid Prototyping

In this part of the tutorial, you use the `eml.extrinsic` function to call your MATLAB code from the Embedded MATLAB Function block for rapid prototyping.

Why Call MATLAB Code As an Extrinsic Function?. Calling MATLAB code as an extrinsic function provides these benefits:

- For rapid prototyping, you do not have to make the MATLAB code compliant with the Embedded MATLAB subset.
- Using `eml.extrinsic` enables you to debug your MATLAB code in MATLAB. You can add one or more breakpoints in the `lms_01.m` file, and then start the simulation in Simulink. When the MATLAB interpreter encounters a breakpoint, it temporarily halts execution so that you can inspect the MATLAB workspace and view the current values of all variables

in memory. For more information about debugging MATLAB code, see "Editing and Debugging MATLAB Code" in the MATLAB documentation.

How to Call MATLAB Code As an Extrinsic Function. To call your MATLAB code from the Embedded MATLAB Function block:

1. Double-click the Embedded MATLAB Function block to open the Embedded MATLAB Editor.
2. Delete the default code displayed in the Embedded MATLAB Editor.
3. Copy the following code to the Embedded MATLAB Function block.

```
function [ Signal_Out, Weights ] = LMS(Noise_In, Signal_In) %#eml
    % Extrinsic:
    eml.extrinsic('lms_01');

    % Compute LMS:
    [ ~, Signal_Out, Weights ] = lms_01(Noise_In, Signal_In);
end
```

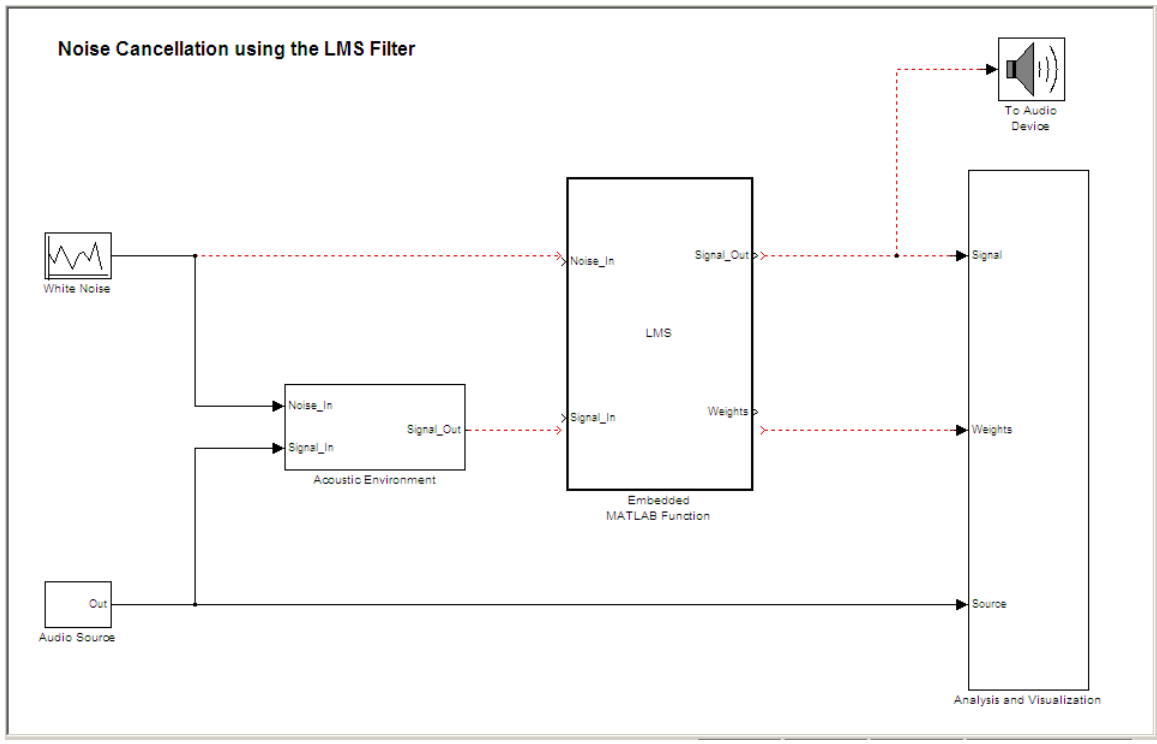
Why Use the Tilde (~) Operator?

Because the `LMS` function does not use the first output from `lms_01`, replace this output with the MATLAB ~ operator. MATLAB ignores inputs and outputs specified by ~. This syntax helps avoid confusion in your program code and unnecessary clutter in your workspace, and allows you to reuse existing algorithms without modification.

4. Save the model.

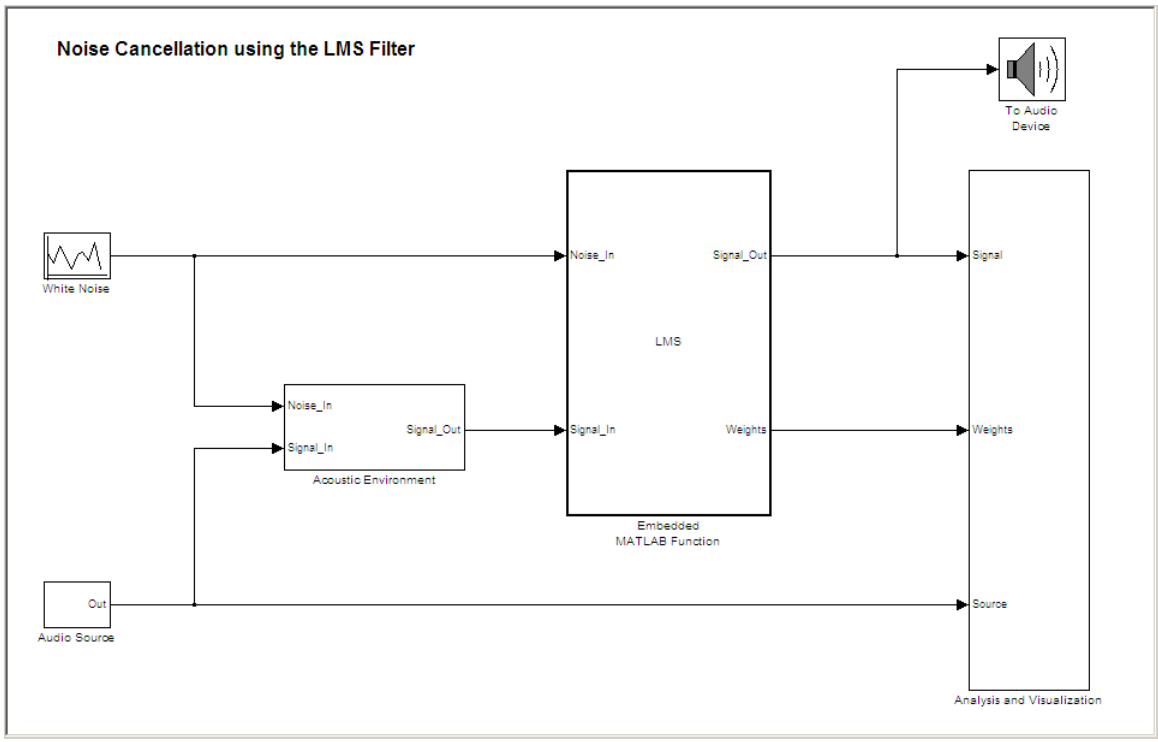
   The `lms_01` function inputs `Noise_In` and `Signal_In` now appear as input ports to the block and the function outputs `Signal_Out` and `Weights` appear as output ports.

5. Resize the Embedded MATLAB Function block.



Connecting the Embedded MATLAB Function Block Inputs and Outputs.

1 Connect the Embedded MATLAB Function block inputs and outputs so that your model looks like this.



See “Connecting Blocks” on page 3-15 in the Simulink documentation for more information.

2 In the Embedded MATLAB Function block code, preallocate the outputs by adding the following code after the extrinsic call:

```
% Outputs:
Signal_Out = zeros(size(Signal_In));
Weights = zeros(32,1);
```

The size of `Weights` is set to match the Numerator coefficients of the Digital Filter in the Acoustic Environment subsystem.

Why Preallocate the Outputs?

In Embedded MATLAB, you must assign variables explicitly to have a specific class, size, and complexity before using them in operations or returning them as outputs in Embedded MATLAB functions. For more information, see "Working with Variables".

3 Save the model.

You are now ready to check your model for errors.

Checking the noise_cancel_01 Model.

1 In the Simulink model window, select **Edit > Update Diagram**.

Simulink fails to update diagram.

Because the Analysis and Visualization block expects to receive a frame-based signal from the LMS filter, you must configure the Embedded MATLAB Function block `Signal_Out` output parameter to be frame-based rather than sample-based.

- **a** Double-click the Embedded MATLAB Function block to open the Embedded MATLAB Editor.
- **b** Select **Tools > Edit Data/Ports** to open the Ports and Data Manager.
- **c** Select the signal called `Signal_Out` from the list in the left pane.
- **d** On the **General** tab, change the **Sampling mode** from `Sample based` to `Frame based`.
- **e** Click the **Apply** button and close the Ports and Data Manager and the Embedded MATLAB Editor.
- **f** Save the model.

2 Check the model again; select **Edit > Update Diagram** in the Simulink model window.

Simulink updates diagram successfully. You are ready for the next task, "Simulating the noise_cancel_01 Model" on page 24-212

Simulating the noise_cancel_01 Model

To simulate the model:

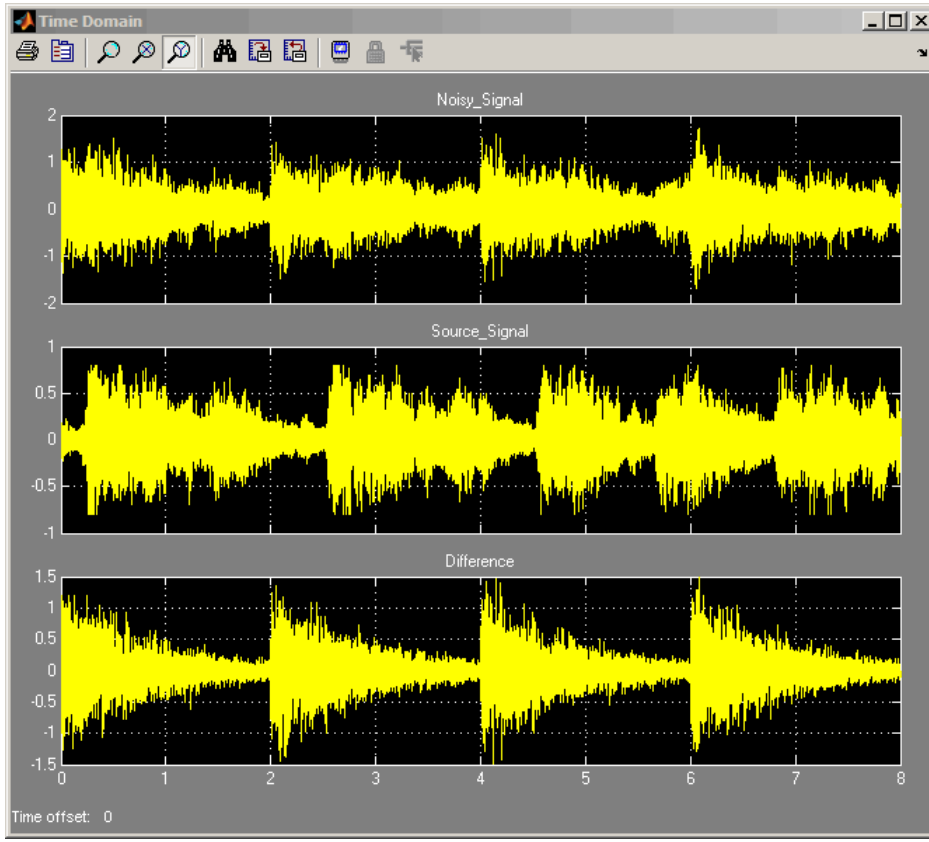
1. Ensure that you can see the **Time Domain** plots.

   To view the plots, in the `noise_cancel_01` model, open the Analysis and Visualization block and then open the Time Domain block.

2. In the Simulink model window, select **Simulation > Start**.

   As Simulink runs the model, you see and hear outputs. Initially, you hear the audio signal distorted by noise. Then the filter attenuates the noise gradually, until you hear only the music playing with very little noise remaining. After two seconds, you hear the distorted noisy signal again and the filter attenuates the noise again. This cycle repeats continuously.

MATLAB displays the following plot showing this cycle.



3 Stop the simulation.

Why Does the Filter Reset Every 2 Seconds?

The filter resets every 2 seconds because the model uses `16384` samples per frame and a sampling rate of `8192`, so the `16384` samples represent 2 seconds of audio.

To see the model configuration:

1. Double-click the White Noise subsystem and note that it uses a **Sample time** of `1/Fs` and **Samples per frame** of `FrameSize`. The `music` in the Audio Source subsystem also uses these values.

2. `FrameSize` is set in the model `InitFcn` callback. To view this callback:
   a. Select **File > Model Properties**.
   b. Select the **Callback** tab.
   c. Select `InitFcn` in the **Model callbacks** pane.

   Note that `FrameSize = 16*1024`, which is `16384`.

3. `Fs` is set in the model `PostLoadFcn` callback. To view this callback:
   a. Select **File > Model Properties**.
   b. Select the **Callback** tab.
   c. Select `PostLoadFcn` in the **Model callbacks** pane.

   The following MATLAB commands set up `Fs`:

```
data = load('handel.mat');
music = data.y;
Fs = data.Fs;
```

Modifying the Filter to Use Streaming

What Is Streaming?. A streaming filter is called repeatedly to process fixed-size chunks of input data, or *frames*, until it has processed the entire input signal. The frame size can be as small as a single sample, in which case the filter would be operating in a sample-based mode, or up to a few thousand samples, for frame-based processing.

Why Use Streaming?. The design of the filter algorithm in `lms_01` has the following disadvantages:

- The algorithm does not use memory efficiently.

  Preallocating a fixed amount of memory for each input signal for the lifetime of the program means more memory is allocated than is in use.

- You must know the size of the input signal at the time you call the function.

  If the input signal is arriving in real time or as a stream of samples, you would have to wait to accumulate the entire signal before you could pass it, as a batch, to the filter.

- The signal size is limited to a maximum size.

In an embedded application, the filter is likely to be processing a continuous input stream. As a result, the input signal can be substantially longer than the maximum length that a filter working in batch mode could possibly handle. To make the filter work for any signal length, it must run in real time. One solution is to convert the filter from batch-based processing to stream-based processing.

Viewing the Modified MATLAB Code. The conversion to streaming involves:

- Introducing a first-in, first-out (FIFO) queue

  The FIFO queue acts as a temporary storage buffer, which holds a small number of samples from the input data stream. The number of samples held by the FIFO queue must be exactly the same as the number of samples in the filter's impulse response, so that the function can perform the convolution operation between the filter coefficients and the input signal.

- Making the FIFO queue and the filter weights persistent

The filter is called repeatedly until it has processed the entire input signal. Therefore, the FIFO queue and filter weights need to persist so that the adaptation process does not have to start over again after each subsequent call to the function.

Open the supplied file `lms_02.m` in your *`work`* subfolder to see the modified algorithm.

Summary of Changes to the Filter Algorithm. Note the following important changes to the filter algorithm:

- The filter weights and the FIFO queue are declared as persistent:

```
persistent weights;
persistent fifo;
```

- The FIFO queue is initialized:

```
fifo = zeros(FilterLength,ChannelCount);
```

- The FIFO queue is used in the filter update loop:

```
% For each channel:
for ch = 1:ChannelCount

   % For each sample time:
   for n = 1:FrameSize

     % Update the FIFO shift register:
     fifo(1:FilterLength-1,ch) = fifo(2:FilterLength,ch);
     fifo(FilterLength,ch) = signal_in(n,ch);

     % Compute the output sample using convolution:
     signal_out(n,ch) = weights' * fifo(:,ch);

     % Update the filter coefficients:
     err(n,ch) = desired(n,ch) - signal_out(n,ch) ;
     weights = weights + mu*err(n,ch)*fifo(:,ch);

   end
end
```

- You cannot output a persistent variable. Therefore, a new variable, `weights_out`, is used to output the filter weights:

```
function [ signal_out, err, weights_out ] = ...
  lms_02(distorted, desired)

weights_out = weights;
```

Modifying Your Model to Call the Updated Algorithm. To modify the model yourself, work through the exercises in this section. Otherwise, open the supplied model `noise_cancel_02.mdl` in your *`solutions`* subfolder to see the modified model.

1. In the `noise_cancel_01` model, double-click the Embedded MATLAB Function block to open the Embedded MATLAB Editor.
2. Modify the Embedded MATLAB Function block code to call `lms_02`.
   a. Modify the extrinsic call.

```
% Extrinsic:
eml.extrinsic('lms_02');
```

   b. Modify the call to the filter algorithm.

```
% Compute LMS:
[ ~, Signal_Out, Weights ] = lms_02(Noise_In, Signal_In);
```

Modified Embedded MATLAB Function Block Code

Your Embedded MATLAB Function block code should now look like this:

```
function [ Signal_Out, Weights ] = LMS(Noise_In, Signal_In)
  % Extrinsic:
  eml.extrinsic('lms_02');
  % Outputs:
  Signal_Out = zeros(size(Signal_In));
  Weights = zeros(32,1);
  % Compute LMS:
  [ ~, Signal_Out, Weights ] = lms_02(Noise_In, Signal_In);
end
```

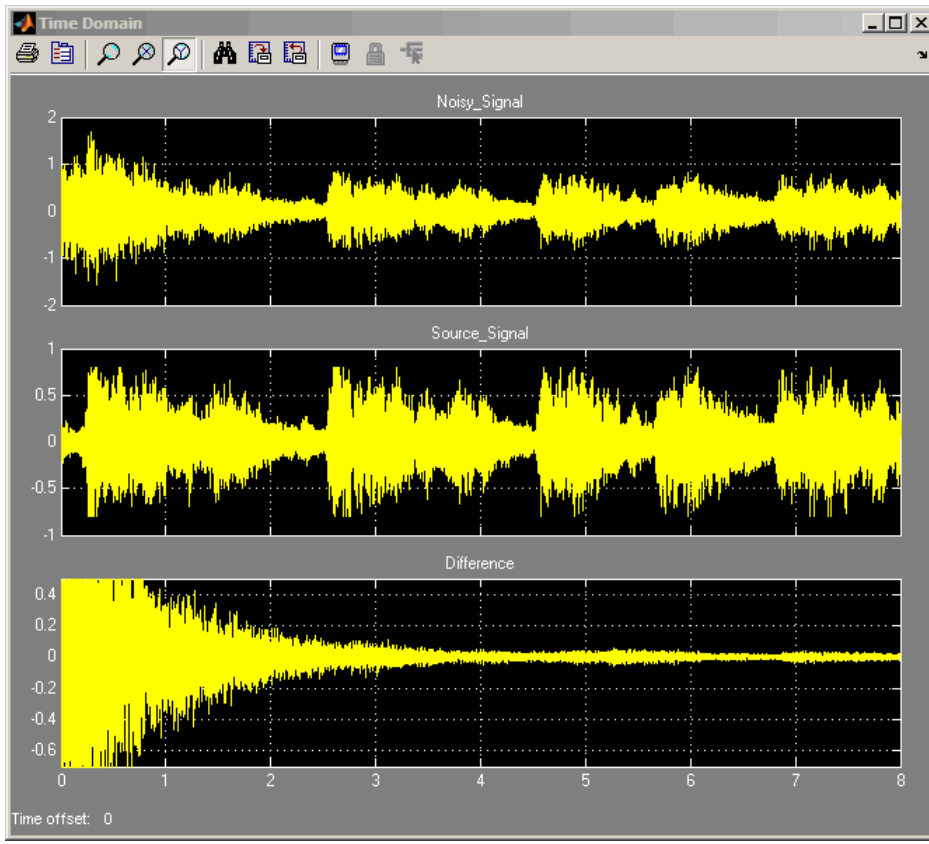
3. Change the frame size from `16384` to `64`, which represents a more realistic value.
   a. In the Simulink model window, select **File > Model Properties**.

      The **Model Properties** dialog box opens.
   b. Select the **Callbacks** tab.
   c. In the **Model callbacks** list, select `InitFcn`.
   d. Change the value of `FrameSize` to `64`.
   e. Click **Apply** and close the dialog box.
4. Save your model as `noise_cancel_02.mdl`.

Simulating the Streaming Algorithm. To simulate the model:

1. Ensure that you can see the **Time Domain** plots.
2. Start the simulation.

   As Simulink runs the model, you see and hear outputs. Initially, you hear the audio signal distorted by noise. Then, during the first few seconds, the filter attenuates the noise gradually, until you hear only the music playing with very little noise remaining. MATLAB displays the following plot showing filter convergence after only a few seconds.



3 Stop the simulation.

The filter algorithm is now suitable for Simulink. You are ready to elaborate your model to use `Adapt` and `Reset` controls.

Adding Adapt and Reset Controls

Why Add Adapt and Reset Controls?. In this part of the tutorial, you add Adapt and Reset controls to your filter. Using these controls, you can turn the filtering on and off. When `Adapt` is enabled, the filter continuously updates the filter weights. When `Adapt` is disabled, the filter weights remain at their current values. If `Reset` is set, the filter resets the filter weights.

Modifying Your MATLAB Code. To modify the code yourself, work through the exercises in this section. Otherwise, open the supplied file `lms_03.m` in your *`solutions`* subfolder to see the modified algorithm.

To modify your filter code:

1. Open `lms_02.m`.
2. In the `Set up` section, replace

   ```
   if ( isempty(weights) )
   ```

   with

   ```
   if ( reset || isempty(weights) )
   ```

3. In the filter loop, update the filter coefficients only if `Adapt` is `ON`.

   ```
   if adapt
     weights = weights + mu*err(n,ch)*fifo(:,ch);
   end
   ```

4. Change the function signature to use the `Adapt` and `Reset` inputs and change the function name to `lms_03`.

   ```
   function [ signal_out, err, weights_out ] = ...
     lms_03(signal_in, desired, reset, adapt)
   ```

5. Save the file in the current folder as `lms_03.m`:

Summary of Changes to the Filter Algorithm

Note the following important changes to the filter algorithm:

- The new input parameter `reset` is used to determine if it is necessary to reset the filter coefficients:

```
if ( reset || isempty(weights) )
  % Filter coefficients:
  weights = zeros(L,1);
  % FIFO Shift Register:
  fifo = zeros(L,1);
end
```

- The new parameter `adapt` is used to control whether the filter coefficients are updated or not.

```
if adapt
  weights = weights + mu*err(n)*fifo;
end
```

Modifying Your Model to Use Reset and Adapt Controls. To modify the model yourself, work through the exercises in this section. Otherwise, open the supplied model `noise_cancel_03.mdl` in your *`solutions`* subfolder to see the modified model.

1. Open the `noise_cancel_02` model.
2. Double-click the Embedded MATLAB Function block to open the Embedded MATLAB Editor.
3. Modify the Embedded MATLAB Function block code:
   a. Update the function declaration.

```
function [ Signal_Out, Weights ] = ...
   LMS(Adapt, Reset, Noise_In, Signal_In )
```

   b. Update the extrinsic call.

```
eml.extrinsic('lms_03');
```

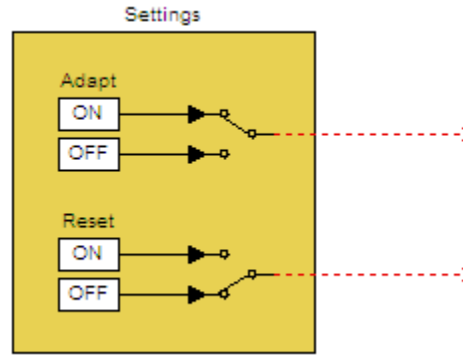
   c. Update the call to the LMS algorithm.

```
% Compute LMS:
[ ~, Signal_Out, Weights ] = ...
   lms_03(Noise_In, Signal_In, Reset, Adapt);
```

   d. Close the Embedded MATLAB Editor.

The `lms_03` function inputs `Reset` and `Adapt` now appear as input ports to the Embedded MATLAB Function block.

4 Open the `design_templates` model.



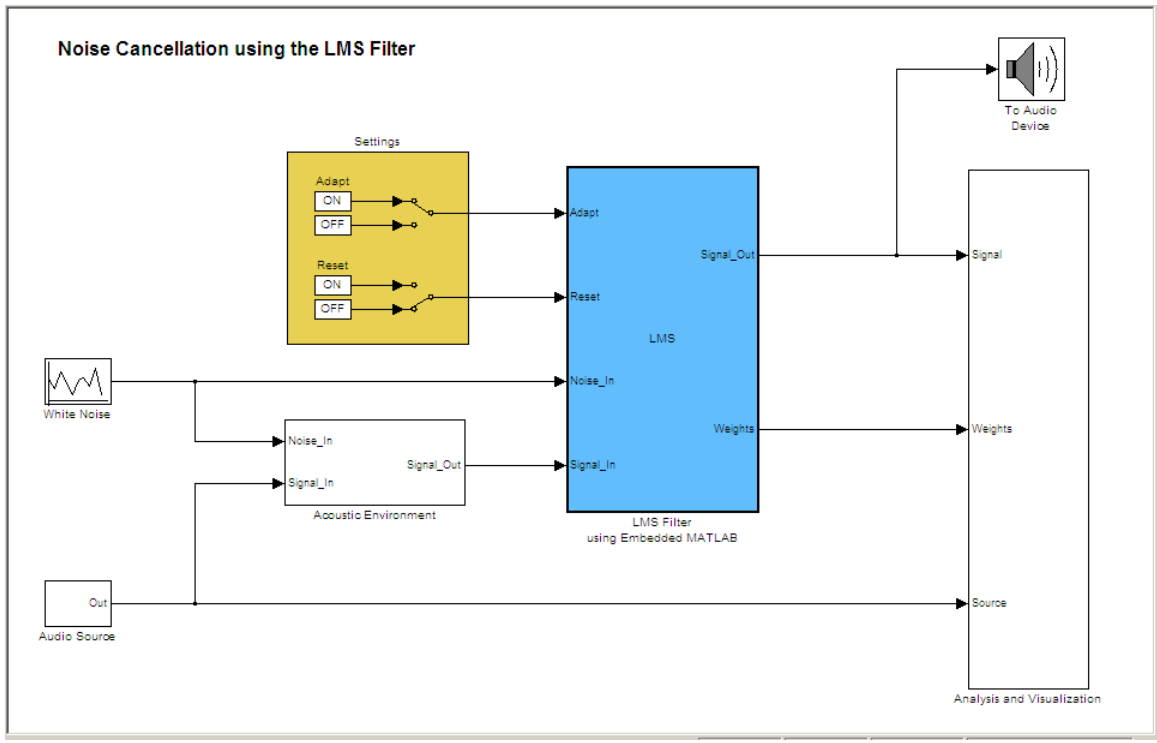
5 Copy the Settings block from this model to your `noise_cancel_02` model:

   a From the `design_templates` model menu, select **Edit > Select All**.

   b Select **Edit > Copy**.

   c From the `noise_cancel_02` model menu, select **Edit > Paste**.

6 Connect the Adapt and Reset outputs of the Settings subsystem to the corresponding inputs on the Embedded MATLAB Function block. Your model should now appear as follows.



7 Save the model as `noise_cancel_03.mdl`.

Simulating the Model with Adapt and Reset Controls. To simulate the model and see the effect of the Adapt and Reset controls:

1 In the `noise_cancel_03` model, view the Convergence scope:

   a Double-click the Analysis and Visualization subsystem.

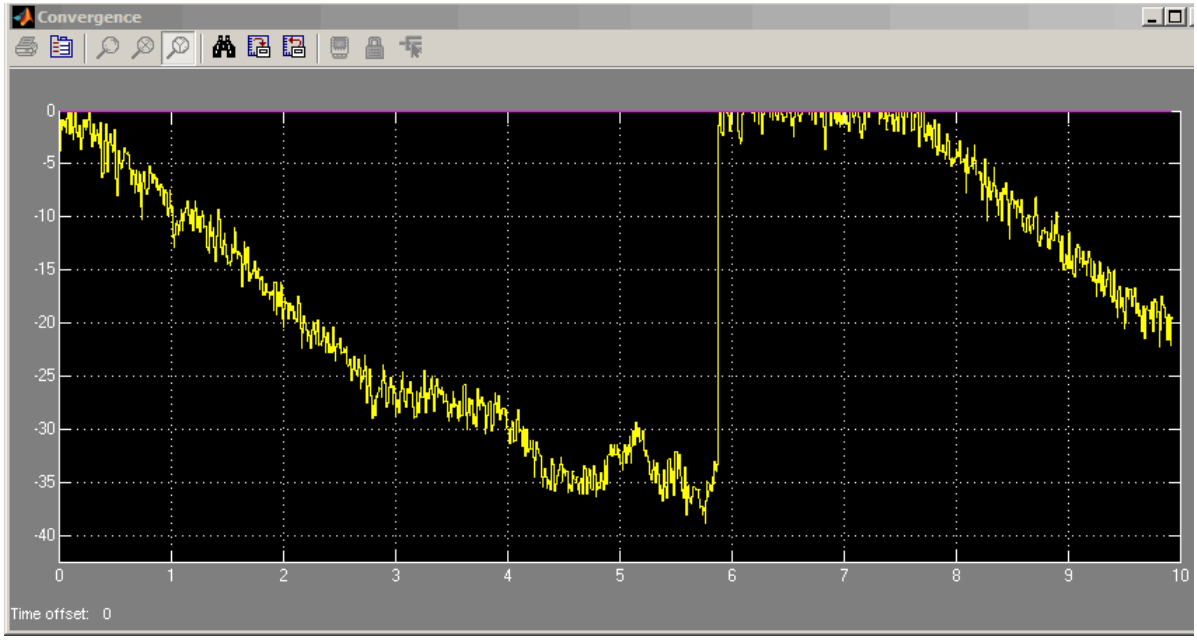
   The contents of the Analysis and Visualization subsystem appear.

   b Double-click the Convergence scope.

2 In the Simulink model window, select **Simulation > Start**.

Simulink runs the model as before. While the model is running, toggle the Adapt and Reset controls and view the Convergence scope to see their effect on the filter.

Here you see the filter converging when `Adapt` is `ON` and `Reset` is `OFF`, then resetting when `Reset` is toggled.



3 Stop the simulation.

Generating Code

You have proved that your algorithm works in Simulink. Next you generate code for your model. Before generating code, you must ensure that your MATLAB code is compliant with the Embedded MATLAB subset. For compliance, you must remove the extrinsic call to your code.

Making Your Code Compliant with the Embedded MATLAB Subset.
To modify the model and code yourself, work through the exercises in this section. Otherwise, open the supplied model `noise_cancel_04.mdl` and file `lms_04.m` in your *`solutions`* subfolder to see the modifications.

1. Rename the Embedded MATLAB Function block to `LMS_Filter`. Double-click the annotation `Embedded MATLAB Function` below the Embedded MATLAB Function block and replace the text with `LMS_Filter`.

   When you generate code for the Embedded MATLAB Function block, Real-Time Workshop uses the name of the block in the generated code. It is good practice to use a meaningful name.

2. In your `noise_cancel_03` model, double-click the Embedded MATLAB Function block.

   The Embedded MATLAB Editor opens.

3. Delete the extrinsic declaration.

   ```
   % Extrinsic:
   eml.extrinsic('lms_03');
   ```

4. Delete the preallocation of outputs.

   ```
   % Outputs:
   Signal_Out = zeros(size(Signal_In));
   Weights = zeros(32,1);
   ```

5. Modify the call to the filter algorithm.

   ```
   % Compute LMS:
   [ ~, Signal_Out, Weights ] = ...
      lms_04(Noise_In, Signal_In, Reset, Adapt);
   ```

6. Save the model as `noise_cancel_04`.

7. Open `lms_03.m`

   a. Modify the function name to `lms_04`.

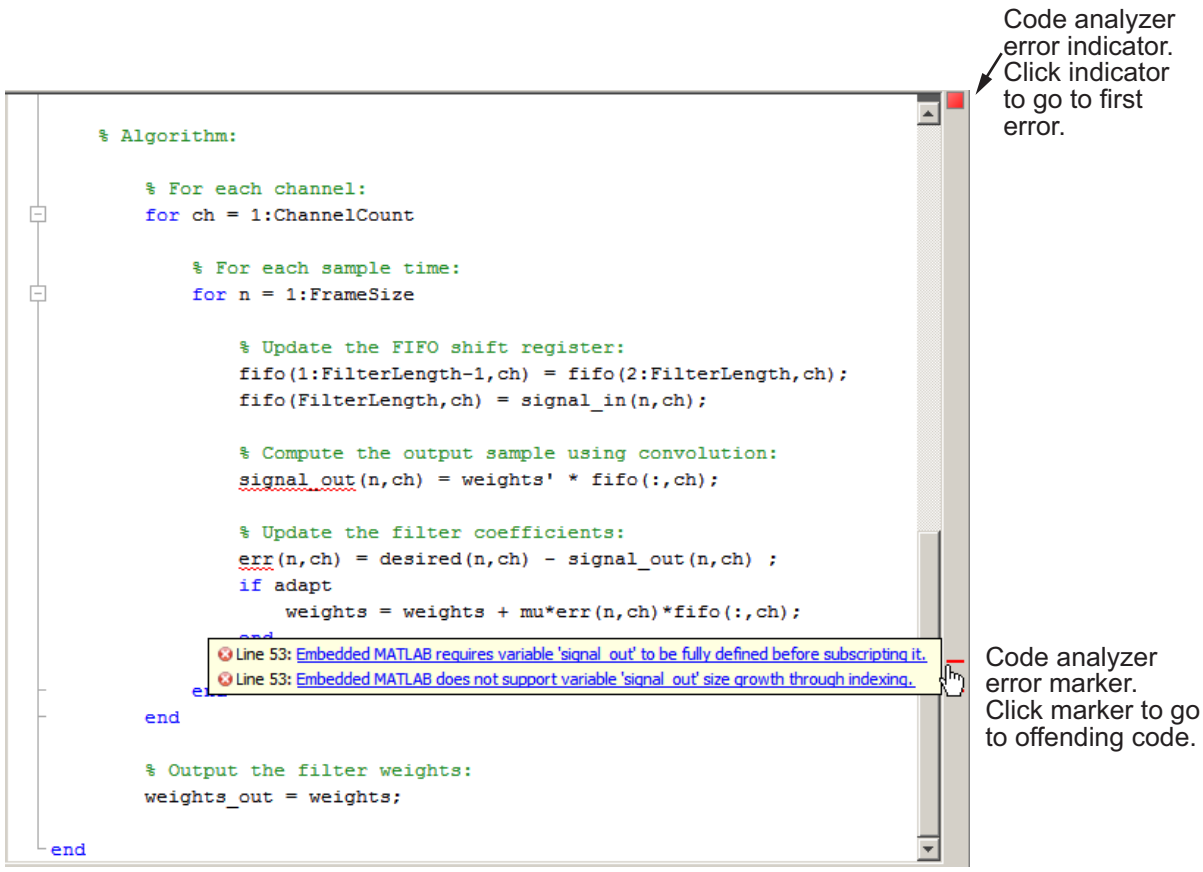
   b. Turn on error checking specific to the Embedded MATLAB subset by adding the `%#eml` compilation directive after the function declaration.

```
function [ signal_out, err, weights_out ] = ...
    lms_04(signal_in, desired, reset, adapt) %#eml
```

The code analyzer message indicator in the top right turns red to indicate that the code analyzer has detected Embedded MATLAB issues. The code analyzer underlines the offending code in red and places a red marker to the right of it.

8 Move your pointer over the first red marker to view the error information.

The code analyzer detects that Embedded MATLAB requires `signal_out` to be fully defined before subscripting it and that Embedded MATLAB does not support growth of variable size data through indexing.



9 Move your pointer over the second red marker and note that the code analyzer detects the same errors for `err`.

10 To address these errors, preallocate the outputs `signal_out` and `err`. Add this code after the filter setup.

```
% Output Arguments:

% Pre-allocate output and error signals:
signal_out = zeros(FrameSize,ChannelCount);
err = zeros(FrameSize,ChannelCount);
```

Why Preallocate the Outputs?

You must preallocate outputs here because theEmbedded MATLAB subset does not support increasing the size of an array over time. Repeatedly expanding the size of an array over time can adversely affect the performance of your program. See "Preallocating Memory" in *MATLAB Mathematics*.

The red error markers for the two lines of code disappear. The code analyzer message indicator in the top right edge of the code turns green, which indicates that you have fixed all the errors and warnings detected by the code analyzer.

For more information on using the code analyzer, see "Using the Code Analyzer Report" in the MATLAB Desktop Tools and Development documentation.

11 Save the file as `lms_04.m`.

Generating Code for noise_cancel_04.mdl.

1 Before generating code, ensure that Real-Time Workshop creates a code generation report. This HTML report provides easy access to the list of generated files with a summary of the configuration settings used to generate the code.

a In the Simulink model window, select **Simulation > Configuration Parameters**.

The Configuration Parameters dialog box opens.

b In the left pane of the Configuration Parameters dialog box, select **Report** under **Real-Time Workshop**.

c In the right pane, select **Create code generation report**.

The **Launch report automatically** option is also selected.

d Click **Apply** and close the Configuration Parameters dialog box.

e Save your model.

2 To generate code for the LMS Filter subsystem:

a In your model, right-click the LMS Filter subsystem to select it and open the context menu.

b From the context menu, select **Real-Time Workshop > Build Subsystem**.

The **Build code for subsystem** dialog box appears. Click the **Build** button.

The Real-Time Workshop software generates C code for the subsystem and launches the code generation report.

For more information on using the code generation report, see "Viewing Generated Code in Generated HTML Reports" in the Real-Time Workshop documentation.

c In the left pane of the code generation report, click the `LMS_Filter.c` link to view the generated C code. Note that the `lms_04` function has no code because inlining is enabled by default.

3 Modify your filter algorithm to disable inlining:

a In `lms_04.m`, after the function declaration, add:

```
eml.inline('never')
```

b Change the function name to `lms_05` and save the file as `lms_05.m` in the current folder.

c In your `noise_cancel_04` model, double-click the Embedded MATLAB Function block.

The Embedded MATLAB Editor opens.

d Modify the call to the filter algorithm to call `lms_05`.

```
% Compute LMS:
[ ~, Signal_Out, Weights ] = ...
   lms_05(Noise_In, Signal_In, Reset, Adapt);
```

e Save the model as `noise_cancel_05.mdl`.

4 Generate code for the updated model.

a In the model, right-click the LMS Filter subsystem to select it and open the context menu.

b From the context menu, select **Real-Time Workshop > Build Subsystem**.

The **Build code for subsystem** dialog box appears.

c Click the **Build** button.

The Real-Time Workshop software generates C code for the subsystem and launches the code generation report.

d In the left pane of the code generation report, click the `LMS_Filter.c` link to view the generated C code.

This time the `lms_05` function has code because you disabled inlining.

```
/* Forward declaration for local functions */
37   static void LMS_Filter_lms_05 ...
       (const real_T eml_signal_in[64],const real_T ...
38       eml_desired[64], real_T eml_reset, ...
           real_T eml_adapt, ...
             real_T eml_signal_out[64], ...
39      real_T eml_err[64], real_T eml_weights_out[32]);
40
41   /* Function for Embedded MATLAB: 'root/LMS_Filter' */
42   static void LMS_Filter_lms_05 ...
      (const real_T eml_signal_in[64], ...
        const real_T
43         eml_desired[64], real_T eml_reset, real_T eml_adapt, ...
             real_T eml_signal_out[64], ...
44     real_T eml_err[64], real_T eml_weights_out[32])
```

Optimizing the LMS Filter Algorithm

This part of the tutorial demonstrates when and how to preallocate memory for a variable without incurring the overhead of initializing memory in the generated code.

In `lms_05.m`, the MATLAB code not only declares `signal_out` and `err` to be a `FrameSize`-by-`ChannelCount` vector of real doubles, but also initializes each element of `signal_out` and `err` to zero. These signals are initialized to zero in the generated C code.

MATLAB Code	Generated C Code

`% Pre-allocate output and error signals:`
`signal_out = zeros(FrameSize,ChannelCount);`
`err = zeros(FrameSize,ChannelCount);`
	`/* Pre-allocate output and error signals:  */`
	`79 for (i = 0; i < 64; i++) {`
	`80 eml_signal_out[i] = 0.0;`
	`81 eml_err[i] = 0.0;`
	`82 }`

This forced initialization is unnecessary because both `signal_out` and `err` are explicitly initialized in the MATLAB code before they are read.

Note You should not use `eml.nullcopy` when declaring the variables `weights` and `fifo` because these variables need to be initialized in the generated code. Neither variable is explicitly initialized in the MATLAB code before they are read.

Use `eml.nullcopy` in the declaration of `signal_out` and `err` to eliminate the unnecessary initialization of memory in the generated code:

1. In `lms_05.m`, preallocate `signal_out` and `err` using `eml.nullcopy`:

```
% Pre-allocate output and error signals:
signal_out = eml.nullcopy(zeros(FrameSize, ChannelCount));
err = eml.nullcopy(zeros(FrameSize, ChannelCount));
```

Caution After declaring a variable with `eml.nullcopy`, you must explicitly initialize the variable in your MATLAB code before reading it. Otherwise, you might get unpredictable results. For more information, see "Uninitialized Variables" in the *Embedded MATLAB User's Guide*.

2 Change the function name to `lms_06` and save the file as `lms_06.m` in the current folder.

3 In your `noise_cancel_05` model, double-click the Embedded MATLAB Function block.

The Embedded MATLAB Editor opens.

4 Modify the call to the filter algorithm.

```
% Compute LMS:
[ ~, Signal_Out, Weights ] = ...
   lms_06(Noise_In, Signal_In, Reset, Adapt);
```

5 Save the model as `noise_cancel_06.mdl`.

Generate code for the updated model.

1 Right-click the LMS Filter subsystem to select it and open the context menu.

2 From the context menu, select **Real-Time Workshop > Build Subsystem**.

The **Build code for subsystem** dialog box appears. Click the **Build** button.

The Real-Time Workshop software and generates C code for the subsystem and launches the code generation report.

3 In the left pane of the code generation report, click the `LMS_Filter.c` link to view the generated C code.

In the generated C code, this time there is no initialization to zero of `signal_out` and `err`.

Managing Data

25

Working with Data

Working with Data Types

In this section...

About Data Types

The term *data type* refers to the way in which a computer represents numbers in memory. A data type determines the amount of storage allocated to a number, the method used to encode the number's value as a pattern of binary digits, and the operations available for manipulating the type. Most computers provide a choice of data types for representing numbers, each with specific advantages in the areas of precision, dynamic range, performance, and memory usage. To optimize performance, you can specify the data types of variables used in the MATLAB technical computing environment. The Simulink software builds on this capability by allowing you to specify the data types of Simulink signals and block parameters.

The ability to specify the data types of a model's signals and block parameters is particularly useful in real-time control applications. For example, it allows a Simulink model to specify the optimal data types to use to represent signals and block parameters in code generated from a model by automatic code-generation tools, such as the Real-Time Workshop product. By choosing the most appropriate data types for your model's signals and parameters, you can dramatically increase performance and decrease the size of the code generated from the model.

Simulink performs extensive checking before and during a simulation to ensure that your model is *typesafe*, that is, that code generated from the model will not overflow or underflow and thus produce incorrect results. Simulink models that use the default data type (`double`) are inherently typesafe. Thus, if you never plan to generate code from your model or use a nondefault data type in your models, you can skip the remainder of this section.

On the other hand, if you plan to generate code from your models and use nondefault data types, read the remainder of this section carefully, especially the section on data type rules (see "Data Typing Rules" on page 25-29). In that way, you can avoid introducing data type errors that prevent your model from running to completion or simulating at all.

Data Types Supported by Simulink

Simulink supports all built-in MATLAB data types except `int64` and `uint64`. The term *built-in data type* refers to data types defined by MATLAB itself as opposed to data types defined by MATLAB users. Unless otherwise specified, the term data type in the Simulink documentation refers to built-in data types. The following table lists the built-in MATLAB data types supported by Simulink.

Name	Description
`double`	Double-precision floating point
`single`	Single-precision floating point
`int8`	Signed 8-bit integer
`uint8`	Unsigned 8-bit integer
`int16`	Signed 16-bit integer

Name	Description
`uint16`	Unsigned 16-bit integer
`int32`	Signed 32-bit integer
`uint32`	Unsigned 32-bit integer

Besides the built-in types, Simulink defines a `boolean` (1 or 0) type, instances of which are represented internally by `uint8` values.

Several blocks support bus objects (`Simulink.Bus`) as data types. See "Bus Objects" on page 25-6.

Many Simulink blocks also support fixed-point data types. See "Blocks — Alphabetical List" in the online documentation for information on the data types supported by specific blocks for parameter and input and output values. If the documentation for a block does not specify a data type, the block inputs or outputs only data of type `double`.

To view a table that summarizes the data types supported by the blocks in the Simulink block libraries, execute the following command at the MATLAB command line:

```
showblockdatatypetable
```

Fixed-Point Data

The Simulink software allows you to create models that use fixed-point numbers to represent signals and parameter values. Use of fixed-point data can reduce the memory requirements and increase the speed of code generated from a model.

To execute a model that uses fixed-point numbers, you must have the Simulink Fixed Point product installed on your system. Specifically, you must have the product to:

- Update a Simulink diagram (**Ctrl+D**) containing fixed-point data types
- Run a model containing fixed-point data types
- Generate code from a model containing fixed-point data types

- Log the minimum and maximum values produced by a simulation
- Automatically scale the output of a model using the autoscaling tool

If the Simulink Fixed Point product is not installed on your system, you can execute a fixed-point model as a floating-point model by enabling automatic conversion of fixed-point data to floating-point data during simulation. See "Overriding Fixed-Point Specifications" on page 25-5 for details.

If you do not have the Simulink Fixed Point product installed and do not enable automatic conversion of fixed-point to floating-point data, an error occurs if you try to execute a fixed-point model.

Note You do not need the Simulink Fixed Point product to edit a model containing fixed-point blocks, or to use the Data Type Assistant to specify fixed-point data types, as described in "Specifying a Fixed-Point Data Type" on page 25-19.

Overriding Fixed-Point Specifications

Most of the functionality in the Fixed-Point Tool is for use with the Simulink Fixed Point software. However, even if you do not have Simulink Fixed Point software, you can configure data type override settings to simulate a model that specifies fixed-point data types. In this mode, the Simulink software temporarily overrides fixed-point data types with floating-point data types when simulating the model.

Note If you use fi objects or embedded numeric data types in your model or workspace, you might introduce fixed-point data types into your model. You can set fipref to prevent the checkout of a Fixed-Point Toolbox license. For more information, see "Licensing" in the Fixed-Point Toolbox documentation.

To simulate a model without using Simulink Fixed Point:

1 In the **Model Hierarchy** pane, select the root model.

2 From the Simulink model **Tools** menu, select **Fixed-Point > Fixed-Point Tool**.

The Fixed-Point Tool appears.

- Set the **Fixed-point instrumentation mode** parameter to `Force Off`.
- Set the **Data type override** parameter to `Double` or `Single`.
- Set the **Data type override applies to** parameter to `All numeric types`.

3 If you use `fi` objects or embedded numeric data types in your model, set the `fipref` `DataTypeOverride` property to `TrueDoubles` and the `DataTypeOverride` property to `All numeric types`.

At the MATLAB command line, enter:

```
p = fipref('DataTypeOverride', 'TrueDoubles', ...
 'DataTypeOverrideAppliesTo', 'AllNumericTypes');
```

Enumerations

An *enumeration* is a user-defined data type with a fixed set of names that represent a single type of value. When the data type of an entity is an enumeration, the value of the entity must be one of the values defined that enumeration. For information about enumerations, see Chapter 26, "Enumerations and Modeling". Do not confuse enumerations with enumerated property types (see "Enumerated Property Types" on page 25-65).

Bus Objects

A bus object (`Simulink.Bus`) specifies the architectural properties of a bus, as distinct from the values of the signals it contains. For example, a bus object can specify the number of elements in a bus, the order of those elements, whether and how elements are nested, and the data types of constituent signals; but not the signal values.

You can specify a bus object as a data type for the following blocks:

- Bus Creator
- Constant

- Inport
- Outport
- Signal Specification

You can specify a bus object as a data type for the following classes:

- `Simulink.BusElement`
- `Simulink.Parameter`
- `Simulink.Signal`

See "Specifying a Bus Object Data Type" on page 25-27 for information about how to specify a bus object as a data type for blocks and classes.

Block Support for Data and Numeric Signal Types

All Simulink blocks accept signals of type `double` by default. Some blocks prefer `boolean` input and others support multiple data types on their inputs. See Simulink Blocks in *Simulink Reference* for information on the data types supported by specific blocks for parameter and input and output values. If the documentation for a block does not specify a data type, the block inputs or outputs only data of type `double`.

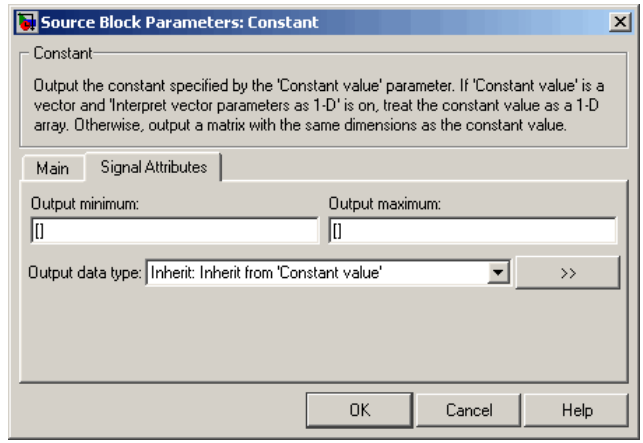
Creating Signals of a Specific Data Type

You can introduce a signal of a specific data type into a model in any of the following ways:

- Load signal data of the desired type from the MATLAB workspace into your model via a root-level Inport block or a From Workspace block.
- Create a Constant block in your model and set its parameter to the desired type.
- Use a Data Type Conversion block to convert a signal to the desired data type.

Specifying Block Output Data Types

Simulink blocks determine the data type of their outputs by default. Many blocks allow you to override the default type and explicitly specify an output data type, using a block parameter that is typically named **Output data type**. For example, the **Output data type** parameter appears on the **Signal Attributes** pane of the Constant block dialog box.



See the following topics for more information:

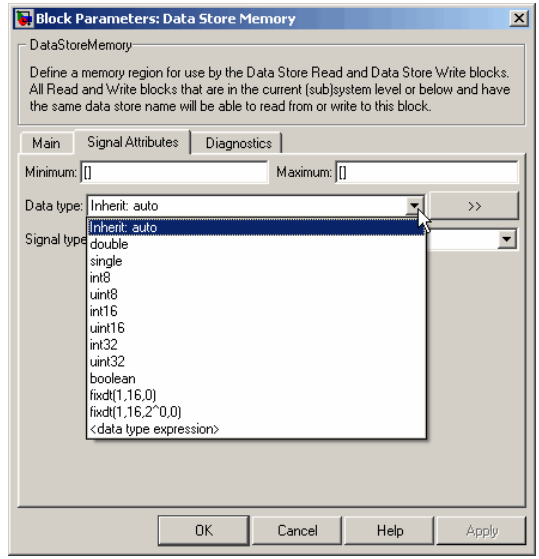
For Information About...	See...
Valid data type values that you can specify	"Entering Valid Data Type Values" on page 25-9
An assistant that helps you specify valid data type values	"Using the Data Type Assistant" on page 25-15
Specifying valid data type values for multiple blocks simultaneously	"Using the Model Explorer for Batch Editing" on page 25-12

Entering Valid Data Type Values

In general, you can specify the output data type as any of the following:

- A rule that inherits a data type (see "Data Type Inheritance Rules" on page 25-10)
- The name of a built-in data type (see "Built-In Data Types" on page 25-11)
- An expression that evaluates to a data type (see "Data Type Expressions" on page 25-11)

Valid data type values vary among blocks. You can use the pull-down menu associated with a block data type parameter to view the data types that a particular block supports. For example, the **Data type** pull-down menu on the Data Store Memory block dialog box lists the data types that it supports, as shown here.



For more information about the data types that a specific block supports, see the documentation for the block in the *Simulink Reference*.

Data Type Inheritance Rules. Blocks can inherit data types from a variety of sources, including signals to which they are connected and particular block parameters. You can specify the value of a data type parameter as a rule that determines how the output signal inherits its data type. To view the inheritance rules that a block supports, use the data type pull-down menu on the block dialog box. The following table lists typical rules that you can select.

Inheritance Rule	Description
`Inherit: Inherit via back propagation`	Simulink automatically determines the output data type of the block during data type propagation (see "Data Type Propagation" on page 25-28). In this case, the block uses the data type of a downstream block or signal object.
`Inherit: Same as input`	The block uses the data type of its sole input signal for its output signal.

Inheritance Rule	Description
`Inherit: Same as first input`	The block uses the data type of its first input signal for its output signal.
`Inherit: Same as second input`	The block uses the data type of its second input signal for its output signal.
`Inherit: Inherit via internal rule`	The block uses an internal rule to determine its output data type. The internal rule chooses a data type that optimizes the accuracy and precision of the block output signal.

Built-In Data Types. You can specify the value of a data type parameter as the name of a built-in data type, for example, `single` or `boolean`. To view the built-in data types that a block supports, use the data type pull-down menu on the block dialog box. See "Data Types Supported by Simulink" on page 25-3 for a list of all built-in data types that are supported.

Data Type Expressions. You can specify the value of a data type parameter as an expression that evaluates to a numeric data type object. Simply enter the expression in the data type field on the block dialog box. In general, enter one of the following expressions:

- **`fixdt` Command**

  Specify the value of a data type parameter as a command that invokes the `fixdt` function. This function allows you to create a `Simulink.NumericType` object that describes a fixed-point or floating-point data type. See the documentation for the `fixdt` function in the *Simulink Reference* for more information.

- **Data Type Object Name**

  Specify the value of a data type parameter as the name of a data object that represents a data type. Simulink data objects that you instantiate from classes, such as `Simulink.NumericType` and `Simulink.AliasType`, simplify the task of making model-wide changes to output data types and

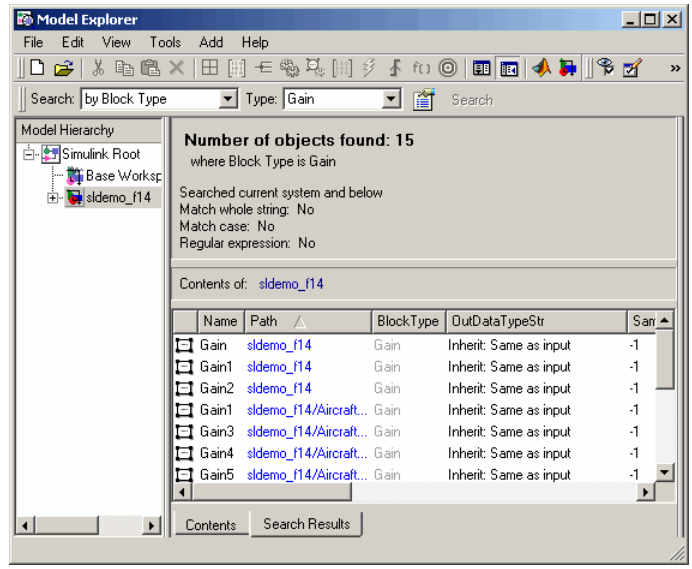
allow you to use custom aliases for data types. See "Working with Data Objects" on page 25-37 for more information about Simulink data objects.

Using the Model Explorer for Batch Editing

Using the Model Explorer (see "The Model Explorer: Overview" on page 8-2), you can assign the same output data type to multiple blocks simultaneously. For example, the `sldemo_f14` model that comes with the Simulink product contains numerous Gain blocks. Suppose you want to specify the **Output data type** parameter of all the Gain blocks in the model as `single`. You can achieve this task as follows:

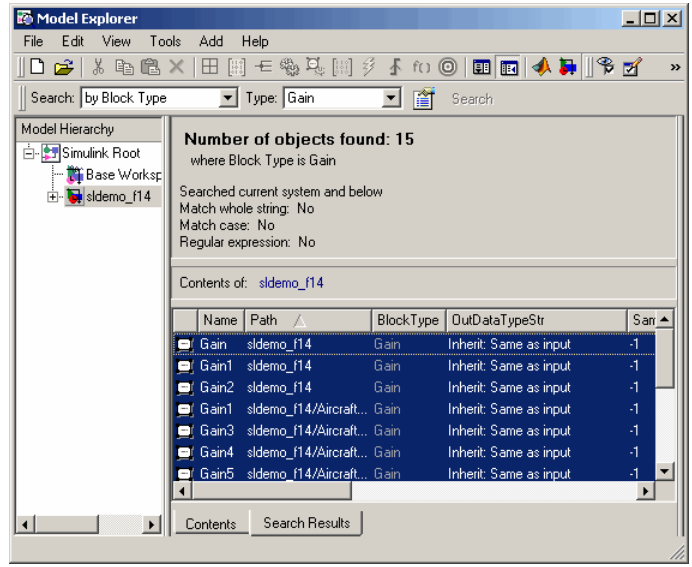
1 Use the Model Explorer search bar (see "The Model Explorer: Search Bar" on page 8-58) to identify all blocks in the `sldemo_f14` model of type `Gain`.

The Model Explorer **Contents** pane lists all Gain blocks in the model.



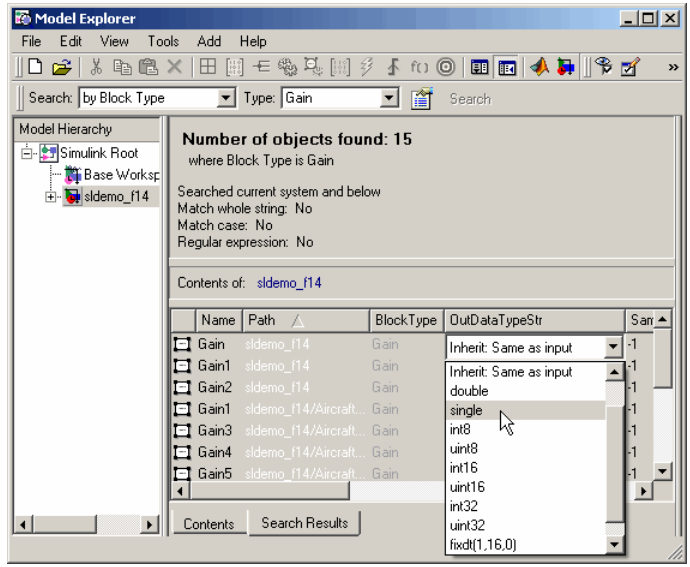
2 In the Model Explorer **Contents** pane, select all the Gain blocks whose **Output data type** parameter you want to specify.

Model Explorer highlights the rows corresponding to your selections.



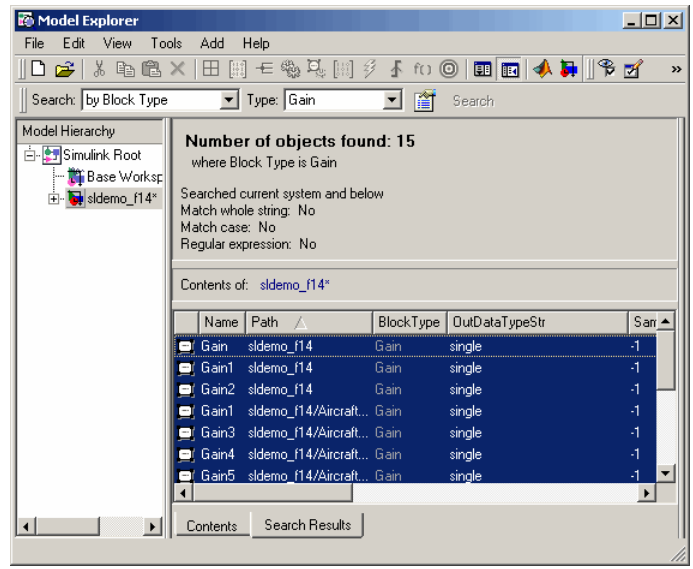
3 In the Model Explorer **Contents** pane, click the data type associated with one of the selected Gain blocks.

Model Explorer displays a pull-down menu with valid data type options.



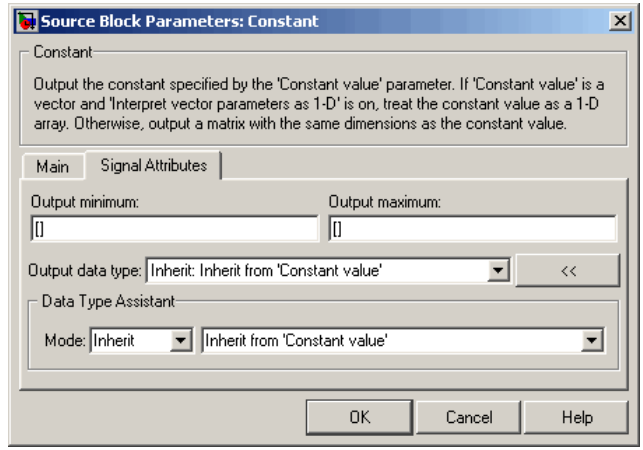
4 In the pull-down menu, enter or select the desired data type, for example, `single`.

Model Explorer specifies the data type of all selected items as `single`.



Using the Data Type Assistant

The **Data Type Assistant** is an interactive graphical tool that simplifies the task of specifying data types for blocks and data objects. The assistant appears on block and object dialog boxes, adjacent to parameters that provide data type control, such as the **Output data type** parameter. For example, it appears on the **Signal Attributes** pane of the Constant block dialog box shown here.



You can selectively show or hide the **Data Type Assistant** by clicking the applicable button:

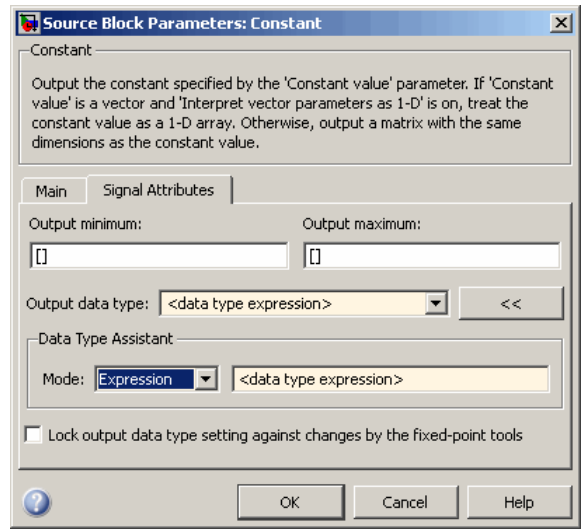
- Click the **Show data type assistant** button  to display the assistant.
- Click the **Hide data type assistant** button  to hide a visible assistant.

Use the **Data Type Assistant** to specify a data type as follows:

1. In the **Mode** field, select the category of data type that you want to specify. In general, the options include the following:

Mode	Description
`Inherit`	Inheritance rules for data types
`Built in`	Built-in data types
`Fixed point`	Fixed-point data types
`Enumerated`	Enumerated data types
`Bus object`	Bus object data types
`Expression`	Expressions that evaluate to data types

The assistant changes dynamically to display different options that correspond to the selected mode. For example, setting **Mode** to `Expression` causes the Constant block dialog box to appear as follows.

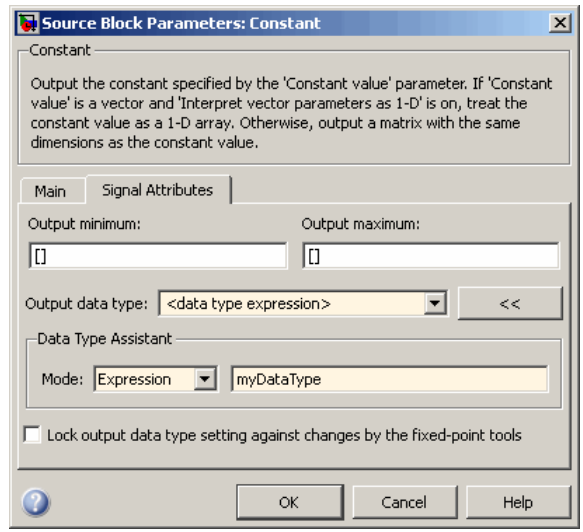


2 In the field that is to the right of the **Mode** field, select or enter a data type.

For example, suppose that you designate the variable `myDataType` as an alias for a `single` data type. You create an instance of the `Simulink.AliasType` class and set its `BaseType` property by entering the following commands:

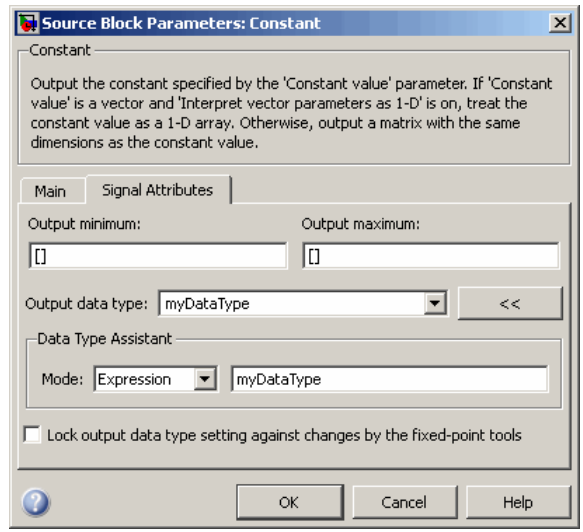
```
myDataType = Simulink.AliasType
myDataType.BaseType = 'single'
```

You can use this data type object to specify the output data type of a Constant block. Enter the data type alias name, `myDataType`, as the value of the expression in the assistant.



3 Click the **OK** or **Apply** button to apply your changes.

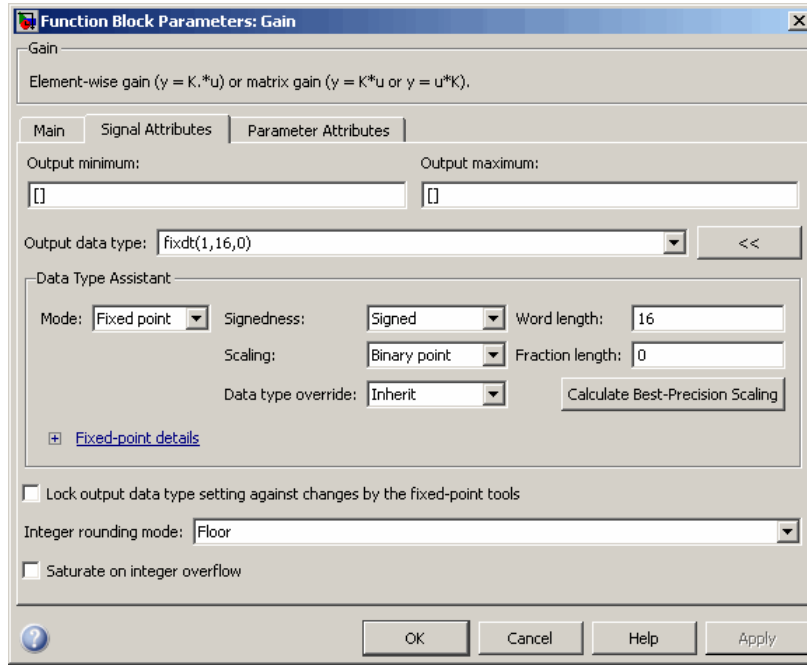
The assistant uses the data type that you specified to populate the associated data type parameter in the block or object dialog box. In the following example, the **Output data type** parameter of the Constant block specifies the same expression that you entered using the assistant.



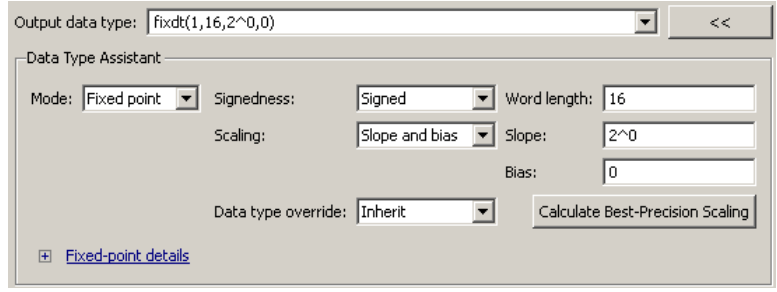
For more information about the data types that you can specify using the **Data Type Assistant**, see "Entering Valid Data Type Values" on page 25-9. See "Specifying Fixed-Point Data Types with the Data Type Assistant" in the *Simulink Fixed Point User's Guide* for details about specifying fixed-point data types.

Specifying a Fixed-Point Data Type

When the Data Type Assistant **Mode** is `Fixed point`, the Data Type Assistant displays fields for specifying information about your fixed-point data type. For a detailed discussion about fixed-point data, see "Fixed-Point Concepts" in the *Simulink Fixed Point User's Guide*. For example, the next figure shows the Block Parameters dialog box for a Gain block, with the **Signal Attributes** tab selected and a fixed-point data type specified.



If the **Scaling** is `Slope and bias` rather than `Binary point`, the Data Type Assistant displays a **Slope** field and a **Bias** field rather than a **Fraction length** field:

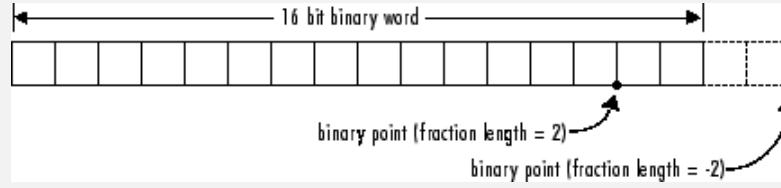


You can use the Data Type Assistant to set these fixed-point properties:

Signedness. Specify whether you want the fixed-point data to be `Signed` or `Unsigned`. Signed data can represent positive and negative values, but unsigned data represents positive values only. The default setting is `Signed`.

Word length. Specify the bit size of the word that will hold the quantized integer. Large word sizes represent large values with greater precision than small word sizes. Word length can be any integer between 0 and 32. The default bit size is 16.

Scaling. Specify the method for scaling your fixed-point data to avoid overflow conditions and minimize quantization errors. The default method is `Binary point` scaling. You can select one of two scaling modes:

Scaling Mode	Description
`Binary point`	If you select this mode, the Data Type Assistant displays the **Fraction Length** field, which specifies the binary point location. Binary points can be positive or negative integers. A positive integer moves the binary point left of the rightmost bit by that amount. For example, an entry of 2 sets the binary point in front of the second bit from the right. A negative integer moves the binary point further right of the rightmost bit by that amount, as in this example:  The default binary point is 0.
`Slope and bias`	If you select this mode, the Data Type Assistant displays fields for entering the **Slope** and **Bias**. Slope can be any positive real number, and the default slope is 1.0. Bias can be any real number, and the default bias is 0.0. You can enter slope and bias as expressions that contain parameters you define in the MATLAB workspace.

Note Use binary-point scaling whenever possible to simplify the implementation of fixed-point data in generated code. Operations with fixed-point data using binary-point scaling are performed with simple bit shifts and eliminate expensive code implementations, which are required for separate slope and bias values.

For more information about fixed-point scaling, see "Scaling" in the *Simulink Fixed Point User's Guide*.

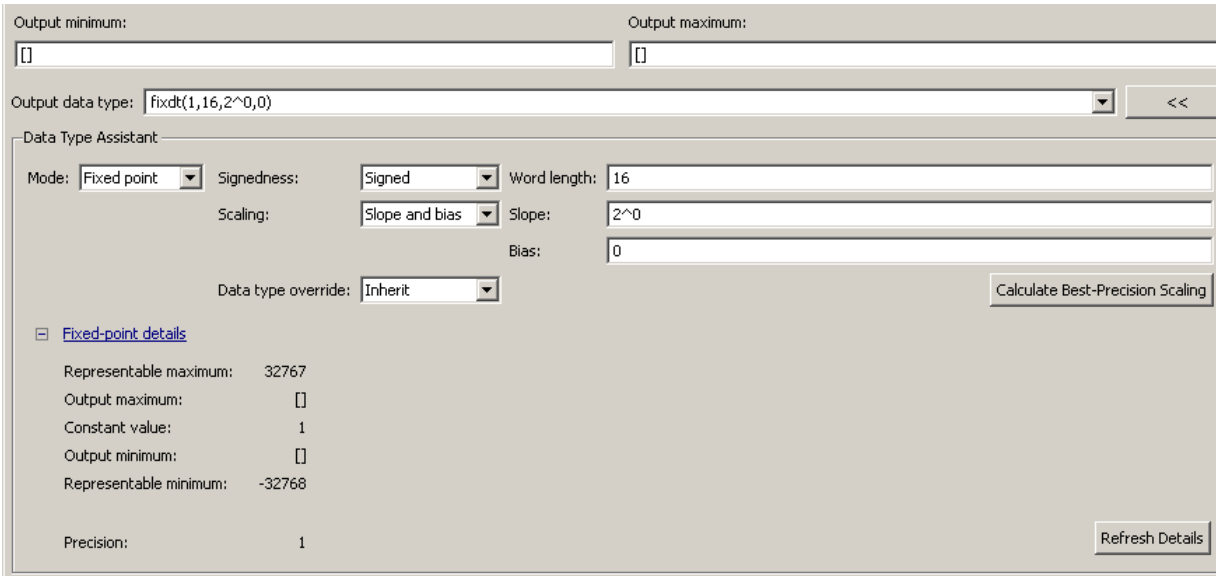
Data type override. When the **Mode** is `Built in` or `Fixed point`, you can use the **Data type override** option to specify whether you want this data type to inherit or ignore the data type override setting specified for its context, that is, for the block, `Simulink.Signal` object or Stateflow chart in Simulink that is using the signal. The default behavior is `Inherit`.

Data Type Override Mode	Description
`Inherit` (default)	Inherits the data type override setting from its context, that is, from the block, `Simulink.Signal` object or Stateflow chart in Simulink that is using the signal.
`Off`	Ignores the data type override setting of its context and uses the fixed-point data type specified for the signal.

The ability to turn off data type override for an individual data type provides greater control over the data types in your model when you apply data type override. For example, you can use this option to ensure that data types meet the requirements of downstream blocks regardless of the data type override setting.

Calculate Best-Precision Scaling. Click this button to calculate best-precision values for both `Binary point` and `Slope and bias` scaling, based on the specified minimum and maximum values. The Simulink software displays the scaling values in the **Fraction Length** field or the **Slope** and **Bias** fields. For more information, see "Constant Scaling for Best Precision" in the *Simulink Fixed Point User's Guide*.

Showing Fixed-Point Details. When you specify a fixed-point data type, you can use the **Fixed-point details** subpane to see information about the fixed-point data type that is currently displayed in the Data Type Assistant. To see the subpane, click the expander next to **Fixed-point details** in the Data Type Assistant. The **Fixed-point details** subpane appears at the bottom of the Data Type Assistant:



The rows labeled `Output minimum` and `Output maximum` show the same values that appear in the corresponding **Output minimum** and **Output maximum** fields above the Data Type Assistant. The names of these fields may differ from those shown. For example, a fixed-point block parameter would show **Parameter minimum** and **Parameter maximum**, and the corresponding **Fixed-point details** rows would be labeled accordingly. See

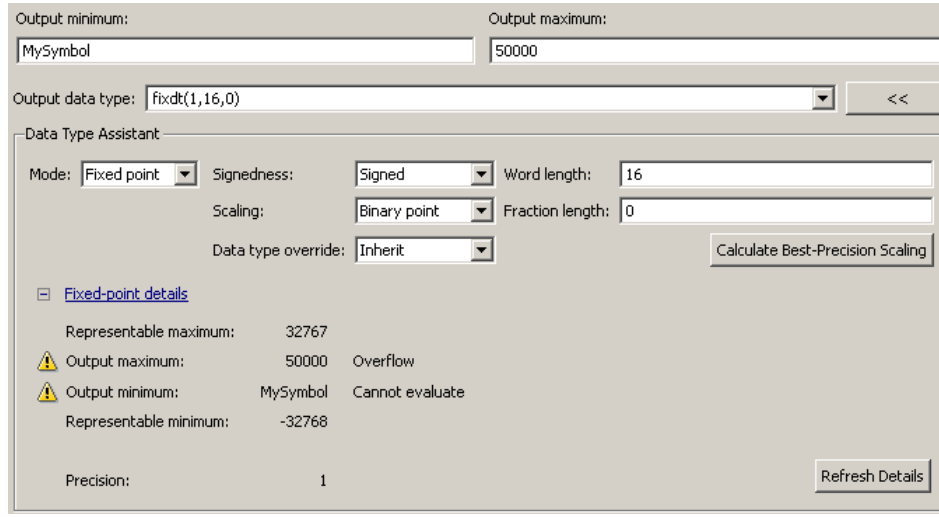
"Checking Signal Ranges" on page 29-31 and "Checking Parameter Values" on page 19-9 for more information.

The rows labeled `Representable minimum`, `Representable maximum`, and `Precision` always appear. These rows show the minimum value, maximum value, and precision that can be represented by the fixed-point data type currently displayed in the Data Type Assistant. See "Fixed-Point Concepts" in the *Simulink Fixed Point User's Guide* for information about these three quantities.

The values displayed by the **Fixed-point details** subpane *do not* automatically update if you click **Calculate Best-Precision Scaling**, or change the range limits, the values that define the fixed-point data type, or anything elsewhere in the model. To update the values shown in the **Fixed-point details** subpane, click **Refresh Details**. The Data Type Assistant then updates or recalculates all values and displays the results.

Clicking **Refresh Details** does not change anything in the model, it only changes the display. Click **OK** or **Apply** to put the displayed values into effect. If the value of a field cannot be known without first compiling the model, the **Fixed-point details** subpane shows the value as `Unknown`.

If any errors occur when you click **Refresh Details**, the **Fixed-point details** subpane shows an error flag on the left of the applicable row, and a description of the error on the right. For example, the next figure shows two errors:

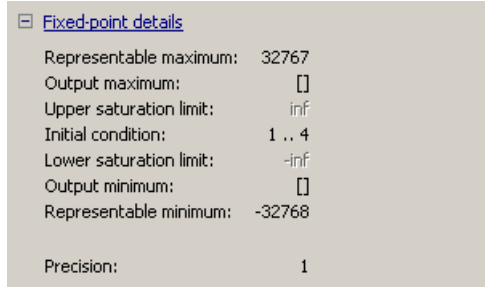


The row labeled `Output minimum` shows the error `Cannot evaluate` because evaluating the expression `MySymbol`, specified in the **Output minimum** field, did not return an appropriate numeric value. When an expression does not evaluate successfully, the **Fixed-point details** subpane displays the unevaluated expression (truncating to 10 characters if necessary to save space) in place of the unavailable value.

To correct the error in this case, you would need to define `MySymbol` in an accessible workspace to provide an appropriate numeric value. After you clicked **Refresh Details**, the value of `MySymbol` would appear in place of its unevaluated text, and the error indicator and error description would disappear.

To correct the error shown for `Output maximum`, you would need to decrease **Output maximum**, increase **Word length**, or decrease **Fraction length** (or some combination of these changes) sufficiently to allow the fixed-point data type to represent the maximum value that it could have.

Other values relevant to a particular block can also appear in the **Fixed-point details** subpane. For example, on a Discrete-Time Integrator block's **Signal Attributes** tab, the subpane could look like this:



Note that the values displayed for `Upper saturation limit` and `Lower saturation limit` are greyed out. This appearance indicates that the corresponding parameters are not currently used by the block. The greyed-out values can be ignored.

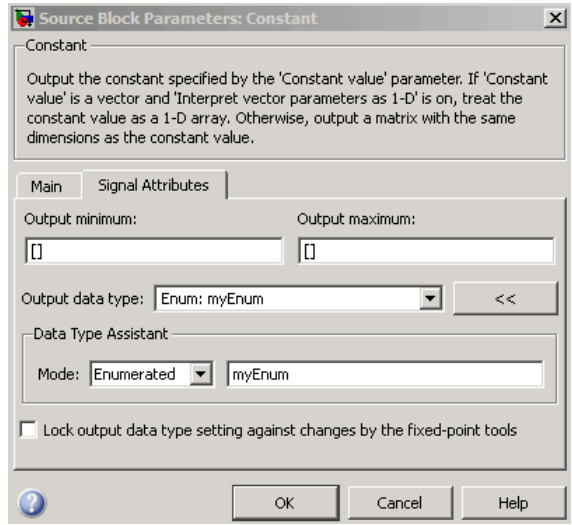
Note also that `Initial condition` displays the value `1..4`. The actual value is a vector or matrix whose smallest element is `1` and largest element is `4`. To conserve space, the **Fixed-point details** subpane shows only the smallest and largest element of a vector or matrix. An ellipsis (`..`) replaces the omitted values. The underlying definition of the vector or matrix is unaffected.

Lock output data type setting against changes by the fixed-point tools. Select this check box to prevent replacement of the current data type with a type that the Fixed-Point Tool or Fixed-Point Advisor chooses. See "Scaling" in the *Simulink Fixed Point User's Guide* for instructions on autoscaling fixed-point data.

Specifying an Enumerated Data Type

You can specify an enumerated data type by selecting the `Enum: <class name>` option and specify an enumerated object.

In the **Data Type Assistant**, you can use the **Mode** parameter to specify a bus as a data object for a block. Select the `Enumerated` option and specify an enumerated object.

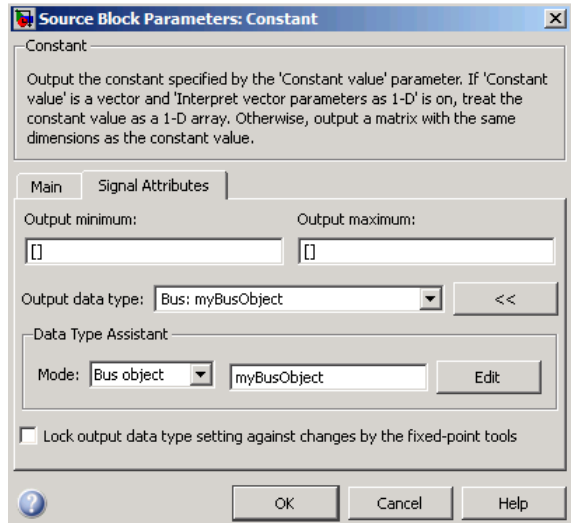


For details about enumerated data types, see Chapter 26, “Enumerations and Modeling”.

Specifying a Bus Object Data Type

The blocks listed in the section called “Bus Objects” on page 25-6 support your specifying a bus object as a data type. For those blocks, in the **Data type** parameter, select the `Bus: <object name>` option and specify a bus object. You cannot use the `Expression` option to specify a bus object as a data type for a block.

In the **Data Type Assistant**, you can use the **Mode** parameter to specify a bus as a data object for a block. Select the `Bus` option and specify a bus object.



You can specify a bus object as the data type for data objects such as `Simulink.Signal`, `Simulink.Parameter`, and `Simulink.BusElement`. In the Model Explorer, in Properties dialog box for a data object, in the **Data type** parameter, select the `Bus: <object name>` option and specify a bus object. You can also use the `Expression` option to specify a bus object.

Displaying Port Data Types

To display the data types of ports in your model, select **Format > Port/Signal Displays > Port Data Types**. The port data type display is not automatically updated when you change the data type of a diagram element. To refresh the display, press **Ctrl+D**.

Data Type Propagation

Whenever you start a simulation, enable display of port data types, or refresh the port data type display, the Simulink software performs a processing step called data type propagation. This step involves determining the types of signals whose type is not otherwise specified and checking the types of signals and input ports to ensure that they do not conflict. If type conflicts arise, an error dialog is displayed that specifies the signal and port whose data types conflict. The signal path that creates the type conflict is also highlighted.

Note You can insert typecasting (data type conversion) blocks in your model to resolve type conflicts. See "Typecasting Signals" on page 25-30 for more information.

Data Typing Rules

Observing the following rules can help you to create models that are typesafe and, therefore, execute without error:

- Signal data types generally do not affect parameter data types, and vice versa.

  A significant exception to this rule is the Constant block, whose output data type is determined by the data type of its parameter.

- If the output of a block is a function of an input and a parameter, and the input and parameter differ in type, the Simulink software converts the parameter to the input type before computing the output.

- In general, a block outputs the data type that appears at its inputs.

  Significant exceptions include Constant blocks and Data Type Conversion blocks, whose output data types are determined by block parameters.

- Virtual blocks accept signals of any type on their inputs.

  Examples of virtual blocks include Mux and Demux blocks and unconditionally executed subsystems.

- The elements of a signal array connected to a port of a nonvirtual block must be of the same data type.

- The signals connected to the input data ports of a nonvirtual block cannot differ in type.

- Control ports (for example, Enable and Trigger ports) accept any data type.

- Solver blocks accept only `double` signals.

- Connecting a non-`double` signal to a block disables zero-crossing detection for that block.

Typecasting Signals

An error is displayed whenever it detects that a signal is connected to a block that does not accept the signal's data type. If you want to create such a connection, you must explicitly typecast (convert) the signal to a type that the block does accept. You can use the Data Type Conversion block to perform such conversions.

Validating a Floating-Point Embedded Model

You can use data type override mode to switch the data types in your model. This capability allows you to maintain one model but simulate and generate code for multiple data types, and also validate the numerical behavior for each type. For example, if you implement an algorithm using double-precision data types and want to check whether the algorithm is also suitable for single-precision use, you can apply a data type override to floating-point data types to replace all doubles with singles without affecting any other data types in your model.

How to Apply a Data Type Override to Floating-Point Data Types

To apply a data type override, you must specify the data type that you want to apply and the data type that you want to replace.

You can set a data type override using one of the following methods. In these examples, both methods change all floating-point data types to single.

From the Command Line. For example:

```
set_param(gcs, 'DataTypeOverride', 'Single');
set_param(gcs, 'DataTypeOverrideAppliesTo','Floating-point');
```

Using the Fixed-Point Tool. For example:

1. From the model menu, select **Tools > Fixed-Point > Fixed-Point Tool**.

   The Fixed-Point Tool opens.

2. In the Fixed-Point Tool **Simulation Settings** panel, set:

   a. **Data type override** to `Single`.

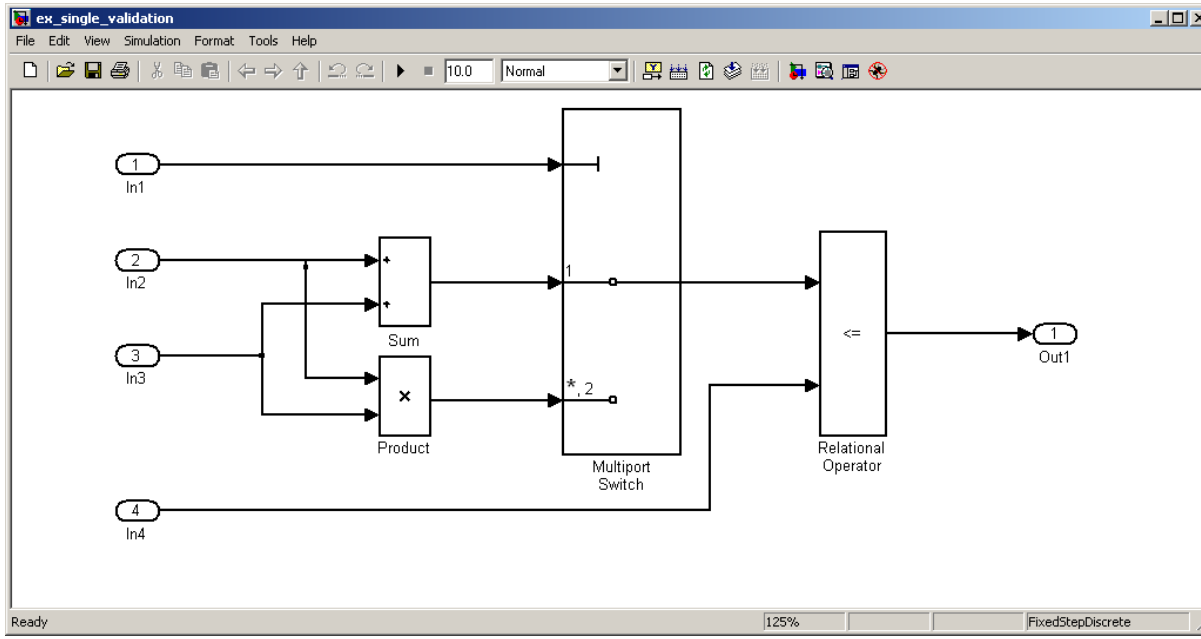
b **Data type override applies** to `Floating-point`.

For more information on data type override settings, see `fxptdlg`.

Tutorial: Validating a Single-Precision Model

This tutorial uses the `ex_single_validation` model to show how you can use data type overrides. It proves that an algorithm, which implements double-precision data types, is also suitable for single-precision embedded use.

About the Model



- The inputs `In2` and `In3` are double-precision inputs to the Sum and Product blocks.
- The outputs of the Sum and Product blocks are data inputs to the Multiport Switch block.
- The input `In1` is the control input to the Multiport Switch block. The value of this control input determines which of its other inputs, the sum of `In2`

and `In3` or the product of `In2` and `In3`, passes to the output port. Because `In1` is a control input, its data type is `int8`.

- The Relational Operator block compares the output of the Multiport Switch block to `In4`, and outputs a Boolean signal.

About the Procedure

In this tutorial, you follow these steps:

1. "Generate Code for the Double-Precision Model" on page 25-33

   First generate code for the double-precision model to act as a reference against which you compare the code generated for the single-precision model.

2. "Convert the Model to Single Precision" on page 25-34

   Use the Fixed-Point Tool to convert all floating-point data types in the model to singles. When you apply the data type override, you do not want to affect the data type of the integer input `In1`, which acts as a control input. Changing the data type of `In1` might change the behavior of the system. Applying the data type override only to floating-point data types ensures that integer data types are not overridden. Similarly, you do not want to override the logical Boolean output of the Relational Operator block. Data type overrides never apply to Boolean data types, so this output data type remains unchanged.

3. "Generate Code for the Single-Precision Model" on page 25-35

   Finally, you generate code for this single-precision model and verify that this code is suitable for single-precision embedded use.

Running the Tutorial

Open the Model.

1. Open the `ex_single_validation` model. At the MATLAB command line, enter:

```
run(docpath(fullfile(docroot,'toolbox','simulink','examples','ex_single_validation.mdl'))
```

Generate Code for the Double-Precision Model.

1. From the model menu, select **Simulation > Configuration Parameters**.

   The Configuration Parameters dialog box opens.

2. In the left pane, under **Real-Time Workshop**, select **Report**.

   On the **Report** pane, verify that **Create code generation report** and **Launch report automatically** are selected so that the Real-Time Workshop software creates a code generation report.

3. From the model menu, select **Tools > Real-Time Workshop > Build Model**.

   Real-Time Workshop generates code and displays the code generation report.

4. Examine the generated code.

   a. In the left pane of the report, click the `ex_single_validation.h` link.

      The report displays the header file in the right pane.

      In the code that defines external inputs and outputs for root inports and outports, the input `In1` has the type `int8_T`, all the remaining inputs are double-precision `real_T`, and the output `Out1` is `boolean_T`.

```
/* External inputs (root inport signals with auto storage) */
typedef struct {
 int8_T In1;
 real_T In2;
 real_T In3;
 real_T In4;
} ExternalInputs_ex_single_valida;

typedef struct {
   boolean_T Out1;
} ExternalOutputs_ex_single_valid;
```

b In the left pane of the report, click the `ex_single_validation.c` link.

The report displays the C code in the right pane. The code for the double-precision model contains only double-precision operations.

```
real_T rtb_MultiportSwitch;

if (ex_single_validation_U.In1 == 1) {
  rtb_MultiportSwitch = ex_single_validation_U.In2 +
     ex_single_validation_U.In3;
} else {
    rtb_MultiportSwitch = ex_single_validation_U.In2 *
      ex_single_validation_U.In3;
}
ex_single_validation_Y.Out1 = (rtb_MultiportSwitch <=
  ex_single_validation_U.In4);
```

Convert the Model to Single Precision.

1 From the model menu, select **Tools > Fixed-Point > Fixed-Point Tool**.

The Fixed-Point Tool opens.

2 In the Fixed-Point Tool **Simulation settings** panel:

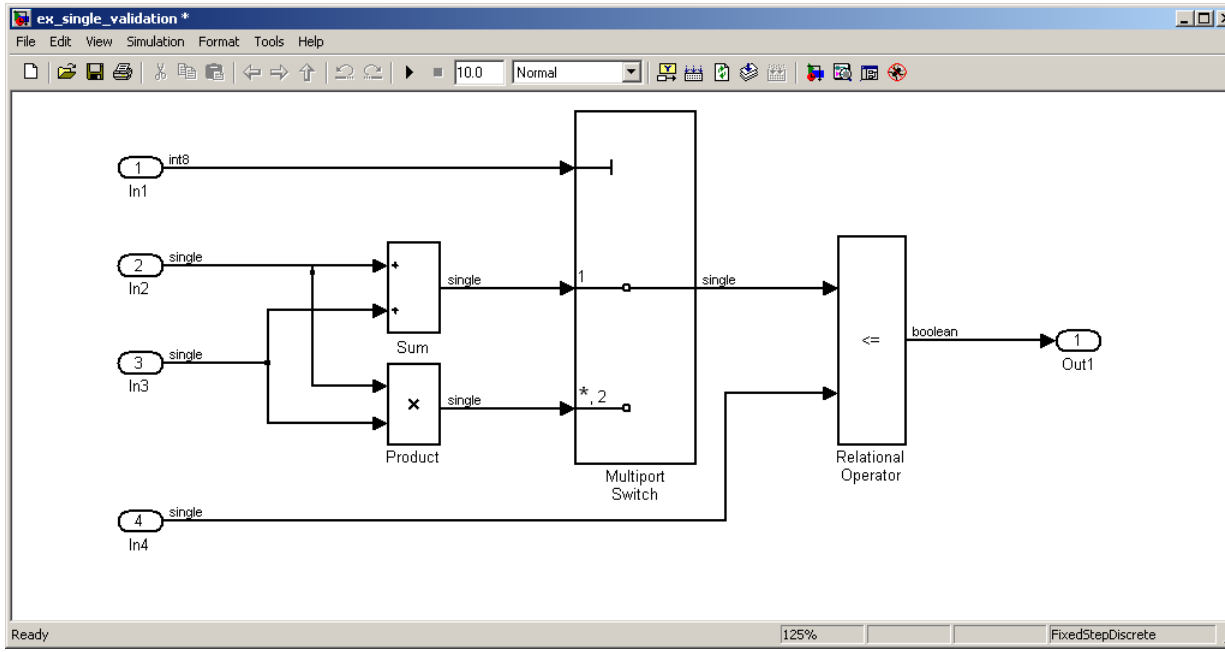
a Set the **Data type override** parameter to `Single`.

b Set the **Data type override applies to** parameter to `Floating-point`.

c Click **Apply**.

3 From the Fixed-Point Tool menu, select **Simulation > Start**.

The simulation runs. The data type override replaces all the floating-point (`double`) data types in the model with `single` data types, but does not affect the integer or Boolean data types.



Generate Code for the Single-Precision Model.

1. From the model menu, select **Tools > Real-Time Workshop > Build Model**.

   Real-Time Workshop generates code and displays the code generation report.

2. Examine the generated code.

   a. In the left pane of the report, click the `ex_single_validation.h` link.

   The report displays the header file in the right pane.

   In the code that defines external inputs, the inputs `In2`, `In3`, and `In4` are now single-precision `real32_T`, whereas `In1` is still `int8_T`, and `Out1` is still `boolean_T`.

```
/* External inputs (root inport signals with auto storage) */
typedef struct {
```

```
  int8_T In1;
  real32_T In2;
  real32_T In3;
  real32_T In4;
} ExternalInputs_ex_single_valida;

typedef struct {
   boolean_T Out1;
} ExternalOutputs_ex_single_valid;
```

b In the left pane of the report, click the `ex_single_validation.c` link.

The report displays the C code in the right pane.

```
real32_T rtb_MultiportSwitch;

if (ex_single_validation_U.In1 == 1) {
  rtb_MultiportSwitch = ex_single_validation_U.In2 +
     ex_single_validation_U.In3;
} else {
    rtb_MultiportSwitch = ex_single_validation_U.In2 *
      ex_single_validation_U.In3;
}
ex_single_validation_Y.Out1 = (rtb_MultiportSwitch <=
  ex_single_validation_U.In4);
```

The code for the single-precision model contains only single-precision operations. Therefore, this code is suitable for single-precision embedded use.

Working with Data Objects

In this section...

About Data Object Classes

You can create entities called data objects that specify values, data types, tunability, value ranges, and other key attributes of block outputs and parameters. You can create various types of data objects and assign them to workspace variables. You can use the variables in Simulink dialog boxes to specify parameter and signal attributes. This allows you to make model-wide changes to parameter and signal specifications simply by changing the values of a few variables. With Simulink objects you can parameterize the specification of a model's data attributes. For information on working with specific kinds of data objects, see "Simulink Classes".

Note This section uses the term *data* to refer generically to signals and parameters.

The Simulink software uses objects called data classes to define the properties of specific types of data objects. The classes also define functions, called

methods, for creating and manipulating instances of particular types of objects. A set of built-in classes are provided for specifying specific types of attributes (see "Simulink Classes" for information on these built-in classes). Some MathWorks products based on Simulink, such as the Real-Time Workshop product, also provide classes for specifying data attributes specific to their applications. See the documentation for those products for information on the classes they provide. You can also create subclasses of some of these built-in classes to specify attributes specific to your applications (see "Subclassing Simulink Data Classes" on page 25-52).

Memory structures called *packages* are used to store the code and data that implement data classes. The classes provided by the Simulink software reside in the Simulink package. Classes provided by products based on Simulink reside in packages provided by those products. You can create your own packages for storing the classes that you define.

Class Naming Convention

Simulink uses dot notation to name classes:

```
PACKAGE.CLASS
```

where CLASS is the name of the class and PACKAGE is the name of the package to which the class belongs, for example, `Simulink.Parameter`. This notation allows you to create and reference identically named classes that belong to different packages. In this notation, the name of the package is said to qualify the name of the class.

Note Class and package names are case sensitive. You cannot, for example, use A.B and a.b interchangeably to refer to the same class.

About Data Object Methods

Data classes define functions, called methods, for creating and manipulating the objects that they define. A class may define any of the following kinds of methods.

Dynamic Methods

A dynamic method is a method whose identity depends on its name and the class of an object specified implicitly or explicitly as its first argument. You can use either function or dot notation to specify this object, which must be an instance of the class that defines the method or an instance of a subclass of the class that defines the method. For example, suppose class `A` defines a method called `setName` that assigns a name to an instance of `A`. Further, suppose the MATLAB workspace contains an instance of A assigned to the variable `obj`. Then, you can use either of the following statements to assign the name `'foo'` to `obj`:

```
obj.setName('foo');
setName(obj, 'foo');
```

A class may define a set of methods having the same name as a method defined by one of its super classes. In this case, the method defined by the subclass overrides the behavior of the method defined by the parent class. The Simulink software determines which method to invoke at runtime from the class of the object that you specify as its first or implicit argument. Hence, the term dynamic method.

Note Most Simulink data object methods are dynamic methods. Unless the documentation for a method specifies otherwise, you can assume that a method is a dynamic method.

Static Methods

A static method is a method whose identity depends only on its name and hence cannot change at runtime. To invoke a static method, use its fully qualified name, which includes the name of the class that defines it followed by the name of the method itself. For example, `Simulink.ModelAdvisor` class defines a static method named `getModelAdvisor`. The fully qualified name of this static method is `Simulink.ModelAdvisor.getModelAdvisor`. The following example illustrates invocation of a static method.

```
ma = Simulink.ModelAdvisor.getModelAdvisor('vdp');
```

Constructors

Every data class defines a method for creating instances of that class. The name of the method is the same as the name of the class. For example, the name of the `Simulink.Parameter` class's constructor is `Simulink.Parameter`. The constructors defined by Simulink data classes take no arguments.

The value returned by a constructor depends on whether its class is a handle class or a value class. The constructor for a handle class returns a handle to the instance that it creates if the class of the instance is a handle class; otherwise, it returns the instance itself (see "Handle Versus Value Classes" on page 25-44).

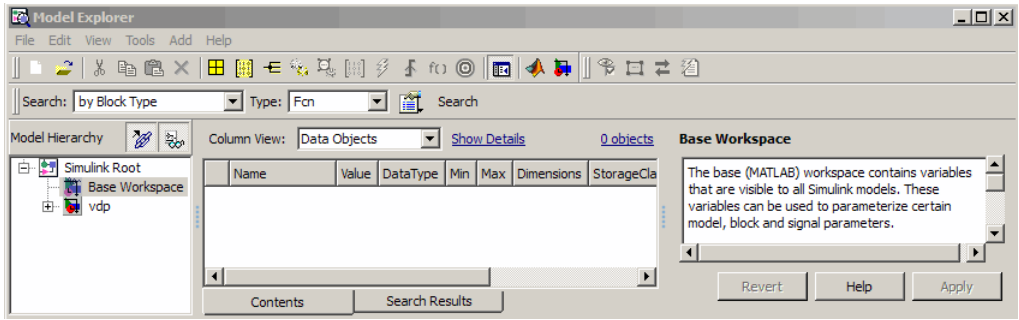
Using the Model Explorer to Create Data Objects

You can use the Model Explorer (see "The Model Explorer: Overview" on page 8-2) as well as MATLAB commands to create data objects. To use the Model Explorer,

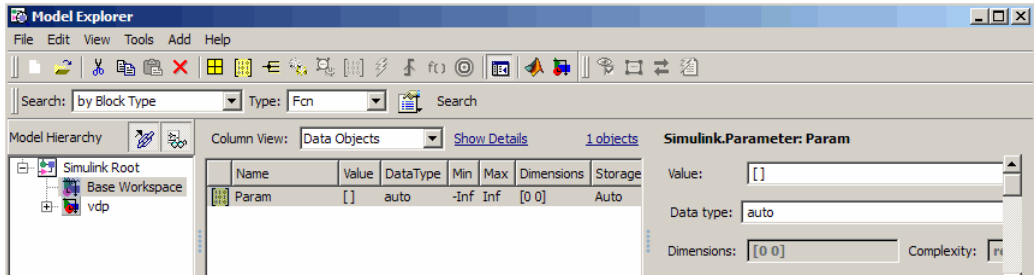
1. Select the workspace in which you want to create the object in the Model Explorer **Model Hierarchy** pane.

   Only `Simulink.Parameter` and `Simulink.Signal` objects for which the storage class is set to `Auto` can reside in a model workspace. You must create all other Simulink data objects in the base MATLAB workspace to ensure the objects are unique within the global Simulink context and accessible to all models.

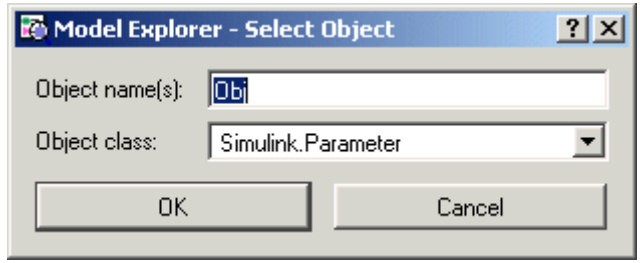
Note Subclasses of `Simulink.Parameter` and `Simulink.Signal` classes, such as `mpt.Parameter` and `mpt.Signal` objects (Real-Time Workshop Embedded Coder license required), can reside in a model workspace only if their storage class is set to `Auto`.



2 Select the type of the object that you want to create (for example, **Simulink Parameter** or **Simulink Signal**) from the Model Explorer's **Add** menu or from its toolbar. The Simulink software creates the object, assigns it to a variable in the selected workspace, and displays its properties in the Model Explorer's **Contents** and **Dialog** panes.



If the type of object you want to create does not appear on the **Add** menu, select **Find Custom** from the menu. The MATLAB path is searched for all data object classes derived from Simulink class on the MATLAB path, including types that you have created, and displays the result in a dialog box.



3 Select the type of object (or objects) that you want to create from the **Object class** list and enter the names of the workspace variables to which you want the objects to be assigned in the **Object name(s)** field. Simulink creates the specified objects and displays them in the Model Explorer's **Contents** pane.

About Object Properties

Object properties are variables associated with an object that specify properties of the entity that the object represents, for example, the size of a data type. The object's class defines the names, value types, default values, and valid value ranges of the object's properties.

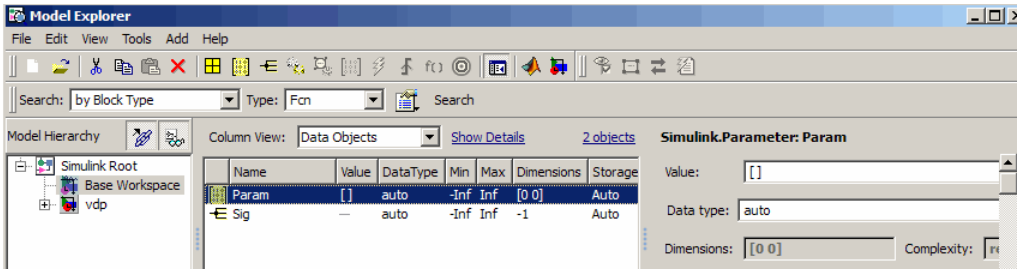
Changing Object Properties

You can use either the Model Explorer (see "Using the Model Explorer to Change an Object's Properties" on page 25-42) or MATLAB commands to change a data object's properties (see "Using MATLAB Commands to Change Workspace Data" on page 3-70).

Using the Model Explorer to Change an Object's Properties

To use the Model Explorer to change an object's properties, select the workspace that contains the object in the Model Explorer's **Model Hierarchy** pane. Then select the object in the Model Explorer's **Contents** pane.

The Model Explorer displays the object's property dialog box in its **Dialog** pane (if the pane is visible).



You can configure the Model Explorer to display some or all of the properties of an object in the **Contents** pane (see "The Model Explorer: Contents Pane" on page 8-18). To edit a property, click its value in the **Contents** or **Dialog** pane. The value is replaced by a control that allows you to change the value.

Using MATLAB Commands to Change an Object's Properties

You can also use MATLAB commands to get and set data object properties. Use the following dot notation in MATLAB commands and programs to get and set a data object's properties:

```
VALUE = OBJ.PROPERTY;
OBJ.PROPERTY = VALUE;
```

where `OBJ` is a variable that references either the object if it is an instance of a value class or a handle to the object if the object is an instance of a handle class (see "Handle Versus Value Classes" on page 25-44), `PROPERTY` is the property's name, and `VALUE` is the property's value. For example, the following MATLAB code creates a data type alias object (i.e., an instance of `Simulink.AliasType`) and sets its base type to `uint8`:

```
gain= Simulink.AliasType;
gain.BaseType = 'uint8';
```

You can use dot notation recursively to get and set the properties of objects that are values of other object's properties, e.g.,

```
gain.RTWInfo.StorageClass = 'ExportedGlobal';
```

Handle Versus Value Classes

Simulink data object classes fall into two categories: value classes and handle classes.

About Value Classes

The constructor for a *value* class (see "Constructors" on page 25-40) returns an instance of the class and the instance is permanently associated with the MATLAB variable to which it is initially assigned. Reassigning or passing the variable to a function causes MATLAB to create and assign or pass a copy of the original object.

For example, `Simulink.NumericType` is a value class. Executing the following statements

```
>> x = Simulink.NumericType;
>> y = x;
```

creates two instances of class `Simulink.NumericType` in the workspace, one assigned to the variable `x` and the other to `y`.

About Handle Classes

The constructor for a *handle* class returns a handle object. The handle can be assigned to multiple variables or passed to functions without causing a copy of the original object to be created. For example, `Simulink.Parameter` class is a handle class. Executing

```
>> x = Simulink.Parameter;
>> y = x;
```

creates only one instance of `Simulink.Parameter` class in the MATLAB workspace. Variables x and y both refer to the instance via its handle.

A program can modify an instance of a handle class by modifying any variable that references it, e.g., continuing the previous example,

```
>> x.Description = 'input gain';
>> y.Description

ans =
```

```
input gain
```

Most Simulink data object classes are value classes. Exceptions include `Simulink.Signal` and `Simulink.Parameter` class.

You can determine whether a variable is assigned to an instance of a class or to a handle to that class by evaluating it at the MATLAB command line. MATLAB appends the text `(handle)` to the name of the object class in the value display, e.g.,

```
>> gain = Simulink.Parameter

gain =

Simulink.Parameter (handle)
          Value: []
        RTWInfo: [1x1 Simulink.ParamRTWInfo]
    Description: ''
       DataType: 'auto'
            Min: -Inf
            Max: Inf
       DocUnits: ''
     Complexity: 'real'
     Dimensions: [0 0]
```

Copying Handle Classes

Use the copy method of a handle class to create copies of instances of that class. For example, `Simulink.ConfigSet` is a handle class that represents model configuration sets. The following code creates a copy of the current model's active configuration set and attaches it to the model as an alternate configuration geared to model development.

```
activeConfig = getActiveConfigSet(gcs);
develConfig = activeConfig.copy;
develConfig.Name = 'develConfig';
attachConfigSet(gcs, develConfig);
```

Comparing Data Objects

Simulink data objects provide a method, named `isContentEqual`, that determines whether object property values are equal. This method compares the property values of one object with those belonging to another object and returns true (`1`) if all of the values are the same or false (`0`) otherwise. For example, the following code instantiates two signal objects (A and B) and specifies values for particular properties.

```
A = Simulink.Signal;
B = Simulink.Signal;
A.DataType = 'int8';
B.DataType = 'int8';
A.InitialValue = '1.5';
B.InitialValue = '1.5';
```

Afterward, use the `isContentEqual` method to verify that the object properties of A and B are equal.

```
>> result = A.isContentEqual(B)

result =

     1
```

Saving and Loading Data Objects

You can use the `save` command to save data objects in a MAT-file and the `load` command to restore them to the MATLAB workspace in the same or a later session. Definitions of the classes of saved objects must exist on the MATLAB path for them to be restored. If the class of a saved object acquires new properties after the object is saved, Simulink adds the new properties to the restored version of the object. If the class loses properties after the object is saved, only the properties that remain are restored.

Using Data Objects in Simulink Models

You can use data objects in Simulink models as parameters and signals. Using data objects as parameters and signals allows you to specify simulation and code generation options on an object-by-object basis.

Creating Persistent Data Objects

To create parameter and signal objects that persist across Simulink sessions, first write a script that creates the objects or create the objects with the Simulink **Data Class Designer** (see "Subclassing Simulink Data Classes" on page 25-52) or at the command line and save them in a MAT-file (see "Saving and Loading Data Objects" on page 25-46). Then use either the script or a load command as the `PreLoadFcn` callback routine for the model that uses the objects. For example, suppose you save the data objects in a file named `data_objects.mat` and the model to which they apply is open and active. Then, entering the following command

```
set_param(gcs, 'PreLoadFcn', 'load data_objects');
```

at the MATLAB command line sets `load data_objects` as the model's preload function. This in turn causes the data objects to be loaded into the model workspace whenever you open the model.

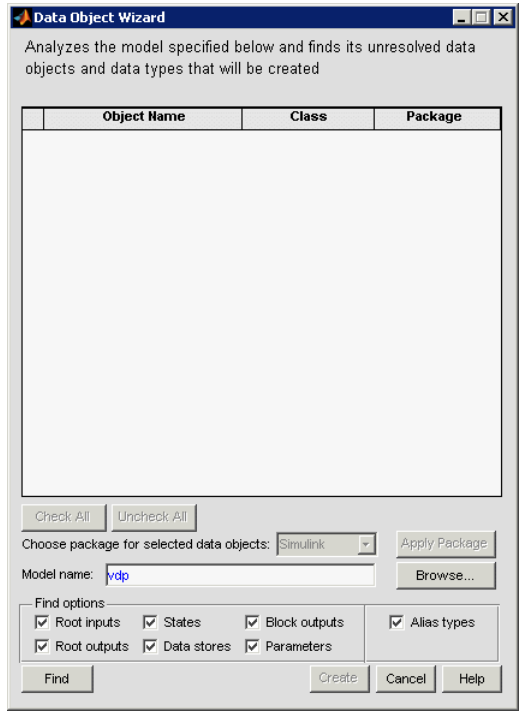
Data Object Wizard

The Data Object Wizard allows you to determine quickly which model data are not associated with data objects and to create and associate data objects with the data.

To use the wizard to create data objects:

1. Select **Tools > Data Object Wizard** from the Model Editor's tool bar.

The Data Object Wizard appears.



2 Enter, if necessary, the name of the model you want to search in the wizard's **Model name** field.

By default the wizard displays the name of the model from which you opened the wizard. You can enter the name of another model in this field. If the model is not open, the wizard opens the model.

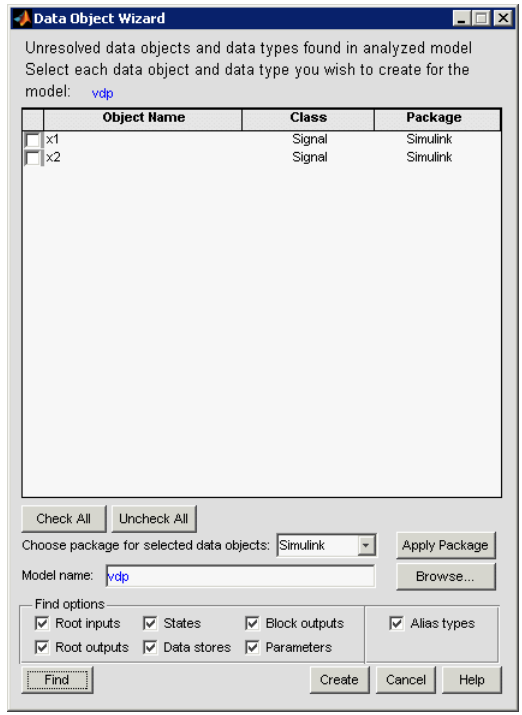
3 In **Find options**, uncheck any of the data object types that you want the search to ignore.

The search options include:

Option	Description
Root inputs	Named signals from root-level input ports
Root outputs	Named signals from root-level output ports
States	States associated with any instances of the following discrete block types: Discrete Filter Discrete State-Space Discrete-Time Integrator Discrete Transfer Fcn Discrete Zero-Pole Memory Unit Delay
Data stores	Data stores (see Chapter 28, "Working with Data Stores")
Block outputs	Named signals emitted by non-root-level blocks.
Parameters	• Parameters of any instances of the following block types: Constant Gain Lookup Table Lookup Table (2-D) Relay • Stateflow data with a **Scope** of `Parameter`. See "Sharing Simulink Parameters with Stateflow Charts" in the online Stateflow documentation for more information.
Alias types	Data whose data type is a registered custom data type. This option applies only if you are generating code from the model. See "Creating Simulink Data Objects with Data Object Wizard" in theReal-Time Workshop Embedded Coder documentation for more information.

4 Click the wizard's **Find** button.

The wizard displays the search results in the data objects table.



5 Check the data for which you want the wizard to create data objects.

6 If you want the wizard to use data object classes from a package other than the Simulink standard class package to create the data objects, select the package from the **Choose package for selected data objects** list and then select **Apply Package** to confirm your choice.

7 Click **Create**.

The wizard creates data objects of the appropriate class for the data selected in the search results table.

Note Use the Model Explorer to view and edit the created data objects.

Subclassing Simulink Data Classes

In this section...

About Packages and Data Classes

Simulink packages and data classes are introduced in "About Data Object Classes" on page 25-37 and "Defining Data Representation and Storage for Code Generation". Simulink resources include several built-in packages and data classes. You can add user-defined packages and data classes with the Simulink **Data Class Designer**, which can:

- Create and delete user-defined packages that can hold user-defined subclasses.
- Create, change, and delete user-defined subclasses of some Simulink classes.
- Add and delete user-defined subclasses contained within user-defined packages.
- Define enumerated property types (not data types) for use by classes in a package.
- Enable defining custom storage classes for classes that have an appropriate parent class.

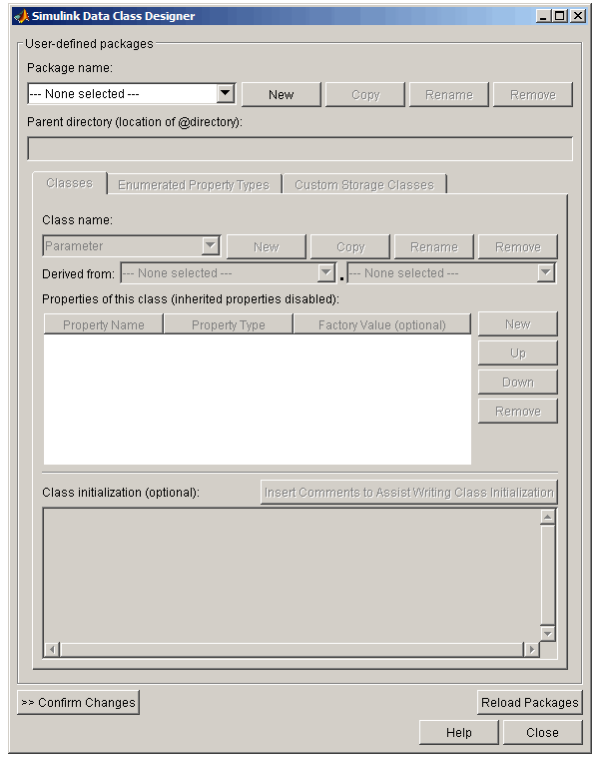
Simulink stores all package and data class definitions as P-files. You can view any package or data class in the Data Class Designer, but you cannot use the Designer to change a built-in package or data class. If you create or change user-defined packages and data classes, do so *only* in the Data Class Designer. Do not try to circumvent the Data Class Designer and directly modify any package or data class definition. An unrecoverable error could result.

Appropriately configured packages and data classes can define custom storage classes, which specify how data is declared, stored, and represented in generated code. Some built-in packages and data classes define built-in custom storage classes. You can use the Data Class Designer to enable a user-defined package and data class to have custom storage classes, as described in "Enabling Custom Storage Classes" on page 25-68.

Custom storage classes are defined and stored in different files than packages and data classes use, and different rules apply to changing them. See "Creating and Using Custom Storage Classes" in the Real-Time Workshop Embedded Coder documentation for complete information about custom storage classes.

Working with Packages

You can use the Simulink Data Class Designer to create and manage user-defined packages. To view the Data Class Designer, choose **Tools > Data Class Designer** from the Simulink menu. When opened, the designer first scans the MATLAB path and loads any packages that it finds. The Data Class Designer looks like this when no package is currently selected:



You can use the fields and buttons at the top and bottom of the Data Class Designer, and a few other designer capabilities, to select an existing package, create a new package, and copy, rename, or delete a package, as described in this section. The rest of the designer manages classes, as described in "Working with Classes" on page 25-57.

Selecting a Package

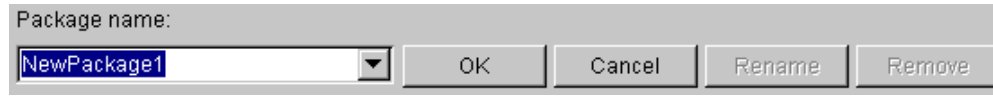
To select an existing user-defined package, select that package in the **Package Name** field of the Simulink **Data Class Designer**. The designer then displays the location of the package and the classes that it contains, plus class initialization and other information.

Creating a Package

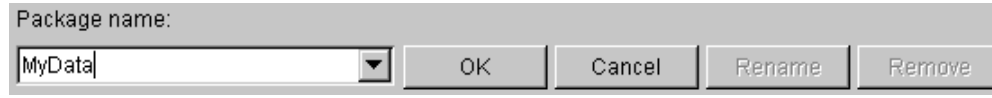
To create a new package to contain your classes:

1 Click the **New** button next to the **Package name** field of the Data Class Designer.

A default package name is displayed in the **Package name** field.



2 Edit the **Package name** field to contain the package name that you want.



3 Click **OK** to create the new package in memory.

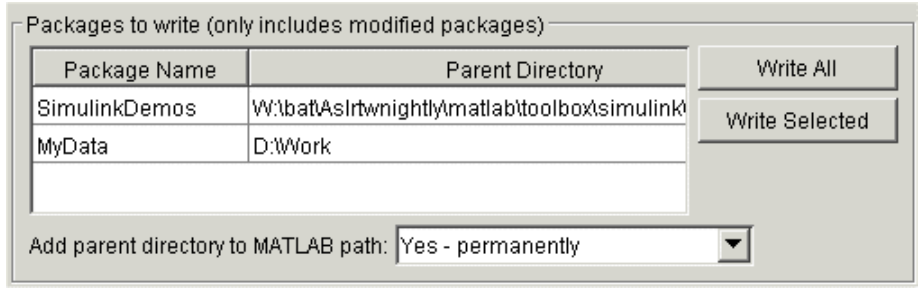
4 In the package **Parent folder** field, enter the path of the folder where you want Simulink to create the new package.

Note Do not create class package directories under *`matlabroot`*. Packages in these directories are treated as built-in and will not be visible in the Data Class Designer.

The Simulink software creates the specified folder, if it does not already exist, when you save the package to your file system in the succeeding steps.

5 Click the **Confirm changes** button on the **Data Class Designer**.

The **Packages to write** panel is displayed.



6 To enable use of this package in the current and future sessions, ensure that the **Add parent folder to MATLAB path** option is set to `Yes - permanently`. The default is `Yes - for this session only`.

This adds the path of the new package's parent folder to the MATLAB path.

7 Click **Write all** or select the new package and click **Write selected** to save the new package.

Copying a package

To copy a package, select the package and click the **Copy** button next to the **Package name** field. The Simulink software creates a copy of the package under a slightly different name. Edit the new name, if desired, and click **OK** to create the package in memory. Then save the package to make it permanent.

Renaming a package

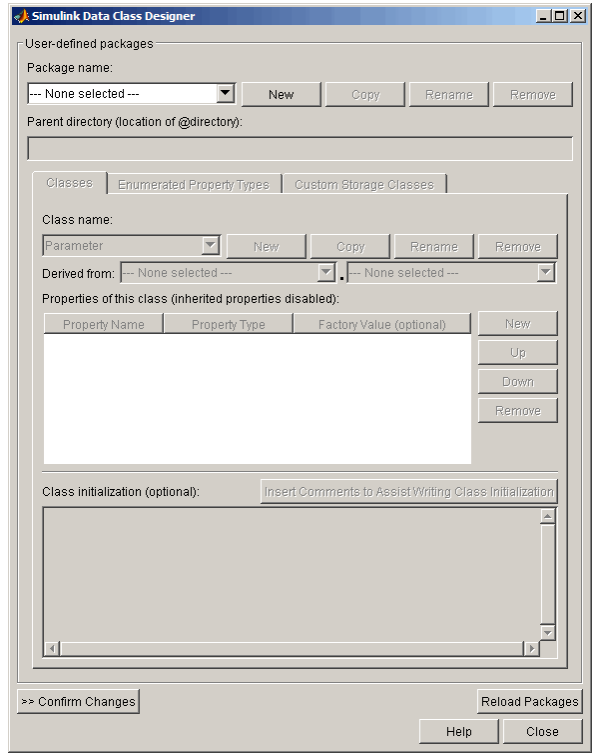
To rename a package, select the package and click the **Rename** button next to the **Package name** field. The field becomes editable. Edit the field to reflect the new name. Save the renamed package.

Removing a package

To remove a package, select the package and click the **Remove** button next to the **Package name** field to remove the package from memory. Click the **Confirm changes** button to display the **Packages to remove** panel. Select the package and click **Remove selected** to remove the package from your file system or click **Remove all** to remove all packages that you have removed from memory from your file system as well.

Working with Classes

You can use the Simulink Data Class Designer to create and manage user-defined classes. To view the Data Class Designer, choose **Tools > Data Class Designer** from the Simulink menu. When opened, the designer first scans the MATLAB path and loads any packages that it finds. The Data Class Designer looks like this when no package is currently selected:



You can use the three tabs in the Data Class Designer, and a few other designer capabilities, to select an existing class, create a new class, copy, rename, or delete a class, and specify various class properties, as described in this section. The rest of the designer manages packages, as described in "Working with Classes" on page 25-57.

Creating a Data Object Class

To create a class within the currently selected package:

1. Select **Data Class Designer** from the Simulink **Tools** menu.

   The **Data Class Designer** dialog box appears.

   The designer initially scans the MATLAB path and loads any packages that it finds.

2. Select the name of the package in which you want to create the class from the **Package name** list.

   Do not create a class in any of the Simulink built-in packages, i.e., packages in *`matlabroot`*`/toolbox/simulink`, or any folder under *`matlabroot`*. See "Working with Packages" on page 25-53 for information on creating your own class packages.

3. Click the **New** button on the **Classes** pane of the **Data Class Designer** dialog box.

4. Enter the name of the new class in the **Class name** field on the **Classes** pane.

   Note The name of the new class must be unique in the package to which the new class belongs. Class names are case sensitive. For example, `Signal` and `signal` is considered to be names of different classes.

5. Press **Enter** or click **OK** on the **Classes** pane to create the specified class in memory.

6 Select a parent class for the new class (see “Specifying a Parent for a Class” on page 25-60).

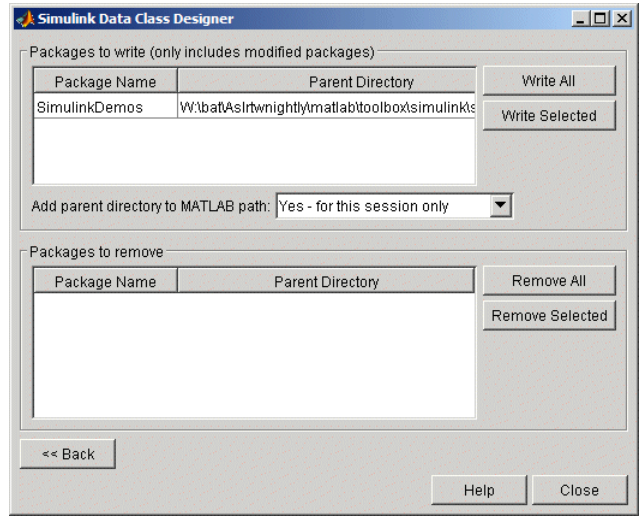
7 Optionally enable custom storage classes for the class (see “Enabling Custom Storage Classes” on page 25-68).

8 Define the properties of the new class (see “Defining Class Properties” on page 25-62).

9 If necessary, create initialization code for the new class (see “Creating Initialization Code” on page 25-64).

10 Click **Confirm Changes**.

Simulink displays the **Confirm Changes** pane.



11 Click **Write All** or select the package containing the new class definition and click **Write Selected** to save the new class definition.

Copying a class

To copy a class, select the class in the **Classes** pane and click **Copy**. The Simulink software creates a copy of the class under a slightly different name.

Edit the name, if desired, click **Confirm Changes**, and click **Write All** or, after selecting the appropriate package, **Write Selected** to save the new class.

Renaming a class

To rename a class, select the class in the **Classes** pane and click **Rename**. The **Class name** field becomes editable. Edit the field to reflect the new name. Save the package containing the renamed class, using the **Confirm changes** pane.

Note You cannot modify an instantiated Simulink data class. If you try to modify a class that has already been instantiated during the current MATLAB session, an error message informs you that you need to restart MATLAB if you want to modify this package.

Removing a class from a package

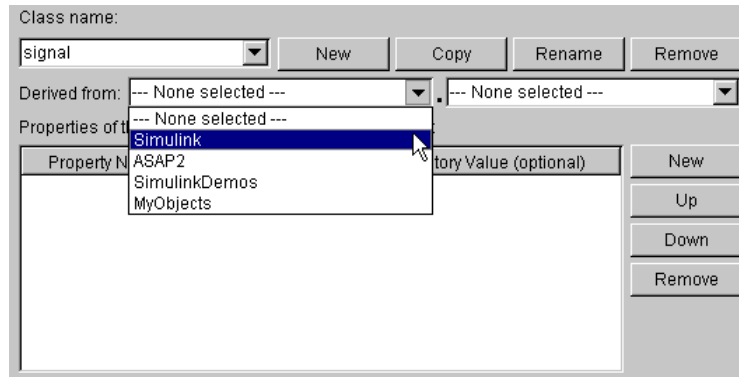
To remove a class definition from the currently selected package, select the class in the **Classes** pane and click **Remove**. The class is removed from the in-memory definition of the class. Save the package that formerly contained the class.

Specifying a Parent for a Class

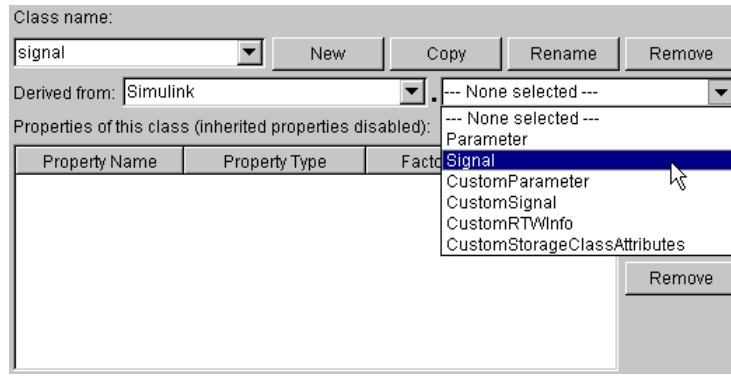
To specify a parent for a class:

1. Select the name of the class from the **Class name** field on the **Classes** pane.

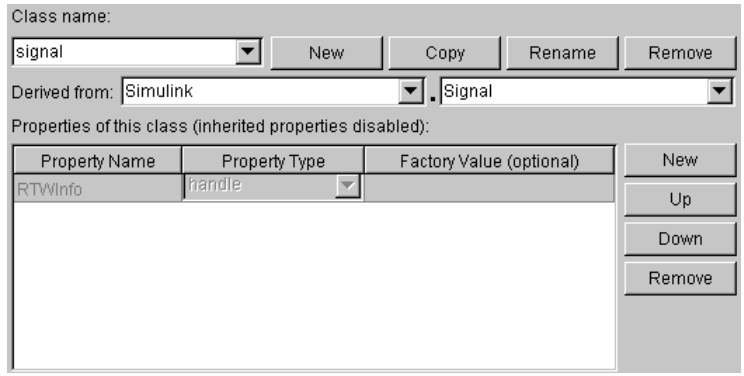
2 Select the package name of the parent class from the left-hand **Derived from** list box.



3 Select the parent class from the right-hand **Derived from** list.



The properties of the selected class derived from the parent class are displayed in the **Properties of this class** field.



The inherited properties are grayed to indicate that they cannot be redefined by the child class.

4 Save the package containing the class.

Defining Class Properties

To add a property to a class:

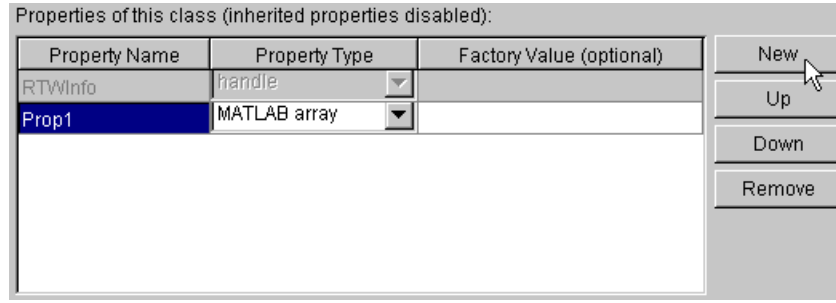
1 Select the name of the class from the **Class name** field on the **Classes** pane.

Note You cannot modify an instantiated Simulink data class. If you try to modify a class that has already been instantiated during the current MATLAB session, an error message informs you that you need to restart MATLAB if you want to modify this package.

---

2 Click the **New** button next to the **Properties of this class** field on the **Classes** pane.

A property is created with a default name and value and displays the property in the **Properties of this class** field.



3 Enter a name for the new property in the **Property Name** column.

Note The property name must be unique to the class. Unlike class names, property names are not case sensitive. For example, `Value` and `value` are treated as referring to the same property.

---

4 Select the data type of the property from the **Property Type** list.

The list includes built-in property types and any enumerated property types that you have defined (see "Enumerated Property Types" on page 25-65).

5 If you want the property to have a default value, enter the default value in the **Factory Value** column.

The default value is the value the property has when an instance of the associated class is created. The initialization code for the class can override this value (see "Creating Initialization Code" on page 25-64 for more information).

The following rules apply to entering factory values for properties:

- Do not use quotation marks when entering the value of a string property. The value that you enter is treated as a literal string.

- The value of a MATLAB array property can be any expression that evaluates to an array, cell array, structure, or object. Enter the expression exactly as you would enter the value on the command line, for example, `[0 1; 1 0]`. The expression that you enter is evaluated to check its validity. A warning is displayed if evaluating the expression results in an error. Regardless of whether an evaluation error occurs, Simulink stores the expression as the factory value of the property. This is because an expression that is invalid at define time might be valid at run-time.
- You can enter any expression that evaluates to a numeric value as the value of a `double` or `int32` property. The expression is evaluated and the result stored as the property's factory value.

6 Save the package containing the class with new or changed properties.

Creating Initialization Code

You can specify code to be executed when the Simulink software creates an instance of a data object class. To specify initialization code for a class, select the class from the **Class name** field of the **Data Class Designer** and enter the initialization code in the **Class initialization** field.

The **Data Class Designer** inserts the code that you enter in the **Class initialization** field in the class instantiation function of the corresponding class. This function is invoked when an instance of this class is created. The class instantiation function has the form

```
function h = ClassName(varargin)
```

where `h` is the handle to the object that is created and `varargin` is a cell array that contains the function's input arguments.

By entering the appropriate code in the **Data Class Designer**, you can cause the instantiation function to perform such initialization operations as

- Error checking
- Loading information from data files
- Overriding factory values
- Initializing properties to user-specified values

For example, suppose you want to let a user initialize the `ParamName` property of instances of a class named `MyPackage.Parameter`. The user does this by passing the initial value of the `ParamName` property to the class constructor:

```
Kp = MyPackage.Parameter('Kp');
```

The following code in the instantiation function would perform the required initialization:

```
switch nargin
 case 0
  % No input arguments - no action
 case 1
  % One input argument
  h.ParamName = varargin{1};
 otherwise
  warning('Invalid number of input arguments');
end
```

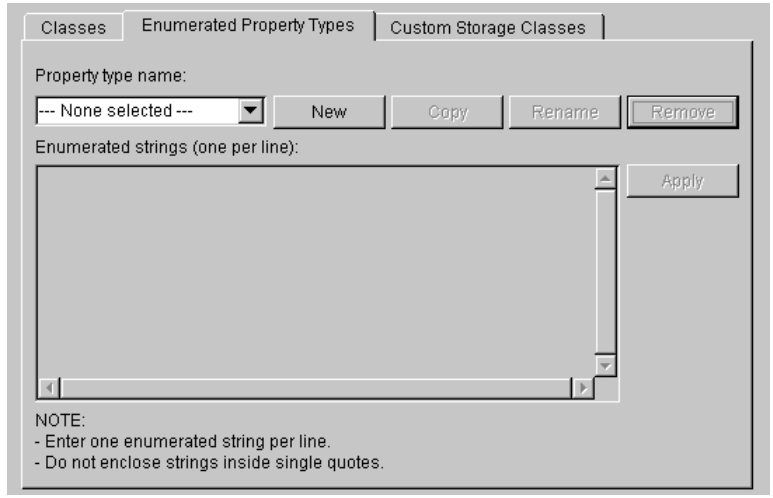
Enumerated Property Types

An *enumerated property type* is a property type whose value must be one of a specified set of values, for example, `red`, `blue`, or `green`. An enumerated property type is valid only in the package that defines it, but must be globally unique throughout all packages.

Note Do not confuse an *enumerated property type* with an *enumeration*. For information on enumerations, see "Using Enumerated Data in Simulink Models" on page 26-11. The Data Class Designer cannot be used for defining enumerations.

To create an enumerated property type:

1 Select the **Enumerated Property Types** tab of the **Data Class Designer**.



2 Click the **New** button next to the **Property type name** field.

An enumerated property type is created with a default name.

3 Change the default name in the **Property type name** field to the desired name for the property.

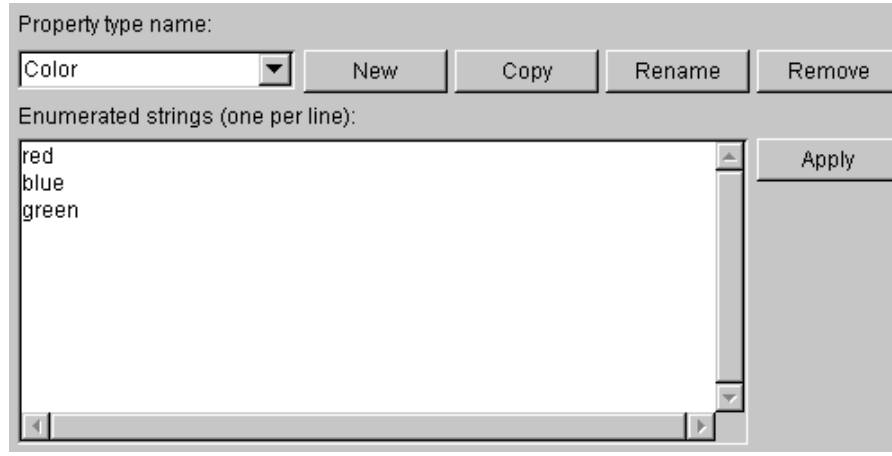
The currently selected package defines an enumerated property type and the type can be referenced only in the package that defines it. However, the name of the enumerated property type must be globally unique. There cannot be any other built-in or user-defined enumerated property type with the same name. An error is displayed if you enter the name of an existing built-in or user-defined enumerated property type.

4 Click the **OK** button.

The new property is created in memory and the **Enumerated strings** field on the **Enumerated Property Types** pane is enabled .

5 Enter the permissible values for the enumerated property type **Enumerated strings** field, one per line.

For example, the following **Enumerated strings** field shows the permissible values for an enumerated property type named `Color`.



6 Click **Apply** to save the changes in memory.

7 Click **Confirm changes**. Then click **Write all** to save this change.

You can also use the **Enumerated Property Type** pane to copy, rename, and remove enumerated property types.

- Click the **Copy** button to copy the currently selected property type. A new property that has a new name, but has the same value set as the original property is created.
- Click the **Rename** button to rename the currently selected property type. The **Property name** field becomes editable. Edit the field to reflect the new name.
- Click the **Remove** button to remove the currently selected property.

Always save the package containing the modified enumerated property type.

Note You must restart the MATLAB software if you modify, add, or remove enumerated property types from a class you have already instantiated.

Enabling Custom Storage Classes

If you select `Simulink.Signal` or `Simulink.Parameter` as the parent of a user-defined class, the Simulink Data Class Designer displays a check box labeled **Create your own custom storage classes for this class**. You can ignore this option if you do not intend to use Real-Time Workshop Embedded Coder to generate code from models that reference this data object class.

Otherwise, select this check box to cause Simulink Data Class Designer to create custom storage classes for this data object class. See "Creating Packages that Support CSC Definitions" in the Real-Time Workshop Embedded Coder documentation for more information. The Data Class Designer also provides a tab labeled Custom Storage Classes, but this tab is now obsolete.

Associating User Data with Blocks

You can use the `set_param` command to associate your own data with a block. For example, the following command associates the value of the variable `mydata` with the currently selected block.

```
set_param(gcb, 'UserData', mydata)
```

The value of `mydata` can be any MATLAB data type, including arrays, structures, objects, and Simulink data objects.

Use `get_param` to retrieve the user data associated with a block.

```
get_param(gcb, 'UserData')
```

The following command saves the user data associated with a block in the model file of the model containing the block.

```
set_param(gcb, 'UserDataPersistent', 'on');
```

Note If persistent UserData for a block contains any Simulink data objects, the directories containing the definitions for the classes of those objects must be on the MATLAB path when you open the model containing the block.

26

Enumerations and Modeling

About Simulink Enumerations

Simulink enumerations are built on enumerations defined for the MATLAB language. They are subclasses of the abstract superclass `Simulink.IntEnumType`, and inherit from that superclass the capabilities necessary to be used in the Simulink environment.

Before you begin to use enumerations in a modeling context, you should understand information provided in "Enumerations".

The following demos show you how to use enumerations in Simulink and Stateflow:

Demo...	Shows How To Use...
Data Typing in Simulink	Data types in Simulink, including enumerated data types
Modeling a CD Player/Radio Using Enumerated Data Types	Enumerated data types in a Simulink model that contains a Stateflow chart

For information on using enumerations in Stateflow, see "Using Enumerated Data in Stateflow Charts".

Defining Simulink Enumerations

In this section...

Basic Workflow for Defining a Simulink Enumeration

1. Create a class definition.
2. Optionally, customize the enumeration.
3. Optionally, save the enumeration in a MATLAB file.

For complete information about the MATLAB Object System, see *Object-Oriented Programming*.

Creating a Simulink Enumeration Class

To create a Simulink enumeration class, in the class definition:

- Define the class as a subclass of `Simulink.IntEnumType`
- Add an `enumeration` block that specifies enumeration values with underlying integer values

Consider the following example:

```
classdef BasicColors < Simulink.IntEnumType
  enumeration
    Red(0)
    Yellow(1)
    Blue(2)
```

```
    end
  end
```

The first line defines an integer-based enumeration that is derived from built-in class `Simulink.IntEnumType`. The enumeration is integer-based because `IntEnumType` is derived from `int32`.

The `enumeration` section specifies three enumerated values.

Enumerated Value	Enumerated Name	Underlying Integer
`Red(0)`	`Red`	`0`
`Yellow(1)`	`Yellow`	`1`
`Blue(2)`	`Blue`	`2`

When defining an enumeration class for use in the Simulink environment, consider the following:

- The name of the enumeration class must be unique among data type names and base workspace variable names, and is case-sensitive.
- Underlying integer values in the `enumeration` section need not be unique within the class and across types.
- Often, the underlying integers of a set of enumerated values are consecutive and monotonically increasing, but they need not be either consecutive or ordered.
- For simulation, an underlying integer can be any `int32` value. Use the MATLAB functions `intmin` and `intmax` to get the limits.
- For code generation, every underlying integer value must be representable as an integer on the target hardware, which may impose different limits. See “Configuring the Hardware Implementation” and “Hardware Implementation Pane” for more information.

For more information on superclasses, see “Converting to Superclass Value”.

Customizing a Simulink Enumeration

About Simulink Enumeration Customizations

You can customize a Simulink enumeration by using the same techniques that work with MATLAB classes, as described in "Modifying Superclass Methods and Properties".

A primary source of customization are the methods associated with an enumeration.

Inherited Methods

Enumeration class definitions can include an optional `methods` section. Simulink enumerated classes inherit four static methods from the superclass `Simulink.IntEnumType`.

Default Method	Description	Default Value Returned or Specified	Usage Context
`getDefaultValue`	Returns the default value of the enumeration.	Enumeration value listed first in the class definition	Simulation and code generation
`getDescription`	Returns a description of the enumeration.	`''`	Code generation
`getHeaderFile`	Specifies the file in which the enumeration is defined for code generation.	`''`	Code generation
`addClassNameToEnumNames`	Specifies whether the class name becomes a prefix in generated code.	`false` — prefix is not used	Code generation

Overriding Inherited Methods

You can override the inherited methods to customize the behavior of an enumeration. To override a method, include a customized version of the method in the `methods` section in the enumerated class definition. If you do not want to override the inherited methods, omit the `methods` section.

"Specifying a Default Enumerated Value" on page 26-6 explains how to specify a default enumerated value by overriding the `getDefaultValue` method. For information on overriding the other three methods, see "Overriding Default Methods (Optional)" in the Real-Time Workshop documentation.

Specifying a Default Enumerated Value

Simulink software and related generated code use an enumeration's default value for ground-value initialization of enumerated data when you provide no other initial value. For example, an enumerated signal inside a conditionally executed subsystem that has not yet executed has the enumeration's default value. Generated code uses an enumeration's default value if a safe cast fails, as described in "Enumerated Type Safe Casting" in the Real-Time Workshop documentation.

Unless you specify otherwise, the default value for an enumeration is the first value in the enumeration class definition. To specify a different default value, add your own `getDefaultValue` method to the `methods` section. The following code shows a shell for the `getDefaultValue` method:

```
function retVal = getDefaultValue()
% GETDEFAULTVALUE  Returns the default enumerated value.
%   This value must be an instance of the enumerated class.
%   If this method is not defined, the first enumeration is used.
  retVal = ThisClass.EnumName;
end
```

To customize this method, provide a value for *`ThisClass.EnumName`* that specifies the desired default.

- *`ThisClass`* must be the name of the class within which the method exists.
- *`EnumName`* must be the name of an enumerated value defined in that class.

For example:

```
classdef BasicColors < Simulink.IntEnumType
  enumeration
    Red(0)
    Yellow(1)
    Blue(2)
  end
  methods (static)
    function retVal = getDefaultValue()
      retVal = BasicColors.Blue;
    end
  end
end
```

This example defines the default as `BasicColors.Blue`. If this method does not appear, the default value would be `BasicColors.Red`, because that is the first value listed in the enumerated class definition.

The seemingly redundant specification of *`ThisClass`* inside the definition of that same class is necessary because `getDefaultValue` returns an instance of the default enumerated value, not just the name of the value. The method, therefore, needs a complete specification of what to instantiate. See "Instantiating Enumerations" on page 26-16 for more information.

Saving an Enumeration in a MATLAB File

You can define an enumeration within a MATLAB file.

- The name of the definition file must match the name of the enumeration exactly, including case. For example, the definition of enumeration `BasicColors` must reside in a file named `BasicColors.m`. Otherwise, MATLAB will not find the definition.
- You must define each class definition in a separate file.
- Save each definition file on the MATLAB search path. MATLAB searches the path to find a definition when necessary.

  To add a file or folder to the MATLAB search path, type `addpath` *`pathname`* at the MATLAB command prompt. For more information, see "Using the MATLAB Search Path", `addpath`, and `savepath`.

- You do not need to execute an enumeration class definition to use the enumeration. The only requirement, as indicated in the preceding bullet, is that the definition file be on the MATLAB search path.

Changing and Reloading Enumerations

You can change the definition of an enumeration by editing and saving the file that contains the definition. You do not need to inform MATLAB that a class definition has changed. MATLAB automatically reads the modified definition when you save the file. However, the class definition changes do not take full effect if any class instances (enumerated values) exist that reflect the previous class definition. Such instances might exist in the base workspace or might be cached.

The following table explains options for removing instances of an enumeration from the base workspace and cache.

If In Base Workspace...	If In Cache...
Do one of the following: • Locate and delete specific obsolete instances. • Delete everything from the workspace by using the `clear` command.	• Delete obsolete instances by closing all models that you updated or simulated while the previous class definition was in effect. • Clear functions and close models that are caching instances of the class.

For more information about applying enumeration changes, see “Modifying and Reloading Classes”.

Importing Enumerations Defined Externally to MATLAB

If you have enumerations defined externally to MATLAB—for example, in a data dictionary, that you want to import for use within the Simulink environment, you can do so programmatically with calls to the function `Simulink.defineIntEnumType`. This function defines an enumeration that you can use in MATLAB as if it is defined by a class definition file. In addition

to specifying the enumeration class name and values, each function call can specify:

- String that describes the enumeration class.
- Which of the enumeration values is the default.

For code generation, you can specify:

- Header file into which the code generator places the enumeration class definition.
- Whether the code generator applies the class name as a prefix to enumeration members—for example, `BasicColors_Red` or `Red`.

As an example, consider the following class definition:

```
classdef BasicColors < Simulink.IntEnumType
  enumeration
    Red(0)
    Yellow(1)
    Blue(2)
  end
  methods (static)
    function retVal = getDescription()
      retVal = "Basic colors...'
    end
    function retVal = getDefaultValue()
      retVal = BasicColors.Blue;
    end
    function getHeaderFile('mybasiccolors.h')
    end
    function addClassNameToEnumNames(true)
    end
end
```

The following function call defines the same class for use in MATLAB:

```
Simulink.defineIntEnumType('BasicColors', ...
     {'Red', 'Yellow', 'Blue'}, [0;1;2],...
     'Description', 'Basic colors', ...
     'DefaultValue', 'Blue', ...
```

```
'HeaderFile', 'mybasiccolors.h'
'AddClassNameToEnumNames', true);
```

Using Enumerated Data in Simulink Models

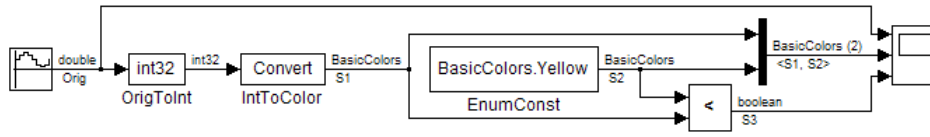
In this section...

Simulating with Enumerations

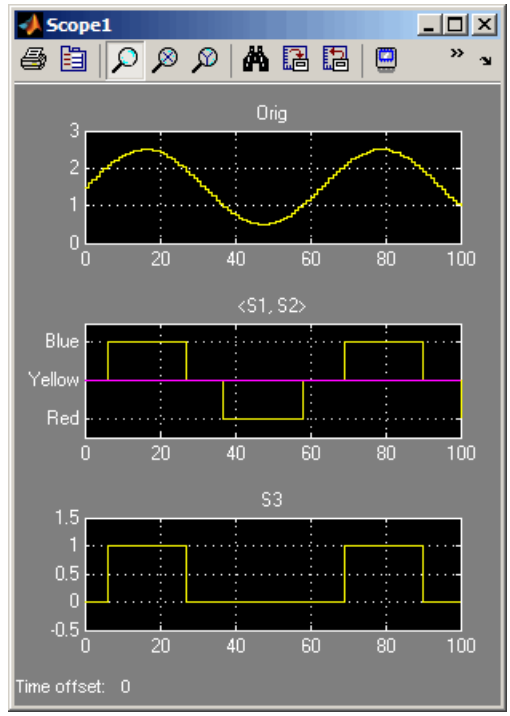
Consider the following enumeration class definition—`BasicColors` with enumerated values `Red`, `Yellow`, and `Blue`, with `Blue` as the default value:

```
classdef BasicColors < Simulink.IntEnumType
  enumeration
    Red(0)
    Yellow(1)
    Blue(2)
  end
  methods (Static)
    function retVal = getDefaultValue()
      retVal = BasicColors.Blue;
    end
  end
end
```

Once this class definition is known to MATLAB, you can use the enumeration in Simulink and Stateflow models. Information specific to enumerations in Stateflow appears in "Using Enumerated Data in Stateflow Charts". The following Simulink model uses the enumeration defined above:



The output of the model looks like this:



The Data Type Conversion block **OrigToInt** specifies an **Output data type** of `int32` and **Integer rounding mode:** `Floor`, so the block converts the Sine Wave block output, which appears in the top graph of the Scope display, to a cycle of integers: `1`, `2`, `1`, `0`, `1`, `2`, `1`. The Data Type Conversion block **IntToColor** uses these values to select colors from the enumerated type `BasicColors` by referencing their underlying integers.

The result is a cycle of colors: `Yellow`, `Blue`, `Yellow`, `Red`, `Yellow`, `Blue`, `Yellow`, as shown in the middle graph. The Enumerated Constant block

EnumConst outputs `Yellow`, which appears in the second graph as a straight line. The Relational Operator block compares the constant `Yellow` to each value in the cycle of colors. It outputs `1` (`true`) when `Yellow` is less than the current color, and `0` (`false`) otherwise, as shown in the third graph.

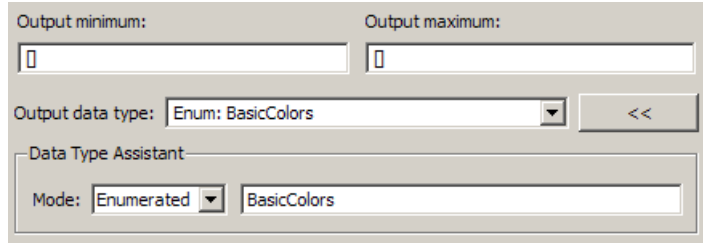
The sort order used by the comparison is the numeric order of the underlying integers of the compared values, *not* the lexical order in which the enumerated values appear in the enumerated class definition. In this example the two orders are the same, but they need not be. See "Specifying Enumerations as Data Types" on page 26-13 and "Enumerated Values in Computation" on page 26-19 for more information.

Specifying Enumerations as Data Types

Once you define an enumeration, you can use it much like any other data type. Because an enumeration is a class rather than an instance, you must use the prefix ? or `Enum:` when specifying the enumeration as a data type. You must use the prefix `?` in the MATLAB Command Window (see "Obtaining Information About Classes from Meta-Classes"). However, you can use either prefix in a Simulink model. `Enum:` has the same effect as the `?` prefix, but `Enum:` is preferred because it is more self-explanatory in the context of a graphical user interface.

Depending on the context, type `Enum:` followed by the name of an enumeration, or select `Enum: <class name>` from a menu (for example, for the **Output data type** block parameter) , and replace `<class name>`.

To use the Data Type Assistant, set the **Mode** to `Enumerated`, then enter the name of the enumeration. For example, in the previous model, the Data Type Conversion block **IntToColor**, which outputs a signal of type `BasicColors`, has the following output signal specification:



You cannot set a minimum or maximum value for a signal defined as an enumeration, because the concepts of minimum and maximum are not relevant to the purpose of enumerations. If you change the minimum or maximum for a signal of an enumeration from the default value of `[]`, an error occurs when you update the model. See "Enumerated Values in Computation" on page 26-19 for more information.

Getting Information About Enumerations

Use the `enumeration` function to:

- Return an array that contains all enumeration values for an enumeration class in the MATLAB Command Window
- Get the enumeration values programmatically
- Provide the values to a Simulink block parameter that accepts an array or vector of enumerated values, such as the **Case conditions** parameter of the Switch Case block

See the `enumeration` function for details.

Enumeration Value Display

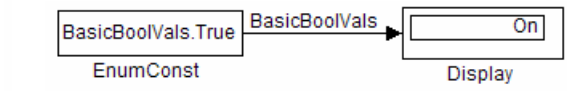
Wherever possible, Simulink software displays enumeration values by name, not by the underlying integer value. However, the underlying integers can affect value display in Scope and Floating Scope blocks.

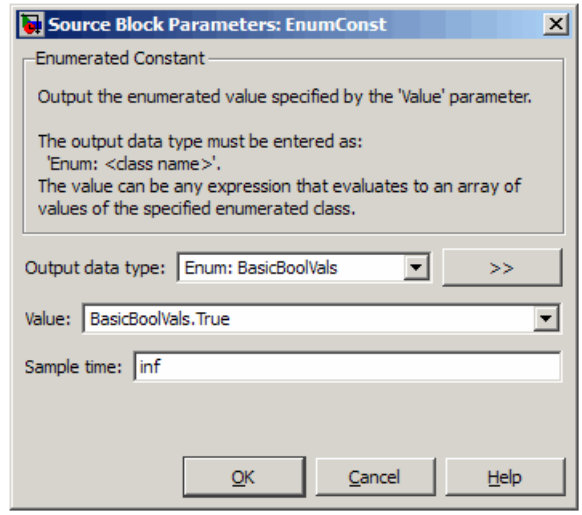
Block...	Affect on Value Display...
Scope	When displaying an enumerated signal, the names of the enumerated values appear as labels on the Y axis. The names appear in the order given by their underlying integers, with the lowest value at the bottom.
Floating Scope	When displaying signals that are of the same enumeration, names appear on the Y axis as they would for a Scope block. If the Floating Scope block displays mixed data types, no names appear, and any enumerated values are represented by their underlying integers.

Enumerated Values with Non-Unique Integers

More than one value in an enumeration can have the same underlying integer value, as described in "Specifying Enumerations as Data Types" on page 26-13. When this occurs, the value on an axis of Scope block output or in Display block output always is the first value listed in the enumerated class definition that has the shared underlying integer. For example:

```
classdef BasicBoolVals < Simulink.IntEnumType
  enumeration
    On(1)
    Off(0)
    True(1)
    False(0)
  end
end
```





Although the Enumerated Constant block outputs `True`, both `On` and `True` have the same underlying integer, and `On` is defined first in the class definition `enumeration` section. Therefore, the Display block shows `On`. Similarly, a Scope axis would show only `On`, never `True`, no matter which of the two values is input to the Scope block.

Instantiating Enumerations

Before you can use an enumeration, you must instantiate it. You can instantiate an enumeration in MATLAB, in a Simulink model, or in a Stateflow chart. The syntax is the same in all contexts.

Instantiating Enumerations in MATLAB

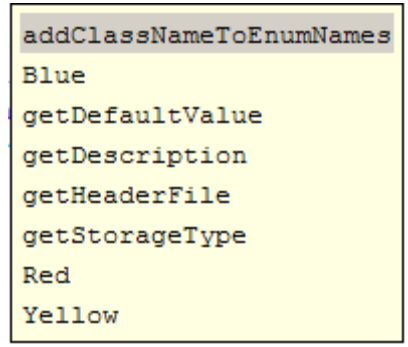
To instantiate an enumeration in MATLAB, enter *`ClassName.EnumName`* in the MATLAB Command Window. The instance is created in the base workspace. For example, if `BasicColors` is defined as in "Creating a Simulink Enumeration Class" on page 26-3, you can type:

```
bcy = BasicColors.Yellow

bcy =

    Yellow
```

Tab completion works for enumerations. For example, if you enter:

```
bcy = BasicColors.<tab>
```

MATLAB displays the elements and methods of `BasicColors` in alphabetical order:



Double-click an element or method to insert it at the position where you pressed `<tab>`. See "Completing Statements in the Command Window — Tab Completion" for more information.

Casting Enumerations in MATLAB

In MATLAB, you can cast directly from an integer to an enumerated value:

```
bcb = BasicColors(2)

bcb =

    Blue
```

You can also cast from an enumerated value to its underlying integer:

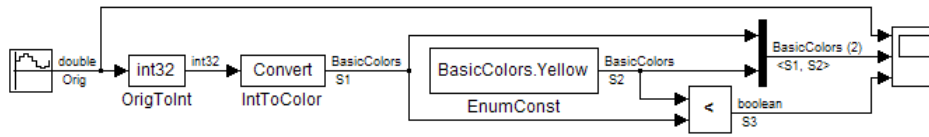
```
>> bci = int32(bcb)

bci =

    2
```

In either case, MATLAB returns the result of the cast in a `1x1` array of the relevant data type.

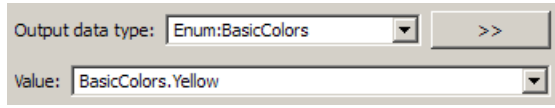
Although casting is possible, use of enumeration values is not robust in cases where enumeration values and the integer equivalents defined for an enumeration class might change.

Instantiating Enumerations in Simulink (or Stateflow)

To instantiate an enumeration in a Simulink model, you can enter *`ClassName.EnumName`* as a value in a dialog box. For example, consider the following model:



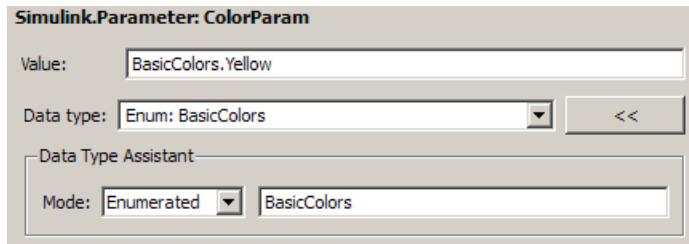
The Enumerated Constant block **EnumConst**, which outputs the enumerated value `Yellow`, defines that value as follows:



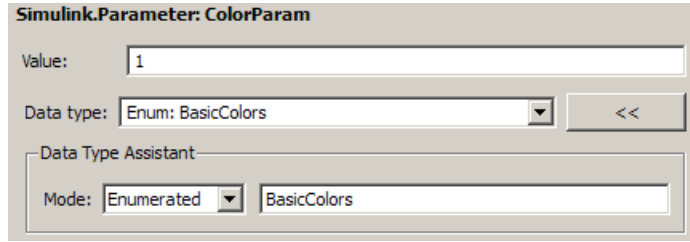
You can enter any valid MATLAB expression that evaluates to an enumerated value, including arrays and workspace variables. For example, you could enter `BasicColors(1)`, or if you had previously executed `bcy = BasicColors.Yellow` in the MATLAB Command Window, you could enter `bcy`. As another example, you couldt enter an array, such as`[BasicColors.Red, BasicColors.Yellow, BasicColors.Blue]` .

You can use a Constant block to output enumerated values. However, that block displays parameters that do not apply to enumerated types, such as **Output Minimum** and **Output Maximum**.

If you create a `Simulink.Parameter` object as an enumeration, you must specify the**Value** parameter as an enumeration member and the **Data type** with the `Enum:` or ? prefix, as explained in "Specifying Enumerations as Data Types" on page 26-13.



You *cannot* specify the integer value of an enumeration member for the **Value** parameter. See "Enumerated Values in Computation" on page 26-19 for more information. Thus, the following fails even though the integer value for `BasicColors.Yellow` is `1`.



The same syntax and considerations apply in Stateflow. See "Using Enumerated Data in Stateflow Charts" for more information.

Enumerated Values in Computation

By design, Simulink prevents enumerated values from being used as numeric values in mathematical computation, even though an enumerated class is a subclass of the MATLAB `int32` class. Thus, an enumerated type does not function as a numeric type despite the existence of its underlying integers. For example, you cannot input an enumerated signal directly to a Gain block.

You can use a Data Type Conversion block to convert in either direction between an integer type and an enumerated type, or between two enumerated types. That is, you can use a Data Type Conversion block to convert an enumerated signal to an integer signal (consisting of the underlying integers of the enumerated signal values) and input the resulting integer signal to a Gain block. See "Casting Enumerated Signals" on page 26-20 for more information.

Enumerated types in Simulink are intended to represent program states and control program logic in blocks like the Relational Operator block and the Switch block. When a Simulink block compares enumerated values, the values compared must be of the same enumerated type. The block compares enumerated values based on their underlying integers, not their order in the enumerated class definition.

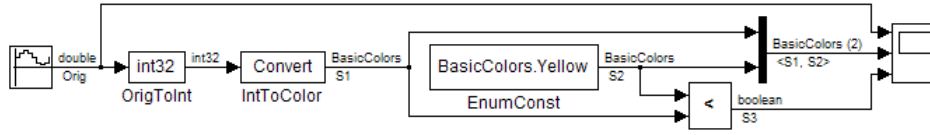
When a block like the Switch block or Multiport Switch block selects among multiple data signals, and any data signal is of an enumerated type, all the data signals must be of that same enumerated type. When a block inputs both control and data signals, as Switch and Multiport Switch do, the control signal type need not match the data signal type.

Casting Enumerated Signals

You can use a Data Type Conversion block to cast an enumerated signal to a signal of any numeric type, provided that the underlying integers of all enumerated values input to the block are within the range of the numeric type. Otherwise, an error occurs during simulation.

Similarly, you can use a Data Type Conversion block to cast a signal of any integer type to an enumerated signal, provided that every value input to the Data Type Conversion block is the underlying integer of some value in the enumerated type. Otherwise, an error occurs during simulation.

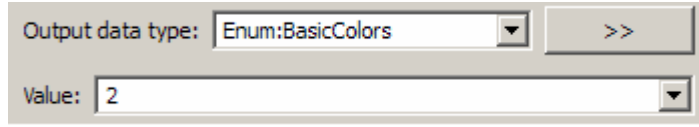
You cannot use a Data Type Conversion block to cast a numeric signal of any non-integer data type to an enumerated type. For example, the model used in "Simulating with Enumerations" on page 26-11 needed two Data Conversion blocks to convert a sine wave to enumerated values.



The first block casts `double` to `int32`, and the second block casts `int32` to `BasicColors`. You cannot cast a complex signal to an enumerated type regardless of the data types of its real and imaginary parts.

Casting Enumerated Block Parameters

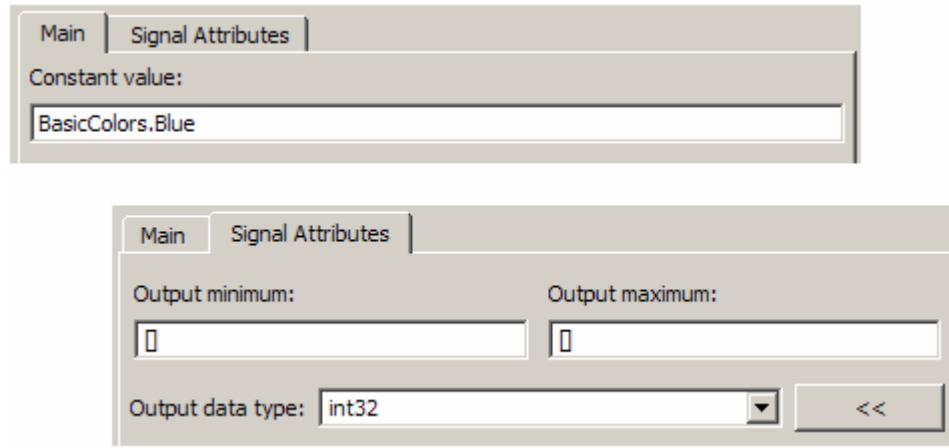
You cannot cast a block parameter of any numeric data type to an enumerated data type. For example, suppose that an Enumerated Constant block specifies a **Value** of `2` and an **Output data type** of `Enum: BasicColors`:



An error occurs because the specifications implicitly cast a `double` value to an enumerated type. The error occurs even though the numeric value

corresponds arithmetically to one of the enumerated values in the enumerated type.

You cannot cast a block parameter of an enumeration to any other data type. For example, suppose that a Constant block specifies a **Constant value** of `BasicColors.Blue` and an **Output data type** of `int32`.



An error occurs because the specifications implicitly cast an enumerated value to a numeric type. The error occurs even though the enumerated value's underlying integer is a valid `int32`.

Simulink Constructs that Support Enumerations

In this section...

Overview

In general, all Simulink tools and constructs support enumerated types for which the support makes sense given the purpose of enumerated types: to represent program states and to control program logic. The Simulink Editor, Simulink Debugger, Port Value Displays, referenced models, subsystems, masks, buses, data logging, and most other Simulink capabilities support enumerated types without imposing any special requirements.

Enumerated types are not intended for mathematical computation, so no block that computes a numeric output (as distinct from passing a numeric input through to the output) supports enumerated types. Thus an enumerated type is not considered to be a numeric type, even though an enumerated value has an underlying integer. See "Enumerated Values in Computation" on page 26-19 for more information.

Most capabilities that do not support enumerated types obviously could not support them. Therefore, the Simulink documentation usually mentions enumerated type nonsupport only where necessary to prevent a misconception or describe an exception. See "Simulink Enumeration Limitations" on page 26-26 for information about certain constructs that could support enumerated types but do not.

Block Support

The following Simulink blocks support enumerated types:

- Constant (but Enumerated Constant is preferable)

- Data Type Conversion
- Data Type Conversion Inherited
- Data Type Duplicate
- Display
- Embedded MATLAB Function
- Enumerated Constant
- Floating Scope
- From File
- From Workspace
- Inport
- Interval Test
- Interval Test Dynamic
- Multiport Switch
- Outport
- Probe (input only)
- Relational Operator
- Relay (output only)
- Repeating Sequence Stair
- Scope
- Signal Specification
- Stateflow Chart
- Switch
- Switch Case
- To File
- To Workspace

All members of the following categories of Simulink blocks support enumerated types:

- Bus-capable blocks (see "Bus-Capable Blocks" on page 30-11)
- Pass-through blocks:
  - With state, like the Data Store Memory and Unit Delay blocks.
  - Without state, like the Mux block.

Many Simulink blocks in addition to those named above support enumerated types, but they either belong to one of the categories listed above, or are rarely used with enumerated types. The Data Type Support section of each block reference page describes all data types that the block supports.

Class Support

The following Simulink classes support enumerated types:

- `Simulink.Signal`
- `Simulink.Parameter`
- `Simulink.AliasType`
- `Simulink.BusElement`
- `Simulink.StructElement`

Logging Enumerated Data

Root-level outports, To Workspace blocks, and Scope blocks can all export enumerated values. Signal and State logging work with enumerated data in the same way as with any other data. All logging formats are supported. The From File block does not support enumerated data. Use the From Workspace block instead, combined with some technique for transferring data between a file and a workspace. See Chapter 27, "Importing and Exporting Data" for more information.

Importing Enumerated Data

Root-level inports and From Workspace blocks can output enumerated signals during simulation. Data must be provided in a `Structure`, `Structure with Time`, or `TimeSeries` object. No interpolation occurs for enumerated values between the specified simulation times. From File blocks produce only data

of type `double`, so they do not support enumerated types. See Chapter 27, "Importing and Exporting Data" for more information.

Simulink Enumeration Limitations

In this section...

Enumerations and Scopes

When a Scope block displays an enumerated signal, the vertical axis displays the names of the enumerated values only if the scope was open during simulation. If you open the Scope block for the first time before any simulation has occurred, or between simulations, the block displays only numeric values. When simulation begins, enumerated names replace the numeric values, and thereafter appear whenever the Scope block is opened.

When a Floating Scope block displays multiple signals, the names of enumerated values appear on the Y axis only if all signals are of the same enumerated type. If the Floating Scope block displays more than one type of enumerated signal, or any numeric signal, no names appear, and any enumerated values are represented by their underlying integers.

Enumerated Types for Switch Blocks

The control input of a Switch block can be of any data type supported by Simulink software. However, the `u2 ~=0` mode is not supported for enumerations. If the control input has an enumeration, choose one of the following methods to specify the criteria for passing the first input:

- Select `u2 >= Threshold` or `u2 > Threshold` and specify a threshold value of the same enumerated type as the control input.
- Use a Relational Operator block to do the comparison and then feed the Boolean result of this comparison into the control port of the Switch block.

Nonsupport of Enumerations

The following limitations exist when using enumerated data types with Simulink:

- Packages cannot contain enumeration class definitions.
- You cannot define enumerations by using a GUI like the Data Class designer.
- The If Action block might support enumerations, but currently does not do so.
- Generated code does not support logging enumerated data.
- Custom Stateflow targets do not support enumerated types.
- Simulink® HDL Coder™ does not support enumerations.

27

Importing and Exporting Data

Introduction

During simulation you can import input signal and initial state data from a workspace or file, and export output signal and state data to a workspace or file. This capability allows you to use standard or custom MATLAB functions to generate a simulated system's input signals and to graph, analyze, or otherwise postprocess the system's outputs.

Logging Signals

In this section...

About Signal Logging

Logging signals refers to the process of saving signal values to the MATLAB workspace during simulation for later retrieval and postprocessing. Simulink allows you to log a signal by:

- Connecting the signal to a To Workspace block, Scope block, or viewer.

  This method allows you to document in the diagram itself the workspace variables used to store signal data. Results are visible during simulation. Be aware that Scopes store data and can be memory intensive.

- Connecting the signal to a root-level Outport block.

This method reduces diagram clutter by eliminating the need to use Scope blocks to log signals. Data is available only when simulation is paused or completed.

- Setting the signal's signal logging properties.

  This method eliminates the need to add blocks. Data is available only when simulation is paused or completed.

All of these methods allow you to specify the names of the workspace variables used to save signal data and to limit the amount of data logged for a particular signal.

See *Simulink Reference* for the To Workspace and Outport blocks for information on using these blocks to log signal data. See the documentation of the `sim` command for some data logging capabilities that are available only for programmatic simulation.

Globally Enabling and Disabling Logging

You can globally enable or disable signal logging for a model by checking or unchecking the **Signal logging** option on the **Data Import/Export** pane of the **Configuration Parameters** dialog box (see "Signal logging"). Simulink logs signals only if this option is checked. If the option is not checked, Simulink ignores the signal logging settings for individual signals.

Enabling Logging for a Signal

To enable signal logging for a signal, select the **Log signal data** option on the signal's **Signal Properties** dialog box. See "Signal Properties Dialog Box" for more information.

Enabling Signal Logging Programmatically

You can enable signal logging programmatically for selected blocks with the outport `DataLogging` property. You can set this property using the `set_param` command. For example:

1. At the MATLAB Command Window, open a model. Type

   ```
   vdp
   ```

2 Select a block in that model. For example, select the Mux block.

3 Get the port handles of the selected block.

```
get_param(gcb,'PortHandles')
```

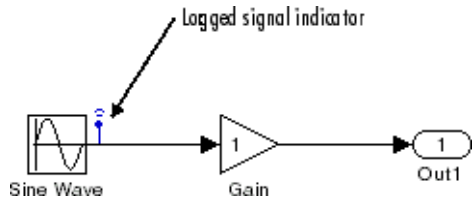
4 Enable signal logging for the desired outport port.

```
set_param(ans.Outport(1),'DataLogging','on')
```

The logged signal indicator ( ) appears.

Displaying Logging Indicators

By default, Simulink displays an indicator on each signal whose **Signal Properties > Log signal data** option is enabled. For example, in the following model the output of the Sine Wave block is logged:



A logged signal can also be a test point. See “Working with Test Points” on page 29-61 for information about test points.

To turn display of logging indicators on or off, select or clear **Port/Signal Displays > Testpoint/Logging Indicators** from the Simulink **Format** menu.

Specifying a Logging Name

You can assign a name, called the logging name, to the object used to log data for a signal during simulation. To specify a log name for a signal, select `Custom` from the **Logging name** list on the signal’s **Signal Properties** dialog box and enter the custom name in the adjacent text field.

If you do not specify a custom logging name, Simulink uses the signal name, or if there is no name, Simulink generates a default name that is composed

of the block name and port number. For example, if the block name is `MyBlock` and the signal being logged is the first output of this block, Simulink generates the following name: `SL_MyBlock1`.

Limiting the Data Logged for a Signal

The **Data** panel of the **Signal Properties** dialog box lets you limit the amount of data logged for a signal. For example, you can specify the maximum amount of data to be logged for a signal or a decimation factor that causes Simulink to skip a specified number of time steps before logging a signal value. See "Data" for more information.

Logging Virtual Signals

A *virtual signal* is a signal that graphically represents other signals or parts of other signals. Virtual signals are purely graphical entities; they have no functional or mathematical significance. The source of a virtual signal is always a virtual block, like a Mux block or Selector block. See "Virtual Signals" on page 29-13 and "Mux Signals" on page 29-16 for more information.

The nonvirtual components of a virtual signal are called *regions*. A virtual signal can contain the same region more than once. For example, if the same nonvirtual signal is connected to two input ports of a Mux block, the block outputs a virtual signal that has two regions.

The log of a virtual signal that contains duplicate regions includes all of the regions, even though the data in each is the same. Logged virtual signal regions appear in the log in a `Simulink.TsArray` object. The log gives the duplicate regions unique names, using the syntax: `<signal_name>_reg<#counter>`.

Logging Multidimensional Signals

You can log multidimensional signals, which are signals whose elements are nonscalar. The techniques for logging multidimensional signals are the same as those for logging any other signal. See "Signal Dimensions" on page 29-8 for information about multidimensional signals.

Logging Composite Signals

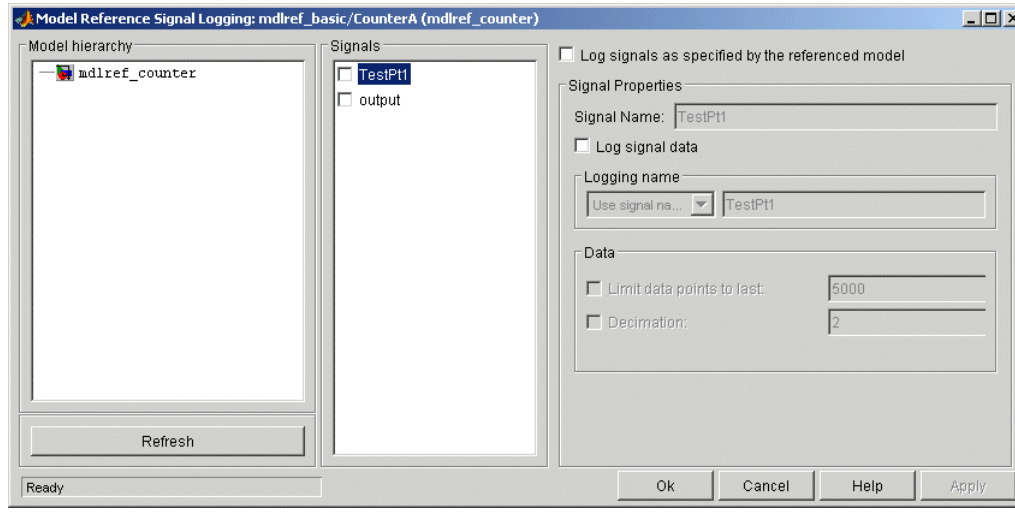
You can log Simulink composite signals, which are called buses. The hierarchy of a bus signal is preserved in the `logsout` object. The logged name of a signal in a virtual bus derives from the name of the source signal. The logged name of a signal in a nonvirtual bus derives from the applicable bus object, and can differ from that of the source signal. See Chapter 30, "Using Composite Signals" and "Using Bus Objects" on page 30-12 for information about those capabilities.

Logging Referenced Model Signals

You can log any signal that is defined as a test point in a referenced model. For information about test points, see "Designating a Signal as a Test Point" on page 29-61. For information about referenced models, see Chapter 5, "Referencing a Model".

To log test pointed signals in referenced models, select the Model block and then select **Log referenced signals** from the model editor's **Edit** menu or from the block's context menu.

The **Model Reference Signal Logging** dialog box appears.



The dialog box contains the following panes and controls.

Model Hierarchy

This pane displays the contents of the referenced model as a tree control with expandable nodes. The top-level node represents the referenced model. Expanding this node displays the subsystems that the referenced model contains and any models that it itself references. Expanding a subsystem node displays the subsystems that it contains and the models that it references.

Refresh Button

Refreshes the dialog box to reflect changes in the model hierarchy.

Signals

This pane displays the test points of the model or subsystem selected in the **Model Hierarchy** pane. See "Working with Test Points" on page 29-61. Check the check box next to a test point's name to specify that it should be logged.

Log signals as specified by the referenced model

Checking this check box causes Simulink to log the signals that the referenced model specifies should be logged.

Signal Properties

This pane is enabled if **Log signals as specified by the referenced model** is not selected. In this case, the controls on this pane allow you to specify the signal logging properties of the signal selected in the **Signals** pane. The values that you specify override for this instance of the referenced model those specified by the model itself. The controls correspond to the controls of the same name on the **Signal Properties** dialog box. See "Signal Properties Dialog Box" for information on how to use them.

Viewing Logged Signal Data

To view logged signal data, either check **Configuration Parameters > Data Import/Export > Inspect signals when simulation is stopped/paused** or select **Tools > Inspect Logged Signals** from the model editor's menu bar. The first method causes Simulink to display logged signals in the Simulation Data Inspector tool (see "Inspecting and Comparing Logged Signal Data" on page 13-25) whenever a simulation ends or you pause a simulation. The

second method launches the Simulation Data Inspector tool to display the data immediately.

Accessing Logged Signal Data

Simulink saves signal data that it logs during simulation in a Simulink data object of type `Simulink.ModelDataLogs` that resides in the MATLAB workspace. The name of the object's handle is `logsout` by default. The **Data Import/Export** configuration pane (see "Data Import/Export Pane") allows you to specify another name for this object. See `Simulink.ModelDataLogs` for information on extracting signal data from this object. The signal logs for particular model elements are contained in the objects in the following table.

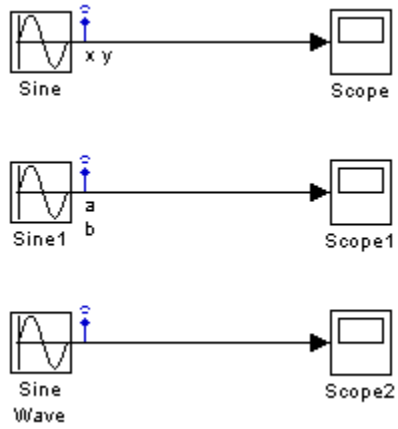
Model Element	Signal Data Object
Top-level or referenced model	`Simulink.ModelDataLogs`
Subsystem in a model	`Simulink.SubsysDataLogs`
Scope block in a model	`Simulink.ScopeDataLogs`
Signal other than a mux or bus	`Simulink.Timeseries`
Mux or bus signal	`Simulink.TsArray`

Handling Spaces and Newlines in Logged Names

Names that include space or newline characters can improve the readability of a block diagram, but referencing names that include such characters in a data log requires special techniques. These techniques allow the MATLAB parser to process the names even though spaces and newlines are not legal in MATLAB identifiers. Signal names in data logs can have spaces or newlines in their names under the following circumstances:

- The signal is named, and the name includes blank or newline characters.
- The signal is unnamed, and originates in a block whose name includes blank or newline characters.
- The signal exists in a subsystem or referenced model, and the name of the subsystem or Model block, or of any superior block, includes blank or newline characters.

The following three examples show a signal whose name contains a space, a signal whose name contains a newline, and an unnamed signal that originates in a block whose name contains a newline:



If you execute these examples with data logging enabled in the Data Import/Export pane, accepting the default logging object name `logsout`, and then type `logsout` in the MATLAB Command Window, MATLAB displays the following data log:

```
logsout =

Simulink.ModelDataLogs (model_name):
  Name                    Elements  Simulink Class

  ('x y')                    1      Timeseries
  ('a
b')                     1      Timeseries
  ('SL_Sine
Wave1')          1      Timeseries
```

You cannot access any of the `Timeseries` objects in this log using TAB name completion, or by typing the name to MATLAB, because the space or newline in each name appears to the MATLAB parser as a separator between identifiers. For example:

```
>> logsout.x y

??? logsout.x y
              |
Error: Unexpected MATLAB expression.
```

To reference a `Timeseries` object whose name contains a space, as in the first example above, single-quote the element containing the space:

```
>> logsout.('x y')

          Name: 'x y'
     BlockPath: 'model_name/Sine'
     PortIndex: 1
    SignalName: 'x y'
    ParentName: 'x y'
      TimeInfo: [1x1 Simulink.TimeInfo]
          Time: [51x1 double]
          Data: [51x1 double]
```

To reference a `Timeseries` object whose name contains a newline, as in the second example above, concatenate to construct the element containing the newline:

```
>> cr=sprintf('\n')
>> logsout.(['a' cr 'b'])
```

The same techniques work when a space or newline in a data log derives from the name of:

- An unnamed logged signal's originating block
- A subsystem or Model block that contains any logged signal
- Any block that is superior to such a block in the model hierarchy

This code can reference logged data for the signal in the third example above:

```
>> logsout.(['SL_Sine' cr 'Wave1'])
```

For names with multiple spaces, newlines, or both, repeat and combine the two techniques as needed to specify the intended name to MATLAB. No

analogous techniques exist for TAB name completion, which never works with names that contain space or newline characters.

Extracting Partial Data from a Running Simulation

Before a simulation ends, you can extract and write the currently logged signal data from `Simulink.ModelDataLogs` with the `set_param WriteDataLogs` command. The currently logged signal is the partial data logged between when the simulation started and when you request an extraction of the signal data. If you use this command during the simulation, Simulink writes the current logging variable values to the MATLAB workspace. If you use this command at the end of the simulation, Simulink writes the values from the last simulation to the MATLAB workspace.

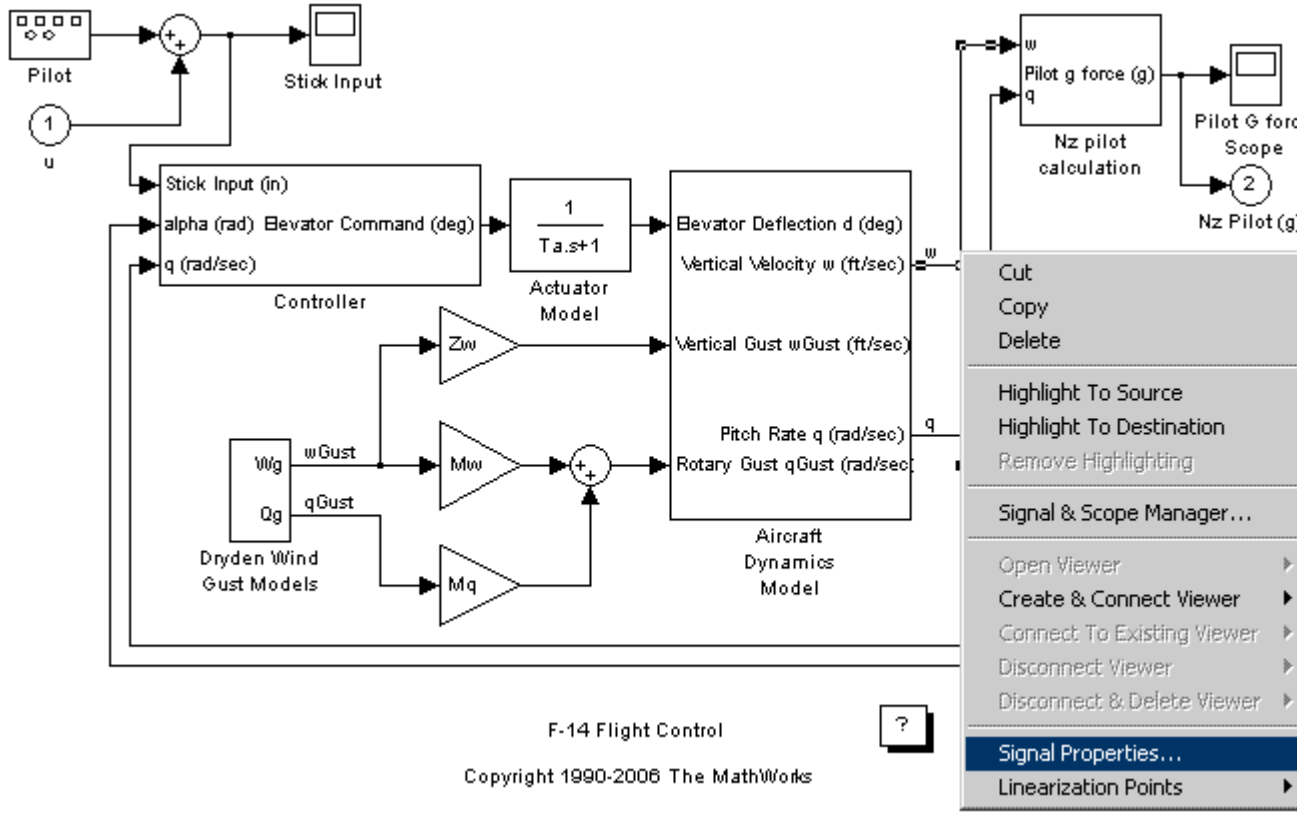
To use this command, type the following at the MATLAB Command Window.

```
set_param(bdroot,'SimulationCommand','WriteDataLogs')
```

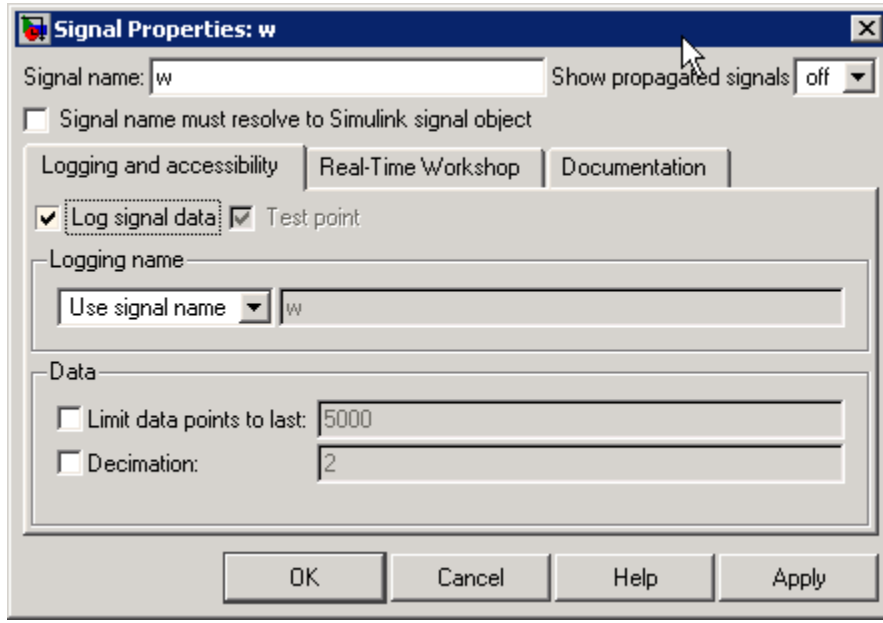
Example: Logging Signal Data in the F14 Model

Enabling signal logging on a signal-by-signal basis allows you to store signal data without modifying the structure of the Simulink diagram. For example, use the following steps to log and access the signal data for the vertical velocity signal `w` in the F14 model.

1. Open the F14 model by typing `f14` at the MATLAB command prompt.
2. Right-click on the signal labeled `w` and select the **Signal Properties** menu.



3 In the **Signal Properties** dialog box that opens, select the **Log signal data** option. The logging name initializes to the signal's name.



4 Click the **OK** button on the **Signal Properties** dialog box. The 'blue antenna' icon appears on the signal labeled `w`, indicating that this signal will be logged during simulation.

5 Ensure that **Configuration Parameters > Data Import/Export > Signal logging** is selected and that the logging name is set to the default variable `logsout`.

6 Run the F14 simulation. The logged signal data is stored in a `Simulink.ModelDataLogs` object named `logsout` in the MATLAB workspace. Typing `logsout` at the MATLAB command prompt displays the following

```
logsout =

Simulink.ModelDataLogs (f14):
  Name                    Elements  Simulink Class

  w                              1      Timeseries
```

7 Type `logsout.w` to view the information stored for the signal `w`.

```
logsout.w
          Name: 'w'
     BlockPath: 'f14/Aircraft Dynamics Model'
     PortIndex: 1
    SignalName: 'w'
    ParentName: 'w'
      TimeInfo: [1x1 Simulink.TimeInfo]
          Time: [1353x1 double]
          Data: [1353x1 double]
```

8 To inspect the signal using the Simulation Data Inspector tool, select **Tools > Inspect Logged Signals** from the `f14` model diagram window (see "Inspecting and Comparing Logged Signal Data" on page 13-25).

Signal Logging Limitations

- When you log data using the `Structure`, `Structure with time`, or `Timeseries` format, each field that contains logged data can contain at most 2^31-1 bytes on a 32–bit platform, and 2^48-1 bytes on a 64–bit platform.
- When you log data using `Array` format, each array that contains logged data can contain at most 2^31-1 bytes on a 32–bit platform, and 2^48-1 bytes on a 64–bit platform.
- Simulink data logging does not support the following types of signals:
  - Output of a Function-Call Generator block
  - Signal connected to the input of a Merge block
  - Outputs of Trigger and Enable blocks
- Rapid Accelerator mode does not support signal logging. For more information, see "Using Scopes and Viewers with Rapid Accelerator Mode" on page 17-16.

Exporting Data to the MATLAB Base Workspace

In this section...

Enabling Data Export

You can export a model's states and root-level outputs to the MATLAB base workspace during simulation of the model. To do this, select the type of data that you want to export on the **Save to workspace** area of the **"Data Import/Export Pane"** pane of the Configuration Parameters dialog box. The field adjacent to each type specifies the name of a MATLAB workspace variable to be used by the Simulink software to store the exported data.

Each field initially specifies a default variable. You can edit the fields to specify names of your own choosing. Select **Signal logging** to enable signal logging for the model. See "Logging Signals" on page 27-3 for more information. See the documentation of the `sim` command for some data export capabilities that are available only for programmatic simulation.

Note The output is saved to the MATLAB workspace at the base sample rate of the model. Use a To Workspace block if you want to save output at a different sample rate.

The **Save options** area enables you to specify the format and restrict the amount of output saved.

See the documentation of the `sim` command for some capabilities that are available only for programmatic simulation. Format options for model states and outputs are listed below.

Format Options

Array

If you select this option, a model's states and outputs are saved in a state and output array, respectively.

The state matrix has the name specified in the **Save to workspace** area (for example, `xout`). Each row of the state matrix corresponds to a time sample of the model's states. Each column corresponds to an element of a state. For example, suppose that your model has two continuous states, each of which is a two-element vector. Then the first two elements of each row of the state matrix contains a time sample of the first state vector. The last two elements of each row contain a time sample of the second state vector.

The model output matrix has the name specified in the **Save to workspace** area (for example, `yout`). Each column corresponds to a model output port, each row to the outputs at a specific time.

Note You can use array format to save your model's outputs and states only if the outputs are either all scalars or all vectors (or all matrices for states), are either all real or all complex, and are all of the same data type. Use the `Structure` or `Structure with time` output formats (see "Structure with time" on page 27-17) if your model's outputs and states do not meet these conditions.

Structure with time

If you select this format, the model's states and outputs are saved in structures having the names specified in the **Save to workspace** area (for example, `xout` and `yout`).

The structure used to save outputs has two top-level fields:

- `time`

  Contains a vector of the simulation times.

- `signals`

Contains an array of substructures, each of which corresponds to a model output port.

Each substructure has four fields:

- `values`

  Contains the outputs for the corresponding output port. If the outputs are scalars or vectors, the `values` field is a matrix each of whose rows represents an output at the time specified by the corresponding element of the time vector. If the outputs are matrix (2-D) values, the `values` field is a 3-D array of dimensions `M-by-N-by-T` where `M-by-N` is the dimensions of the output signal and `T` is the number of output samples. If `T = 1`, MATLAB drops the last dimension. Therefore, the `values` field is an `M-by-N` matrix.

- `dimensions`

  Specifies the dimensions of the output signal.

- `label`

  Specifies the label of the signal connected to the output port or the type of state (continuous or discrete).

- `blockName`

  Specifies the name of the corresponding output port or block with states.

- `inReferencedModel`

  Contains a value of `1` if the `signals` field records the final state of a block that resides in the submodel. Otherwise, the value is false (`0`).

The following is an example of the structure-with-time format for a nonreferenced model.

```
>> xout.signals(1)

ans =

              values: [296206x1 double]
          dimensions: 1
               label: 'CSTATE'
           blockName: 'vdp/x1'
```

```
    inReferencedModel: 0
```

The structure used to save states has a similar organization. The states structure has two top-level fields:

- `time`

  The `time` field contains a vector of the simulation times.

- `signals`

  The field contains an array of substructures, each of which corresponds to one of the model's states.

Each `signals` structure has four fields: `values`, `dimensions`, `label`, and `blockName`. The `values` field contains time samples of a state of the block specified by the `blockName` field. The `label` field for built-in blocks indicates the type of state: either `CSTATE` (continuous state) or `DSTATE` (discrete state). For S-Function blocks, the label contains whatever name is assigned to the state by the S-Function block.

The time samples of a state are stored in the `values` field as a matrix of values. Each row corresponds to a time sample. Each element of a row corresponds to an element of the state. If the state is a matrix, the matrix is stored in the `values` array in column-major order. For example, suppose that the model includes a 2-by-2 matrix state and that 51 samples of the state are logged during a simulation run. The `values` field for this state would contain a 51-by-4 matrix where each row corresponds to a time sample of the state and where the first two elements of each row correspond to the first column of the sample and the last two elements correspond to the second column of the sample.

Note The Simulink software can read back simulation data saved to the MATLAB workspace in the `Structure with time` output format. See "Importing Signal-and-Time Data Structures" on page 27-31 for more information.

Structure

This format is the same as the preceding except that the Simulink software does not store simulation times in the `time` field of the saved structure.

Per-Port Structures

This format consists of a separate structure-with-time or structure-without-time for each output port. Each output data structure has only one `signals` field. To specify this option, enter the names of the structures in the **Output** text field as a comma-separated list, `out1, out2,..., outN`, where `out1` is the data for your model's first port, `out2` for the second input port, and so on.

Exporting Data Using a Simulink Block

In addition to the techniques for exporting listed above, you can use the To Workspace block to export data to the MATLAB base workspace, and the To File block to export data to a file. See To Workspaceand To File for details.

Importing Data from a Workspace

In this section...

Input Data

The Simulink software can input data from a workspace and apply it to the root-level input ports of a model during a simulation run.

The input data can take any of the following forms:

- Timeseries — see
  - "Importing MATLAB timeseries Data" on page 27-23
  - "Importing Structures of MATLAB timeseries Objects for Bus Signals" on page 27-24
  - "Importing Simulink.Timeseries and Simulink.TsArray Data" on page 27-27
- Array — see "Importing Data Arrays" on page 27-29

- Time expression — see "Using a MATLAB Time Expression to Import Data" on page 27-30
- Structure — see "Importing Data Structures" on page 27-30

The Simulink software linearly interpolates or extrapolates input values as necessary if you select the **Interpolate data** option for the corresponding Inport block.

Root-Level Input Ports

You can import data from a workspace and apply it to a root-level:

- Inport block
- Trigger block that has an edge-based (rising, falling, or either) trigger type

Use the same approach for importing data from a workspace to a root-level Inport and Trigger block, except that for a Trigger block, the signal driving the trigger port must be the last data item.

Importing Bus Data

To import bus data to root input ports, use a structure of MATLAB `timeseries` objects. For details, see "Importing Structures of MATLAB timeseries Objects for Bus Signals" on page 27-24.

Enabling Data Import

To enable data import:

1. Select the **Input** box in the **Load from workspace** area of the "Data Import/Export Pane" pane.
2. Enter an external input specification in the adjacent edit box and click **Apply**.

In the **Input** box, specify one of the following expressions:

- A MATLAB function (expressed as a string) that specifies the input `u = UT(t)` at each simulation time step

- A table of input values versus time for all input ports `UT = [T, U1, ... Un]`, where `T = [t1, ..., tm]'`
- A structure array containing data for all input ports
- A comma-separated list of tables. Each table corresponds to a specific input port, and must be an array, a structure, a MATLAB `timeseries` object, a structure of MATLAB `timeseries` objects, a `Simulink.Timeseries` object, or a Simulink.TsArray object. Each variable or expression in the list should evaluate to the appropriate object that corresponds to one of the root-level input ports of the model, with the first item corresponding to the first root-level input port, the second to the second root-level input port, and so on. For a Trigger block, the signal driving the trigger port must be the last data item.

Note The use of the **Input** box is independent of the setting of the **Format** list on the **Data Import/Export** pane.

Simulink resolves symbols used in the external input specification as described in "Resolving Symbols" on page 3-75. See the documentation of the `sim` command for some data import capabilities that are available only for programmatic simulation.

Importing MATLAB timeseries Data

Any root-level Inport block or Trigger block can import data specified by a MATLAB `timeseries` object residing in a workspace.

You can manipulate MATLAB `timeseries` objects using the MATLAB Time Series Tools. See "Time Series Tools" in the MATLAB Data Analysis documentation for further details.

Note If you use a MATLAB `timeseries` object for a root Inport block in a model that has multiple root Inport blocks, convert all of the other root Inport block data that uses `Simulink.TsArray` or `Simulink.Timeseries` objects to MATLAB `timeseries` objects.

You can use the `Simulink.Timeseries.convertToMATLABTimeseries` method to convert a `Simulink.Timeseries` object to a MATLAB `timeseries` object. For example, if `sim_ts` is a `Simulink.Timeseries` object, then the following line converts `sim_ts` to a MATLAB `timeseries` object:

```
ts = sim_ts.convertToMATLABTimeseries;
```

Importing Structures of MATLAB timeseries Objects for Bus Signals

A root-level input port defined by a bus object (see `Simulink.Bus`) can import data from a structure of MATLAB `timeseries` objects that represent the bus elements for which you do not want to use the ground values. The bus elements that you do not include in the structure use ground values.

The structure of MATLAB `timeseries` objects must match the bus elements in terms of:

- Hierarchy
- The name of the structure field (The name property of the `timeseries` object does not need to match the bus element name.)
- Data type
- Dimensions
- Complexity

The order of the structure fields does not have to match the order of the bus elements.

When to Use a Structure of MATLAB timeseries Objects Instead of a Simulink.TsArray Object

Although you can use `Simulink.TsArray` objects for time series data, using MATLAB `timeseries` objects provides the following benefits:

- Creating a `Simulink.TsArray` object can be difficult and often involves having a harness of models or custom scripts.

- Using a structure of MATLAB `timeseries` objects supports using a partial specification of bus elements (using ground values for those elements that you do not specify in the structure).

Data that comes directly from a logged signal during simulation is stored as `Simulink.TsArray` objects. Although you can convert the `Simulink.TsArray` objects to MATLAB `timeseries` objects, in most situations it makes sense to leave the data in `Simulink.TsArray` format.

Note If you use a structure of MATLAB `timeseries` objects for a root Inport block in a model that has multiple root Inport blocks, convert all of the other root Inport block data that uses `Simulink.TsArray` or `Simulink.Timeseries` objects to MATLAB `timeseries` objects.

You can create a structure of MATLAB `timeseries` objects from a `Simulink.TsArray` object. For example, if `tsa` is a `Simulink.TsArray` object:

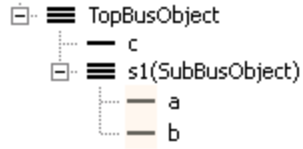
```
input = Simulink.SimulationData.createStructOfTimeseries(tsa);
```

How to Use a Structure of MATLAB timeseries Objects to Import Bus Signals

Use the following procedure to set up a model to import bus data to a root Inport block or Trigger blocks.

The examples in this procedure assume you have a model that is set up as follows:

- The `TopBusObject` bus object has two elements:
  - `c`
  - `s1`, which is a sub-bus that has two elements: `a` and `b`.



- The model has two root Inport blocks: `In1` and `In2`.
  - The `In1` Inport block imports non-bus data.
  - The `In2` Inport block imports bus data of type `TopBusObject`.

1. Create a MATLAB `timeseries` object for each root Inport or Trigger block for which you want to import non-bus data.

   For example:

   ```
   t1 = (0:10)';
   d1 = sin(t1);
   in1 = timeseries(d1,t1)
   ```

2. Create a structure of MATLAB `timeseries` objects, with one `timeseries` object for each leaf bus element for which you do not want to use ground values.

   For example, to specify non-ground values for all the elements in the `s2` bus:

   ```
   in2.c = timeseries(d1,t1);
   in2.s1.a = timeseries(d2,t2);
   in2.s1.b = timerseries(d3,t3);
   ```

   The MATLAB `timeseries` objects that you create must match the corresponding bus element in terms of:

   - Hierarchy
   - Name — The name of the structure field must match the bus element name.
   - Data type
   - Dimensions
   - Complexity

   The `Name` property of the MATLAB `timeseries` object does not need to match the bus element name.

   The order of the structure fields does not matter.

To determine the number of MATLAB `timeseries` objects and data type, complexity, and dimensions needed for creating a structure of `timeseries` objects from a bus, you can use the `Simulink.Bus.getNumLeafBusElements` and `Simulink.Bus.getLeafBusElements` methods. For example, you could use these methods in conjunction with the `Simulink.SimulationData.createStructOfTimeseries` utility (where `MyBus` is a bus object):

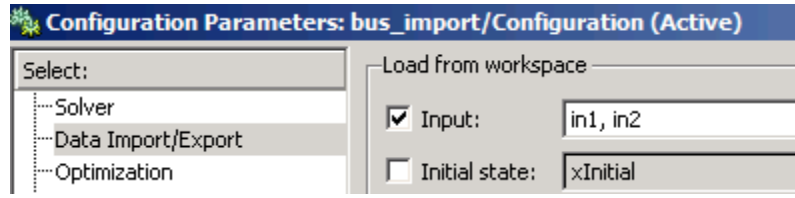
```
num_el = MyBus.getNumLeafBusElements;
el_list = MyBus.getLeafBusElements;
```

To create a structure of MATLAB`timeseries` objects from a bus object and a cell array of `timeseries` or `Simulink.Timeseries` objects, use the `Simulink.SimulationData.createStructOfTimeseries` utility. For example:

```
input = ...
Simulink.SimulationData.createStructOfTimeseries('MyBus',...
{ts1,ts2,ts3});
```

3 In the **Configuration Parameters > Import/Export** pane, select the **Input** parameter and enter a comma-separated list of MATLAB `timeseries` objects and structures of MATLAB `timeseries` objects.

For example, the `in1 timeseries` object and the `in2` structure of `timeseries` objects.



Importing Simulink.Timeseries and Simulink.TsArray Data

As an alternative to importing MATLAB `timeseries` data (see "Importing MATLAB timeseries Data" on page 27-23), any root-level Inport block or Trigger block can import a `Simulink.Timeseries` object.

Importing `Simulink.Timeseries` objects allows you to import data logged by a previous simulation run (see "Logging Signals" on page 27-3). For example, suppose that you have a model that references several other models. You can log data from the inputs of the referenced models during the simulation of the top model. Then you can use that logged data as inputs for the referenced models when you simulate the referenced models individually. This approach allows you to test the referenced models independently of the top model and each other.

However, using a structure of MATLAB`timeseries` objects provides some benefits, which are described in "Importing Structures of MATLAB timeseries Objects for Bus Signals" on page 27-24.

Simulink.Timeseries Data

`Simulink.Timeseries` objects are a derivation of standard MATLAB`timeseries` objects. You can manipulate MATLAB `timeseries` objects using the MATLAB Time Series Tools. See "Time Series Tools" in the MATLAB Data Analysis documentation for further details.

Simulink.TsArray Data

Objects of the `Simulink.TsArray` class have a variable number of properties. The first property, called Name, specifies the log name of the logged signal. The remaining properties reference logs for the elements of the logged signal: `Simulink.Timeseries` objects for elementary signals and `Simulink.TsArray`objects for mux or bus signals. The name of each property is the log name of the corresponding signal.

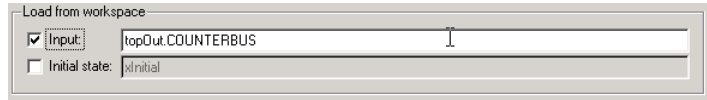
The model `sldemo_mdlref_counter_bus`, referenced by the top model `sldemo_mdlref_bus`, contains an example of importing `Simulink.TsArray` objects.

To use this demo, open `sldemo_mdlref_bus` and run the simulation. The top model is configured to store logged signals into a variable named `topOut`. Currently, two signals are being logged: `COUNTERBUS` and `OUTPUTBUS`. After running the simulation, you can view the logged signals by typing `topOut` at the MATLAB prompt.

```
topOut =
```

```
Simulink.ModelDataLogs (sldemo_mdlref_bus):
  Name                    Elements  Simulink Class

  COUNTERBUS                 2      TsArray
  OUTPUTBUS                  2      TsArray
```

The variable `topOut` is a `Simulink.ModelDataLogs` object that contains, in this case, two `Simulink.TsArray` objects corresponding to the two logged bus signals. The `Simulink.TsArray` object `COUNTERBUS` can be used as the input to the submodel `sldemo_mdlref_counter_bus` to run this model independently of the top model. To run this model independently of the top model, enter `topOut.COUNTERBUS` into the **Input** edit field on the **Data Import/Export** pane of the Configuration Parameters dialog box, as shown below.



By using the time-series array object as the input to `sldemo_mdlref_counter_bus`, independently running this model produces the same output as when run within the top model `sldemo_mdlref_bus`.

Importing Data Arrays

This import format consists of a real (noncomplex) matrix of data type `double`. The first column of the matrix must be a vector of times in ascending order. The remaining columns specify input values. In particular, each column represents the input for a different Inport or Trigger block signal (in sequential order) and each row is the input value for the corresponding time point. For a Trigger block, the signal driving the trigger port must be the last data item.

The total number of columns of the input matrix must equal `n + 1`, where `n` is the total number of signals entering the model's input ports.

The default input expression for a model is `[t,u]` and the default input format is `Array`. So if you define `t` and `u` in the MATLAB workspace, you need only select the **Input** option to input data from the model workspace. For example, suppose that a model has two input ports, `In1` that accepts two

signals, and `In2` that accepts one signal. Also, suppose that the MATLAB workspace defines `t` and `u` as follows:

```
t = (0:0.1:1)';
u = [sin(t), cos(t), 4*cos(t)];
```

When the simulation runs, the signals `sin(t)` and `cos(t)` will be assigned to `In1` and the signal `4*cos(t)` will be assigned to `In2`.

Note The array input format allows you to load only real (noncomplex) scalar or vector data of type `double`. Use the structure format to input complex data, matrix (2-D) data, and/or data types other than `double`.

Using a MATLAB Time Expression to Import Data

You can use a MATLAB time expression to import data from a workspace. To use a time expression, enter the expression as a string (i.e., enclosed in single quotes) in the **Input** field of the **Data Import/Export** pane. The time expression can be any MATLAB expression that evaluates to a row vector equal in length to the number of signals entering the input ports of the model. For example, suppose that a model has one vector Inport that accepts two signals. Furthermore, suppose that `timefcn` is a user-defined function that returns a row vector two elements long. The following are valid input time expressions for such a model:

```
'[3*sin(t), cos(2*t)]'

'4*timefcn(w*t)+7'
```

The expression is evaluated at each step of the simulation, applying the resulting values to the model's input ports. Note that the Simulink software defines the variable `t` when it runs the simulation. Also, you can omit the time variable in expressions for functions of one variable. For example, the expression `sin` is interpreted as `sin(t)`.

Importing Data Structures

The Simulink software can read data from the workspace in the form of a structure whose name is specified in the **Input** text field. You can import

structures that include only signal data or both signal and time data. The type of data structure is evaluated based on the structure itself.

Importing Signal-and-Time Data Structures

To import structures that include both signal and time data, the input structure must have two top-level fields: `time` and `signals`. The `time` field contains a column vector of the simulation times. The `signals` field contains an array of substructures, each of which corresponds to a model input port.

Each `signals` substructure must contain two fields named `values` and `dimensions`, respectively. The `values` field must contain an array of inputs for the corresponding input port where each input corresponds to a time point specified by the `time` field. The `dimensions` field specifies the dimensions of the input. If each input is a scalar or vector (1-D array) value, the `dimensions` field must be a scalar value that specifies the length of the vector (1 for a scalar). If each input is a matrix (2-D array), the `dimensions` field must be a two-element vector whose first element specifies the number of rows in the matrix and whose second element specifies the number of columns.

Note You must set the **Port dimensions** parameter of the Inport or the Trigger block to be the same value as the `dimensions` field of the corresponding input structure. If the values differ, an error message is displayed when you try to simulate the model.

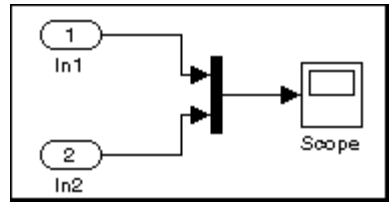
If the inputs for a port are scalar or vector values, the `values` field must be an `M-by-N` array where `M` is the number of time points specified by the `time` field and `N` is the length of each vector value. For example, the following code creates an input structure for loading 11 time samples of a two-element signal vector of type `int8` into a model with a single input port:

```
a.time = (0:0.1:1)';
c1 = int8([0:1:10]');
c2 = int8([0:10:100]');
a.signals(1).values = [c1 c2];
a.signals(1).dimensions = 2;
```

To load this data into the input port of the model, select the **Input** option on the **Data Import/Export** pane and enter `a` in the input expression field.

If the inputs for a port are matrices (2-D arrays), the `values` field must be an `M-by-N-by-T` array where `M` and `N` are the dimensions of each matrix input and `T` is the number of time points. For example, suppose that you want to input 51 time samples of a 4-by-5 matrix signal into one of your model's input ports. Then, the corresponding `dimensions` field of the workspace structure must equal `[4 5]` and the `values` array must have the dimensions `4-by-5-by-51`.

As another example, consider the following model, which has two inputs.



Suppose that you want to input a sine wave into the first port and a cosine wave into the second port. To do this, define a vector, `a`, as follows, in the MATLAB workspace:

```
a.time = (0:0.1:1)';
a.signals(1).values = sin(a.time);
a.signals(1).dimensions = 1;
a.signals(2).values = cos(a.time);
a.signals(2).dimensions = 1;
```

Select the **Input** box for this model, and enter `a` in the adjacent text field.

Importing Signal-Only Structures

The `Structure` format is the same as the `Structure with time` format except that the `time` field is empty. For example, in the preceding example, you could set the `time` field as follows:

```
a.time = []
```

In this case, the input for the first time step is read from the first element of an input port's value array, the value for the second time step from the second element of the value array, etc. If you enter the structure without time, the Inport block must have a discrete sample time.

Per-Port Structures

This format consists of a separate structure-with-time or structure-without-time for each port. Each port's input data structure has only one `signals` field. To specify this option, enter the names of the structures in the **Input** text field as a comma-separated list, `in1, in2,..., inN`, where `in1` is the data for your model's first port, `in2` for the second input port, and so on.

Specifying Time Vectors for Discrete Systems

In some cases, the Simulink software calculates block sample hits at sample times different from those specified by a time vector generated in MATLAB. Typically, these are small floating point inaccuracies that can cause the Simulink product to apparently miss a specified time step in lieu of a different sample point. In order to avoid these numerical inaccuracies, generate the time vector either in MATLAB or in Simulink based on the fundamental sample time of the model.

For example, if the model has a fundamental sample time `Ts` (see "Purely Discrete Systems" on page 4-22) of 0.001 then the time vector `Tvector` should be calculated with the command

```
Tvector = Ts*[n1, n2, n3...];
```

where *n1*, *n2*, *n3*, etc. are integers that, when multiplied by the fundamental sample time, yield the desired time vector.

Importing Data Using a Simulink Block

In addition to the techniques for importing listed above, you can use the From Workspace block to import data from a workspace, and the From File block to import data from a file. See From Workspace and From File for details.

Importing and Exporting States

In this section...

Introduction

You can import the initial values of the states in a system (in other words, the initial conditions of the system), at the beginning of a simulation. You can then save the final values of the states at the end of the simulation. Using this approach saves a steady-state solution so that you can restart the simulation at that known state.

Saving States

To save the model state at each simulation step, select **Configuration Parameters > Data Import/Export > States** (in the **Save to workspace** area) and enter a name in the adjacent edit field . Simulink saves the state in a workspace variable that has the name you specify. The default variable name is `xout`. The saved data has the format that you specify in the **Data Import/Export > Save options** area.

You can save the final model state instead of the state at each simulation step. Select **Configuration Parameters > Data Import/Export > Final states**. The default name of the final state variable is `xFinal`.

When Simulink saves states from a referenced model in the structure-with-time format, Simulink adds a Boolean subfield (named `inReferencedModel`) to the `signals` field of the saved data structure. The value of this additional field is true (`1`) if the `signals` field records the final state of a block that resides in the submodel, and a `0` otherwise. For example:

```
>> xout.signals(1)

ans =
```

```
              values: [101x1 double]
          dimensions: 1
               label: 'DSTATE'
           blockName: [1x66 char]
    inReferencedModel: 1
```

If the model has no states saved, then `xout` is an empty variable. To determine whether a model has states saved, use the `isempty(xout)` command.

If the signals field records a submodel state, its `blockName` subfield contains a compound path of a top model path and a submodel path. The top model path is the path from the model root to the Model block that references the submodel. The submodel path is the path from the submodel root to the block whose state the `signals` field records. The compound path uses a `|` character to separate the top and submodel paths. For example:

```
>> xout.signals(1).blockName

ans =

sldemo_mdlref_basic/CounterA|sldemo_mdlref_counter/Previous Output
```

Loading Initial States

To load states, check **Initial state** in the **Load from workspace** area of the **Data Import/Export** pane and specify the name of a variable that contains the initial state values (for example, a variable containing states saved from a previous simulation). The initial values that the workspace variable specifies override the initial state values that the blocks in the model specify in initial condition parameters.

Use the structure or structure-with-time option to specify initial states to accomplish any of the following:

- Associate initial state values directly with the full path name to the states. This association eliminates errors that can occur if Simulink reorders the states, but the order of the initial state array does not change correspondingly.
- Assign a different data type to the initial value of each state.

- Initialize only a subset of the states.

For example, the following commands create an initial state structure that initialize the `x2` state of the vdp model. The `x1` state is not initialized in the structure. Therefore, during simulation, Simulink uses the value in the Integrator block associated with the state.

```
% Open the vdp demo model
vdp

% Use getInitialState to obtain an initial state structure
states = Simulink.BlockDiagram.getInitialState('vdp');

% Set the initial value of the signals structure element
% associated with x2 to 2.
states.signals(2).values = 2;

% Remove the signals structure element associated with x1
states.signals(1) = [];
```

To use the `states` variable, for the `vdp` model, enable the **Configuration Parameters > Data Import/Export > Initial state** option (in the **Load from workspace** area). Enter `states` into the associated edit field. When you run the model, note that both states have the initial value of 2. The initial value of the `x2` state is assigned in the `states` structure, while the initial value of the `x1` state is assigned in its Integrator block.

Note Use the structure or structure-with-time format to initialize the states of a top model and the models that it references.

Specifying Output Options

In this section...

Introduction

The **Output options** list on the **Data Import/Export** configuration pane ("Data Import/Export Pane") enables you to control how much output the simulation generates. You can choose from three options:

- Refine output
- Produce additional output
- Produce specified output only

Refining Output

The `Refine output` choice provides additional output points when the simulation output is too coarse. This parameter provides an integer number of output points between time steps; for example, a refine factor of 2 provides output midway between the time steps as well as at the steps. The default refine factor is 1.

To get smoother output, it is much faster to change the refine factor instead of reducing the step size. When the refine factor is changed, the solvers generate additional points by evaluating a continuous extension formula at those points. This option changes the simulation step size so that time steps coincide with the times that you have specified for additional output.

The refine factor applies to variable-step solvers and is most useful when you are using `ode45`. The `ode45` solver is capable of taking large steps; when

graphing simulation output, you might find that output from this solver is not sufficiently smooth. If this is the case, run the simulation again with a larger refine factor. A value of 4 should provide much smoother results.

Note This option helps the solver locate zero crossings (see "Zero-Crossing Detection" on page 2-23). In particular, it helps reduce the chance of missing a zero crossing. It does not help locate the missed zero crossings.

Producing Additional Output

The `Produce additional output` choice enables you to specify directly those additional times at which the solver generates output. When you select this option, an **Output times** field is displayed on the **Data Import/Export** pane. Enter a MATLAB expression in this field that evaluates to an additional time or a vector of additional times. This option causes the solver to produce hit times at the output times you have specified, in addition to the times it needs to accurately simulate the model.

Note This option helps the solver locate zero crossings (see "Zero-Crossing Detection" on page 2-23). In particular, it helps reduce the chance of missing a zero crossing. It does not help locate the missed zero crossings.

Producing Specified Output Only

The `Produce specified output only` choice provides simulation output *only* at the simulation start time, simulation stop time, and the specified output times. For example, if the simulation start time is set to `0` and the simulation stop time is set to `60`, entering `[10:  10:  50]` in the `Output times` field results in simulation output at these times:

```
0, 10, 20, 30, 40, 50, 60
```

This option changes the simulation step size so that time steps coincide with the times that you have specified for producing output. The solver may hit other time steps to accurately simulate the model, however the output will not include these points. This choice is useful when you are comparing different simulations to ensure that the simulations produce output at the same times.

Note This option helps the solver locate zero crossings (see "Zero-Crossing Detection" on page 2-23). In particular, it helps reduce the chance of missing a zero crossing. It does not help locate the missed zero crossings.

Comparing Output Options

A sample simulation generates output at these times:

```
0, 2.5, 5, 8.5, 10
```

Choosing `Refine output` and specifying a refine factor of 2 generates output at these times:

```
0, 1.25, 2.5, 3.75, 5, 6.75, 8.5, 9.25, 10
```

Choosing the `Produce additional output` option and specifying `[0:10]` generates output at these times

```
0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10
```

and perhaps at additional times, depending on the step size chosen by the variable-step solver.

Choosing the `Produce specified output only` option and specifying `[0:10]` generates output at these times:

```
0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10
```

Limiting Output

Saving data to a workspace can slow down the simulation and consume memory. To avoid this, you can limit the number of samples saved to the most recent samples or you can skip samples by applying a decimation factor. To set a limit on the number of data samples saved, select the check box labeled **Limit data points to last** and specify the number of samples to save. To apply a decimation factor, enter a value in the field to the right of the **Decimation** label. For example, a value of 2 saves every other point generated.

28

Working with Data Stores

About Data Stores

In this section...

Introduction

A *data store* is a repository to which you can write data, and from which you can read data, without having to connect an input or output signal directly to the data store. Data stores are accessible across model levels, so subsystems and referenced models can use data stores to share data without using I/O ports. Two types of data stores exist:

- A *local data store* is accessible anywhere in the model hierarchy at or below the level at which it is defined, except in referenced models. Local data stores can be defined graphically in a model or by creating a model workspace signal object.
- A *global data store* is accessible throughout the model hierarchy, including in referenced models. Global data stores can be defined only in the MATLAB base workspace, and are the only type of data store accessible in referenced models.

The scope of a data store should be no greater than necessary to let it access the relevant parts of the model hierarchy. Some examples of local and global data stores appear in "Data Store Examples" on page 28-19.

Real-Time Workshop Embedded Coder provides a custom storage class that you can use to specify customized data store access functions in generated code. See "Creating and Using Custom Storage Classes" and "GetSet Custom Storage Class for Data Store Memory".

When to Use a Data Store

Data stores can be useful when multiple signals at different levels of a model need the same global values, and connecting all the signals explicitly would clutter the model unacceptably or take too long to be feasible. Data stores are analogous to global variables in programs, and have similar advantages and disadvantages. See "Data Stores and Software Verification" on page 28-33 for more information.

In some cases, you may be able to use a simpler technique, Goto blocks and From blocks, to obtain results similar to those provided by data stores. The principal disadvantage of data Goto/From links is that they generally are not accessible across nonvirtual subsystem boundaries, while an appropriately configured data store can be accessed anywhere. See the Goto and From block reference pages for more information about Goto/From links.

Creating Data Stores

To create a data store, you create a Data Store Memory block or a `Simulink.Signal` object. The block or object represents the data store and specifies its properties. Every data store must have a unique name.

- A Data Store Memory block implements a local data store. See "Defining Data Stores with Data Store Memory Blocks" on page 28-6.
- A `Simulink.Signal` object can act as a local or global data store. See "Defining Data Stores with Signal Objects" on page 28-10.

Data stores implemented with Data Store Memory blocks:

- Support data store initialization
- Provide finer-grained control of data store scope and options
- Require a block to represent the data store
- Cannot be accessed within referenced models
- Cannot be in a subsystem that a For Each Subsystem block represents.

Data stores implemented with `Simulink.Signal` objects:

- Provide coarser-grained control of data store scope and options

- Do not require a block to represent the data store
- Can be accessed in referenced models if the data store is global

Be careful not to equate local data stores with Data Store Memory blocks, and global data stores with `Simulink.Signal` objects. Either technique can define a local data store, and a signal object can define either a local or a global data store.

Accessing Data Stores

To write a signal to a data store, use a Data Store Write block, which inputs the value of a signal and writes that value to the data store.

To read a signal from a data store, use a Data Store Read block, which reads the value of the data store and outputs that value data as a signal.

For `Data Store Write` and `Data Store Read` blocks, to identify the data store to be read or written to, specify the data store name as a block parameter. See "Accessing Data Stores with Simulink Blocks" on page 28-12 for more information.

Data Store Logging

You can log the values of a local or global data store data variable for all the steps in a simulation. See "Logging Data Stores" on page 28-14.

Workflow for Configuring Data Stores

The following is a general workflow for configuring data stores. Many of the actions listed can be executed in a different order, or separately from the rest, depending on how you use data stores.

1. Where applicable, plan your use of data stores to minimize their effect on software verification. For more information, see "Data Stores and Software Verification" on page 28-33.
2. Create data stores using the techniques described in "Defining Data Stores with Data Store Memory Blocks" on page 28-6 or "Defining Data Stores with Signal Objects" on page 28-10. For greater reliability, consider

assigning rather than inheriting data store attributes, as described in "Specifying Data Store Memory Block Attributes" on page 28-6.

3. Create the blocks that will read and write the data store, as described in "Accessing Data Stores with Simulink Blocks" on page 28-12.

4. Configure the model and the blocks that access each data store to avoid concurrency failures when reading and writing the data store, as described in "Ordering Data Store Access" on page 28-22.

5. Apply the techniques described in "Using Data Store Diagnostics" on page 28-25 as needed to prevent data store errors, or diagnose them if they occur during simulation.

6. If you intend to generate code for your model, see "Data Store Memory Considerations" in the Real-Time Workshop documentation.

See Chapter 5, "Referencing a Model" for information about referenced models.

Defining Data Stores with Data Store Memory Blocks

In this section...

Creating the Data Store

To use a Data Store Memory block to define a data store, drag an instance of the block into the model at the topmost level from which you want the data store to be visible. The result is a local data store, which is not accessible within referenced models.

- To define a data store that is visible at every level within a given model, except within Model blocks, drag the Data Store Memory block into the root level of the model.
- To define a data store that is visible only within a particular subsystem and the subsystems that it contains, though not within Model blocks, drag the block into the subsystem.

Once you have created the Data Store Memory block, use its parameters dialog box to define the data store's properties. The **Data store name** property specifies the name to be used to read and write the data store. See Data Store Memory for information about all of the block's parameters.

You can specify data store properties beyond those definable with Data Store Memory block parameters by selecting the block's **Data store name must resolve to Simulink signal object** option and providing a signal object. See "Specifying Attributes Using a Signal Object" on page 28-8 for details.

Specifying Data Store Memory Block Attributes

A Data Store Memory block can inherit three data attributes from its corresponding Data Store Read and Data Store Write blocks. The inheritable attributes are:

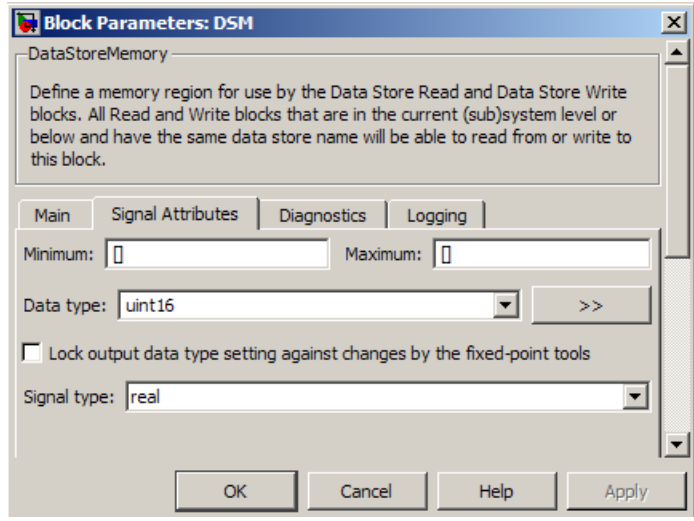
- Data type

- Complexity
- Sample time

However, allowing these attributes to be inherited can cause unexpected results that can be difficult to debug. To prevent such errors, use the Data Store Memory block dialog or a `Simulink.Signal` object to specify the attributes explicitly.

Specifying Attributes Using Block Parameters

You can use the Data Store Memory block dialog box to specify the data type and complexity of a data store. The next figure illustrates such a specification:

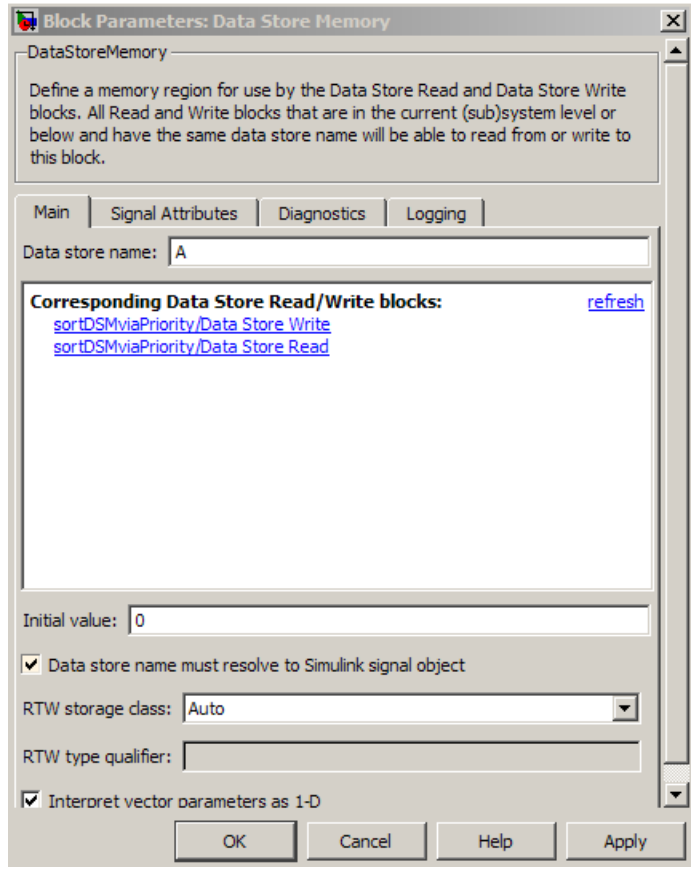



```
A =

Simulink.Signal (handle)
         RTWInfo: [1x1 Simulink.SignalRTWInfo]
     Description: ''
        DataType: 'uint16'
             Min: -4
             Max: 4
        DocUnits: ''
      Dimensions: -1
```

```
    Complexity: 'real'
    SampleTime: 1
  SamplingMode: 'Sample based'
  InitialValue: ''
```

Specifying Attributes Using a Signal Object

You can use a `Simulink.Signal` object to specify data store attributes. The technique is the same whether the data object is explicitly associated with a Data Store Memory block, or establishes an implicit data store, as described in "Defining Data Stores with Signal Objects" on page 28-10. The next figure shows a Data Store Memory block named `A` that specifies resolution to a `Simulink.Signal` object, and the fields of that signal object as shown in the MATLAB Command Window:



The signal object specifies values for all three data attributes that the data store would otherwise inherit: `DataType`, `Complexity`, and `SampleTime`.

Defining Data Stores with Signal Objects

In this section...

Creating the Data Store

To use a `Simulink.Signal` object to define a data store, create the object in a workspace that is visible to every component that needs to access the data store. Simulink creates an associated data store when you use the signal object for data storage. The name of the associated data store is the name of the signal object. You can use this name in Data Store Read and Data Store Write blocks just as if it were the **Data store name** of a Data Store Memory block.

Local and Global Data Stores

You can use a `Simulink.Signal` object to define either a local or a global data store.

- If you define the object in the MATLAB base workspace, the result is a global data store, which is accessible in every model within Simulink, including all referenced models.
- If you create the object in a model workspace, the result is a local data store, which is accessible at every level in a model except any referenced models.

Specifying Signal Object Data Store Attributes

Data store attributes that a signal object does not define have the same default values that they do in a Data Store Memory block. Some restrictions exist on the parameter values of a signal object used as a data store. These restrictions vary depending on whether the data store is global or local.

Parameter	Local Store Value	Global Store Value
`DataType`	Can be set or inherited	Must be set explicitly
`Complexity`	Can be set or inherited	Must be set explicitly
`Dimensions`	Can be set or inherited	Must be set explicitly
`SampleTime`	Can be set or inherited	Can be set or inherited
`SamplingMode`	Can be set or inherited	Must be `'Sample based'`

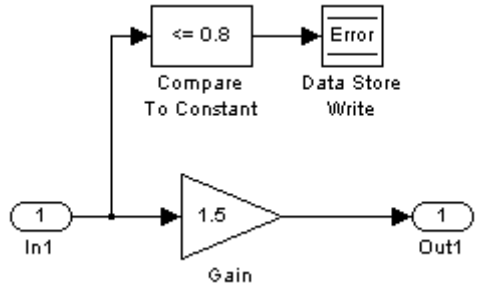
Once you have created the object, set the properties of the signal object to the values that you want the corresponding data store properties to have. For example, the following commands define a data store named `Error` in the MATLAB base workspace:

```
Error = Simulink.Signal;
Error.Description = 'Use to signal that subsystem output is invalid';
Error.DataType = 'boolean';
Error.Complexity = 'real';
Error.Dimensions = 1;
Error.SamplingMode='Sample based';
Error.SampleTime = 0.1;
```

Accessing Data Stores with Simulink Blocks

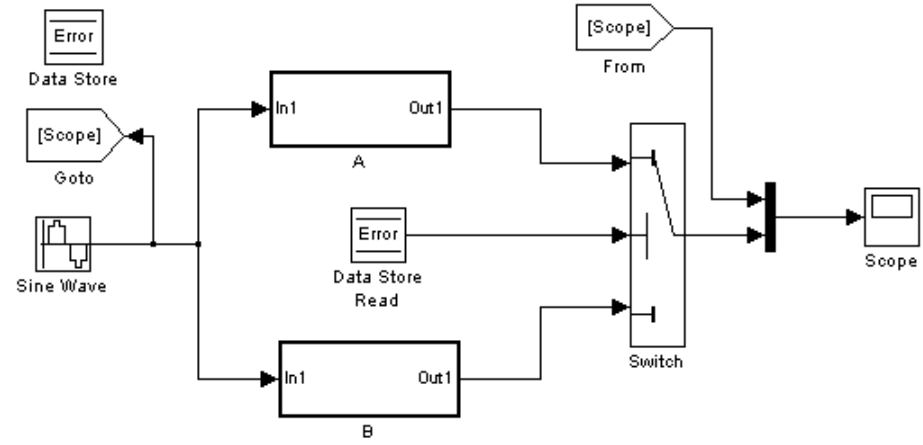
To set the value of a data store at each time step:

1. Create an instance of a Data Store Write block at the level of your model that computes the value.
2. Set the block's **Data store name** parameter to the name of the data store to be updated.
3. Connect the output of the block that computes the value to the input of the Data Store Write block.

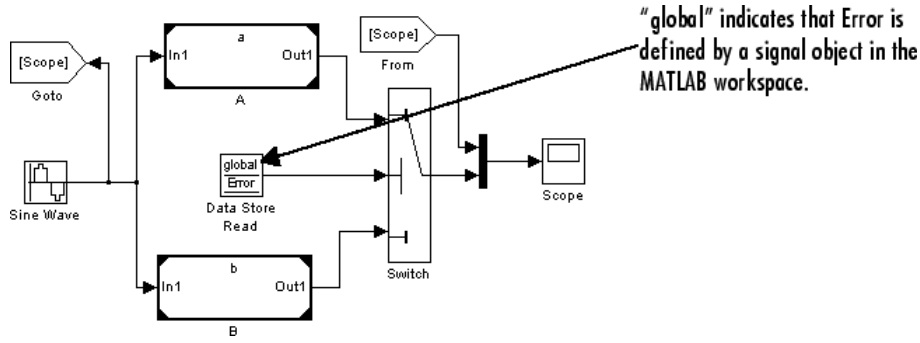


To get the value of a data store at each time step:

1. Create an instance of a Data Store Read block at the level of your model that needs the value.
2. Set the block's **Data store name** parameter to the name of the data store to be read.
3. Connect the output of the data store read block to the input of the block that need's the data store's value.



When connected to a global data store (one that is defined by a signal object in the MATLAB workspace) a Data Store Read or Data Store Write block displays the word `global` above the data store's name.



Logging Data Stores

In this section...

Logging Local and Global Data Store Values

You can log the values of a local or global data store data variable for all the steps in a simulation. Two common uses of data store logging are for:

- Model debugging – view the order of all data store writes
- Confirming a model modification – use the logged data to establish a baseline for comparing results for identifying the impact of a model modification

To see an example of logging a global data store, run the `sldemo_mdlref_dsm` demo.

Supported Data Types, Dimensions, and Complexity for Logging Data Stores

You can log data stores that use the following data types:

- All built-in data types
- Enumerated data types
- Fixed-point data types

You can log data stores that use any dimension level or complexity.

Data Store Logging Limitations

Limitations for using data store logging in a model are:

- To log data for a data store memory:
  - Simulate the top-level model in Normal mode.
  - For local data stores, the model containing the Data Store Memory block must be in model reference Normal mode.
  - Any block in a referenced model that writes to the data store memory must be executed in model reference Normal mode.
- If you set the **Configuration Parameters > Solver > Tasking mode for periodic sample times** parameter to `MultiTasking`, then you cannot log Data Store Memory blocks that use asynchronous sample times or hybrid sample times (that is, sample times resulting from when different data sources for the data store have different sample times).

  To about viewing information about sample times, see "How to View Sample Time Information" on page 4-9.
- You cannot log data stores that use custom data types.

Logging Data Stores Created with a Data Store Memory Block

To log a local data store that you create with a Data Store Memory block:

1. In the Block Parameters dialog box for the Data Store Memory block that you want to log, select the **Logging** pane.
2. Select the **Log signal** data check box.
3. Specify a name for the logged data, using the **Logging Name** parameter.
4. Specify limits for the amount of data logged, using the **Data** parameters.
5. Enable data store logging with the **Configuration Parameters > Data Import/Export > Data stores** parameter.

6 Simulate the model.

Logging Data Stores Created with a Simulink.Signal Object

You can create local and global data stores using a `Simulink.Signal` object. See "Defining Data Stores with Signal Objects" on page 28-10 for details.

To log a data store that you create with a `Simulink.Signal` object:

1 Create a `Simulink.Signal` object in a workspace that is visible to every component that needs to access the data store, as described in "Defining Data Stores with Signal Objects" on page 28-10.

2 Use the name of the `Simulink.Signal` object in the **Data store name** block parameters of the Data Store Read and Data Store Write blocks that you want to write to and read from the data store.

3 From the MATLAB command line, set `DataLogging` (which is a property of the `LoggingInfo` property of `Simulink.Signal`) to `1`.

   For example, if you use a `Simulink.Signal` object called `DataStoreSignalObject` to create a data store, use the following command:

   ```
   DataStoreSignalObject.LoggingInfo.DataLogging = 1
   ```

4 Specify a name for the logged data, in the `Simulink.Signal` object, by setting the `NameMode` property to 1 and the `LoggingName` property to the name you want to associate with the logged data.

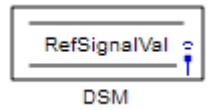
5 Specify limits for the amount of data logged, using the `Simulink.Signal` object `Decimation`, `LimitDataPoints`, and `MaxPoints` properties.

6 Enable data store logging with the **Configuration Parameters > Data Import/Export > Data stores** parameter.

7 Simulate the model.

Logging Icon for the Data Store Memory Block

When you enable logging for a model, and you configure a local data store for logging, the Data Store Memory block displays a blue icon. If you do not enable logging for the model, then the icon is gray.



Accessing Data Store Logging Data

The following Simulink classes represent data from data store logging and provide methods for accessing that data:

Class	Description
`Simulink.SimulationData.BlockPath`	Represents a fully specified Simulink block path; use for capturing the full model reference hierarchy
`Simulink.SimulationData.Dataset`	Stores logged data elements and provides searching capabilities; use to group `Simulink.SimulationData.Element` objects in a single object
`Simulink.SimulationData.DataStoreMemory`	Stores logging information from a Data Store Memory block during simulation

For more information about these classes, use the `help` command, specifying the class name. For example:

```
help Simulink.SimulationData.DataStoreMemory
```

Viewing Data Store Data

To view data store logging data from the command line, view the output data set in the base workspace. The default variable for the data store logging data set is `dsmout`.

The `sldemo_mdlref_dsm` demo illustrates approaches for viewing data store logging data.

Finding Elements in the Data Store Logging Data

To find an element in the data store logging data, based on the `Name` or `BlockType` property, use the `find` method of `Simulink.SimulationData.Dataset`. For example:

```
dsmout.find('RefSignalVal')

ans =
Simulink.SimulationData.DataStoreMemory
Package: Simulink.SimulationData

Properties:
                    Name: 'RefSignalVal'
              Blockpath: [1x1 Simulink.SimulationData.BlockPath]
                  Scope: 'local'
    DSMWriterBlockPaths: [1x2 Simulinkl.SimulationData.BlockPath]
             DSMWriters: [101x1 uint32]
                 Values: 101x1 timeseries]
```

To access an element by index, use the `Simulink.SimulationData.Dataset.getElement` method.

Data Store Examples

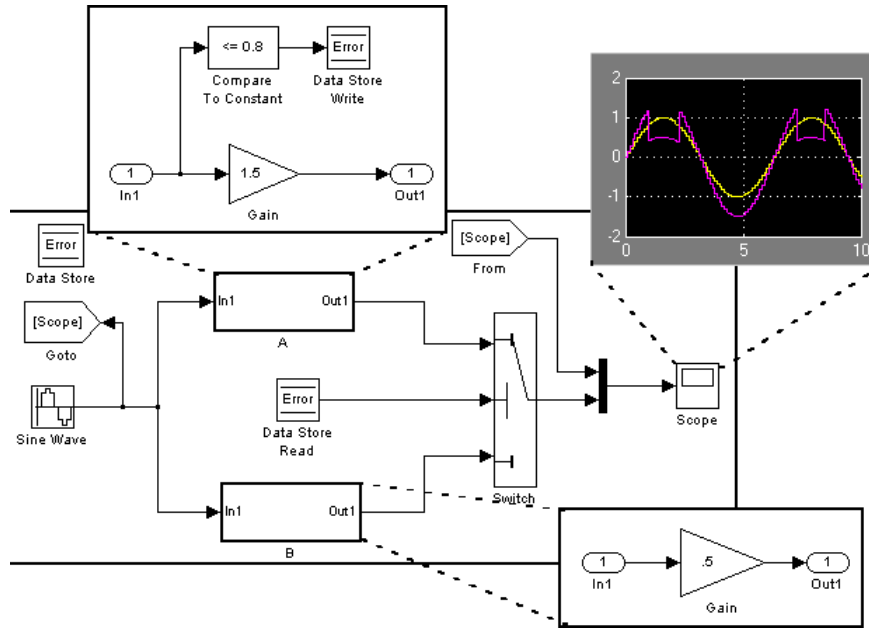
In this section...

Overview

The following examples illustrate techniques for defining and accessing data stores. See "Ordering Data Store Access" on page 28-22 for techniques that control data store access over time, such as ensuring that a given data store is always written before it is read. See "Using Data Store Diagnostics" on page 28-25 for techniques you can use to help detect and correct potential data store errors without needing to run any simulations.

Local Data Store Example

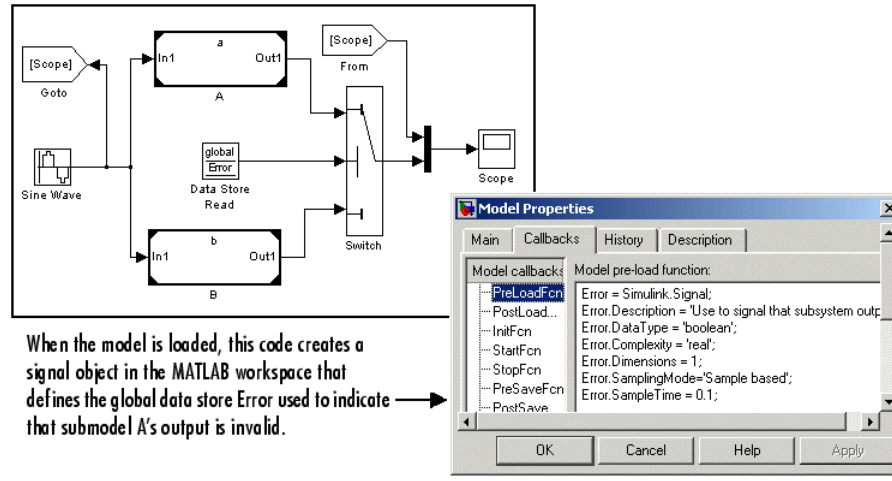
The following model illustrates creation and access of a local data store, which is visible only in a model or particular subsystem.



This model uses a data store to permit subsystem A to signal that its output is invalid. If subsystem A's output is invalid, the model uses the output of subsystem B.

Global Data Store Example

The following model replaces the subsystems of the previous example with functionally identical submodels to illustrate use of a global data store to share data in a model reference hierarchy.



In this example, the top model uses a signal object in the MATLAB workspace to define the error data store. This is necessary because data stores are visible across model boundaries only if they are defined by signal objects in the MATLAB workspace.

Ordering Data Store Access

In this section...

About Data Store Access Order

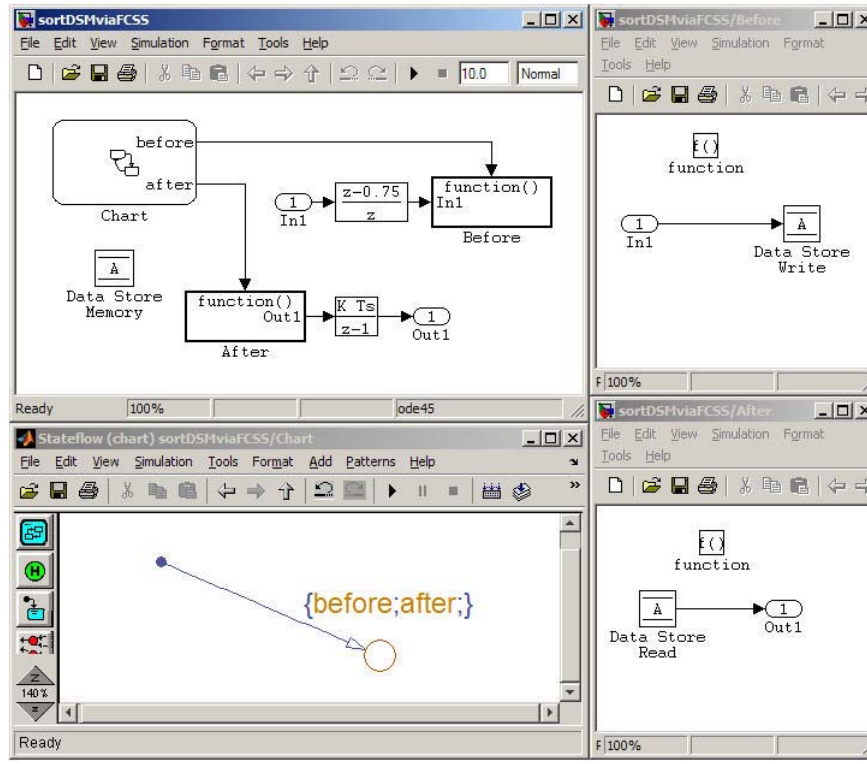
To obtain correct results from data stores, you must control the order of execution of the data store's reads and writes. If a data store's read occurs before its write, latency is introduced into the algorithm: the read obtains the value that was computed and stored in the previous time step, rather than the value computed and stored in the current time step.

Such latency may cause the system to behave other than as designed, and in some cases may destabilize the system. Even if these problems do not occur, an uncontrolled access order could change from one release of Simulink to the next.

This section describes several strategies for explicitly controlling the order of execution of a data store's reads and writes. See "Using Data Store Diagnostics" on page 28-25 for techniques you can use to detect and correct potential data store errors without running simulations.

Ordering Access Using Function Call Subsystems

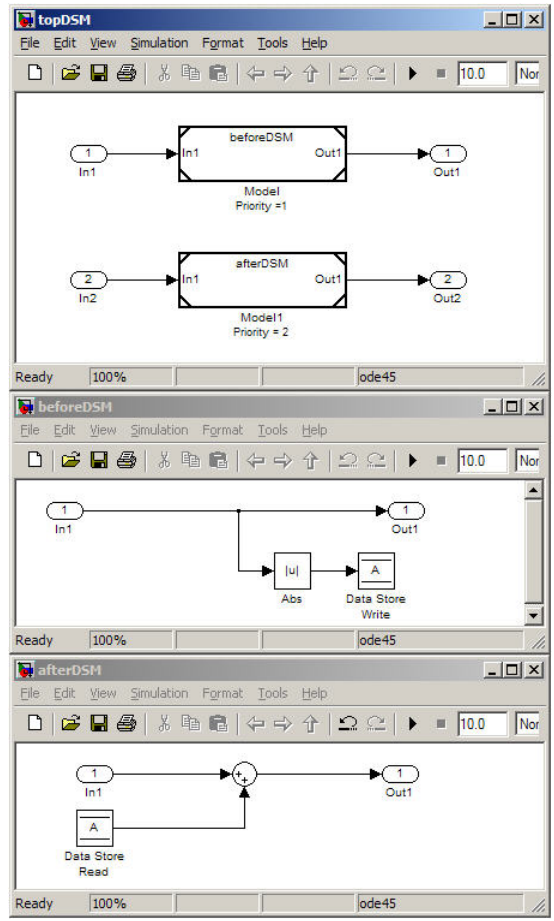
You can use function call subsystems to control the execution order of model components that access data stores. The next figure shows this technique:



The subsystem `Before` contains the Data Store Write, and the Stateflow chart calls that subsystem before it calls the subsystem `After`, which contains the Data Store Read.

Ordering Access Using Block Priorities

You can embed data store reads and writes inside atomic subsystems or Model blocks whose priorities specify their relative execution order. The next figure shows this technique:



The Model block `beforeDSM` has a lower priority then `afterDSM`, so it is guaranteed to execute first. Since `beforeDSM` is atomic, all of its operations, including the Data Store Write, will execute prior to `afterDSM` and all of its operations, including the Data Store Read.

Using Data Store Diagnostics

In this section...

About Data Store Diagnostics

Simulink provides various run-time and compile-time diagnostics that you can use to help avoid problems with data stores. Diagnostics are available in the Configuration Parameters dialog box and the Data Store Memory block's parameters dialog box. The Simulink Model Advisor provides support by listing cases where data store errors are more likely because diagnostics are disabled.

Detecting Access Order Errors

You can use data store run-time diagnostics to detect unintended sequences of data store reads and writes that occur during simulation. You can apply these diagnostics to all data stores, or allow each Data Store Memory block to set its own value. The diagnostics are:

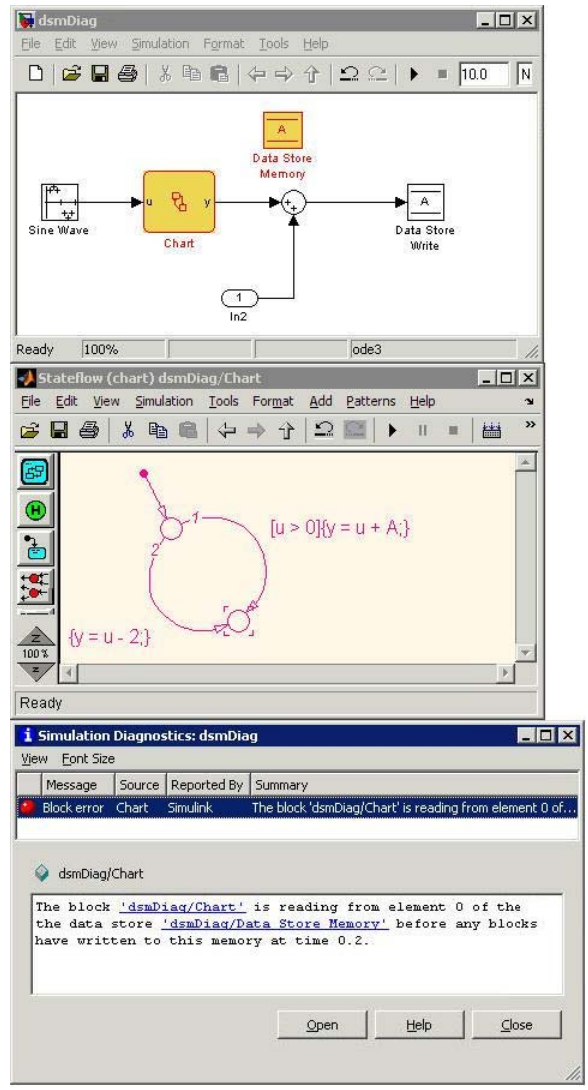
- **Detect read before write:** Detect when a data store is read from before written to within a given time step
- **Detect write after read:** Detect when a data store is written to after being read from within a given time step
- **Detect write after write:** Detect when a data store is written to multiple times within a given time step

These diagnostics appear in the **Configuration Parameters > Diagnostics > Data Validity > Data Store Memory Block** pane, where each can have one of the following values:

- `Disable all` — Disables this diagnostic for all data stores accessed by the model.
- `Enable all as warnings` — Displays the diagnostic as a warning in the MATLAB Command Window.
- `Enable all as errors` — Halts the simulation and displays the diagnostic in an error dialog box.
- `Use local settings` — Allow each Data Store Memory block to set its own value for this diagnostic (default).

The same diagnostics also appear in each Data Store Memory block's **Diagnostics** tab, where each can have the value `none`, `warning`, or `error`. The value specified by an individual block takes effect only if the corresponding configuration parameter is `Use local settings`. See "Diagnostics Pane: Data Validity" and Data Store Memory for more information.

The most conservative technique is to set all data store diagnostics to `Enable all as errors` in **Configuration Parameters > Diagnostics > Data Validity > Data Store Memory Block**. However, this setting is not best in all cases, because it can flag intended behavior as erroneous. For example, the next figure shows a model that uses block priorities to force the Data Store Read block to execute before the Data Store Write block:



An error occurred during simulation because the data store `A` is read from the Stateflow chart before the Data Store Write updates it. If the associated delay is intended, you can suppress the error by setting the global parameter **Detect read before write** to `Use local settings`, then setting that parameter to disable in the Data Store Write block. If you use this technique,

be sure to set the parameter to `error` in all other Data Store Write blocks aside from those which are to be intentionally excluded from the diagnostic.

Data Store Diagnostics and the Embedded MATLAB Function Block

Diagnostics might be more conservative for data store memory used by Embedded MATLAB Function blocks. For example, if you pass arrays of data store memory to Embedded MATLAB functions, optimizations such as `A=foo(A)` might result in Embedded MATLAB marking the entire contents of the array as read or written even though only some elements were accessed.

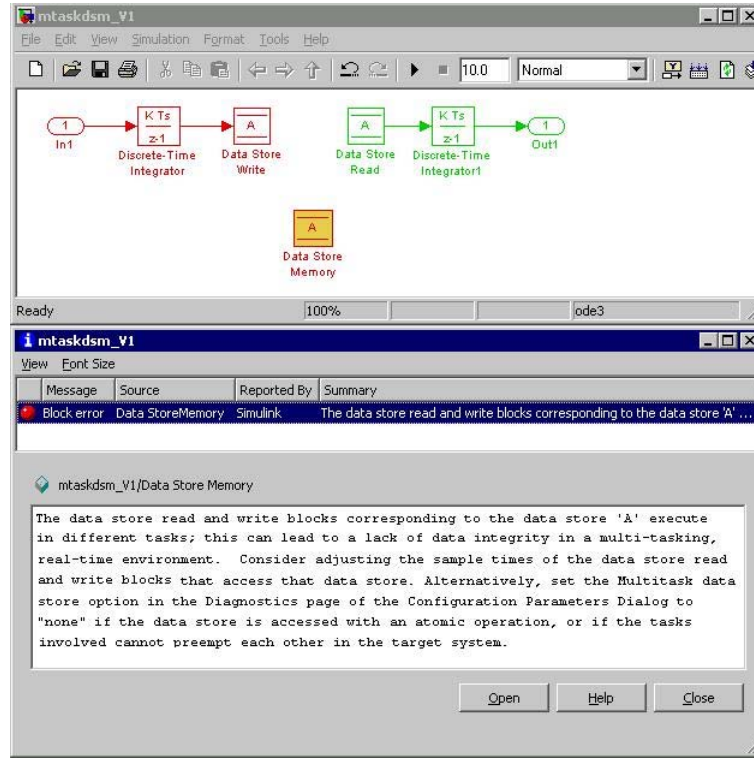
Detecting Multitasking Access Errors

Data integrity may be compromised if a data store is read from in one task and written to in another task. For example, suppose that:

1. A task is writing to a data store.
2. A second task interrupts the first task.
3. The second task reads from that data store.

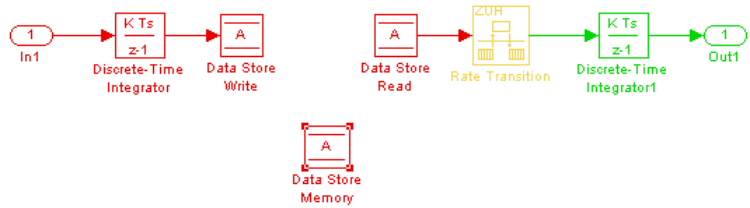
If the first task had only partly updated the data store when the second task interrupted, the resulting data in the store will be inconsistent. For example, if the value is a vector, some of its elements may have been written in the current time step, while the rest were written in the previous step. If the value is a multi-word datum, it may be left in an inconsistent state that is not even partly correct.

Unless you are certain that task preemption cannot cause data integrity problems, set the compile-time diagnostic **Configuration Parameters > Diagnostics > Data Validity > Data Store Memory Block > Multitask Data Store** to `warning` (the default) or `error`. This diagnostic flags any case of a data store that is read from and written to in different tasks. The next figure illustrates a problem detected by setting **Multitask Data Store** to `error`:



Since the data store A is written to in the fast task and read from in the slow task, an error is reported, with suggested remedy. This diagnostic is applicable even in the case that a data store read or write is inside of a conditional subsystem. Simulink correctly identifies the task that the block is executing within, and uses that task for the purpose of evaluating the diagnostic.

The next figure shows one solution to the problem shown above: place a rate transition block after the data store read, which previously accessed the data store at the slower rate.



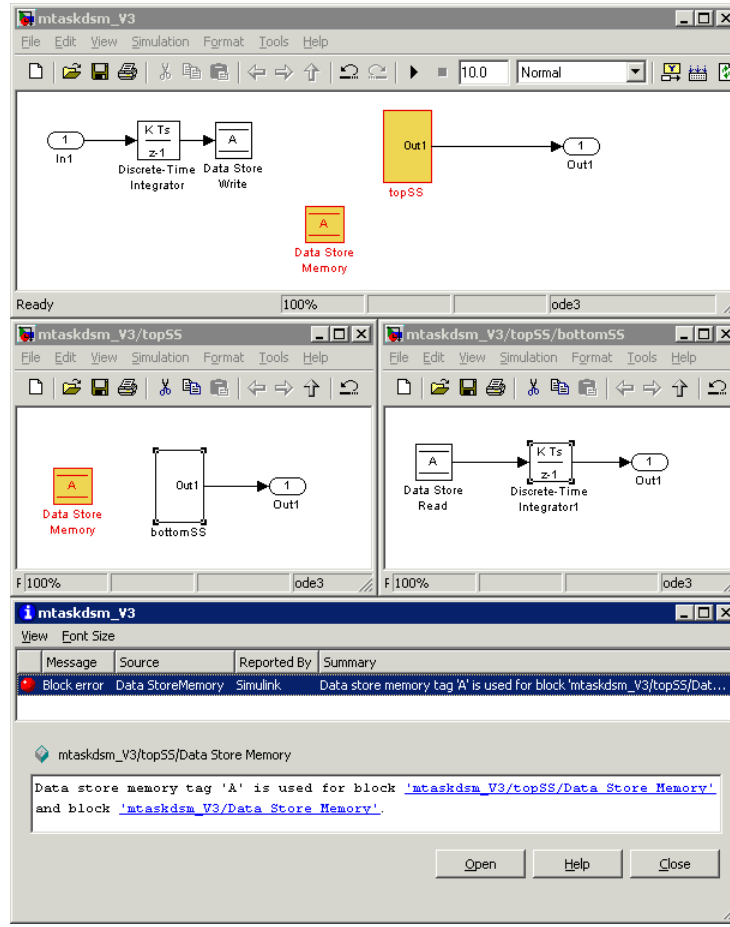
With this change, the data store write can continue to occur at the faster rate. This may be important if that data store must be read at that faster rate elsewhere in the model.

The **Multitask Data Store** diagnostic also applies to data store reads and writes in referenced models. If two different child models execute a data store's reads and writes in differing tasks, the error will be detected when Simulink compiles their common parent model.

Detecting Duplicate Name Errors

Data store errors can occur due to duplicate uses of a data store name within a model. For instance, data store shadowing occurs when two or mote data store memories in different nested scopes have the same data store name. In this situation, the data store memory referenced by a data store read or write block at a low level may not be the intended store.

To prevent errors caused by duplicate data store names, set the compile-time diagnostic **Configuration Parameters > Diagnostics > Data Validity > Data Store Memory Block > Duplicate Data Store Names** to `warning` or `error`. By default, the value of the diagnostic is `none`, suppressing duplicate name detection. The next figure shows a problem detected by setting **Duplicate Data Store Names** to `error`:



The data store read at the bottom level of a subsystem hierarchy refers to a data store named A, and two Data Store Memory blocks in the same model have that name, so an error is reported. This diagnostic guards against assuming that the data store read refers to the Data Store Memory block in the top level of the model. The read actually refers to the Data Store Memory block at the intermediate level, which is closer in scope to the Data Store Read block.

Data Store Diagnostics in the Model Advisor

The Model Advisor provides several diagnostics that you can use with data stores. See these sections for information about Model Advisor diagnostics for data stores:

"Check Data Store Memory blocks for multitasking, strong typing, and shadowing issues"

"Check block sample times for modeling errors"

"Check if read/write diagnostics are enabled for data store blocks"

Data Stores and Software Verification

Data stores can have significant effects on software verification, especially in the area of data coupling and control. Models and subsystems that use only inports and outports to pass data result in clean, well-specified, and easily verifiable interfaces in the generated code.

Data stores, like any type of global data, make verification more difficult. If your development process includes software verification, consider planning for the effect of data stores early in the design process.

For more information, see RTCA DO-178B, “Software Considerations in Airborne Systems and Equipment Certification,” Section 6.3.3b.

Managing Signals

29

Working with Signals

Signal Basics

In this section...

About Signals

The term *signal* refers to a time varying quantity that has values at all points in time. You can specify a wide range of signal attributes, including signal name, data type (e.g., 8-bit, 16-bit, or 32-bit integer), numeric type (real or complex), and dimensionality (one-dimensional, two-dimensional, or multidimensional array). Many blocks can accept or output signals of any data or numeric type and dimensionality. Others impose restrictions on the attributes of the signals they can handle.

Simulink defines signals as the outputs of dynamic systems represented by blocks in a Simulink diagram and by the diagram itself. The lines in a block diagram represent mathematical relationships among the signals defined by the block diagram. For example, a line connecting the output of block A to

the input of block B indicates that the signal output by B depends on the signal output by A.

On the block diagram, signals are represented with lines that have an arrowhead. The source of the signal corresponds to the block that writes to the signal during evaluation of its block methods (equations). The destinations of the signal are blocks that read the signal during the evaluation of the block methods (equations).

Note It is tempting but misleading to think of Simulink signals as traveling along the lines that connect blocks the way electrical signals travel along a telephone wire. This analogy is misleading because it suggests that a block diagram represents physical connections between blocks, which is not the case. Simulink signals are mathematical, not physical, entities and the lines in a block diagram represent mathematical, not physical, relationships among blocks.

Creating Signals

You can create signals by creating source blocks in your model. For example, you can create a signal that varies sinusoidally with time by dragging an instance of the Sine block from the Simulink Sources library into the model. See "Sources" for information on blocks that you can use to create signals in a model. You can also use the Signal & Scope Manager to create signals in your model without using blocks. See "Introducing the Signal and Scope Manager" on page 29-38 for more information.

Naming Signals

You can give any signal a name. The syntactic requirements for a signal name vary depending on how the name will be used. The most common cases are:

- The signal is named so that it can be resolved to a `Simulink.Signal` object. (See `Simulink.Signal`.) The signal name must then be a legal MATLAB identifier. Such an identifier starts with an alphabetic character, followed by alphanumeric or underscore characters up to the length given by the function `namelengthmax`.

- The signal has a name so the signal can be identified and referenced by name in a data log. (See "Logging Signals" on page 27-3.) Such a signal name can contain space and newline characters. These can improve readability but sometimes require special handling techniques, as described in "Handling Spaces and Newlines in Logged Names" on page 27-9.
- The signal name exists only to clarify the diagram, and has no computational significance. Such a signal name can contain anything and never needs special handling.
- If a signal is an element of a bus object, use a valid C language identifier for the signal name.

To avoid any doubt about whether a signal name will serve all present and future purposes, make every signal name a legal MATLAB identifier. Otherwise, unexpected requirements may require going back and changing signal names to follow a more restrictive syntax. You can use the function `isvarname` to determine whether a signal name is a legal MATLAB identifier.

Assigning a Signal Name

To assign a name to a signal, double-click the signal. An edit box appears next to the signal near where you double-clicked. Enter the desired name, then click somewhere outside the edit box. The signal now has the specified name, and a label showing that name appears at the location where you entered it. For a named multibranched signal, you can put a duplicate label on any branch of the signal by double-clicking the branch.

Another way to name a signal is to right-click the signal, choose **Signal Properties** from the Context menu, enter a name in the **Signal Name** field, then click **OK** or **Apply**. A label showing the name then appears on every branch of the signal. See "Signal Properties Dialog Box" for more information.

You can also use the API to set the name parameter of the port or line that represents the signal:

```
p = get_param(gcb, 'PortHandles')
l = get_param(p.Inport, 'Line')
set_param(l, 'Name', 's9')
```

Changing a Signal Name

To change the name of a signal, click to set the cursor in any label that shows the name, than change the text as needed; or edit the name in the **Signal Properties > Signal Name** field. All labels automatically update to reflect the change.

To change the location of a label that displays a signal name, drag it with the mouse. You cannot drag a label away from its signal, but only to a different location adjacent to the signal.

Deleting a Signal Name

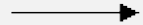
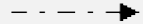
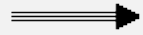
To delete a signal's name, leaving it nameless, delete all characters in the name, in any label on the signal or in the **Signal Properties > Signal Name** field. To delete a label without deleting the signal name, click near the edge of the label to select its surrounding box, then press Delete. The label disappears, but the signal name itself is unaffected.

Displaying Signal Values

As with creating signals, you can use either blocks or the Signal & Scope Manager to display the values of signals during a simulation. For example, you can use either the Scope block or the Signal & Scope Manager to graph time-varying signals on an oscilloscope-like display during simulation. See "Sinks" in the Simulink block reference for information on blocks that you can use to display signals in a model.

Signal Line Styles

Simulink uses a variety of line styles to display different types of signals in the model window. Assorted line styles help you to differentiate the signal types in Simulink diagrams. The signal types and their line styles are as follows:

Signal Type	Line Style	Description
Scalar and Nonscalar		Simulink uses a thin, solid line to represent a diagram's scalar and nonscalar signals.
Nonscalar		When the **Wide nonscalar lines** option is enabled, Simulink uses a thick, solid line to represent a diagram's nonscalar signals. See also "Using Muxes" on page 29-17.
Control		Simulink uses a thin, dash-dot line to represent a diagram's control signals.
Virtual Bus		Simulink uses a triple line with a solid core to represent a diagram's virtual signal buses. See "Virtual and Nonvirtual Buses" on page 30-48.
Nonvirtual Bus		Simulink uses a triple line with a dotted core to represent a diagram's nonvirtual signal buses. See "Virtual and Nonvirtual Buses" on page 30-48.
Array of Buses		Simulink uses a heavy triple line with a dotted core to represent a diagram's array of bus signals. See "Combining Buses into an Array of Buses" on page 30-67.
Variable-Size		Simulink uses a solid wide line with a white dotted core to represent a variable-size signal. See "Variable-Size Signal Basics" on page 31-2.

Other than using the **Wide nonscalar lines** option to display nonscalar signals as thick, solid lines, you cannot customize or control the line style with which Simulink displays signals. See "Wide Nonscalar Lines" on page 29-67 for more information about this option.

Note As you construct a block diagram, Simulink uses a thin, solid line to represent all signal types. The lines are then redrawn using the specified line styles only after you update or start simulation of the block diagram.

Signal Labels

A signal label is text that appears next to the line that represents a signal that has a name. The signal label displays the signal's name. In addition, if the signal is a virtual signal (see "Virtual Signals" on page 29-13) and its **Show propagated signals** property is on (see "Show propagated signals"), the label displays the names of the signals that make up the virtual signal.

Simulink creates a label for a signal when you assign it a name in the "Signal Properties Dialog Box". You can change the signal's name by editing its label on the block diagram. To edit the label, left-click the label. Simulink replaces the label with an edit field. Edit the name in the edit field, then click outside the label to apply the change.

A signal's label displays the signal's name. A virtual signal's label optionally displays the signals it represents in angle brackets. You can edit a signal's label, thereby changing the signal's name.

To create a signal label (and thereby name the signal), double-click the line that represents the signal. The text cursor appears. Enter the name and click anywhere outside the label to exit label editing mode. See "Naming Signals" on page 29-3 for guidelines for signal names.

Note When you create a signal label, take care to double-click the line. If you click in an unoccupied area close to the line, you will create a model annotation instead.

Labels can appear above or below horizontal lines or line segments, and left or right of vertical lines or line segments. Labels can appear at either end, at the center, or in any combination of these locations.

To move a signal label, drag the label to a new location on the line. When you release the mouse button, the label fixes its position near the line.

To copy a signal label, hold down the **Ctrl** key while dragging the label to another location on the line. When you release the mouse button, the label appears in both the original and the new locations.

To edit an existing signal label, select it:

- To replace the label, click the label, double-click or drag the cursor to select the entire label, then enter the new label.
- To insert characters, click between two characters to position the insertion point, then insert text.
- To replace characters, drag the mouse to select a range of text to replace, then enter the new text.

To delete all occurrences of a signal label, delete all the characters in the label. When you click outside the label, the labels are deleted. To delete a single occurrence of the label, hold down the **Shift** key while you select the label, then press the **Delete** or **Backspace** key.

To change the font of a signal label, select the signal, choose **Font** from the **Format** menu, then select a font from the **Set Font** dialog box.

Signal Data Types

Data type refers to the format used to represent signal values internally. The data type of Simulink signals is double by default. However, you can create signals of other data types. Simulink supports the same range of data types as MATLAB. See “Working with Data Types” on page 25-2 for more information.

Signal Dimensions

Simulink blocks can output one-, two-, or multidimensional signals. A one-dimensional (1-D) signal consists of a stream of one-dimensional arrays output at a frequency of one array (vector) per simulation time step. A two-dimensional (2-D) signal consists of a stream of two-dimensional arrays output at a frequency of one 2-D array (matrix) per block sample time. A multidimensional signal consists of a stream of multidimensional (two

or more dimensions) arrays output at a frequency of one array per block sample time. You can specify multidimensional arrays with any valid MATLAB multidimensional expression, such as [4 3]. (See "Multidimensional Arrays" in the MATLAB Getting Started documentation for information on multidimensional arrays.) The Simulink user interface and documentation generally refer to 1-D signals as *vectors* and 2-D or multidimensional signals as *matrices*. A one-element array is frequently referred to as a *scalar*. A *row vector* is a 2-D array that has one row. A *column vector* is a 2-D array that has one column.

The following Simulink blocks support multidimensional signals. Simulink supports signals with up to 32 dimensions. Do not use signals with more than 32 dimensions.

- Abs
- Assertion
- Assignment
- Bitwise Operator
- Bus Assignment
- Bus Creator
- Bus Selector
- Check Discrete Gradient
- Check Dynamic Gap
- Check Dynamic Lower Bound
- Check Dynamic Range
- Check Dynamic Upper Bound
- Check Input Resolution
- Check Static Gap
- Check Static Lower Bound
- Check Static Range
- Check Static Upper Bound

- Compare To Constant
- Compare To Zero
- Complex to Magnitude-Angle
- Complex to Real-Imag
- Concatenate
- Constant
- Data Store Memory
- Data Store Read
- Data Store Write
- Data Type Conversion
- Data Type Conversion Inherited
- Data Type Duplicate
- Data Type Propagation
- Data Type Scaling Strip
- Direct Lookup Table (n-D)
- Dot Product
- Embedded MATLAB Function
- Enabled Subsystem
- Enabled and Triggered Subsystem
- Environment Controller
- Extract Bits
- Find
- For Each Subsystem
- For Iterator Subsystem
- From
- From File
- From Workspace

- Function-Call Subsystem
- Gain (only if the **Multiplication** parameter specifies `Element-wise(K.*u)`)
- Goto
- Ground
- IC
- If Action Subsystem
- Inport
- Level-2 MATLAB S-Function
- Logical Operator
- Magnitude-Angle to Complex
- Manual Switch
- Math Function (no multidimensional signal support for the `transpose` and `hermitian` functions)
- Memory
- Merge
- MinMax
- Model
- Multiport Switch
- Outport
- Product, Product of Elements — only if the **Multiplication** parameter specifies `Element-wise(.*)`
- Probe
- Random Number
- Rate Transition
- Real-Imag to Complex
- Relational Operator
- Reshape

- Scope, Floating Scope
- Selector
- S-Function
- Signal Conversion
- Signal Generator
- Signal Specification
- Slider Gain
- Squeeze
- Subsystem, Atomic Subsystem, CodeReuse Subsystem
- Add, Subtract, Sum, Sum of Elements — along specified dimension
- Switch
- Switch Case Action Subsystem
- Terminator
- To File
- To Workspace
- Triggered Subsystem
- Trigonometric Function
- Unary Minus
- Uniform Random Number
- Unit Delay
- While Iterator Subsystem
- Width
- Wrap to Zero

Simulink blocks vary in the dimensionality of the signals they can accept or output. Some blocks can accept or output signals of any dimensions. Some can accept or output only scalar or vector signals. To determine the signal dimensionality of a particular block, see the block's description in Blocks — Alphabetical List in the online Simulink reference. See "Determining Output

Signal Dimensions" on page 29-26 for information on what determines the dimensions of output signals for blocks that can output nonscalar signals.

Note Simulink does not support dynamic signal dimensions during simulation. That is, the size of a signal must remain constant while the simulation executes. You can alter a signal's size only after terminating the simulation.

Complex Signals

The values of Simulink signals can be complex numbers. A signal whose values are complex numbers is called a complex signal. You can introduce a complex-valued signal into a model in the following ways:

- Load complex-valued signal data from the MATLAB workspace into the model via a root-level Inport block.
- Create a Constant block in your model and set its value to a complex number.
- Create real signals corresponding to the real and imaginary parts of a complex signal, then combine the parts into a complex signal, using the Real-Imag to Complex conversion block.

You can manipulate complex signals via blocks that accept them. If you are not sure whether a block accepts complex signals, see the documentation for the block in Blocks — Alphabetical List in the online Simulink reference.

Virtual Signals

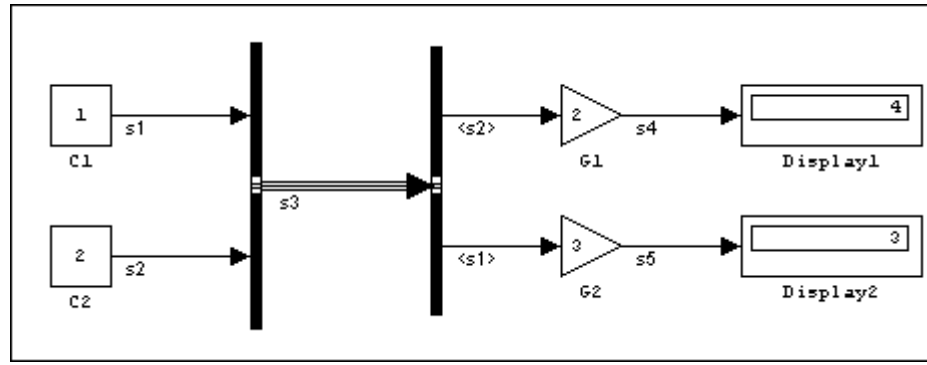
A *virtual signal* is a signal that graphically represents other signals or parts of other signals. Virtual signals are purely graphical entities; they have no mathematical or physical significance. Simulink ignores them when simulating a model, and they do not exist in generated code. Some blocks, such as the Mux block, always generate virtual signals. Others, such as Bus Creator, can generate either virtual or nonvirtual signals.

The nonvirtual components of a virtual signal are called *regions*. A virtual signal can contain the same region more than once. For example, if the same

nonvirtual signal is connected to two input ports of a Mux block, the block outputs a virtual signal that has two regions. The regions behave as they would if they had originated in two different nonvirtual signals, even though the resulting behavior duplicates information.

Whenever you update or run a model, Simulink determines the nonvirtual signal(s) represented by the model's virtual signal(s), using a procedure known as *signal propagation*. When running the model, Simulink uses the corresponding nonvirtual signal(s), determined via signal propagation, to drive the blocks to which the virtual signals are connected.

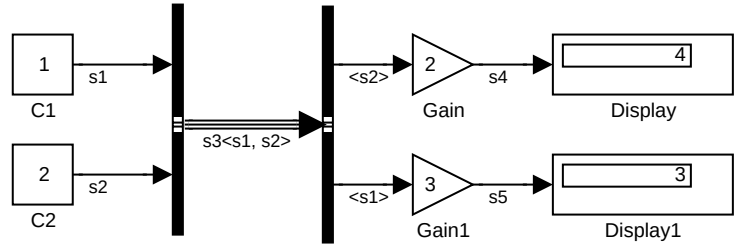
Consider, for example, the following model.



The signals driving Gain blocks `G1` and `G2` are virtual signals corresponding to signals `s2` and `s1`, respectively. Simulink determines this automatically whenever you update or simulate the model.

Displaying the Nonvirtual Components of Virtual Signals

The **Show propagated signals** option (see "Signal Properties Dialog Box") displays the nonvirtual signals represented by virtual signals in the labels of the virtual signals.



When you change the name of a nonvirtual signal, Simulink immediately updates the labels of all virtual signals that represent the nonvirtual signal and whose **Show propagated signals** is `on`, except if the path from the nonvirtual signal to the virtual signal includes an unresolved reference to a library block. In such cases, to avoid time-consuming library reference resolutions while you are editing a block diagram, Simulink defers updating the virtual signal's label until you update the model's block diagram either directly (e.g., by pressing **Ctrl+D**) or by simulating the model.

Note Virtual signals can represent virtual as well as nonvirtual signals. For example, you can use a Bus Creator block to combine multiple virtual and nonvirtual signals into a single virtual signal. If during signal propagation, Simulink determines that a component of a virtual signal is itself virtual, Simulink uses signal propagation to determine the nonvirtual components of the virtual component. This process continues until Simulink has determined all nonvirtual components of a virtual signal.

To display the signal(s) represented by a virtual signal, right-click the signal line and select **Signal Properties**. The Signal Properties dialog box (see "Signal Properties Dialog Box") appears. Select `on` for **Show propagated signals**, then click **OK**. Simulink displays the signals represented by the virtual signal in brackets in the label.

You can also provide a signal name. As a shortcut, you can click the signal's label, clear the name (if one exists) and enter an angle bracket (<). Click anywhere outside the signal's label. Simulink exits label editing mode and displays the signals represented by the virtual signal in brackets in the label. After you enable the **Show propagated signals** parameter, you can enter a signal name in the label.

Mux Signals

A Simulink *mux* is a virtual signal that graphically combines two or more scalar or vector signals into one signal line. A Simulink mux should not be confused with a hardware multiplexer, which combines multiple data streams into a single channel. A Simulink mux does not combine signals in any functional sense: it exists only virtually, and has no purpose except to simplify a model's visual appearance. Using a mux has no effect on simulation or generated code.

You can use a mux anywhere that you could use an ordinary (contiguous) vector, including performing calculations on it. The computation affects each constituent value in the mux just as if the values existed in a contiguous vector, and the result is a contiguous vector, not a mux. Models can use this capability to perform computations on multiple vectors without the overhead of first copying the separate values to contiguous storage.

The Simulink documentation refers, sometimes interchangeably, to "muxes", "vectors", and "wide signals", and all three terms appear in Simulink GUI labels and API names. This terminology can be confusing, because most vector signals, which are also called wide signals, are nonvirtual and hence are not muxes. To avoid confusion, reserve the term "mux" to refer specifically to a virtual vector.

A mux is, by definition, a *virtual* vector signal: its constituent signals retain their separate existence in every way except visually. You can also combine scalar and vector signals into a *nonvirtual* vector signal, by using a Vector Concatenate block. The signal output by a Vector Concatenate block is an ordinary contiguous vector, inheriting no special properties from the fact that it was created from separate signals.

If you want to create a composite signal, in which the constituent signals retain their identities and can have different data types, use a Bus Creator

block rather than a Mux block, as described in Chapter 30, "Using Composite Signals". Although you can use a Mux block to create a composite signal in some cases, MathWorks discourages this practice. See "Avoiding Mux/Bus Mixtures" on page 30-84 for more information.

Using Muxes

The Signal Routing library provides two virtual blocks that you can use for implementing muxes:

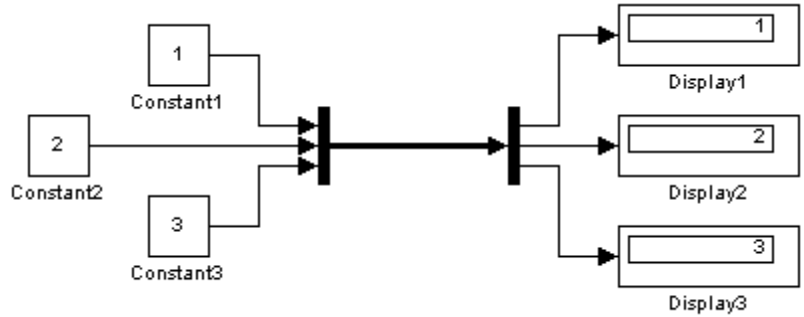
Mux
: Combine several input signals into a mux (virtual vector) signal

Demux
: Extract and output the values in a mux (virtual vector) signal

To implement a mux signal:

1. Clone a Mux and Demux block from the Signal Routing library.
2. Set the Mux block's **Number of inputs** and the Demux block's **Number of outputs** properties to the desired values.
3. Connect the Mux, Demux, and other blocks as needed to implement the desired signal.

The next figure shows three signals that are input to a Mux block, transmitted as a mux signal to a Demux block, and output as separate signals.



The Mux and Demux blocks are the left and right vertical bars, respectively. Consistent with the goal of reducing visual complexity, neither block displays a name. The line connecting the blocks, representing the mux signal, is wide because the model has been built with **Format > Port/Signal Displays > Wide Nonscalar Lines** enabled in the model menu. See "Displaying Signal Properties" on page 29-64 for details.

Signals input to a Mux block can any combination of scalars, vectors, and muxes. The signals in the output mux appear in the order in which they were input to the Mux block. You can use multiple Mux blocks to create a mux in several stages, but the result is flat, not hierarchical, just as if the constituent signals had been combined using a single mux block.

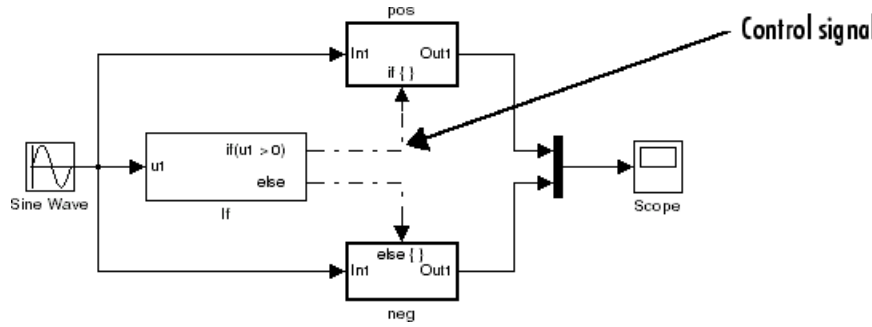
The values in all signals input to a Mux block must have the same data type. If they do not, the block will output a bus rather than a mux unless you have configured the model to disable this practice. MathWorks discourages using Mux blocks to create buses. See "Avoiding Mux/Bus Mixtures" on page 30-84 for details.

If a Demux block attempts to output more values than exist in the input signal, an error occurs. A Demux block can output fewer values than exist in the input mux, and can group the values it outputs into different scalars and vectors than were input to the Mux block, but it cannot rearrange the order of those values. See the Demux block documentation for details.

A Demux block can input a bus unless you have configured the model to disable this practice. MathWorks discourages using Demux blocks to access buses under any circumstances. See "Avoiding Mux/Bus Mixtures" on page 30-84 for details.

Control Signals

A *control signal* is a signal used by one block to initiate execution of another block, e.g., a function-call or action subsystem. When you update or start simulation of a block diagram, Simulink uses a dash-dot pattern to redraw lines representing the diagram's control signals as illustrated in the following example.



Composite Signals

The Simulink software provides capabilities that you can use to group multiple signals into a hierarchical composite signal called a *bus*, route the bus from block to block, and extract constituent signals from the bus where needed. Buses can simplify the appearance of a model when many parallel signals exist, and help to clarify generated code. A bus can be either virtual or nonvirtual. See Chapter 30, "Using Composite Signals" for details.

Signal Glossary

The following table summarizes the terminology used to describe signals in the Simulink user interface and documentation.

Term	Meaning
Bus	A Simulink composite signal
Complex signal	Signal whose values are complex numbers.
Composite Signal	A signal made up of other signals, optionally including other composite signals. See Chapter 30, "Using Composite Signals".
Data type	Format used to represent signal values internally. See "Working with Data Types" on page 25-2.
Matrix	Two-dimensional signal array.
Mux	A virtual vector created with a Mux block.
Real signal	Signal whose values are real (as opposed to complex) numbers.
Scalar	One-element array.
Signal bus	Same as a composite signal
Signal propagation	Process used by the Simulink to determine attributes of signals and blocks, such as data types, labels, sample time, dimensionality, and so on, that are determined by connectivity.
Size	Number of elements that a signal contains. The size of a matrix (2-D) signal is generally expressed as M-by-N, where M is the number of columns and N is the number of rows making up the signal.
Test point	A signal that must be accessible during simulation. See "Working with Test Points" on page 29-61 for more information.
Vector	One-dimensional signal array.
Virtual signal	Signal that represents another signal or set of signals.
Width	Size of a vector signal.

Validating Signal Connections

Many Simulink blocks have limitations on the types of signals they can accept. Before simulating a model, Simulink checks all blocks to ensure that they can accommodate the types of signals output by the ports to which they are connected. If any incompatibilities exist, Simulink reports an error and terminates the simulation.

To detect signal compatibility errors before running a simulation, choose **Update Diagram** from the Simulink **Edit** menu. Simulink reports any invalid connections found in the process of updating the diagram.

Displaying Signal Sources and Destinations

In this section...

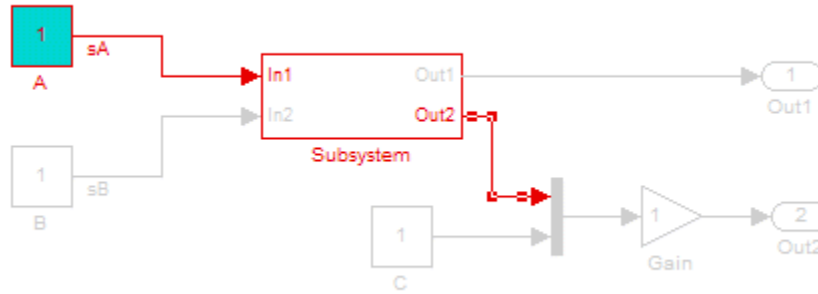
About Signal Highlighting

You can highlight a signal and its source or destination block(s), then remove the highlighting once it has served its purpose. Signal highlighting crosses subsystem boundaries, allowing you to trace a signal across multiple subsystem levels. Highlighting does not cross the boundary into or out of a referenced model. If a signal is composite, all source or destination blocks are highlighted. (See Chapter 30, "Using Composite Signals".)

Highlighting Signal Sources

To display the source block(s) of a signal, choose the **Highlight to Source** option from the context menu for the signal. This option highlights:

- All branches of the signal anywhere in the model
- All virtual blocks through which the signal passes
- The nonvirtual block(s) that write the value of the signal

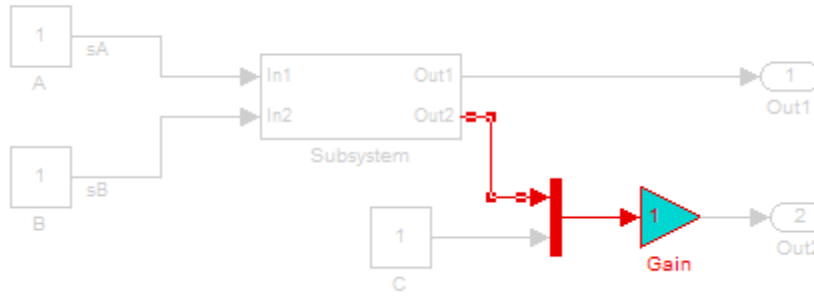


Highlighting Signal Destinations

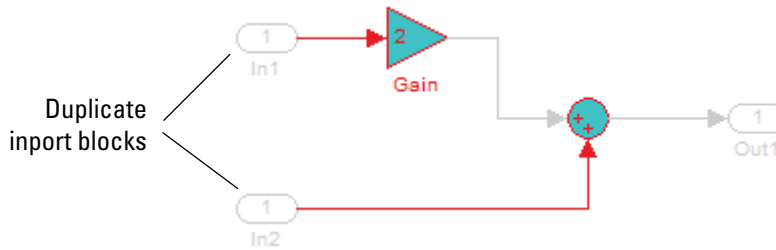
To display the destination blocks of a signal, choose the **Highlight to Destination** option from the context menu for the signal. This option highlights:

- All branches of the signal anywhere in the model
- All virtual blocks through which the signal passes
- The nonvirtual block(s) that read the value of the signal
- The signal and destination block for all blocks that are duplicates of the inport block for the line that you select

In this example, the selected signal highlights the Gain block as the destination block.



In the next example, selecting the signal from In2 and choosing the **Highlight to Destination** option highlights the signal and destination block for In2 and In1, because In1 and In2 are duplicate inport blocks.



Removing Highlighting

To remove all highlighting, choose **Remove Highlighting** from the model's context menu, or choose **View > Remove Highlighting**.

Resolving Incomplete Highlighting to Library Blocks

If the path from a source block or to a destination block includes an unresolved reference to a library block, the highlighting options highlight the path from or to the library block, respectively. To display the complete path, first update

the diagram (for example, by pressing **Ctrl+D**). The update of the diagram resolves all library references and displays the complete path to a destination block or from a source block.

Determining Output Signal Dimensions

In this section...

About Signal Dimensions

If a block can emit nonscalar signals, the dimensions of the signals that the block outputs depend on the block's parameters, if the block is a source block; otherwise, the output dimensions depend on the dimensions of the block's input and parameters.

Determining the Output Dimensions of Source Blocks

A *source* block is a block that has no inputs. Examples of source blocks include the Constant block and the Sine Wave block. See the "Sources" table in the online Simulink block reference for a complete listing of Simulink source blocks. The output dimensions of a source block are the same as those of its output value parameters if the block's **Interpret vector parameters as 1-D** parameter is off (that is, not selected in the block parameter dialog box). If the **Interpret vector parameters as 1-D** parameter is on, the output dimensions equal the output value parameter dimensions unless the parameter dimensions are N-by-1 or 1-by-N. In the latter case, the block outputs a vector signal of width N.

As an example of how a source block's output value parameter(s) and **Interpret vector parameters as 1-D** parameter determine the dimensionality of its output, consider the Constant block. This block outputs a constant signal equal to its **Constant value** parameter. The following table illustrates how the dimensionality of the **Constant value** parameter and the setting of the **Interpret vector parameters as 1-D** parameter determine the dimensionality of the block's output.

Constant Value	Interpret vector parameters as 1-D	Output
scalar	off	one-element array
scalar	on	one-element array
1-by-N matrix	off	1-by-N matrix
1-by-N matrix	on	N-element vector
N-by-1 matrix	off	N-by-1 matrix
N-by-1 matrix	on	N-element vector
M-by-N matrix	off	M-by-N matrix
M-by-N matrix	on	M-by-N matrix

Simulink source blocks allow you to specify the dimensions of the signals that they output. You can therefore use them to introduce signals of various dimensions into your model.

Determining the Output Dimensions of Nonsource Blocks

If a block has inputs, the dimensions of its outputs are, after scalar expansion, the same as those of its inputs. (All inputs must have the same dimensions, as discussed in "Signal and Parameter Dimension Rules" on page 29-27).

Signal and Parameter Dimension Rules

When creating a Simulink model, you must observe the following rules regarding signal and parameter dimensions.

Input Signal Dimension Rule

All nonscalar inputs to a block must have the same dimensions.

A block can have a mix of scalar and nonscalar inputs as long as all the nonscalar inputs have the same dimensions. Simulink expands the scalar inputs to have the same dimensions as the nonscalar inputs (see "Scalar Expansion of Inputs" on page 29-29) thus preserving the general rule.

Block Parameter Dimension Rule

In general, a block's parameters must have the same dimensions as the corresponding inputs.

Two seeming exceptions exist to this general rule:

- A block can have scalar parameters corresponding to nonscalar inputs. In this case, Simulink expands a scalar parameter to have the same dimensions as the corresponding input (see "Scalar Expansion of Parameters" on page 29-30) thus preserving the general rule.
- If an input is a vector, the corresponding parameter can be either an N-by-1 or a 1-by-N matrix. In this case, Simulink applies the N matrix elements to the corresponding elements of the input vector. This exception allows use of MATLAB row or column vectors, which are actually 1-by-N or N-by-1 matrices, respectively, to specify parameters that apply to vector inputs.

Vector or Matrix Input Conversion Rules

Simulink converts vectors to row or column matrices and row or column matrices to vectors under the following circumstances:

- If a vector signal is connected to an input that requires a matrix, Simulink converts the vector to a one-row or one-column matrix.
- If a one-column or one-row matrix is connected to an input that requires a vector, Simulink converts the matrix to a vector.
- If the inputs to a block consist of a mixture of vectors and matrices and the matrix inputs all have one column or one row, Simulink converts the vectors to matrices having one column or one row, respectively.

Note You can configure Simulink to display a warning or error message if a vector or matrix conversion occurs during a simulation. See "Vector/matrix block input conversion" for more information.

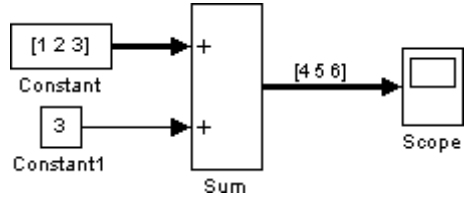
Scalar Expansion of Inputs and Parameters

Scalar expansion is the conversion of a scalar value into a nonscalar array of the same dimensions. Many Simulink blocks support scalar expansion of inputs and parameters. Block descriptions in the *Simulink Reference* indicate whether Simulink applies scalar expansion to a block's inputs and parameters.

Scalar Expansion of Inputs

Scalar expansion of inputs refers to the expansion of scalar inputs to match the dimensions of other nonscalar inputs or nonscalar parameters. When the input to a block is a mix of scalar and nonscalar signals, Simulink expands the scalar inputs into nonscalar signals having the same dimensions as the other nonscalar inputs. The elements of an expanded signal equal the value of the scalar from which the signal was expanded.

The following model illustrates scalar expansion of inputs. This model adds scalar and vector inputs. The input from block Constant1 is scalar expanded to match the size of the vector input from the Constant block. The input is expanded to the vector `[3 3 3]`.

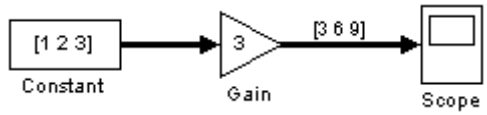


When a block's output is a function of a parameter and the parameter is nonscalar, Simulink expands a scalar input to match the dimensions of the parameter. For example, Simulink expands a scalar input to a Gain block to match the dimensions of a nonscalar gain parameter.

Scalar Expansion of Parameters

If a block has a nonscalar input and a corresponding parameter is a scalar, Simulink expands the scalar parameter to have the same number of elements as the input. Each element of the expanded parameter equals the value of the original scalar. Simulink then applies each element of the expanded parameter to the corresponding input element.

This example shows that a scalar parameter (the Gain) is expanded to a vector of identically valued elements to match the size of the block input, a three-element vector.



Checking Signal Ranges

In this section...

About Signal Range Checking

Many Simulink blocks allow you to specify a range of valid values for their output signals. Simulink provides a diagnostic that you can enable to detect when blocks generate signals that exceed their specified ranges during simulation. See the sections that follow for more information.

Blocks That Allow Signal Range Specification

The following blocks allow you to specify ranges for their output signals:

- Abs
- Constant
- Data Store Memory
- Data Type Conversion
- Difference
- Discrete Derivative
- Discrete-Time Integrator
- Gain
- Inport
- Interpolation Using Prelookup
- Lookup Table
- Lookup Table (2-D)

- Math Function
- MinMax
- Multiport Switch
- Outport
- Product, Divide, Product of Elements
- Relay
- Repeating Sequence Interpolated
- Repeating Sequence Stair
- Saturation
- Saturation Dynamic
- Signal Specification
- Sum, Add, Subtract, Sum of Elements
- Switch

See "Blocks — Alphabetical List" in the *Simulink Reference* for more information about these blocks and their parameters.

Specifying Ranges for Signals

In general, use the **Output minimum** and **Output maximum** parameters that appear on a block parameter dialog box to specify a range of valid values for the block output signal. Exceptions include the Data Store Memory, Inport, Outport, and Signal Specification blocks, for which you use their **Minimum** and **Maximum** parameters to specify a signal range. See "Blocks That Allow Signal Range Specification" on page 29-31 for a list of applicable blocks.

When specifying minimum and maximum values that constitute a range, enter only expressions that evaluate to a scalar, real number with `double` data type. The default value, `[]`, is equivalent to the representable minimum or maximum value for the signal data type. For floating-point data types, the default value is `-Inf` for the minimum value and `Inf` for the maximum value. The scalar values that you specify are subject to expansion, for example, when the block inputs are nonscalar or bus signals (see "Scalar Expansion of Inputs and Parameters" on page 29-29).

Note You cannot specify the minimum or maximum value as `NaN`.

Specifying Ranges for Complex Numbers

When you specify an **Output minimum** and/or **Output maximum** for a signal that is a complex number, the specified minimum and maximum values apply separately to the real part and to the imaginary part of the complex number. If the value of either part of the number is less than the minimum, or greater than the maximum, the complex number is outside the specified range. No range checking occurs against any combination of the real and imaginary parts, such as `(sqrt(a^2+b^2))`

Checking for Signal Range Errors

Simulink provides a diagnostic named **Simulation range checking**, which you can enable to detect when signals exceed their specified ranges during simulation. When enabled, Simulink compares the signal values that a block outputs with both the specified range (see "Specifying Ranges for Signals" on page 29-32) and the block data type. That is, Simulink performs the following check:

```
DataTypeMin   MinValue   VALUE   MaxValue   DataTypeMax
```

where

- `DataTypeMin` is the minimum value representable by the block data type.
- `MinValue` is the minimum value the block should output, specified by, e.g., **Output minimum**.
- `VALUE` is the signal value that the block outputs.
- `MaxValue` is the maximum value the block should output, specified by, e.g., **Output maximum**.
- `DataTypeMax` is the maximum value representable by the block data type.

Note It is possible to overspecify how a block handles signals that exceed particular ranges. For example, you can specify values (other than the default values) for both signal range parameters and enable the **Saturate on integer overflow** parameter. In this case, Simulink displays a warning message that advises you to disable the **Saturate on integer overflow** parameter.

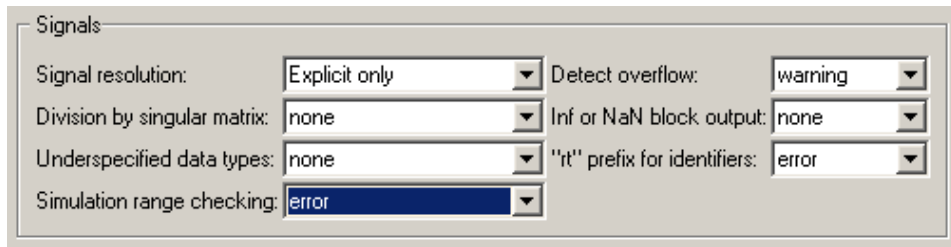
Enabling Simulation Range Checking

To enable the **Simulation range checking** diagnostic:

1. In your model window, select **Simulation > Configuration Parameters**.

   Simulink displays the Configuration Parameters dialog box.

2. In the **Select** tree on the left side of the Configuration Parameters dialog box, click the **Diagnostics > Data Validity** category. On the right side under **Signals**, set the **Simulation range checking** diagnostic to `error` or `warning`.



3. Click **OK** to apply your changes and close the Configuration Parameters dialog box.

See "Simulation range checking" in the *Simulink Graphical User Interface* documentation for more information.

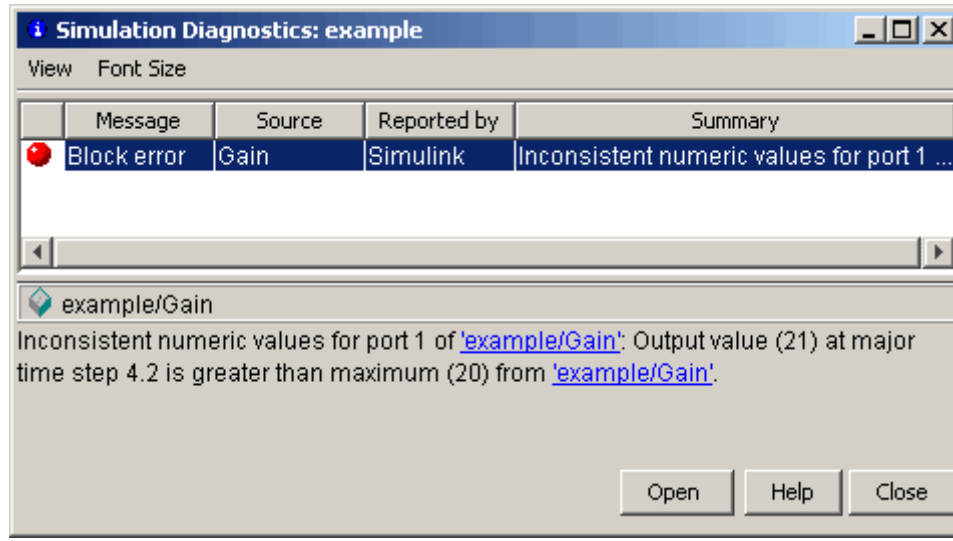
Simulating Models with Simulation Range Checking

To check for signal range errors or warnings:

1 Enable the **Simulation range checking** diagnostic for your model (see "Enabling Simulation Range Checking" on page 29-34).

2 In your model window, select **Simulation > Start** to simulate the model.

Simulink simulates your model and performs signal range checking. If a signal exceeds its specified range when the **Simulation range checking** diagnostic specifies `error`, Simulink stops the simulation and displays an error message:



Otherwise, if a signal exceeds its specified range when the **Simulation range checking** diagnostic specifies `warning`, Simulink displays a warning message in the MATLAB Command Window:

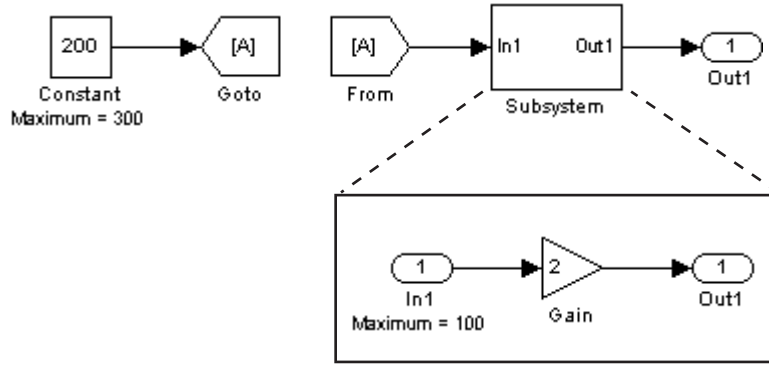
```
Warning: Inconsistent numeric values for port 1
of 'example/Gain': Output value (21) at major
time step 4.2 is greater than maximum (20) from
'example/Gain'.
```

Each message identifies the block whose output signal exceeds its specified range, and the time step at which this violation occurs.

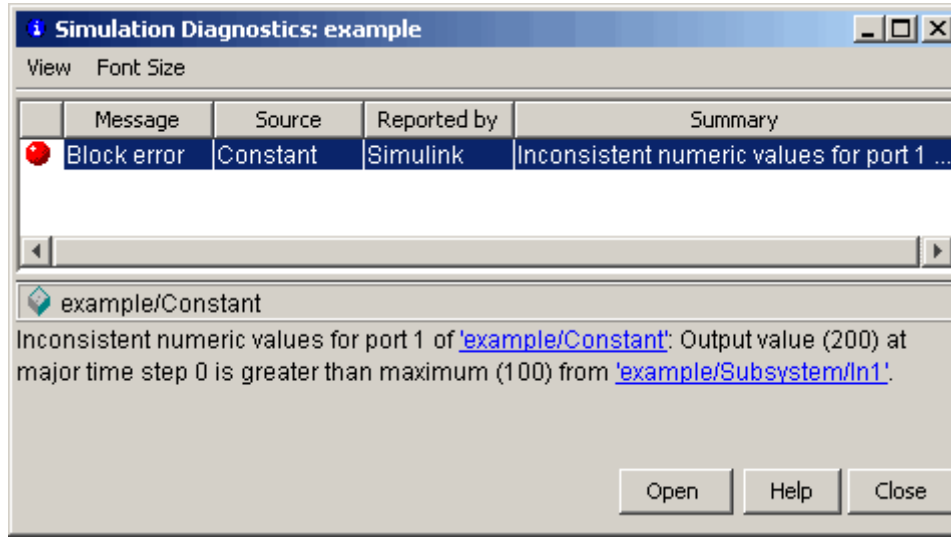
Signal Range Propagation for Virtual Blocks

Some virtual blocks (see “Virtual Blocks” on page 18-2) allow you to specify ranges for their output signals, for example, the Inport and Outport blocks. When the **Simulation range checking** diagnostic is enabled for a model that contains such blocks, the signal range of the virtual block propagates backward to the first instance of a nonvirtual block whose output signal it receives. If the nonvirtual block specifies different values for its own range, Simulink performs signal range checking with the *tightest* range possible. That is, Simulink checks the signal using the larger minimum value and the smaller maximum value.

For example, consider the following model:



In this model, the Constant block specifies its **Output maximum** parameter as 300, and that of the Inport block is set to 100. Suppose you enable the **Simulation range checking** diagnostic and simulate the model. The Inport block back propagates its maximum value to the nonvirtual block that precedes it, i.e., the Constant block. Simulink then uses the smaller of the two maximum values to check the signal that the Constant block outputs. Because the Constant block outputs a signal whose value (200) exceeds the tightest range, Simulink displays the following error message:


Simulation Diagnostics: example
View
Font Size
Message
Source
Reported by
Summary
Block error
Constant
Simulink
Inconsistent numeric values for port 1 ...
example/Constant
Inconsistent numeric values for port 1 of 'example/Constant': Output value (200) at major time step 0 is greater than maximum (100) from 'example/Subsystem/In1'.
Open
Help
Close

Introducing the Signal and Scope Manager

In this section...

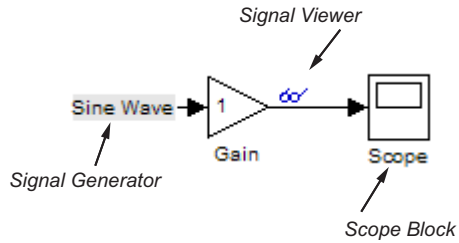
What Is the Signal & Scope Manager?

The Signal & Scope Manager is a user interface to the Signal Viewers and Generator objects. From the Signal and Scope Manager you manage all signal generators and viewers from a central place.

Note The Signal and Scope Manager requires that you have Java™ enabled when you start MATLAB. This is the default.

What Are Viewer and Generator Objects?

The small icons identifying a viewer or generator are called Viewer and Generator Objects. These objects are not the same as scope or signal blocks. Objects are managed by the Signal and Scope Manager, and are placed on signals. Blocks are dragged from the Library browser and are not managed by the Signal and Scope manager.

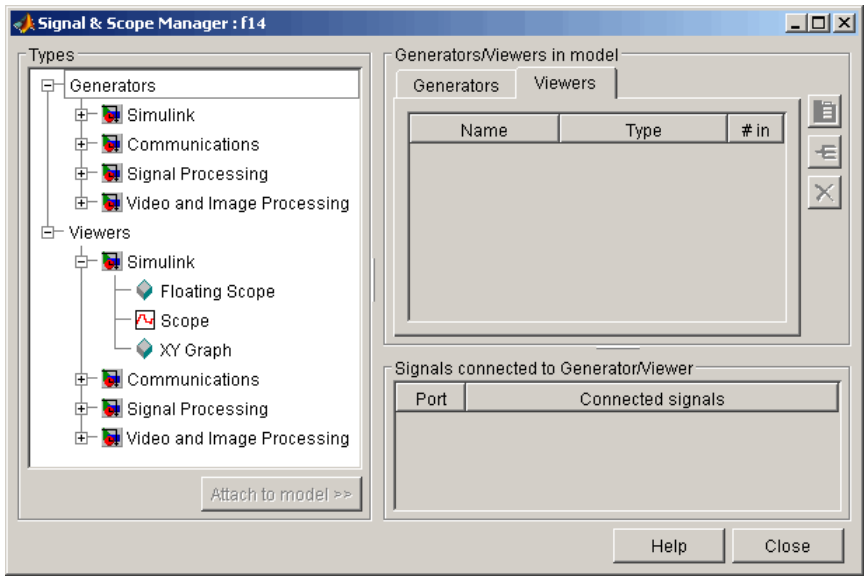


Displaying the Signal and Scope Manager User Interface

Access the Signal and Scope Manager from the model editor's **Tools** menu.

Alternatively, right click within your model and select **Signal & Scope Manager** from the context menu.

Understanding the Signal and Scope Manager User Interface



The Signal and Scope manager user interface is comprised of three panes:

- **Types**. Selects the viewer or generator to attach to your model. For more information, see "Types Pane" on page 29-40.
- **Generators/Viewers in model**. Selects signal sources and viewers for your model.

  For more information on sources, see "Generators Tab" on page 29-40.

  For more information on viewers, see "Viewers Tab" on page 29-41.

- **Signals connected to Generator/Viewer**. Manages the connections to the generators and viewers present in your model. For more information, see "Signals Connected to Generator/Viewer Pane" on page 29-43.

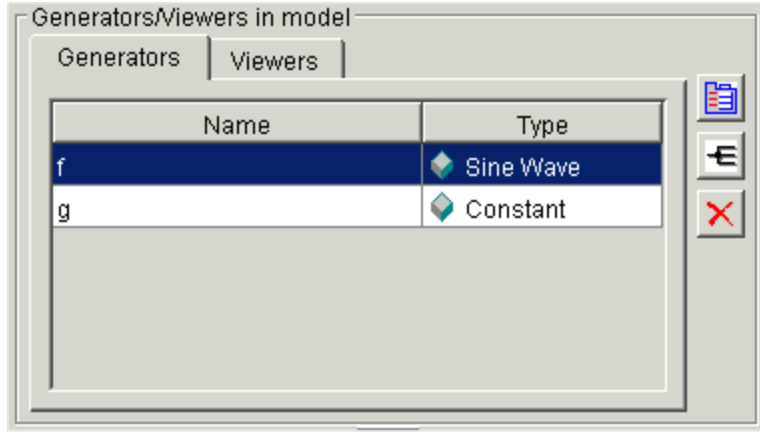
Types Pane

The **Types** pane shows the generators and viewers associated with the products installed on your system. Expand a products node list to show all the generators and viewers available to you.

Note The Simulink Scope displayed in the Signal and Scope Manager Types pane is not the same as the Simulink Scope Block. For an explanation of the differences, see "How Scope Blocks and Signal Viewers Differ" on page 13-3.

Generators Tab

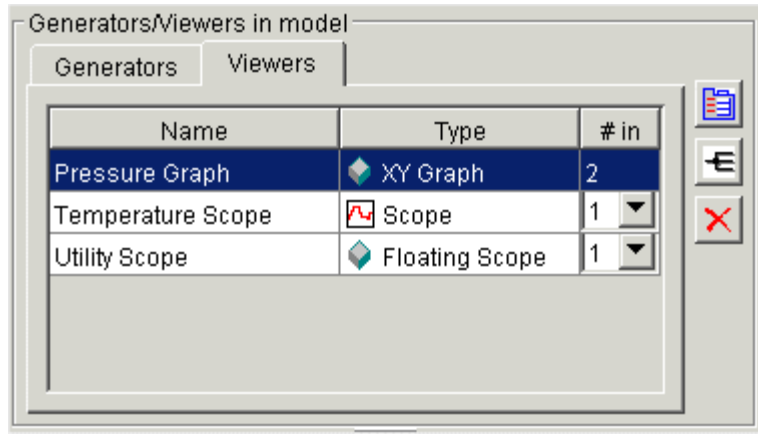
The **Generators** tab displays a table listing the generators associated with your model.



Each row corresponds to a generator. The columns specify each generator's name and type.

Viewers Tab

The **Viewers** tab displays a table listing the viewers present in your model.



Each row corresponds to a viewer. The columns specify each viewer's name, type, and number of inputs. If a viewer accepts a variable number of inputs, the **#in** entry for the viewer contains a pull-down list that displays the range of inputs that the viewer can accept. To change the number of inputs accepted by the viewer, pull down the list and select the desired value.

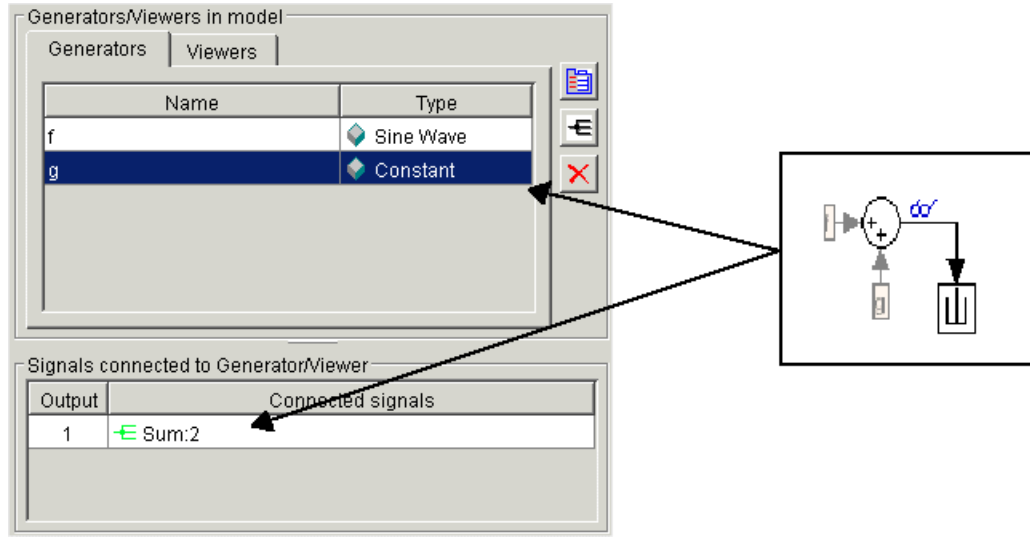
Edit Buttons

Use these buttons to manage generators and viewers after you have selected them in the Generators or Viewers table:

Button	Description
	Opens the parameter dialog box for the selected generator or viewer. From the parameter dialog you view and change object parameters. See "Scope Viewer Parameters Dialog Box" on page 13-13 for more information.
	Opens the Signal Selector for the selected generator or viewer. You use the Signal Selector to connect and disconnect generators and viewers. See "The Signal Selector" on page 29-49 for information on the signal selector.
	Deletes the selected generator or viewer.

Signals Connected to Generator/Viewer Pane

This table lists the signals connected to the generator or viewer selected in the Generators/Viewers control group of the Signal and Scope Manager.



This graphic illustrates the table display when two generators are connected to a sum block. The Viewers display works in the same way.

Clicking on the name of a generator displays the connected signals. For instance, the constant is shown connected to the second input of the sum block.

Connection Menu

Selecting a connection in the **Signals connected to Generator/Viewer** table and pressing the right button on your mouse displays a context menu. From this context menu you can:

- Open the Properties dialog
- Highlight the connections in your block diagram
- Open the Signal Selector

Using the Signal and Scope Manager

In this section...

Introduction

This section shows you how to use the Signal and Scope Manager to perform some basic Viewer and Generator object tasks.

If you are not familiar with the Signal and Scope manager, or Viewer or Generator objects, or if you do not know how to display the Signal and Scope manager, see "Introducing the Signal and Scope Manager" on page 29-38.

To learn how to use and adjust the viewers you have created, see "The Scope Viewer Toolbar" on page 13-12.

Attaching a New Viewer or Generator

To connect a new viewer or generator to a signal in the currently selected model:

1. Display the Signal and Scope manager.
2. Select a viewer or generator from the **Types** pane.
3. Click **Attach to Model**.
4. Click the **Signal Selector** button to display the Signal Selector dialog.

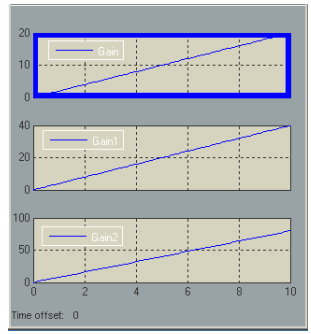
   For more information, see "The Signal Selector" on page 29-49.

5 Select the signals to be displayed by this viewer, and close the dialog.

Tip To display a viewer that has been attached, double click on the viewer of interest in the Viewers pane.

Creating a Multiple Axes Viewer

To create a viewer with more than one axes:



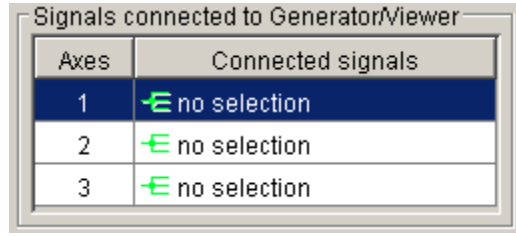
1 Display the Signal and Scope manager.

2 Select a viewer from the **Types** pane.

3 Click **Attach to Model**.

4 Click the `#in` pulldown, and select the total number of axes for the graph.

5 Navigate to the **Signals connected to Generator/Viewer** pane and select **Axes 1**.



6 Click the **Signal Selector** button to display the Signal Selector dialog.

   For more information, see "The Signal Selector" on page 29-49.

7 Select the signals to add to this axis, and close the dialog.

8 Select the next axes, and repeat steps 6 and 7. Continue in this way until signals have been added to all axes.

Tip

- Click on the Scope Viewer icon to display the scope.
- Run the simulation after adding the new signals to make them visible.

Adding Additional Signals to an Existing Viewer

To add signals to a viewer you have already created:

1 Display the Signal and Scope manager.

2 Navigate to the **Viewers** pane, and select the scope to which you will add signals.

3 Click the **Signal Selector** button to display the Signal Selector dialog.

   For more information, see "The Signal Selector" on page 29-49.

4 Select the signals to add to this viewer, and close the dialog.

Tip Run the simulation after adding the new signals to make them visible.

Viewing Test Point Data

You can use the Signal and Scope Manager to view any signal that is defined as a test point in a submodel. A test point is a signal that is guaranteed to be observable when using a signal viewer in a model.

For more information, see “Working with Test Points” on page 29-61 and Chapter 5, “Referencing a Model”.

Adding Custom Viewers and Generators

You can add custom signal viewers or generators so that they appear in the Signal and Scope Manager. The following procedure assumes that you have a custom viewer named `newviewer` that you want to add.

Note If the viewer is a compound viewer, such as a subsystem with multiple blocks, make the top-level subsystem atomic.

---

1. Open a new Simulink library.

   For example, open the Simulink browser and select **File > New > Library**.

2. Save the library.

   For example, save it as `newlib`.

3. In the MATLAB Command Window, set the library type.

   For example, use this command to set the library type of `newviewer` to `viewer`,

   ```
   set_param('newlib','LibraryType','SSMgrViewerLibrary')
   ```

   To set library type for generators, use the type `'SSMgrGenLibrary'` as in this example:

   ```
   set_param('newlib','LibraryType','SSMgrGenLibrary')
   ```

4. Set the display name of the library, as in this example:.

   ```
   set_param('newlib','SSMgrDisplayString','My Custom Library')
   ```

5. Add the viewer or generator to the library.

6. Set the `iotype` of the viewer, as in this example:

```
set_param('newlib/newviewer','iotype','viewer')
```

7. Save the library `newlib`.

   Select **File > Save**.

8. Using the MATLAB editor, create a file named `sl_customization.m`. In this file, enter a directive to incorporate the new library as a viewer library.

   For example, to save `newlib` as a viewer library, add the following lines:

   ```
   function sl_customization(cm)
   cm.addSigScopeMgrViewerLibrary('newlib')
   %end function
   ```

   To add a library as a generator library, add a line like the following:

   ```
   cm.addSigScopeMgrGeneratorLibrary('newlib')
   ```

9. Add a corresponding `cm.addSigScope` line for each viewer or generator library you want to add.

10. Save the `sl_customization.m` file on your MATLAB path. Edit this file to add new viewer or generator libraries.

11. To see the new custom libraries, restart MATLAB and start the Signal and Scope Manager.

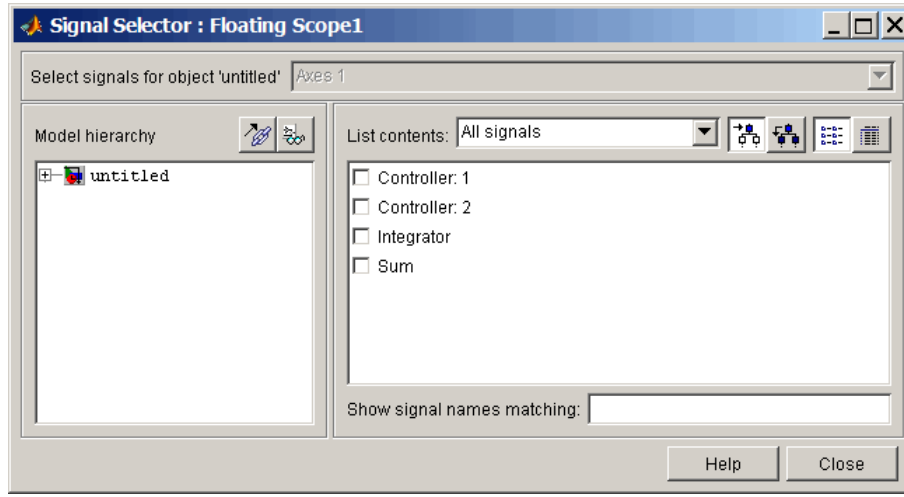
The Signal Selector

In this section...

About the Signal Selector

The Signal Selector allows you to connect a generator or viewer object (see "Introducing the Signal and Scope Manager" on page 29-38) or the Floating Scope to block inputs and outputs. It appears when you click the **Signal selection** button for a generator or viewer object in the Signal & Scope Manager or on the toolbar of the Floating Scope's window.

The Signal Selector that appears when you click the **Signal selection** button applies only to the currently selected generator or viewer object (or the Floating Scope). If you want to connect blocks to another generator or viewer object, you must select the object in the Signal & Scope Manager and launch another instance of the Signal Selector. The object used to launch a particular instance of the Signal Selector is called that instance's owner.



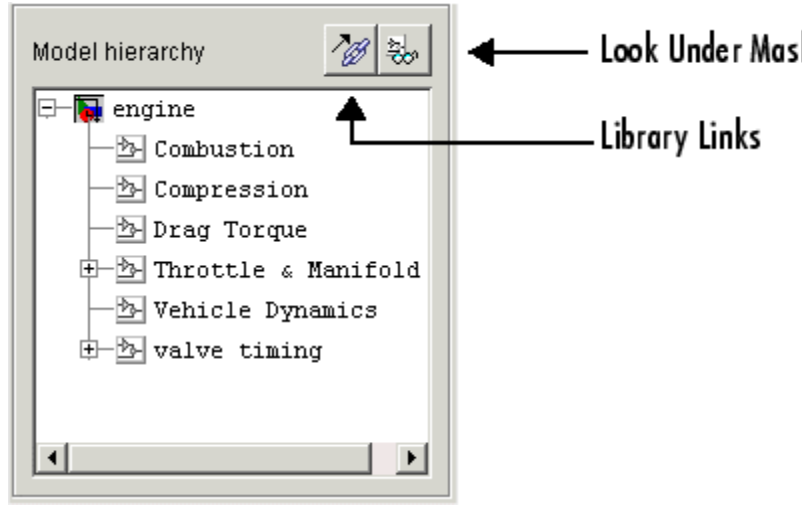
Port/Axis Selector

This list box allows you to select the owner output port (in the case of signal generators) or display axis (in the case of signal viewers) to which you want to connect blocks in your model.

The list box is enabled only if the signal generator has multiple outputs or the signal viewer has multiple axes.

Model Hierarchy

This tree-structured list lets you select any subsystem in your model.

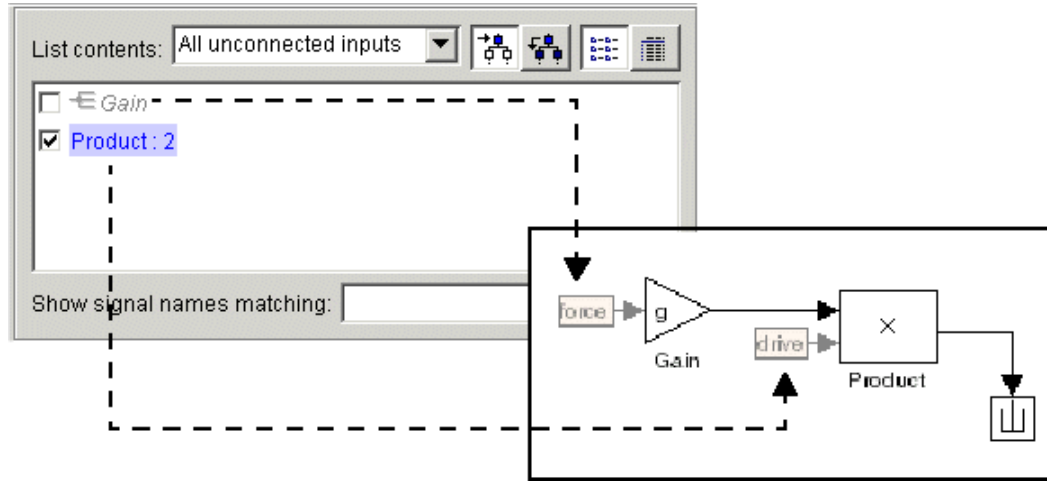


Selecting a subsystem causes the adjacent port list to display the ports available for connection in the selected subsystem. To display subsystems included as library links in your model, click the **Library Links** button at the top of the **Model hierarchy** control. To display subsystems contained by masked subsystems, click the **Look Under Masks** button at the top of the panel.

Inputs/Signals List

The contents of this panel displays input ports available for connection to the Signal Selector's owner if the owner is a signal generator or signals available for connection to the owner if the owner is a signal viewer.

If the Signal Selector's owner is a signal generator, the inputs/signals list by default lists each input port in the system selected in the model hierarchy tree that is either unconnected or connected to a signal generator.



The label for each entry indicates the name of the block of which the port is an input. If the block has more than one input, the label indicates the number of the displayed port. A greyed label indicates that the port is connected to a signal generator other than the Signal Selectors' owner. Selecting the check box next to a port's entry in the list connects the Signal Selector's owner to the port, replacing, if necessary, the signal generator previously connected to the port.

To display more information on each signal, click the **Detailed view** button at the top of the pane. The detailed view shows the path and data type of each signal and whether the signal is a test point. The controls at the top and bottom of the panel let you restrict the amount of information shown in the ports list.

- To show named signals only, select `Named signals only` from the **List contents** control at the top of the pane.
- To show only signals selected in the Signal Selector, select `Selected signals only` from the **List contents** control.

- To show test point signals only, select `Testpointed/Logged signals only` from the **List contents** control.
- To show only signals whose signals match a specified string of characters, enter the characters in the **Show signals matching** control at the bottom of the **Signals** pane and press the **Enter** key.
- To show the selected types of signals for all subsystems below the currently selected subsystem in the model hierarchy, click the **Current and Below** button at the top of the **Signals** pane.

To select or deselect a signal in the **Signals** pane, click its entry or use the arrow keys to move the selection highlight to the signal entry and press the **Enter** key. You can also move the selection highlight to a signal entry by typing the first few characters of its name (enough to uniquely identify it).

Note You can continue to select and deselect signals on the block diagram with the Signal Selector open. For example, shift-clicking a line in the block diagram adds the corresponding signal to the set of signals that you previously selected with the Signal Selector. If the simulation is running when you open and use the Signal Selector, Simulink updates the Signal Selector to reflect signal selection changes you have made on the block diagram. However, the changes do not appear until you select the Signal Selector window itself. You can also use the Signal Selector before running a model. If no simulation is running, selecting a signal in the model does not change the Signal Selector.

Initializing Signals and Discrete States

In this section...

About Initialization

Note For information about initializing bus signals, see "Specifying Initial Conditions for Bus Signals" on page 30-56.

Simulink allows you to specify the initial values of signals and discrete states, i.e., the values of the signals and discrete states at the **Start time** of the simulation. You can use signal objects to specify the initial values of any signal or discrete state in a model. In addition, for some blocks, e.g., Outport, Data Store Memory, or Memory, you can use either a signal object or a block parameter or both to specify the initial value of a block state or output. In such cases, Simulink checks to ensure that the values specified by the signal object and the parameter are consistent.

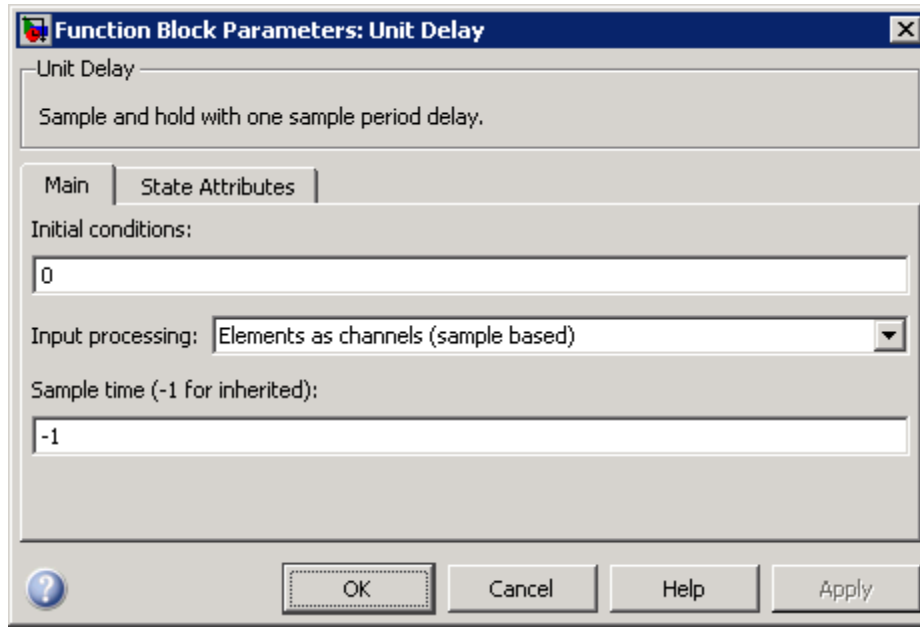
When you specify a signal object for signal or discrete state initialization, or a variable as the value of a block parameter, Simulink resolves the name that you specify to an appropriate object or variable, as described in "Resolving Symbols" on page 3-75.

A given signal can be associated with at most one signal object under any circumstances. The signal can refer to the object more that once, but every

reference must resolve to exactly the same object. A different signal object that has exactly the same properties will not meet the requirement for uniqueness. A compile-time error occurs if a model associates more than one signal object with any signal. For more information, see `Simulink.Signal` and the Merge block.

Using Block Parameters to Initialize Signals and Discrete States

For blocks that have an initial value or initial condition parameter, you can use that parameter to initialize a signal. For example, the following Block Parameters dialog box initializes the signal for a Unit Delay block with an initial condition of 0.



Using Signal Objects to Initialize Signals and Discrete States

To use a signal object to specify an initial value:

1 Create the signal object in the MATLAB workspace, as explained in "Working with Data Objects" on page 25-37.

   The name of the signal object must be the same as the name of the signal or discrete state that the object is initializing.

Note Consider also setting the **Signal name must resolve to Simulink signal object** option in the Signal Properties dialog box. This setting ensures consistency between signal objects in the MATLAB workspace and the signals that appear in your model.

---

2 Set the signal object's storage class to a value other than `'Auto'` or `'SimulinkGlobal'`.

3 Set the signal object's `Initial value` property to the initial value of the signal or state. For details on what you can specify, see the description of `Simulink.Signal`.

   If you can also use a block parameter to set the initial value of the signal or state, you should set the parameter either to null (`[]`) or to the same value as the initial value of the signal object. If you set the parameter value to null, Simulink uses the value specified by the signal object to initialize the signal or state. If you set the parameter to any other value, Simulink compares the parameter value to the signal object value and displays an error if they differ.

Using Signal Objects to Tune Initial Values

Simulink allows you to use signal objects as an alternative to parameter objects (see `Simulink.Parameter` class in the Simulink online reference) to tune the initial values of block outputs and states that can be specified via a tunable parameter. To use a signal object to tune an initial value, create a signal object with the same name as the signal or state and set the signal object's initial value to an expression that includes a variable defined in the MATLAB workspace. You can then tune the initial value by changing the value of the corresponding workspace variable during the simulation.

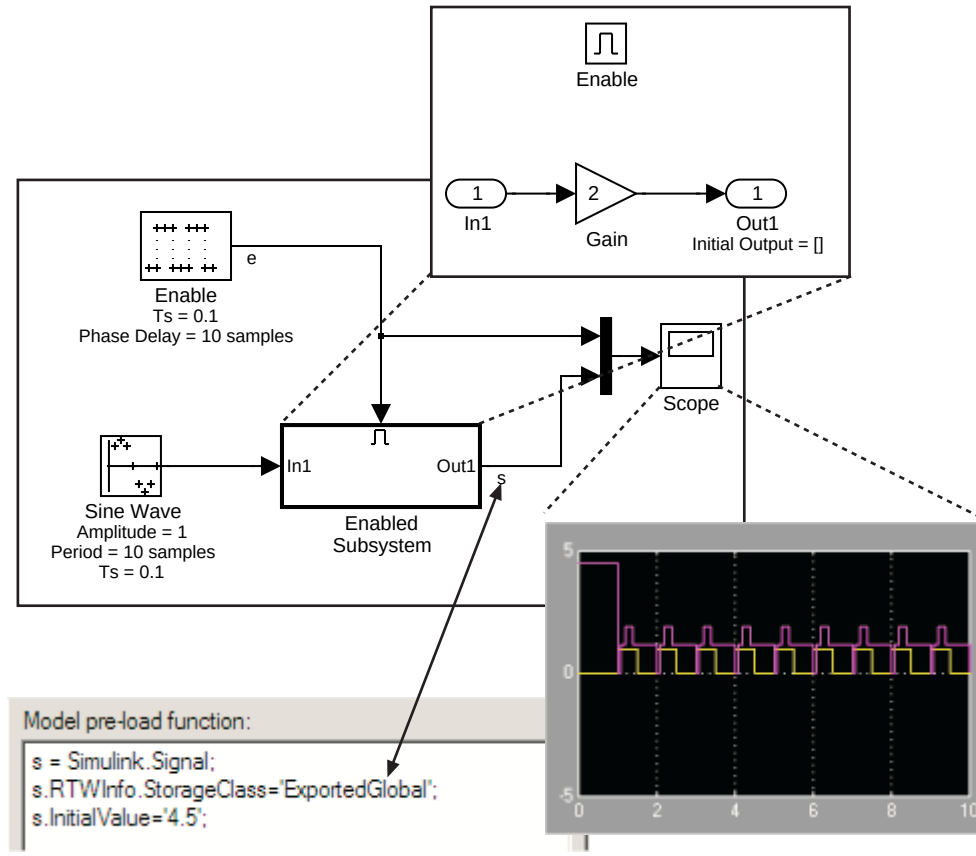
For example, suppose you want to tune the initial value of a Memory block state named `M1`. To do this, you might create a signal object named

`M1`, set its storage class to `'ExportedGlobal'`, set its initial value to `K` (`M1.InitialValue='K'`), where `K` is a workspace variable in the MATLAB workspace, and set the corresponding initial condition parameter of the Memory block to `[]` to avoid consistency errors. You could then change the initial value of the Memory block's state any time during the simulation by changing the value of `K` at the MATLAB command line and updating the block diagram (e.g., by typing **Ctrl+D**).

Note To be tunable via a signal object, a signal or state's corresponding initial condition parameter must be tunable, e.g., the inline parameter optimization for the model containing the signal or state must be off or the parameter must be declared tunable in the Model Parameter Configuration dialog box. For more information, see "Tunable Parameters" on page 2-9 and "Using Tunable Parameters" on page 19-13.

Example: Using a Signal Object to Initialize a Subsystem Output

The following example shows a signal object specifying the initial output of an enabled subsystem.

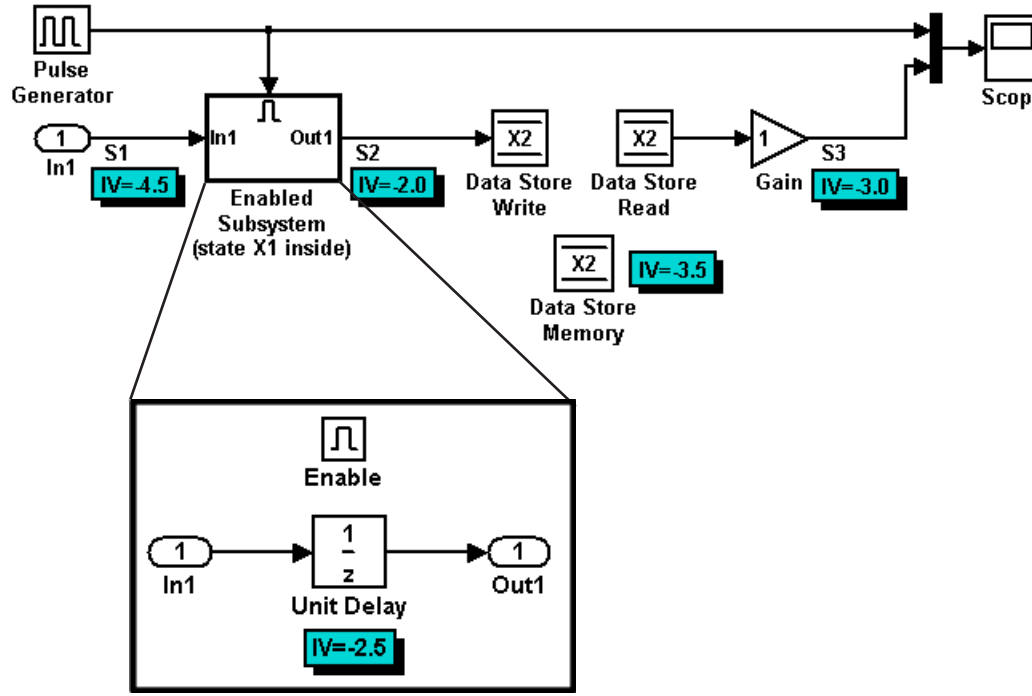


Signal `s` is initialized to 4.5. To avoid a consistency error, the initial value of the enabled subsystem's Outport block must be `[ ]` or 4.5.

If you need a signal object and its initial value setting to persist across Simulink sessions, see "Creating Persistent Data Objects" on page 25-47.

Initialization Behavior Summary for Signal Objects

The following model and table show different types of signals and discrete states that you can initialize and the simulation behavior that results for each.



Signal or Discrete State	Description	Behavior
S1	Root inport	• Initialized to `S1.InitialValue`. • If you use the **Data Import/Export** pane of the Configuration Parameters dialog to specify values for the root inputs, the initial value is overwritten and may differ at each time step. Otherwise, the value remains constant.
X1	Unit Delay block — Block with a discrete	• Initialized to `X1.InitialValue`. • Simulink checks whether `X1.InitialValue` matches the initial condition specified for the block and displays an error if a mismatch occurs.

Signal or Discrete State	Description	Behavior
	state that has an initial condition	• At first write, the output equals `X1.InitialValue` and the state equals `S1`. • At each time step after the first write, the output equals the state and the state is updated to equal `S1`. • If the block is inside an enabled subsystem, you can use the initial value as a reset value if the subsystem's Enable block parameter **States when enabling** is set to `reset`.
X2	Data Store Memory block	• Data type work (DWork) vector initialized to `X2.InitialValue`. For information on work vectors, see "Using Work Vectors" in Writing S-Functions. • Simulink checks whether `X2.InitialValue` matches the initial condition specified for the block, and displays an error if a mismatch occurs. • Data Store Write blocks overwrite the value.
S2	Output of an enabled subsystem	• Initialized to `S2.InitialValue` or the value of the Outport block. If multiple initial values are specified for the same signal, all initial values must be the same. • The first write occurs when the subsystem is enabled. The block feeding the subsystem output sets the value. • The initial value is also used as a reset value if the subsystem's Enable block parameter **States when enabling** or Outport block parameter **Output when disabled** is set to `reset`.
S3	Persistent signals	• Initialized to `S3.InitialValue`. • The output value is reset by the block at each time step. • Affects code generation only. For simulation, setting the initial value for `S3` is irrelevant because the values are overwritten at the model's simulation start time.

Working with Test Points

In this section...

What Is a Test Point?

A *test point* is a signal that Simulink guarantees to be observable when using a Floating Scope block in a model. Simulink allows you to designate any signal in a model as a test point.

Designating a signal as a test point exempts the signal from model optimizations, such as signal storage reuse (see "Signal storage reuse") and block reduction (see "Implement logic signals as Boolean data (vs. double)"). These optimizations render signals inaccessible and hence unobservable during simulation.

Signals designated as test points will not have algebraic loops minimized, even if **Minimize algebraic loop occurrences** is selected (for more information about algebraic loops, see "Algebraic Loops" on page 2-39).

Test points are primarily intended for use when generating code from a model with Real-Time Workshop. For more information about test points in the context of code generation, see "Signals with Test Points" in the Real-Time Workshop documentation.

Designating a Signal as a Test Point

To specify that a signal whose storage class is `Auto` is a test point, open the signal's **Signal Properties** dialog box and select **Logging and accessibility > Test point**. The signal is now a test point. Selecting or clearing this option has no effect unless the signal's storage class is Auto.

Any signal whose storage class is not `Auto` is automatically a test point, regardless of the setting of **Signal Properties > Logging and accessibility > Test point**. You can specify a non-`Auto` signal storage class in three ways:

- Set **Signal Properties > Real-time Workshop > Storage class** to anything other than `Auto`.
- Resolve the signal to a base workspace `Simulink.Signal` object that specifies a storage class other than `Auto`.
- Embed a signal object that specifies a storage class other than `Auto` on the port where the signal originates.

Using a base workspace signal object to specify that a signal is a test point can be convenient, because it allows you to control testpointing without having to change the model itself. Assigning storage class `SimulinkGlobal` has exactly the same effect as assigning storage class Auto and selecting **Signal Properties > Logging and accessibility > Test point**.

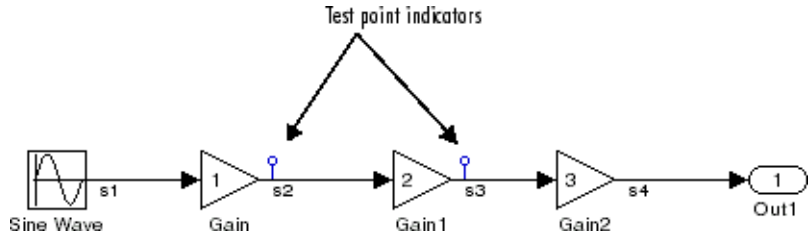
See "Signal Properties Dialog Box" for more information about specifying signal properties.

Test Points in Referenced Models that Use Library Blocks

If you set the test point property of a signal in a library block that is referenced by a model that is itself referenced by another model, you must update the referenced model containing the test pointed signal by opening and saving it. Otherwise, Simulink will be unable to log or display the referenced signal.

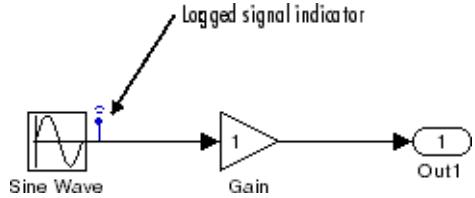
Displaying Test Point Indicators

By default, Simulink displays an indicator on each signal whose **Signal Properties > Test point** option is enabled. For example, in the following model signals `s2` and `s3` are test points:



Note Simulink does not display an indicator on a signal that is specified as a test point by a `Simulink.Signal` object, because such a specification is external to the graphical model.

A signal that is a test point can also be logged. See Chapter 27, "Importing and Exporting Data" for information about signal logging. The appearance of the indicator changes to indicate signals for which logging is also enabled.



To turn display of test point indicators on or off, select or clear **Port/Signal Displays > Testpoint/Logging Indicators** from the Simulink **Format** menu.

Displaying Signal Properties

In this section...

Port/Signal Displays Menu

The **Format >Port/Signal Displays** submenu of the model window offers the following options for displaying signal properties on the block diagram:

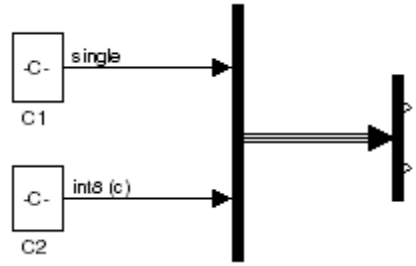
- Linearization Indicators
- Port Data Types (See "Port Data Types" on page 29-65)
- Signal Dimensions (See "Signal Dimensions" on page 29-65)
- Storage Class
- Testpoint/Logging Indicators
- Signal Resolution Indicators (See "Signal Resolution Indicators" on page 29-66)
- Viewer Indicators
- Wide Nonscalar Lines (See "Wide Nonscalar Lines" on page 29-67)

In addition, you can display sample time information. If you first select **Format > Sample Time Display**, a submenu provides the choices of **Colors**, **Annotations** and **All**. The **Colors** option allows the block diagram signal lines and blocks to be color-coded based on the sample time types and relative rates. The **Annotations** option provides black codes on the signal lines which indicate the type of sample time. **All** causes both the colors and the annotations to display. All of these options cause a Sample Time Legend to appear. The legend contains a description of the type of sample time and the

sample time rate. If **Colors** is turned 'on', color codes also appear in the legend. The same is true if **Annotations** are turned 'on'.

Port Data Types

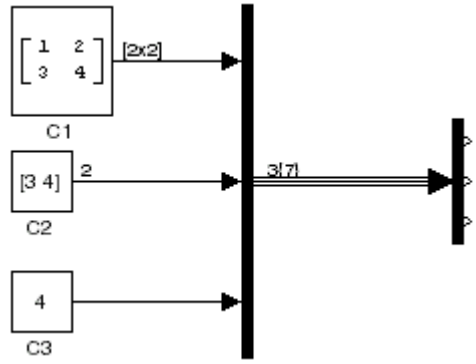
Displays the data type of a signal next to the output port that emits the signal.



The notation `(c)` following the data type of a signal indicates that the signal is complex.

Signal Dimensions

Display the dimensions of nonscalar signals next to the line that carries the signal.



The format of the display depends on whether the line represents a single signal or a bus. If the line represents a single vector signal, Simulink displays

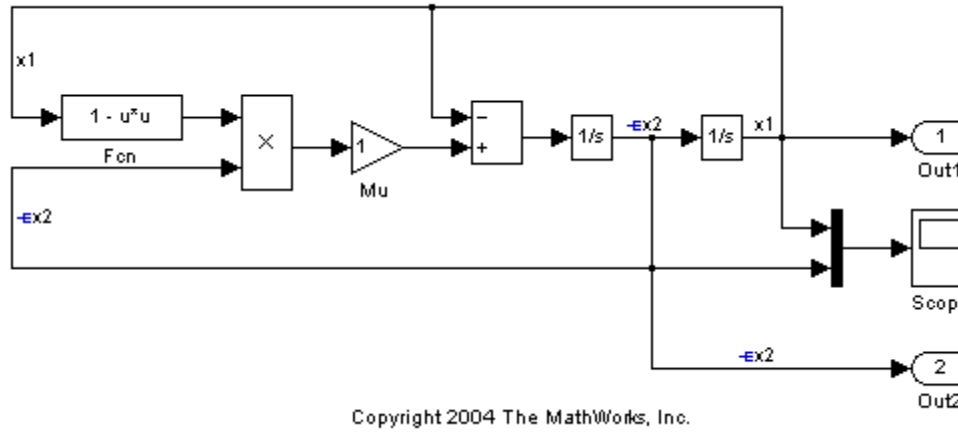
the width of the signal. If the line represents a single matrix signal, Simulink displays its dimensions as `[N1xN2]` where N_i is the size of the `i`th dimension of the signal. If the line represents a bus carrying signals of the same data type, Simulink displays `N{M}` where `N` is the number of signals carried by the bus and `M` is the total number of signal elements carried by the bus. If the bus carries signals of different data types, Simulink displays only the total number of signal elements `{M}`.

Signal Resolution Indicators

The Simulink Editor by default graphically indicates signals that must resolve to signal objects. For any labeled signal whose **Signal name must resolve to signal object** property is enabled, a signal resolution icon appears to the left of the signal name. The icon looks like this:

A signal resolution icon indicates only that a signal's **Signal name must resolve to signal object** property is enabled. The icon does not indicate whether the signal is actually resolved, and does not appear on a signal that is implicitly resolved without its **Signal name must resolve to signal object** property being enabled.

Where multiple labels exist, each label displays a signal resolution icon. No icon appears on an unlabeled branch. In the next figure, signal `x2` must resolve to a signal object, so a signal resolution icon appears to the left of the signal name in each label:

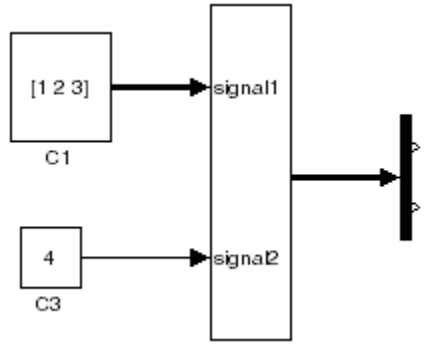


To suppress the display of signal resolution icons, in the model window deselect **Format > Port/Signal Displays > Signal Resolution Indicators**, which is selected by default. To restore signal resolution icons, reselect **Signal Resolution Indicators**. Individual signals cannot be set to show or hide signal resolution indicators independently of the setting for the whole model. For additional information, see:

- "Resolving Symbols" on page 3-75
- "Initializing Signals and Discrete States" on page 29-54
- Simulink.Signal

Wide Nonscalar Lines

Draws lines that carry vector or matrix signals wider than lines that carry scalar signals.



See Chapter 30, “Using Composite Signals” for more information about vector and matrix signals.

Working with Signal Groups

In this section...

About Signal Groups

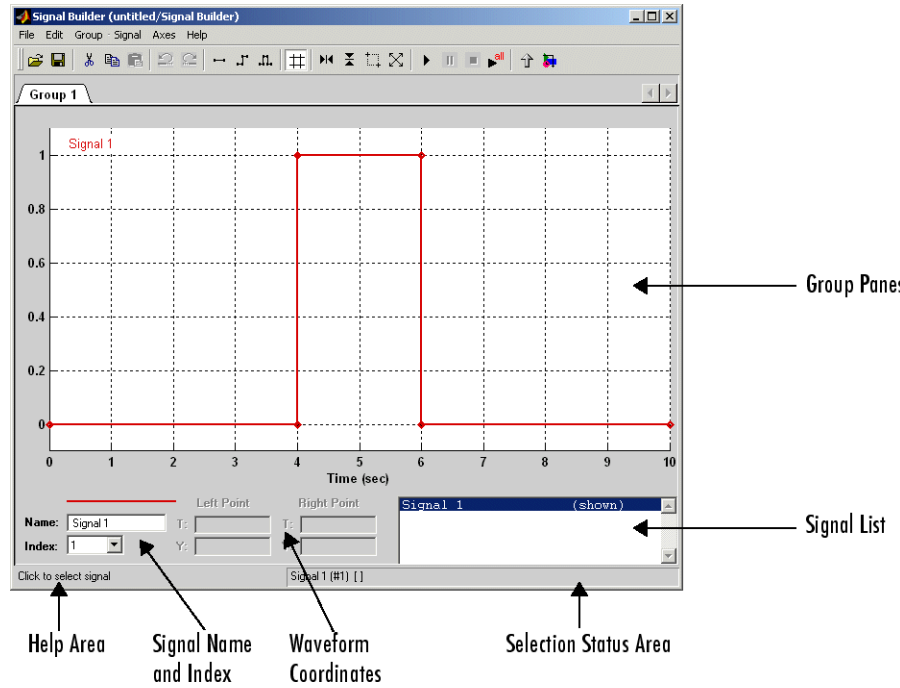
The Signal Builder block displays and allows you to create or edit interchangeable groups of signal sources and quickly switch the groups into and out of a model.

Signal groups can greatly facilitate testing a model, especially when you use them with conjunction with Simulink Assertion blocks and the Model Coverage Tool from the Simulink Verification and Validation. For a description of the Model Coverage Tool, see the "Simulink Verification and Validation User's Guide" on the MathWorks Web site (`www.mathworks.com`).

Signal Builder Window

The Signal Builder block window allows you to define the shape of the signals (waveform) output by the block. You can specify any waveform that is piecewise linear.

To open the window, double-click the block. The Signal Builder window appears.



The Signal Builder window allows you to create and modify signal groups represented by a Signal Builder block. The Signal Builder window includes the following controls.

Group Pane

Displays the set of interchangeable signal source groups represented by the block. The pane for each group displays an editable representation of each waveform in the group. The name of the group appears on the pane tab. Only one pane is visible at a time. To display a group that is not visible, select the tab that shows its name. The block outputs the group of signals whose pane is currently visible. Each pane occupies a tab in the Signal Builder block dialog box.

Signal Axes

The signals appear on separate axes that share a common time range (see "Signal Builder Time Range" on page 29-108). This presentation allows you to compare the relative timing of changes in each signal. The Signal Builder automatically scales the range of each axis to accommodate the signal that it displays. Use the Signal Builder **Axes** menu to change the time (T) and amplitude (Y) ranges of the selected axis.

Signal List

Displays the names and visibility (see "Editing Signals" on page 29-72) of the signals that belong to the currently selected signal group. Clicking an entry in the list selects the signal. Double-clicking a signal entry in the list hides or displays the waveform on the group pane.

Selection Status Area

Displays the name of the currently selected signal and the index of the currently selected waveform segment or point.

Waveform Coordinates

Displays the coordinates of the currently selected waveform segment or point. You can change the coordinates by editing the displayed values (see "Editing Waveforms" on page 29-102).

Name

Name of the currently selected signal. You can change the name of a signal by editing this field (see "Renaming a Signal" on page 29-74).

Index

Index of the currently selected signal. The index indicates the output port at which the signal appears. An index of 1 indicates the topmost output port, 2 indicates the second port from the top, and so on. You can change the index of a signal by editing this field (see "Changing a Signal Index" on page 29-74).

Help Area

Displays context-sensitive tips on using Signal Builder window features.

Editing Signal Groups

The Signal Builder window allows you to create, rename, move, and delete signal groups from the set of groups represented by a Signal Builder block.

Creating and Deleting Signal Groups. To create a signal group, copy an existing signal group and then modify it to suit your needs. To copy an existing signal group, select its tab and then select **Copy** from the Signal Builder **Group** menu. To delete a group, select its tab and then select **Delete** from the **Group** menu.

Renaming Signal Groups. To rename a signal group, select the group tab and then select **Rename** from the Signal Builder **Group** menu. A dialog box appears. Edit the existing name in the dialog box or enter a new name. Click **OK**.

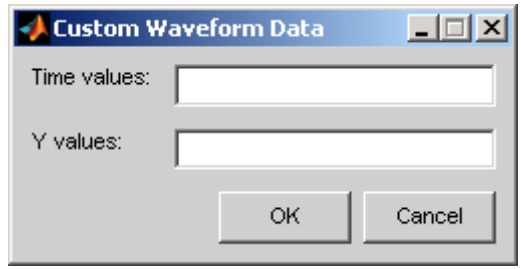
Moving Signal Groups. To reposition a group in the stack of group panes, select the pane and then select **Move Right** from the Signal Builder **Group** menu to move the group lower in the stack or **Move Left** to move the pane higher in the stack.

Editing Signals

The Signal Builder window allows you to create, cut and paste, hide, and delete signals from signal groups.

Creating Signals. To create a signal in the currently selected signal group, select **New** from the Signal Builder **Signal** menu. A menu of waveforms appears. The menu includes a set of standard waveforms (**Constant**, **Step**, and so on) and a **Custom** waveform option. Select one of the waveforms. If you select a standard waveform, the Signal Builder adds a signal with that waveform to the currently selected group.

If you select **Custom**, a custom waveform dialog box appears.



The dialog box allows you to add a custom piecewise linear waveform to the groups defined by the Signal Builder block. Enter the custom waveform time coordinates in the **Time values** field and the corresponding signal amplitudes in the **Y values** field. The entries in either field can be any MATLAB expression that evaluates to a vector. The resulting vectors must be of equal length. Click **OK**. The Signal Builder adds a signal having the specified shape to the currently selected group.

Copying and Pasting Signals. To copy a signal from one group and paste it into another group as a new signal:

1. Select the signal you want to copy.
2. Select **Copy** from the Signal Builder **Edit** menu or click the corresponding button on the toolbar.
3. Select the group into which you want to paste the signal.
4. Select **Paste** from the Signal Builder **Edit** menu or click the corresponding button on the toolbar.

To copy a signal from one axis and paste it into another axis to replace its signal:

1. Select the signal you want to copy.
2. Select **Copy** from the Signal Builder **Edit** menu or click the corresponding button on the toolbar.

3 Select the signal on the axes that you want to replace.

4 Select **Paste** from the Signal Builder **Edit** menu or click the corresponding button on the toolbar.

Deleting Signals. To delete a signal, select the signal and choose **Delete** or **Cut** from the Signal Builder **Edit** menu. As a result, Signal Builder deletes the signal from the current group. Because each signal group must contain the same number of signals, Signal Builder also deletes all signals sharing the same index in the other groups.

Renaming a Signal. To rename a signal, select the signal and choose **Rename** from the Signal Builder **Signal** menu. A dialog box appears with an edit field that displays the current name of the signal. Edit or replace the current name with a new name. Click **OK**. Or edit the signal name in the **Name** field in the lower-left corner of the Signal Builder window.

Changing a Signal Index. To change a signal index, select the signal and choose **Change Index** from the Signal Builder **Signal** menu. A dialog box appears with an edit field containing the existing index of the signal. Edit the field and select **OK**. Or select an index from the **Index** list in the lower-left corner of the Signal Builder window.

Hiding Signals. By default, the Signal Builder window displays the group waveforms in the group pane. To hide a waveform, select the waveform and then select **Hide** from the Signal Builder **Signal** menu. To redisplay a hidden waveform, select the **Group** pane, then select **Show** from the Signal Builder **Signal** menu to display a menu of hidden signals. Select the signal from the menu. Alternatively, you can hide and redisplay a hidden waveform by double-clicking its name in the Signal Builder signal list (see "Signal List" on page 29-71).

Creating Signal Group Sets

You can create signal groups in the Signal Builder block by:

- "Creating Signal Group Sets Manually" on page 29-75
- "Importing Signal Group Sets" on page 29-76

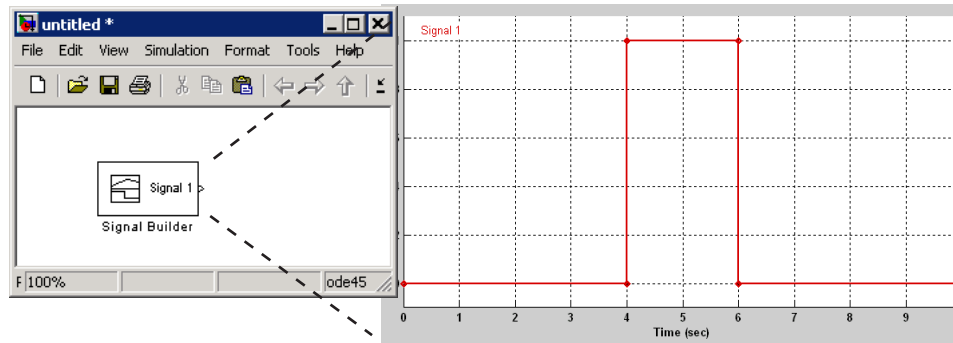
You can also use the `signalbuilder` function to populate the Signal Builder block.

Creating Signal Group Sets Manually

This topic describes how to create signal group sets manually. If you have signal data files, such as those from test cases, consider importing this data as described in "Importing Signal Group Sets" on page 29-76.

To create an interchangeable set of signal groups:

1. Drag an instance of the Signal Builder block from the Simulink Sources library and drop it into your model.



   By default, the block represents a single signal group containing a single signal source that outputs a square wave pulse.

2. Use the block signal editor (see "Signal Builder Window" on page 29-69) to create additional signal groups, add signals to the signal groups, modify existing signals and signal groups, and select the signal group that the block outputs.

   Note Each signal group must contain the same number of signals.

3. Connect the output of the block to your diagram.

   The block displays an output port for each signal that the block can output.

You can create as many Signal Builder blocks as you like in a model, each representing a distinct set of interchangeable groups of signal sources. When a group has multiple signals, the signals might have different end times. However, Signal Builder block requires the end times of signals within a group to match. If a mismatch occurs, Signal Builder block matches the end times by holding the last value of the signal with the smaller end time.

See "Simulating with Signal Groups" on page 29-110 for information on using signal groups in a model.

Importing Signal Group Sets

The topics in this section describe how to import signal data into the Signal Builder block. You should already have a signal data file whose contents you want to import. For example, you might have signal data from previously run test cases. See "Importing Signal Groups from Existing Data Sets" on page 29-76 for a description of the data formats that the Signal Builder block accepts. The procedures in the following topics use the file *matlabroot*`\help\toolbox\simulink\ug\examples\signals\3Grp_3Sig.xls`.

See "Completing a Basic Simulation Workflow" in the *Simulink Getting Started Guide* for a description of the Signal Builder block in a simulation workflow.

Importing Signal Groups from Existing Data Sets. You might have existing signal data sets that you want to enter into the Signal Builder block. The **File > Import from File** command on the Signal Builder window starts the Import File dialog box. This dialog box is modal, which means that focus cannot change to another MATLAB window while the dialog box is running. If you want to see changes in the Signal Builder window after you import data, do one of the following:

- Close the Import File dialog box.
- Set up the Import File dialog box and Signal Builder window side by side.

Note You cannot undo the results of importing a signal data file. In addition, you cannot undo the last action performed before opening the Import File dialog box. When you close the Import File dialog box, the **Undo last edit** and **Redo last edit** buttons on the Signal Builder window are grayed out. These buttons are grayed out regardless of whether you imported a data file.

The Import File dialog box accepts the following appropriately formatted file types:

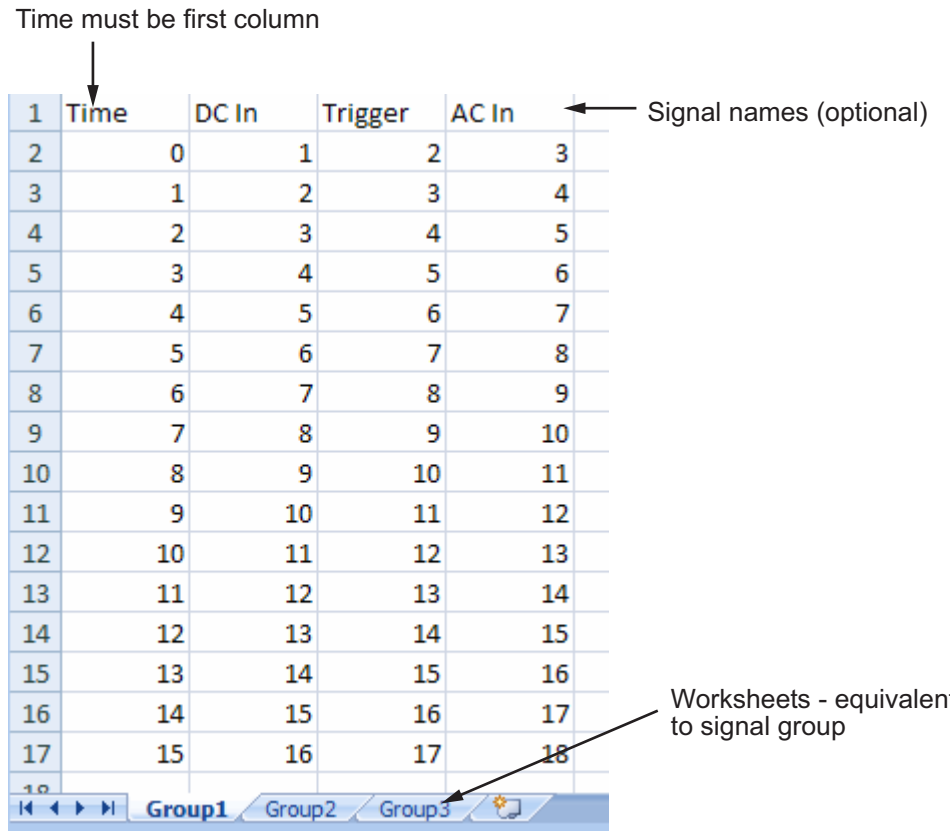
- Microsoft Excel (`.xls`, `.xlsx`)
- Comma-separated value (CSV) text files (`.csv`)
- MAT-files (`.mat`)

You can import your data set file only if it is appropriately formatted.

For Microsoft Excel spreadsheets:

- The Signal Builder block interprets the first row as signal name. If you do not specify a signal name, the Signal Builder block assigns a default one with the format `Imported_Signal #`, where # increments with each additional unnamed signal.
- The Signal Builder block interprets the first column as time. In this column, the time values must increase.
- The Signal Builder block interprets the remaining columns as signals.
- If there are multiple sheets:
  - Each sheet must have the same number of signals (columns).
  - Each sheet must have the same set of signal names (if any).
  - Each column on each sheet must have the same number of rows.
- Signal Builder block interprets each worksheet as a signal group.
- Linux® and Mac OS® X platforms support only Microsoft Excel 97–2003 Workbook (`*.xls`) formats.

This example contains an acceptably formatted Microsoft Excel spreadsheet. It has three worksheets named Group1, Group2, and Group3, representing three signal groups.



	Time	DC In	Trigger	AC In
2	0	1	2	3
3	1	2	3	4
4	2	3	4	5
5	3	4	5	6
6	4	5	6	7
7	5	6	7	8
8	6	7	8	9
9	7	8	9	10
10	8	9	10	11
11	9	10	11	12
12	10	11	12	13
13	11	12	13	14
14	12	13	14	15
15	13	14	15	16
16	14	15	16	17
17	15	16	17	18

For CSV text files:

- Each file contains only numbers. Do not name signals in a CSV file.
- The Signal Builder block interprets the first column as time. In this column, the time values must increase.
- The Signal Builder block interprets the remaining columns as signals.
- Each column must have the same number of entries.

- The Signal Builder block interprets each file as one signal group.
- The Signal Builder block assigns a default signal name to each signal with the format `Imported_Signal #`, where # increments with each additional signal.

This example contains an acceptably formatted CSV file. The contents represent one signal group.

```
0,0,0,5,0
1,0,1,5,0
2,0,1,5,0
3,0,1,5,0
4,5,1,5,0
5,5,1,5,0
6,5,1,5,0
7,0,1,5,0
8,0,1,5,1
9,0,1,5,1
10,0,1,5,0
```

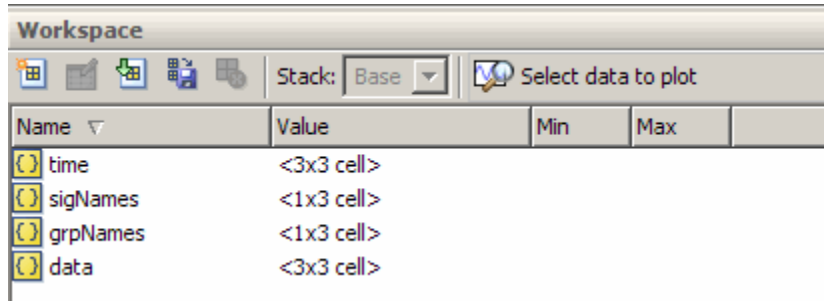
For MAT-files:

- The Signal Builder block supports logged data from the `Simulink.ModelDataLogs` object and interprets this data as a single group.
- The Signal Builder block supports data store logging that the `Simulink.SimulationData.Dataset` object represents and interprets this data as a single group.
- The Signal Builder block supports Simulink output saved as a structure with time.
- The Signal Builder block supports the Signal Builder data format. This format is a group of cell arrays that must be labeled:
  - `time`
  - `data`
  - `sigName`
  - `groupName`

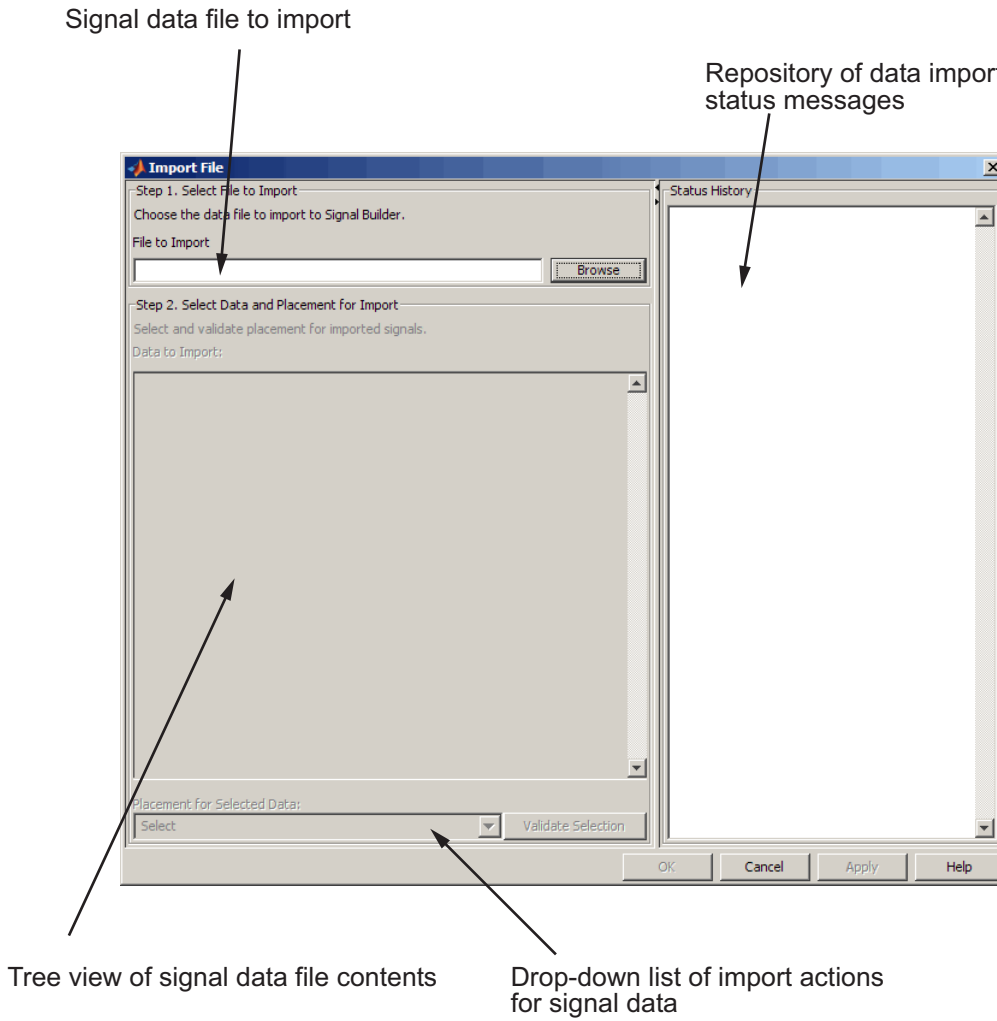
  `sigName` and `groupName` are optional.

- Signal Builder block does not support:
  - Simulink output as only a structure
  - Simulink output as only an array

This example contains an acceptably logged MATLAB workspace. Use the MATLAB workspace **Save** command to save the variables to a MAT-file. Import this file to the Signal Builder block.



Signal Builder Block Import File Dialog Box. The Signal Builder Import File dialog box allows you to import existing signal data files into the Signal Builder block.



Replacing All Signal Data with Selected Data. Simulink software creates a default Signal Builder block with one signal. To replace this signal and all other signal data that the block might display:

1. Create a model and drag a Signal Builder block into that model.
2. Double-click the block.

The Signal Builder window appears with its default Signal 1.

3 In the Signal Builder window, select **File > Import from File**.

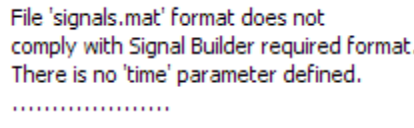
The Import File dialog box appears.

4 In the **File to Import** field, enter a signal data file name or click **Browse**.

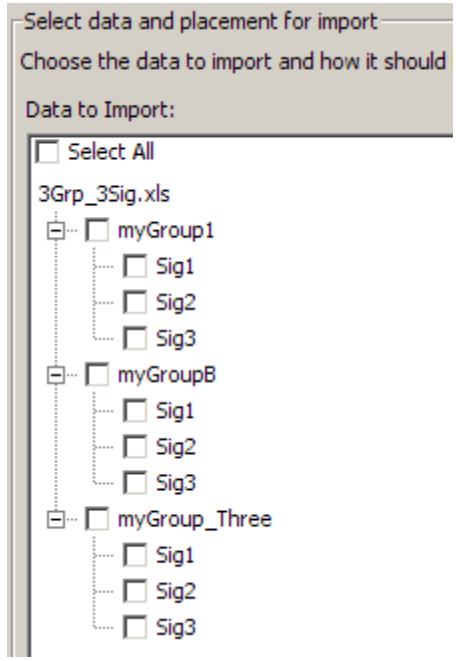
The file browser appears.

5 If you select the file browser, navigate to and select a signal data file. For example, select `3Grp_3Sig.xls`.

Note If you try to import an improperly formatted data file, an error message pops up. When you click to dismiss this window, the **Status History** pane displays a more detailed error message (if there is one). For example:



The **Data to Import** pane contains the signal data from the file. Click the expander to display all the signals.



6 Select the signals you want to import. To import all the signals, click **Select All**.

7 From the **Placement for Selected Data** list, select the action to take on the signal data. For example, select `Replace existing dataset`.

The **Confirm Selection** button is activated. Validate your signal selection before the Signal Builder block performs the specified action. If the signal data selection is not appropriate, **Confirm Selection** remains grayed out. For example, **Confirm Selection** remains grayed out if the number of signals you select is not the same as the number of signals in the Signal Builder group that you want to replace.

8 Click the **Confirm Selection** button.

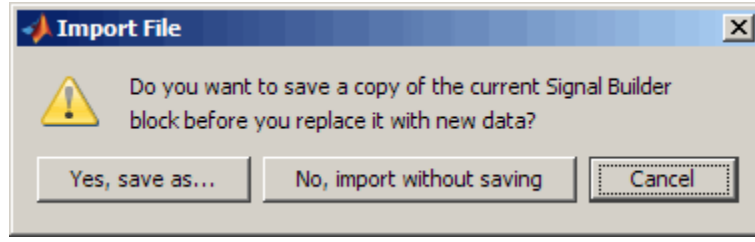
If the requested action is a valid one, the Status History pane displays messages to indicate the status. For example:

```
Current data in Signal Builder will be replaced
by new data.
Number of groups: 3
Group name(s):
  myGroup1
  myGroupB
  myGroup_Three

Number of signals per group: 3
Signal name(s):
  Sig1
  Sig2
  Sig3


 (Names may have been renamed for uniqueness.)
 ......................
```

The confirmation also enables the **OK** and **Apply** buttons.

9 If you are satisfied with the status message, click **Apply** to replace the existing signal data with the contents of this file.

When using the `Replace existing dataset` command, the software gives you the opportunity to save the existing contents of the Signal Builder block.

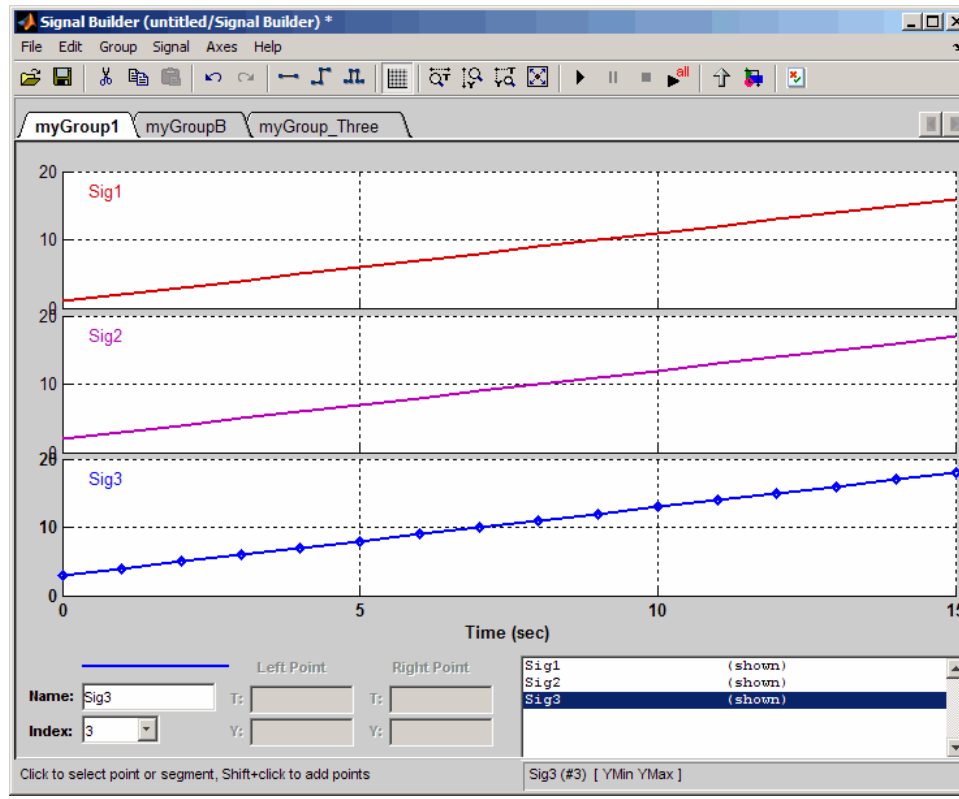


10 Click a button, as follows:

To...	Click...
Save the contents of the Signal Builder block before replacing it with the new signal data. **Note** This selection prompts you to save the Signal Builder block in a model name of your choice. The software saves only the Signal Builder block and no other model content.	**Yes, save as**
Replace the contents of the Signal Builder block without saving them first.	**No, import without saving**
Stop the replacement process.	**Cancel**

For this example, select **No, import without saving** to replace the contents of the Signal Builder block.

11 The Signal Builder block updates with the new signal data. Click **OK** to close the Import File dialog box and inspect the Signal Builder block.



12 Click **OK**.

13 Inspect the updated Signal Builder window to confirm that your signal data is intact.

14 Close the Signal Builder window and save and close the model. For example, save the model as `signalbuilder1.mdl`.

Appending Selected Signals to All Existing Signal Groups. You can import signals from a signal data file and append selected signals to the end of all existing signal groups. If the signal names to be appended are not unique, the software renames them by incrementing each name by 1 or higher until it is a unique signal name. For example, if the block and data file contain signals named `thermostat`, the software renames the imported signal to `thermostat1` upon appending. If you add another signal named `thermostat`, the software names that latest version `thermostat2`.

This topic uses `signalbuilder1.mdl` from the procedure in "Replacing All Signal Data with Selected Data" on page 29-81.

1. In the MATLAB Command Window, type `signalbuilder1.mdl`.
2. Double-click the Signal Builder block.

   The Signal Builder window appears.
3. In the Signal Builder window, select **File > Import from File**.

   The Import File dialog box appears.
4. In the **File to Import** field, enter a signal data file name or click **Browse**.

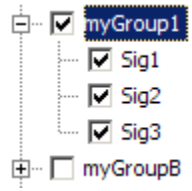
   The file browser is displayed.
5. If you select the file browser, navigate to and select a signal data file. For example, select `3Grp_3Sig.xls`.

Note If you try to import an improperly formatted signal data file, an error message pops up. When you click to dismiss this window, the **Status History** pane displays an error message. For example:

```
File 'signals.mat' format does not
comply with Signal Builder required format.
There is no 'time' parameter defined.
.....................
```

The **Data to Import** pane contains the signal data from the file. Click the expander to display all the signals.

6 Select the signals you want to import. In this example, there are three groups, myGroup1, myGroupB, and myGroup_Three. Select all the signals in myGroup1.

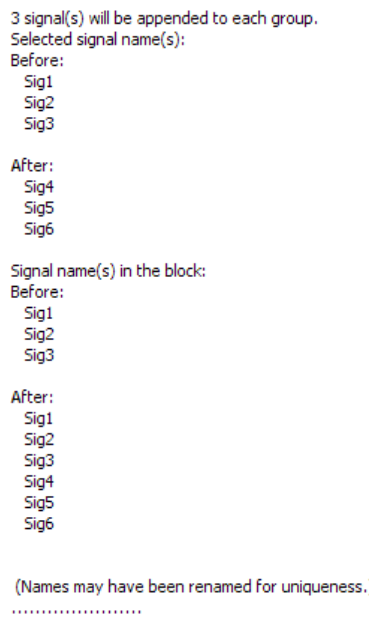


7 From the **Placement for Selected Data** list, select the action to take on the signal data. For example, select `Append selected signals to all groups`.

The **Confirm Selection** button is activated. Validate your signal selection before the Signal Builder block performs the specified action. If the signal data selection is not appropriate, **Confirm Selection** remains grayed out. For example, **Confirm Selection** remains grayed out if the number of signals you select is not the same as the number of signals in the Signal Builder group that you want to replace.

8 Click the **Confirm Selection** button.

If the requested action is a valid one, the Status History pane displays messages to indicate the state. For example:

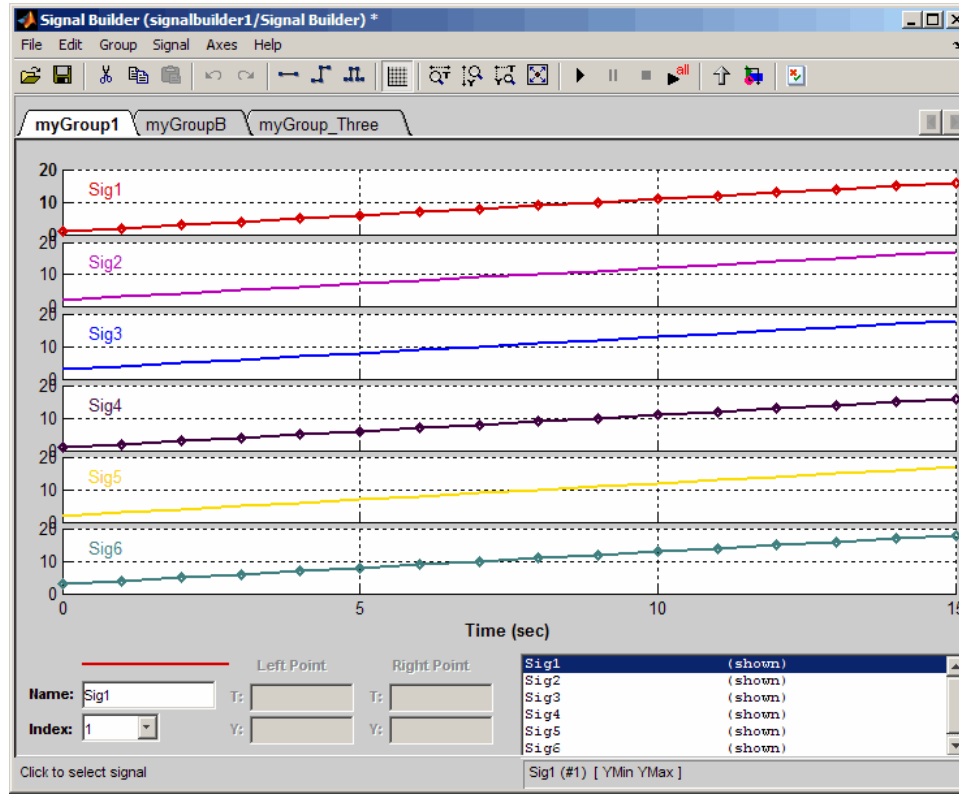


The confirmation also enables the **OK** and **Apply** buttons.

Observe the `Before` and `After` headings for the signals. These sections indicate the names of the block and imported data signals before and after the append action.

9 If you are satisfied with the status message, click **Apply** to append the selected signals to all the signal groups in the Signal Builder block.

10 The Signal Builder block updates with the new signal data. Click **OK** to close the Import File dialog box and inspect the Signal Builder block.



11 Click **OK**.

12 Inspect the updated Signal Builder window to confirm that your signal data is intact. Notice that the software has renamed the signals Sig1, Sig2, and Sig3 from the signal data file to Sig4, Sig5, and Sig6 in the Signal Builder block.

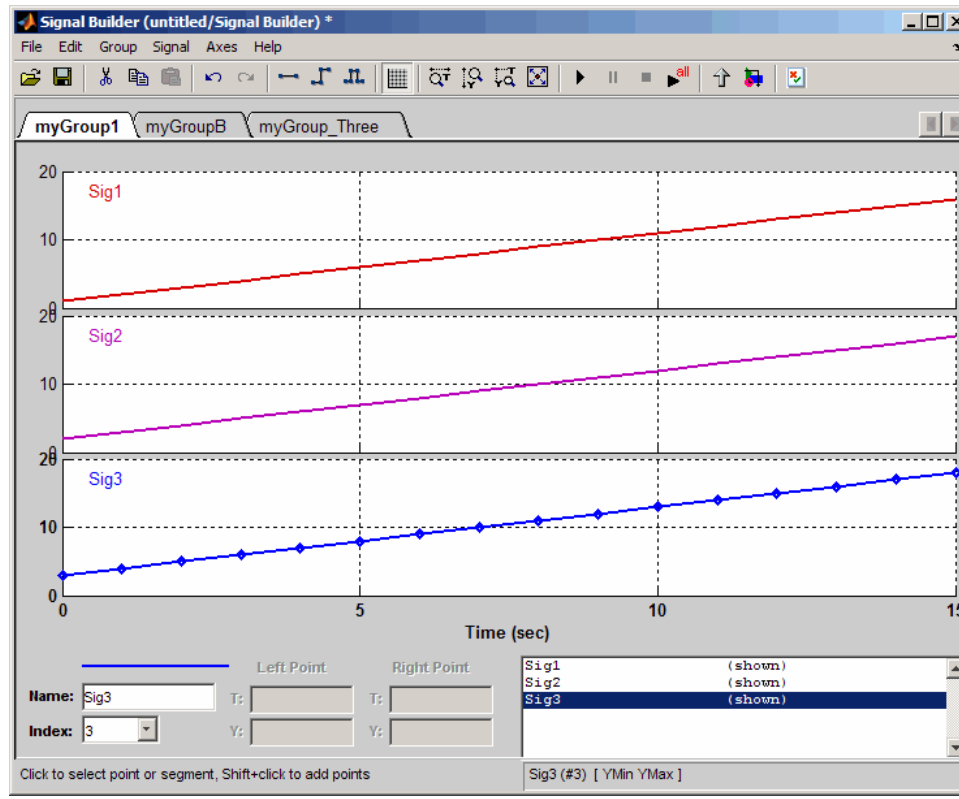
13 Close the Signal Builder window and save and close the model. For example, save the model as `signalbuilder2.mdl`.

Appending Selected Signals to Sequential Existing Signal Groups. You can append signals, in the order in which they are selected, to the end of sequential signal groups. This statement means that you select the same number of signals as there are signal groups, and sequentially append each signal to a different group. The software renames each appended signal to the name of the last appended signal.

This topic uses `signalbuilder1.mdl` from the procedure in "Replacing All Signal Data with Selected Data" on page 29-81.

1. In the MATLAB Command Window, type `signalbuilder1.mdl`.
2. Double-click the Signal Builder block.

   The Signal Builder window appears.
3. Note how many groups exist in the Signal Builder block. For example, this Signal Builder block has three groups, myGroup1, myGroupB, and myGroup_Three.



4 Double-click the block.

The Import File dialog box appears.

5 In the **File to Import** field, enter a signal data file name or click **Browse**.

The file browser appears.

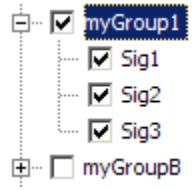
6 If you select the file browser, navigate to and select a signal data file. For example, select `3Grp_3Sig.xls`.

Note If you try to import an improperly formatted signal data file, an error message popup window. When you click to dismiss this window, the **Status History** pane displays an error message. For example:

```
File 'signals.mat' format does not
comply with Signal Builder required format.
There is no 'time' parameter defined.
```

The **Data to Import** pane contains the signal data from the file. Click the expander to display all the signals.

7 Select the signals you want to import. In this example, there are three groups, myGroup1, myGroupB, and myGroup_Three. Select all the signals in myGroup1.



8 From the **Placement for Selected Data** list, select the action to take on the signal data. For example, select `Append selected signals to different groups (in order)`.

The **Confirm Selection** button is activated. Validate your signal selection before the Signal Builder block performs the specified action.

9 Click the **Confirm Selection** button.

If the requested action is a valid one, the Status History pane displays messages to indicate the state. For example:

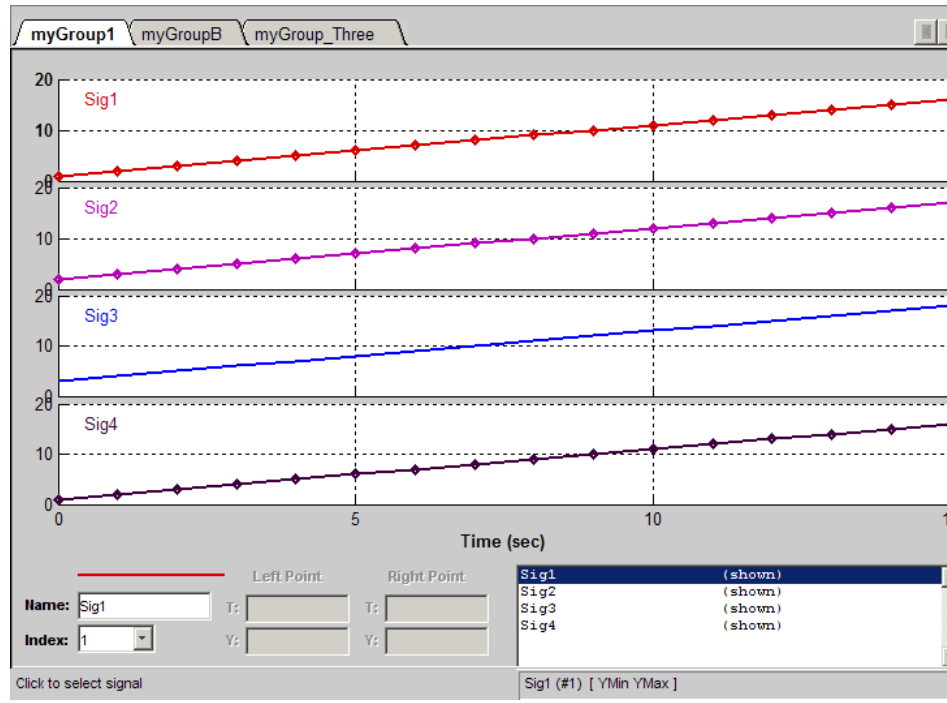
```
 1 signal will be appended to each group.
Selected signal names:
Before:
  Sig1
  Sig2
  Sig3

Selected unique signal name:
After:
  Sig4
```

The confirmation also enables the **OK** and **Apply** buttons.

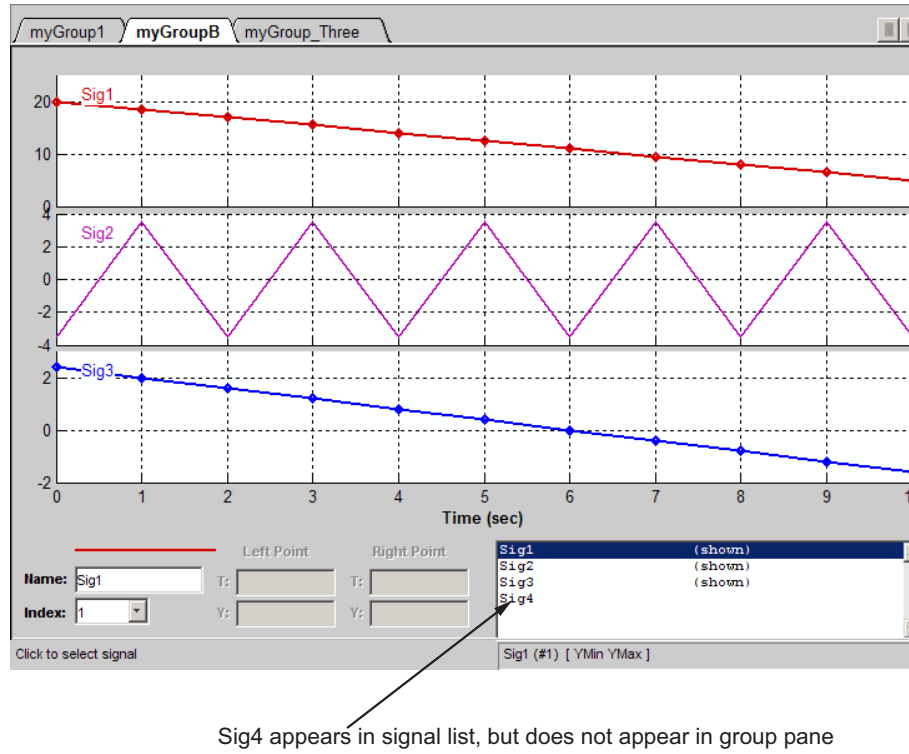
10 If you are satisfied with the status message, click **Apply** to append the signals.

The Signal Builder block updates with the new signal data. Click **OK** to close the Import File dialog box and inspect the three groups of the Signal Builder block.

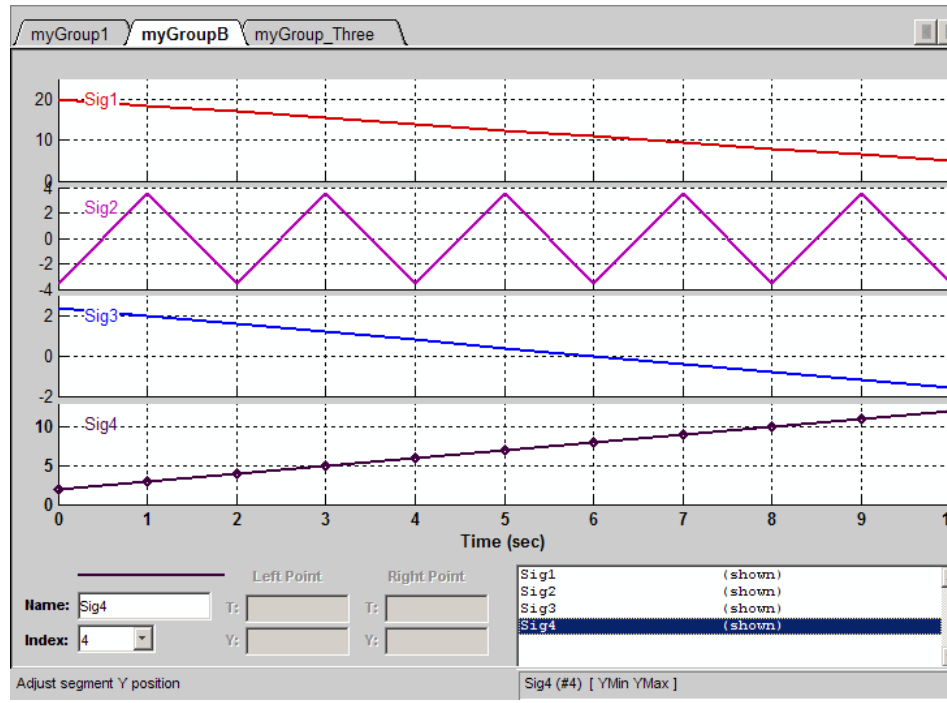
The topmost signal group, myGroup1, shows all signals by default, including the new Sig4.



11 Click another tab, for example, myGroupB. Notice that Sig4 exists for the group, hidden by default.



12 To show Sig4 on this tab, double-click Sig4 in the Selection Status area of the tab. The graph is updated to reflect Sig4.



13 Close the Signal Builder window and save and close the model. For example, save the model as `signalbuilder3.mdl`.

Appending Signal Groups to Existing Groups. You can append one or more signal groups to the end of the list of existing signal groups. If the block already has a signal group with the same name as the one you are adding, the software increments the group name by 1 or higher until it is unique before adding it. For example, if the block and data file contain groups named `MyGroup1`, the software renames the imported group to `MyGroup2` upon appending. If you add another group named `MyGroup1`. the software names that latest version `MyGroup3`.

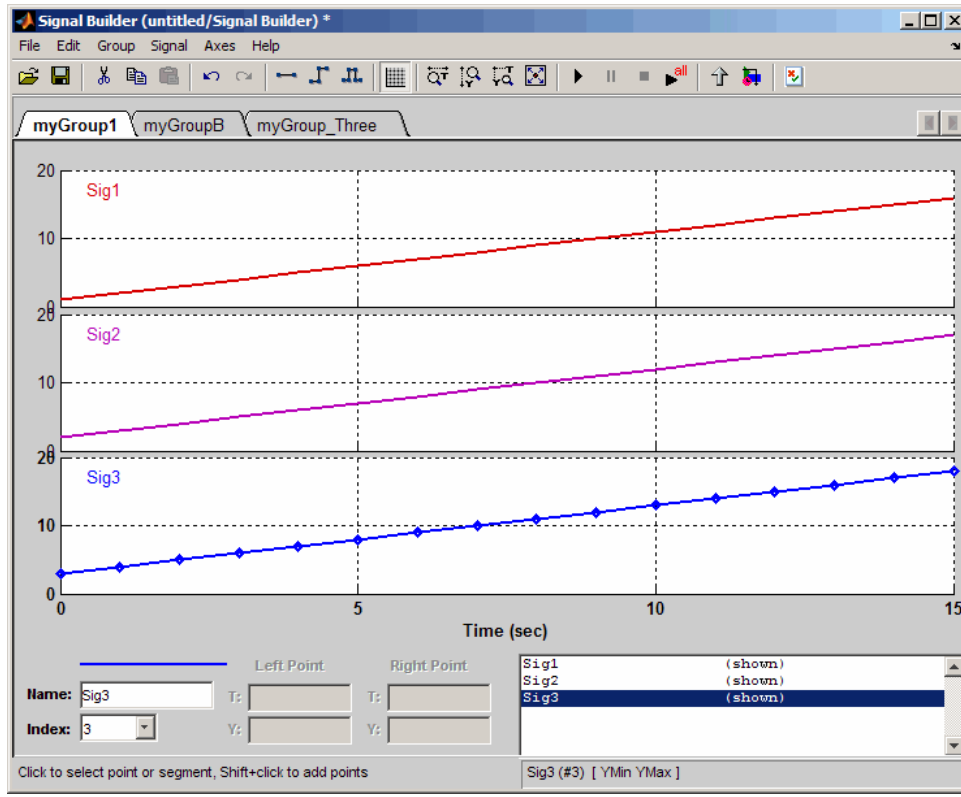
This topic uses `signalbuilder1.mdl` from the procedure in “Replacing All Signal Data with Selected Data” on page 29-81.

1 In the MATLAB Command Window, type `signalbuilder1.mdl`.

2 Double-click the Signal Builder block.

The Signal Builder window appears.

3 Note how many groups exist in the Signal Builder block, and how many signals exist in each group. The Signal Builder block requires that all groups have the same number of signals. For example, this Signal Builder block has three groups, myGroup1, myGroupB, and myGroup_Three. Three signals exist in each group.



4 Double-click the block.

The Import File dialog box appears.

5 In the **File to Import** text field, enter a signal data file name or click **Browse**.

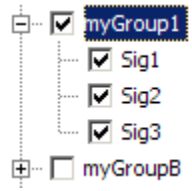
The file browser appears.

6 If you select the file browser, navigate to and select a signal data file. For example, select `3Grp_3Sig.xls`.

The **Data to Import** pane contains the signal data from the file. Click the expander to display all the signals.

7 Evaluate the number of signals in the groups of this data file. If the number of signals in each group equals the number of signals in the groups that exist in the block, you can append one of these groups to the block.

8 Select the group you want to import. In this example, there are three groups, myGroup1, myGroupB, and myGroup_Three. Select myGroup1.



9 From the **Placement for Selected Data** list, select the action to take on the signal group. For example, select `Append groups`.

The **Confirm Selection** button is activated. Validate your signal selection before the Signal Builder block performs the specified action.

10 Click the **Confirm Selection** button.

If the requested action is a valid one, the Status History pane displays messages to indicate the state. For example:

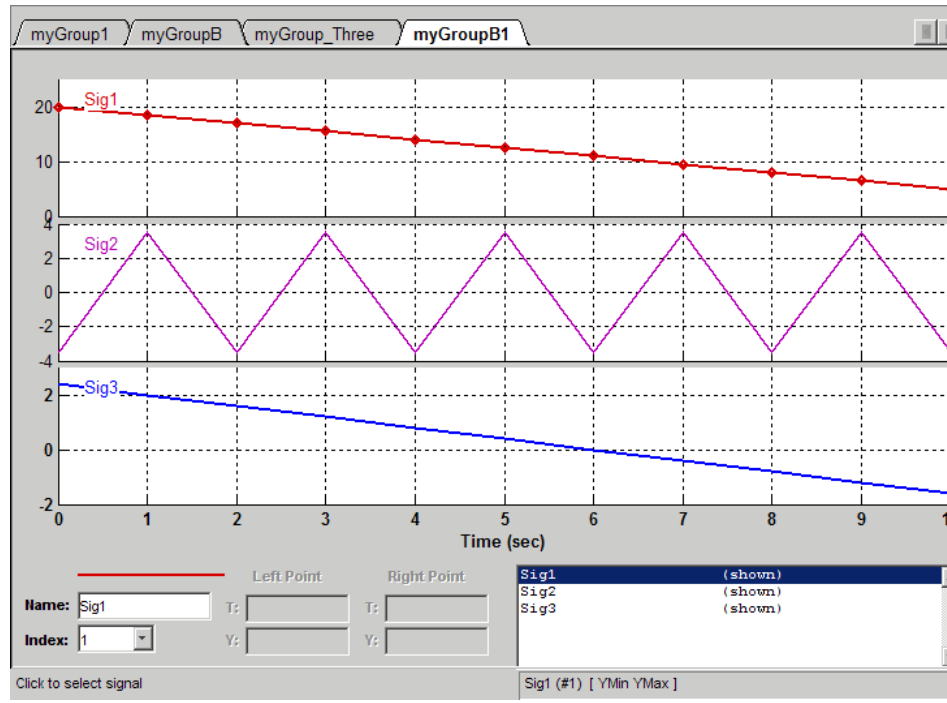
```
1 group(s) (each with 3 signal(s)),
will be appended to the existing block.
Selected group name(s):
Before:
  myGroup1

After:
  myGroup2


Signal name(s) in selected group(s):
Before:
  Sig1
  Sig2
  Sig3

Signal name(s) in the block:
Before:
  Sig1
  Sig2
  Sig3

After:
  Sig1
  Sig2
  Sig3
```

The confirmation also enables the **OK** and **Apply** buttons.

11 If you are satisfied with the status message, click **Apply** to append the signals.

The Signal Builder block updates with the new signal data. Click **OK** to close the Import File dialog box and inspect the groups of the Signal Builder block.

Notice the addition of the new signal group as the last tab. Because there is already a signal group named myGroupB, the software automatically increments the new signal group name by 1.



12 Close the Signal Builder window and save and close the model. For example, save the model as `signalbuilder4.mdl`.

Appending Signals with the Same Name to Existing Signal Groups. If you append a signal whose name is the same as a signal that exists in the Signal Builder block, the software increments the name of the appended signal by 1. The software repeats incrementing until the appended signal name is unique. For example:

1 Assume your Signal Builder block has a signal group, `myGroup1`, with the signals Sig1, Sig2, and Sig3.

2 Append a signal named Sig1 to `myGroup1`.

3 Observe that the software increments Sig1 to Sig4 before appending it to `myGroup1`.

Appending a Group of Signals with Different Signal Names. If you append a signal group whose signal names differ from those that exist in the Signal Builder block, the software changes the names of the existing signals to be the same as the appended signals. For example,

1. Assume your Signal Builder block has a signal group, `myGroup1`, with the signals Sig1, Sig2, and Sig3.
2. Append a signal group named `myGroup2` whose signal names are SigA SigB, and SigC.
3. Observe that the software:
   - Appends `myGroup2`.
   - Renames the signals in `myGroup1` to be the same as those in `myGroup2`.

   .

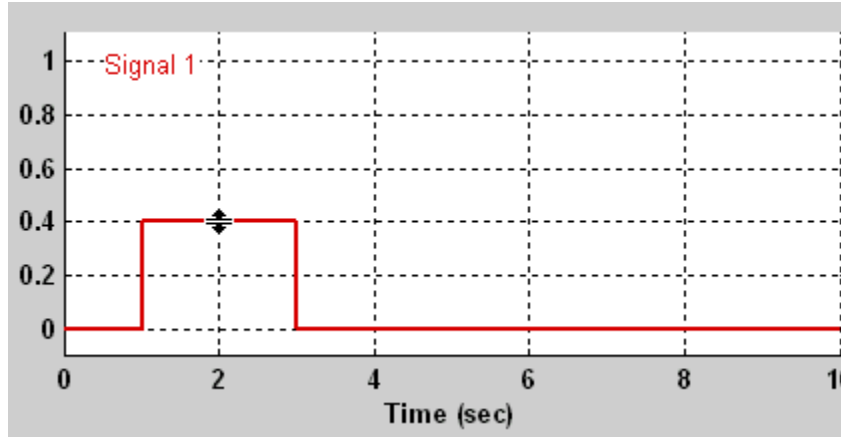
Editing Waveforms

The Signal Builder window allows you to change the shape, color, and line style and thickness of the waveforms output by a group.

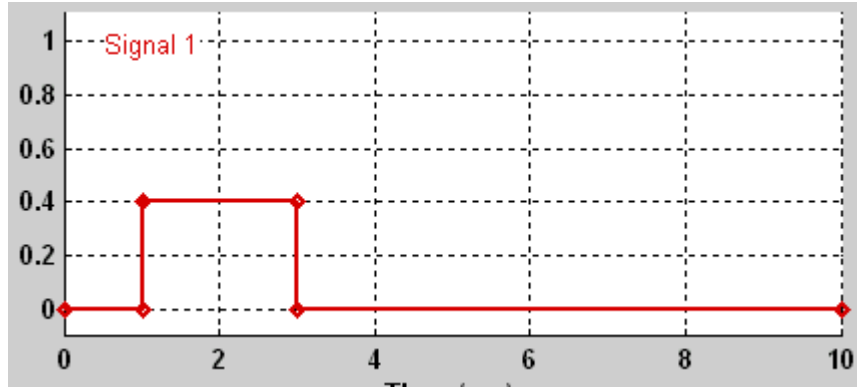
Reshaping a Waveform

The Signal Builder window allows you to change the waveform by selecting and dragging its line segments and points with the mouse or arrow keys or by editing the coordinates of segments or points.

Selecting a Waveform. To select a waveform, left-click the mouse on any point on the waveform.

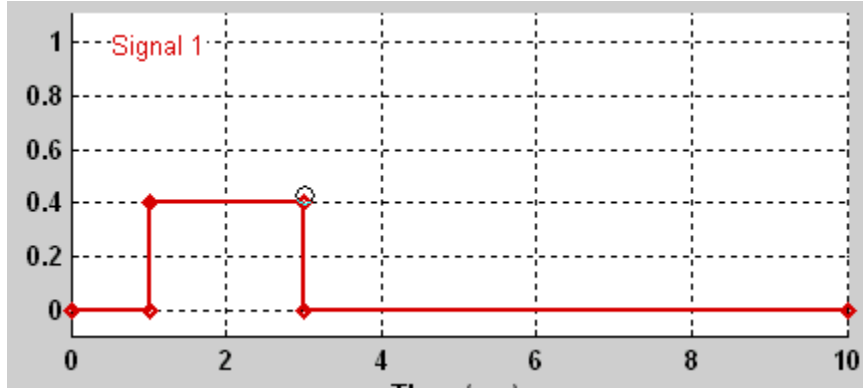


The Signal Builder displays the waveform points to indicate that the waveform is selected.

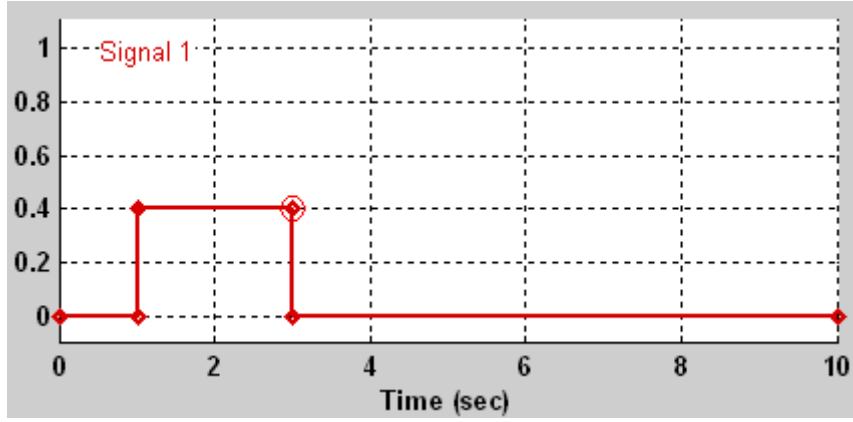


To deselect a waveform, left-click any point on the waveform axis that is not on the waveform itself or press the **Esc** key.

Selecting Points. To select a point of a waveform, first select the waveform. Then position the mouse cursor over the point. The cursor changes shape to indicate that it is over a point.

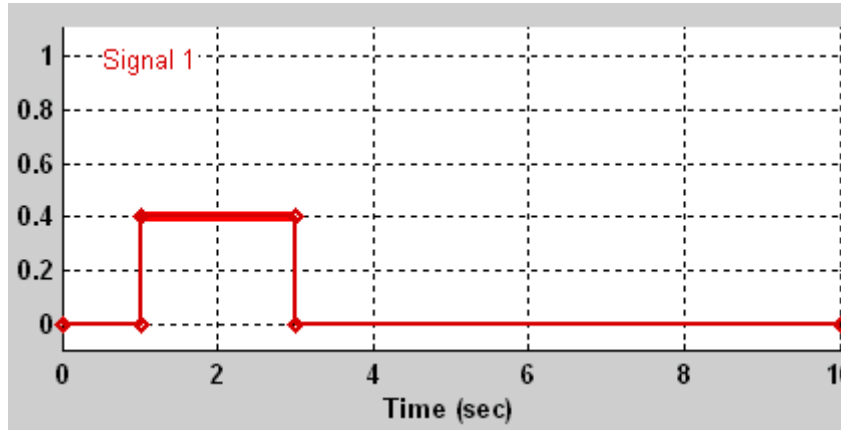


Left-click the point with the mouse. The Signal Builder draws a circle around the point to indicate your selection.



To deselect the point, press the **Esc** key.

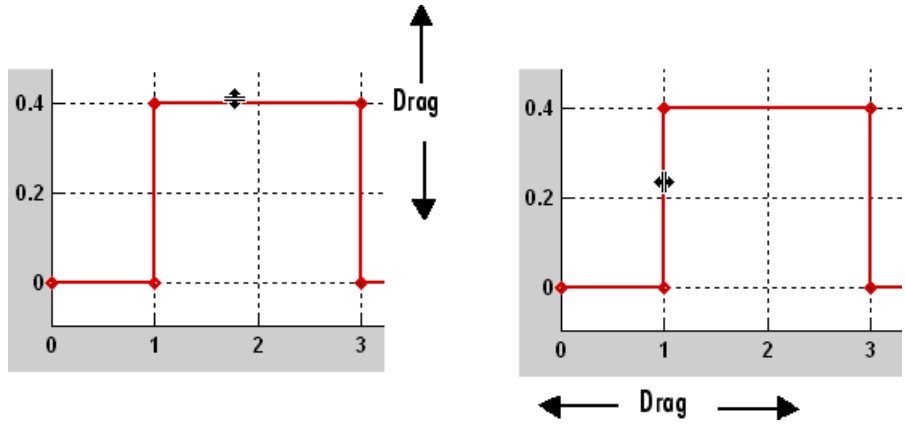
Selecting Segments. To select a line segment, first select the waveform that contains it. Then left-click the segment. The Signal Builder thickens the segment to indicate that it is selected.



To deselect the segment, press the **Esc** key.

Moving Waveforms. To move a waveform, select it and use the arrow keys on your keyboard to move the waveform in the desired direction. Each key stroke moves the waveform to the next location on the snap grid (see "Snap Grid" on page 29-106) or by `0.1` inches if the snap grid is not enabled.

Dragging Segments. To drag a line segment to a new location, position the mouse cursor over the line segment. The mouse cursor changes shape to show the direction in which you can drag the segment.



Press the left mouse button and drag the segment in the direction indicated to the desired location. You can also use the arrow keys on your keyboard to move the selected line segment.

Dragging points. To drag a point along the signal amplitude (vertical) axis, move the mouse cursor over the point. The cursor changes shape to a circle to indicate that you can drag the point. Drag the point parallel to the *y*-axis to the desired location. To drag the point along the time (horizontal) axis, press the **Shift** key while dragging the point. You can also use the arrow keys on your keyboard to move the selected point.

Snap Grid. Each waveform axis contains an invisible snap grid that facilitates precise positioning of waveform points. The origin of the snap grid coincides with the origin of the waveform axis. When you drop a point or segment that you have been dragging, the Signal Builder moves the point or the segment points to the nearest point or points on the grid, respectively. The Signal Builder **Axes** menu allows you to specify the grid horizontal (time) axis and vertical (amplitude) axis spacing independently. The finer the spacing, the more freedom you have in placing points but the harder it is to position points precisely. By default, the grid spacing is 0, which means that you can place points anywhere on the grid; i.e., the grid is effectively off. Use the **Axes** menu to select the spacing that you prefer.

Inserting and Deleting points. To insert a point, first select the waveform. Then hold down the **Shift** key and left-click the waveform at the point where you want to insert the point. To delete a point, select the point and press the **Del** key.

Editing Point Coordinates. To change the coordinates of a point, first select the point. The Signal Builder displays the current coordinates of the point in the **Left Point** edit fields at the bottom of the Signal Builder window. To change the amplitude of the selected point, edit or replace the value in the **Y** field with the new value and press **Enter**. The Signal Builder moves the point to its new location. Similarly edit the value in the **T** field to change the time of the selected point.

Editing Segment Coordinates. To change the coordinates of a segment, first select the segment. The Signal Builder displays the current coordinates of the endpoints of the segment in the **Left Point** and **Right Point** edit fields at the bottom of the Signal Builder window. To change a coordinate, edit the value in its corresponding edit field and press **Enter**.

Changing the Color of a Waveform

To change the color of a waveform, select the waveform and then select **Color** from the Signal Builder **Signal** menu. The Signal Builder displays the MATLAB color chooser. Choose a new color for the waveform. Click **OK**.

Changing a Waveform Line Style and Thickness

The Signal Builder can display a waveform as a solid, dashed, or dotted line. It uses a solid line by default. To change the line style of a waveform, select the waveform, then select **Line Style** from the Signal Builder **Signal** menu. A menu of line styles pops up. Select a line style from the menu.

To change the line thickness of a waveform, select the waveform, then select **Line Width** from the **Signal** menu. A dialog box appears with the line current thickness. Edit the thickness value and click **OK**.

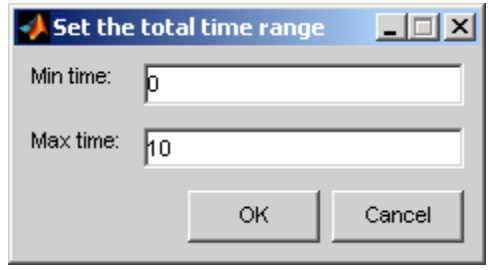
Signal Builder Time Range

The Signal Builder time range determines the span of time over which its output is explicitly defined. By default, the time range runs from 0 to 10 seconds. You can change both the beginning and ending times of a block time range (see "Changing a Signal Builder Time Range" on page 29-108).

If the simulation starts before the start time of a block time range, the block extrapolates its initial output from its first two defined outputs. If the simulation runs beyond the block time range, the block by default outputs values extrapolated from the last defined signal values for the remainder of the simulation. The Signal Builder **Simulation Options** dialog box allows you to specify other final output options (see "Signal values after final time" on page 29-111 for more information).

Changing a Signal Builder Time Range

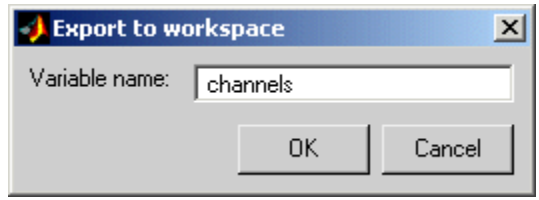
To change the time range, select **Change Time Range** from the Signal Builder **Axes** menu. A dialog box appears.



Edit the **Min time** and **Max time** fields as necessary to reflect the beginning and ending times of the new time range, respectively. Click **OK**.

Exporting Signal Group Data

To export the data that define a Signal Builder block signal groups to the MATLAB workspace, select **Export to Workspace** from the block **File** menu. A dialog box appears.



The Signal Builder exports the data by default to a workspace variable named `channels`. To export to a differently named variable, enter the variable name in the **Variable name** field. Click **OK**. The Signal Builder exports the data to the workspace as the value of the specified variable.

The exported data is an array of structures. The structure `xData` and `yData` fields contain the coordinate points defining signals in the currently selected signal group. You can access the coordinate values defining signals associated with other signal groups from the structure `allXData` and `allYData` fields.

Printing, Exporting, and Copying Waveforms

The Signal Builder window allows you to print, export, and copy the waveforms visible in the active signal group.

To print the waveforms to a printer, select **Print** from the block **File** menu.

You can also export the waveforms to other destinations by using the **Export** option from the block **File** menu. From this submenu, select one of the following destinations:

- **To File** — Converts the current view to a graphics file.

  Select the format of the graphics file from the **Save as type** drop-down list on the resulting **Export** dialog box.

- **To Figure** — Converts the current view to a MATLAB figure window.

To copy the waveforms to the system clipboard for pasting into other applications, select **Copy Figure To Clipboard** from the block **Edit** menu.

Simulating with Signal Groups

You can use standard simulation commands to run models containing Signal Builder blocks or you can use the **Run** or **Run all** command in the Signal Builder window (see "Running All Signal Groups" on page 29-110).

If you want to capture inputs and outputs that the **Run all** command generates, consider using the SystemTest™ software.

Activating a Signal Group

During a simulation, a Signal Builder block always outputs the active signal group. The active signal group is the group selected in the Signal Builder window for that block, if the dialog box is open. Otherwise, the active group is the group that was selected when the dialog box was last closed. To activate a group, open the group Signal Builder window and select the group.

Running Different Signal Groups in Succession

The Signal Builder toolbar includes the standard Simulink buttons for running a simulation. This facilitates running several different signal groups in succession. For example, you can open the dialog box, select a group, run a simulation, select another group, run a simulation, etc., all from the Signal Builder window.

Running All Signal Groups

To run all the signal groups defined by a Signal Builder block, open the block dialog box and click the **Run all** button

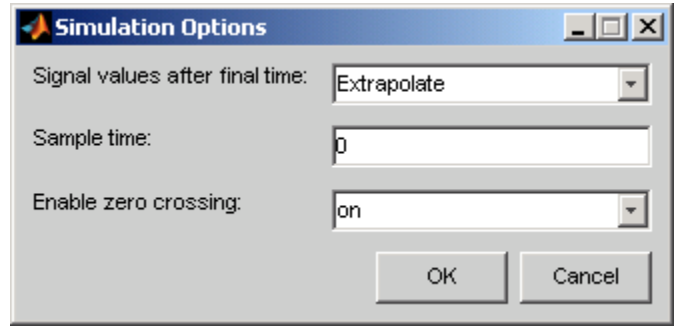
from the Signal Builder toolbar. The **Run all** command runs a series of simulations, one for each signal group defined by the block. If you installed Simulink Verification and Validation on your system and are using the Model Coverage Tool, the **Run all** command configures the tool to collect and save coverage data for each simulation in the MATLAB workspace and display a

report of the combined coverage results at the end of the last simulation. This allows you to quickly determine how well a set of signal groups tests your model.

Note To stop a series of simulations started by the **Run all** command, enter **Ctrl+C** at the MATLAB command line.

Simulation Options Dialog Box

The **Simulation Options** dialog box allows you to specify simulation options pertaining to the Signal Builder. To display the dialog box, select **Simulation Options** from the **File** menu of the Signal Builder window. The dialog box appears.



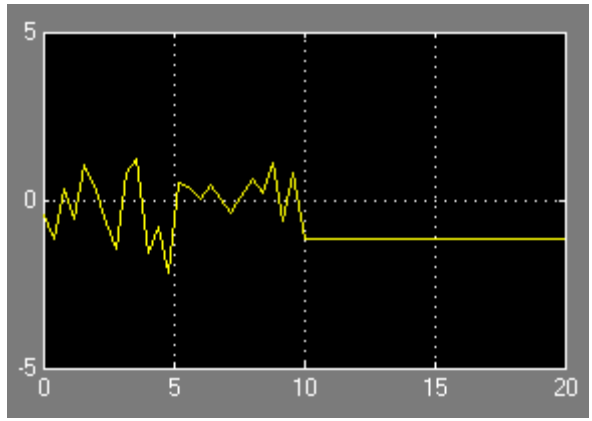
The dialog box allows you to specify the following options.

Signal values after final time

The setting of this control determines the output of the Signal Builder block if a simulation runs longer than the period defined by the block. The options are

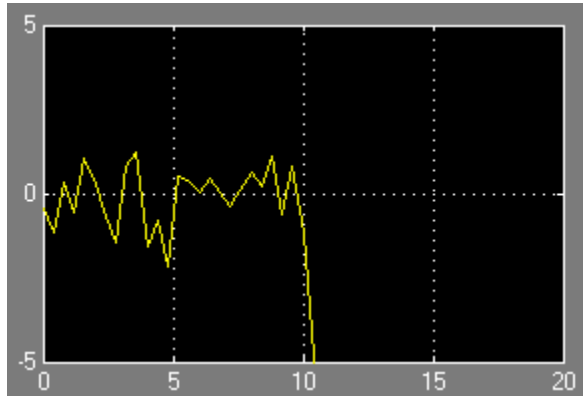
- `Hold final value`

Selecting this option causes the Signal Builder block to output the last defined value of each signal in the currently active group for the remainder of the simulation.



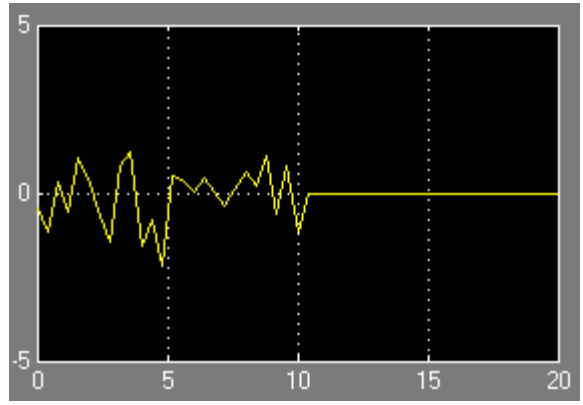
- `Extrapolate`

  Selecting this option causes the Signal Builder block to output values extrapolated from the last defined value of each signal in the currently active group for the remainder of the simulation.



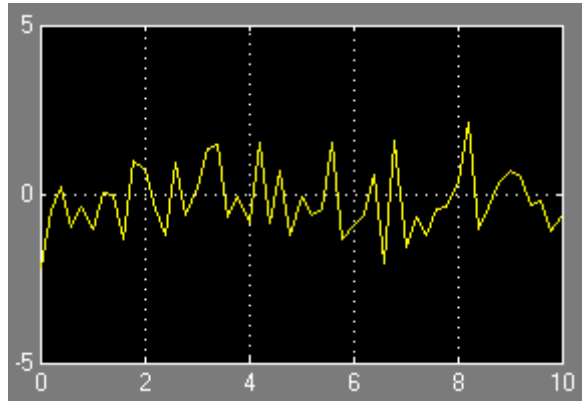
- `Set to zero`

Selecting this option causes the Signal Builder block to output zero for the remainder of the simulation.

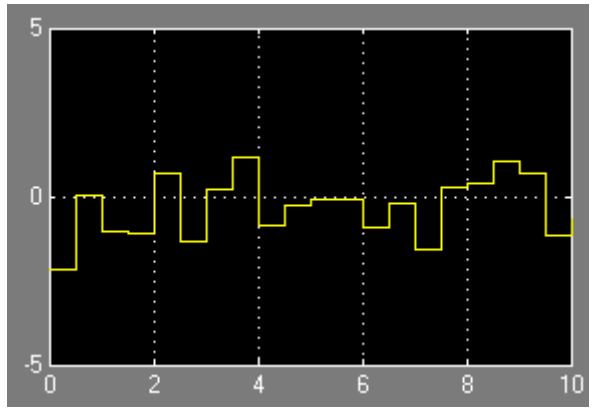


Sample time

Determines whether the Signal Builder block outputs a continuous (the default) or a discrete signal. If you want the block to output a continuous signal, enter 0 in this field. For example, the following display shows the output of a Signal Builder block set to output a continuous Gaussian waveform over a period of 10 seconds.



If you want the block to output a discrete signal, enter the sample time of the signal in this field. The following example shows the output of a Signal Builder block set to emit a discrete Gaussian waveform having a `0.5` second sample time.



Enable zero crossing

Specifies whether the Signal Builder block detects zero-crossing events (enabled by default). For more information, see "Zero-Crossing Detection" on page 2-23.

Using Composite Signals

About Composite Signals

In this section...

Composite Signal Terminology

A *composite signal* is a signal that is composed of other signals. The constituent signals originate separately and join to form the composite signal. They can then be extracted from the composite signal downstream and used as if they had never been joined. Composite signals can reduce visual complexity in models by grouping signals that run in parallel over some or all of their courses, and can serve various other purposes.

A Simulink composite signal is called a *bus signal*, or just a *bus*. A Simulink bus is analogous to a bundle of wires held together by tie wraps. Simulink implements a bus as a name-based hierarchical structure. A Simulink bus should not be confused with a hardware bus, like the bus in the backplane of many computers. It is more like a programmatic structure defined in a language like C.

The signals that constitute a bus are called *elements*. The constituent signals retain their separate identities within the bus and can be of any type or types, including other buses nested to any level. The elements of a bus can be any of the following:

- Mixed data type signals (e.g. double, integer, fixed point)
- Mixture of scalar and vector elements
- Buses as elements
- N-D signals

- Mixture of Real and Complex signals

Some requirements and limitations apply when you connect buses to blocks or to nonvirtual subsystems. See "Bus-Capable Blocks" on page 30-11, "Connecting Buses to Inports and Outports" on page 30-51, and "Composite Signal Limitations" on page 30-94 for more information.

Types of Simulink Buses

A bus can be either *virtual* or *nonvirtual*. Both virtual and nonvirtual buses provide the same visual simplification, but their implementations are different.

- Virtual buses exist only graphically. They have no functional effects and do not appear in generated code; only the constituent signals appear. See "Virtual Signals" on page 29-13 for details. Simulink implements virtual buses with pointers, so virtual buses add no data copying overhead and do not affect performance.
- Nonvirtual buses may have functional effects. They appear as structures in generated code, which can simplify the code and clarify its correspondence with the model. Simulink implements nonvirtual buses by copying data from the source signals to the bus, which can affect performance.

The two types of buses are interchangeable for many purposes, but some situations require a nonvirtual bus. See "Virtual and Nonvirtual Buses" on page 30-48 for more information.

Getting Information about Buses

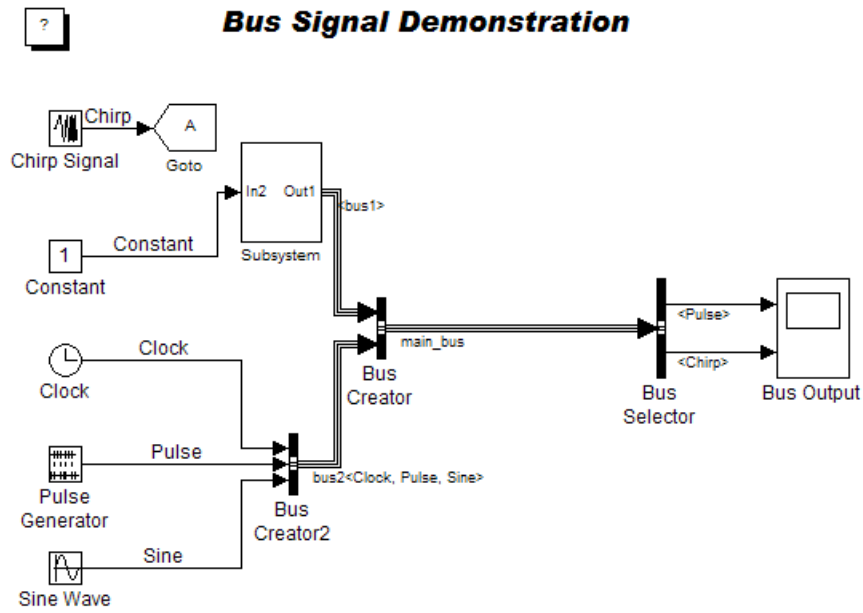
To get information about the type and hierarchy of a bus signal in a compiled model, use these parameters with the `get_param` command:

- `CompiledBusType` — Returns information about whether the signal connected to a port is a bus, and if so, whether the signal is a virtual or nonvirtual bus
- `SignalHierarchy` — Returns the signal name of the signal. If the signal is a bus, the parameter also returns the hierarchy and names of the bus signal

Before you use these commands:

1. In the **Configuration Parameters > Diagnostics > Connectivity** pane, set the Mux blocks used to create bus signals diagnostic to `error`.
2. Place the model in a compiled state.

For example, if you open the `busdemo` demo, you see the following model:



The following code illustrates how you can use the `SignalName` and `CompiledBusType` parameters:

```
busdemo
set_param(bdroot, 'StrictBusMsg','ErrorLevel1')
busdemo([],[],[],'compile')
/* After model compiles, proceed */
ph = get_param('busdemo/Bus Creator', 'PortHandles');
sh = get_param(ph.Outport, 'SignalHierarchy')

sh =
```

```
    SignalName: 'main_bus'
     BusOjbect: ''
      Children: [2x1 struct]

bt = get_param(ph.Outport, 'CompiledBusType')

bt =

VIRTUAL_BUS
```

Buses and Muxes

If all signals in a bus are the same type, you may be able to use a contiguous vector or a virtual vector (mux) instead of a bus. See "Mux Signals" on page 29-16 for more information. In some cases, muxes and virtual buses can be treated interchangeably; implicit type conversion occurs when needed.

Do not mix muxes and buses in new applications.

One way that such a mux/bus mixture occurs is when you use a Mux block to create a virtual bus, such as a Mux block that outputs to a Bus Selector. This kind of mixture does not support strong type checking and increases the likelihood of run-time errors. MathWorks discourages treating muxes and buses interchangeably. Mux/bus mixtures may become unsupported in the future. Simulink generates a warning for this kind of mux/bus mixture when you load a model created in a release prior to R2010a. For new models, Simulink generates an error. Do not create such mux/bus mixtures in new applications, and consider upgrading existing applications to avoid such mixtures. The **Configuration Parameters > Diagnostics > Connectivity** pane provides diagnostics that report cases where muxes and virtual buses are used interchangeably, and includes capabilities that you can use to upgrade a model to eliminate such mixtures. See "Avoiding Mux/Bus Mixtures" on page 30-84 for details.

Another way for a mux/bus mixture to occur is when a virtual bus signal is treated as a mux, such as a bus signal that inputs directly to a Gain block. To detect such mixtures, in the **Configuration Parameters > Diagnostics > Connectivity** pane, set the **Bus signal treated as vector** diagnostic to `warning` or `error`.

Bus Objects

A bus can have an associated *bus object*, which can both provide and validate bus properties. A bus object is an instance of class `Simulink.Bus` that is defined in the base workspace. The object defines the structure of the bus and the properties of its elements, such as nesting, data type, and size. Bus objects are optional for virtual buses and required for nonvirtual buses. See "Using Bus Objects" on page 30-12 for more information. You can create bus objects programmatically or by using the Simulink Bus Editor, which facilitates bus object creation and management. See "Using the Bus Editor" on page 30-14 for more information.

Bus Code

The various techniques for defining buses are essentially equivalent for simulation, but the techniques used can make a significant difference in the efficiency, size, and readability of generated code. If you intend to generate production code for a model that uses buses, see "Optimizing Buses for Code Generation" for information about the best techniques to use.

Creating and Accessing a Bus

The Signal Routing library provides three blocks that you can use for implementing buses:

Bus Creator
Create a bus that contains specified elements

Bus Assignment
Replace specified bus elements

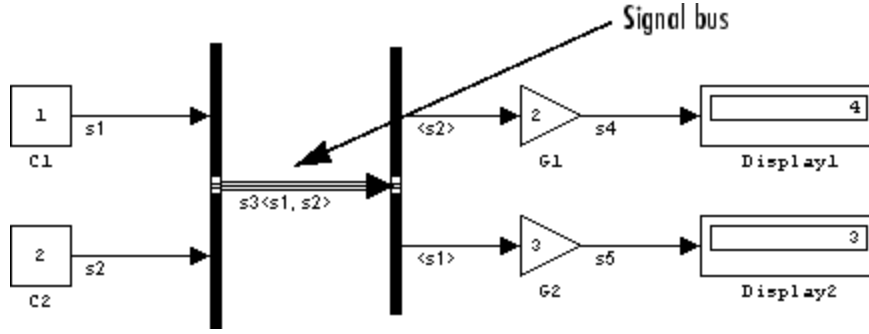
Bus Selector
Select elements from a bus

Each of these blocks is virtual or nonvirtual depending on whether the bus that it processes is virtual or nonvirtual. The Simulink software chooses the block type, and changes it automatically if the bus type changes.

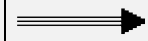
To create and access a bus signal that has default properties:

1. Clone a Bus Creator and Bus Selector block from the Signal Routing library.
2. Connect the Bus Creator, Bus Selector, and other blocks as needed to implement the desired bus.

The next figure shows two signals that are input to a Bus Creator block, transmitted as a bus signal to a Bus Selector block, and output as separate signals.



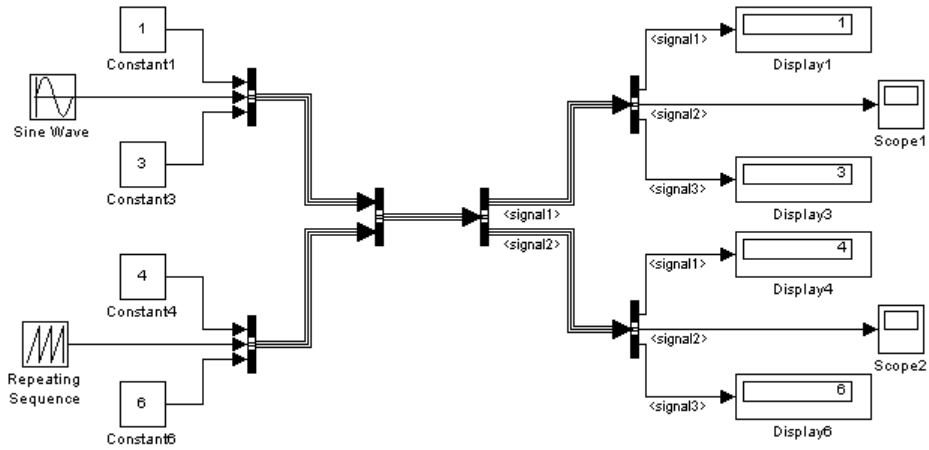
The Bus Creator and Bus Selector blocks are the left and right vertical bars, respectively. Consistent with the goal of reducing visual complexity, neither block displays a name. The line connecting the blocks, representing the bus signal, is tripled because the model has been built, and the middle line is solid because the bus is virtual. The line would be dashed if the bus were nonvirtual:

Virtual Bus	
Nonvirtual Bus	

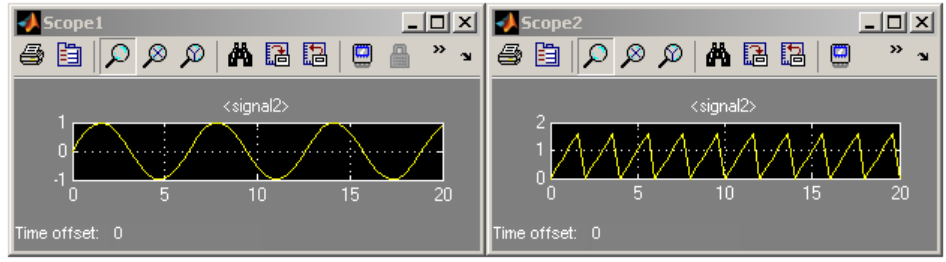
See “Signal Line Styles” on page 29-6 for more about the graphical appearance of signals. You can also display other signal characteristics graphically, as described under “Displaying Signal Properties” on page 29-64. For more information about creating and accessing buses, see the reference documentation for the Bus Creator, Bus Selector, and Bus Assignment blocks.

Nesting Buses

You can nest buses to any depth. For example, the next figure shows six signals nested into two buses, which are nested into one, followed by separation into two buses and then into six separate signals:



The six signals retain their separate identities just as if no bus creation and selection occurred, as shown by the Display and Scope blocks:



Specifying nonvirtual buses, like those in the previous figure, requires only cloning blocks, setting parameters, and connecting signals. Bus Creator and Bus Selector blocks have two ports by default. See the Bus Creator and Bus Selector block documentation for information about how to specify buses of different widths.

The Simulink software automatically handles most of the complexities involved. For example, you can specify to have Simulink repair broken selections in the Bus Selector and Bus Assignment block parameter dialog boxes due to upstream bus hierarchy changes. To enable these automatic repairs, in the**Configuration Parameters > Diagnostics > Connectivity** pane, set the **Repair bus selections** diagnostic to `Warn and repair`. The repairs occur when you update a model. To save the repairs, save the model.

Circular Bus Definitions

The ability to nest a bus as an element of another bus creates the possibility of a loop of Bus Creator blocks, Bus Selector blocks, and bus-capable blocks that inadvertently includes a bus as an element of itself. The resulting circular definition cannot be resolved and therefore causes an error.

The error message that appears specifies the location at which the Simulink software determined that the circular structure exists. The error is not really at any one location: the structure as a whole is in error. Nonetheless, the location cited in the error message can be useful for beginning to trace the definition cycle; its structure may not be obvious on visual inspection.

1. Begin by selecting a signal line associated with the location cited in the error message.
2. Choose **Highlight to Source** or **Highlight to Destination** from the signal's Context menu. (See "Displaying Signal Sources and Destinations" on page 29-22 for more information.)
3. Continue choosing signals and highlighting their sources and destinations until the cycle becomes clear.
4. Restructure the model as needed to eliminate the circular bus definition.

Because the problem is a circular definition rather than a circular computation, the cycle cannot be broken by inserting additional blocks, in the way that an algebraic loop can be broken by inserting a Unit Delay block. No alternative exists but to restructure the model to eliminate the circular bus definition.

Bus-Capable Blocks

Buses are not intended to support computation performed directly on the bus. Therefore, only a small subset of blocks, called *bus-capable blocks*, can process buses directly. All virtual blocks are bus-capable. The following nonvirtual blocks are also bus-capable:

- Memory
- Merge
- Multiport Switch
- Rate Transition
- Switch
- Unit Delay
- Zero-Order Hold

All signals in a nonvirtual bus input to a bus-capable block must have the same sample time, even if the elements of the associated bus object specify inherited sample times. You can use a Rate Transition block to change the sample time of an individual signal, or of all signals in a bus.

Some bus-capable blocks impose other constraints on bus propagation through them. See the documentation for the specific block in Blocks-Alphabetical List for more information.

You can sometimes connect a virtual bus to a block that is not bus-capable without generating an error, but such a connection intermixes buses and muxes, which MathWorks discourages. See “Avoiding Mux/Bus Mixtures” on page 30-84 for details.

Using Bus Objects

In this section...

About Bus Objects

The properties that you specify for a bus signal by using Bus Creator block parameters are inherited by all downstream blocks that use the bus. Using Bus Creator block parameters is adequate for defining virtual buses and performing limited error checking. However, to define a nonvirtual bus, or to perform complete error checking on any bus, use a *bus object* to specify additional information.

Creating a bus object establishes a composite data type whose name is the name of the bus object and whose properties are given by the object. A bus object specifies only the architectural properties of a bus, as distinct from the values of the signals it contains. For example, a bus object can specify the number of elements in a bus, the order of those elements, whether and how elements are nested, and the data types of constituent signals; but not the signal values.

A bus object is analogous to a structure definition in C: it defines the members of the bus but does not create a bus. A bus object is an instance of class `Simulink.Bus` that is defined in the base workspace. A bus object serves as the root of an ordered hierarchy of *bus elements*, which are instances of class `Simulink.BusElement`. Each element completely specifies the properties of one signal in a bus: its name, data type, dimensionality, etc. The order of the elements contained in the bus object defines the order of the signals in the bus.

Referenced models, Stateflow charts, and Embedded MATLAB blocks that input and output buses require those buses to be defined with bus objects. Inport and Outport blocks can use bus objects to specify the structure of the bus passing through them. Root inport blocks use bus objects to specify the structure of the bus. Root outport blocks use bus objects to check the

structure of the incoming bus and to specify the structure of the bus in the parent model, if any.

Bus Object Capabilities

You can associate a bus object with a Bus Creator block, Inport block, Outport, or Signal Specification block. When a bus object governs a signal output by a block, the signal is a bus that has exactly the properties specified by the object. When a bus object governs a signal input by a block, the signal must be a bus that has exactly the properties specified by the object; any variance causes an error.

A bus object can also specify properties that were not defined by constituent signals, but were left to be inherited. A property specification in a bus object can either validate or provide the corresponding property in the bus. If the bus specifies a different property, an error occurs. If the bus does not specify the property, but leaves it to be inherited, the bus inherits the property from the bus object. Note again that such inheritance never includes signal values.

You can use the Simulink Bus Editor to create and manage bus objects, as described in "Using the Bus Editor" on page 30-14, or you can use the Simulink API, as described in "Using the Bus Object API" on page 30-47. After you create a bus object and specify its attributes, you can associate it with any block that needs to use the bus definition that the object provides.

Associating Bus Objects with Simulink Blocks

You can associate a bus object with a Bus Creator block, Inport block, Outport, or Signal Specification block. In the Block Parameters dialog box, set **Data type** to `Bus: <object name>` and replace `<object name>` with the bus object name.

Using the Bus Editor

In this section...

Introduction

The Simulink Bus Editor is a tool similar to the Model Explorer, but is customized for use with bus objects. You can use the Simulink Bus Editor to:

- Create new bus objects and elements
- Navigate, change, and nest bus objects
- Import existing bus objects from a MATLAB code file or MAT-file
- Export bus objects to a MATLAB code file or MAT-file

For a description of bus objects and their use, see "Using Bus Objects" on page 30-12.

Base Workspace Bus Objects

All bus objects exist in the MATLAB base workspace. Bus Editor actions take effect in the base workspace immediately, and can be used by Simulink models as soon as each action is complete. The Bus Editor does not have a workspace of its own: it acts only on the base workspace. Bus Editor actions

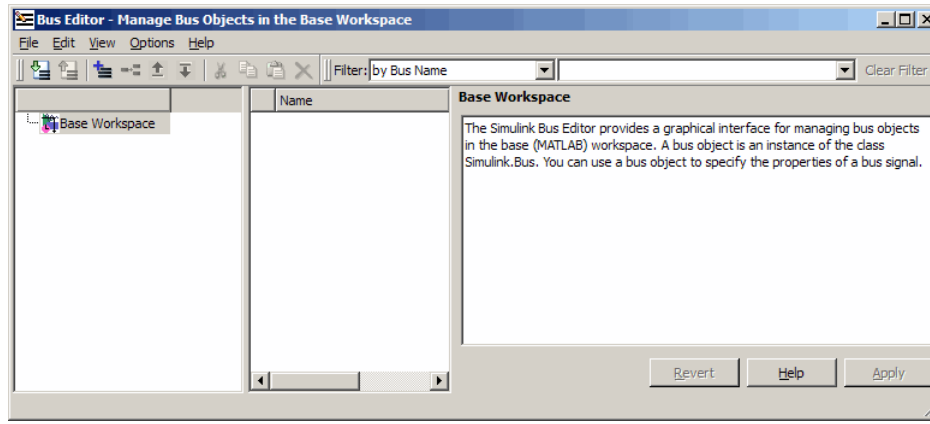
do not directly affect bus object definitions in saved MATLAB code files or MAT-files. To save changed bus object definitions, export them from the base workspace into MATLAB code files or MAT-files, as described in “Exporting Bus Objects” on page 30-31.

Opening the Bus Editor

You can open the Bus Editor in any of these ways:

- Select **Bus Editor** from the model editor’s **Tools** menu.
- Click the **Launch Bus Editor** button on a bus object’s dialog box in the Model Explorer.
- Enter `buseditor` at the command line of the MATLAB software.

After you have performed any of these actions, the Bus Editor appears. If no bus objects exist, the Bus Editor looks like this:



The Bus Editor provides menu choices that you can use to execute all Bus Editor commands. The editor also provides toolbar icons and keyboard shortcuts for all commonly used commands, including the standard MATLAB GUI shortcuts for Cut, Copy, Paste, and Delete. The Toolbar Tip for each icon describes the command, and the menu entry for each command shows any shortcut. The icons for commands that are specific to the Bus Editor are:

Command	Icon	Description
Import		Import the contents of a MATLAB code file or MAT-file into the base workspace.
Export		Export all bus objects and elements to a MATLAB code file or MAT-file.
Create		Create a new bus object in the base workspace.
Insert		Add a bus element below the currently selected bus entity.
Move Up		Move the selected element up in the list of a bus object's elements.
Move Down		Move the selected element down in the list of bus object elements.

For brevity, this section refers only to menu commands. You can use toolbar icons and keyboard shortcuts instead wherever that is convenient.

Displaying Bus Objects

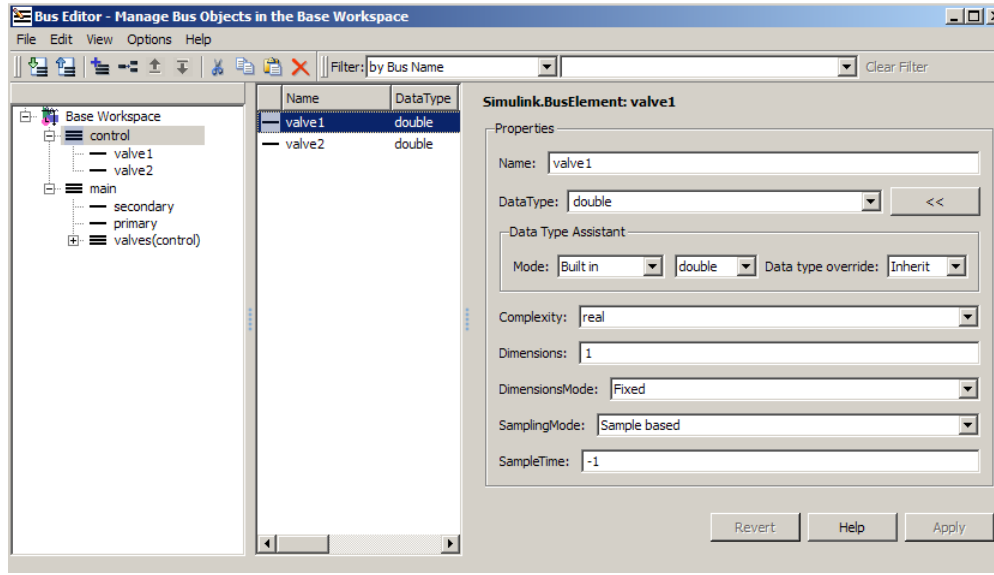
The Bus Editor is similar to the Model Explorer (which can display bus objects but cannot edit them) and uses the same three panes to display bus objects:

- **Hierarchy pane** (left) — Displays the bus objects defined in the base workspace
- **Contents pane** (center) — Displays the elements of the bus object selected in the Hierarchy pane
- **Dialog pane** (right) — Displays for editing the current selection in the Contents or Hierarchy pane

Items that appear in the Hierarchy pane or the Contents pane have Context menus that provide immediate access to the capabilities most likely to be useful with that item. The contents of an item's Context menu depend on the item and the current state within the Bus Editor. All Context menu options are also available from the menu bar and/or the toolbar. Right-click any item in the Hierarchy or Contents pane to see its Context menu.

Hierarchy Pane

If no bus objects exist in the base workspace, the Hierarchy pane shows only **Base Workspace**, which is the root of the hierarchy of bus objects. The Bus Editor then looks as shown in the previous figure. As you create or import bus objects, they appear in the Hierarchy Pane as nodes subordinate to **Base Workspace**. The bus objects appear in alphabetical order. The next figure shows the Bus Editor with two bus objects, `control` and `main`, defined in the base workspace:



The Hierarchy pane displays each bus object as an expandable node. The root of the node displays the name of the bus object, and (if the bus contains any elements) a button for expanding and collapsing the node. Expanding a bus node displays named subnodes that represent the bus's top-level elements.

In the preceding figure, both bus objects are fully expanded , and `control` is selected.

Contents Pane

Selecting any top-level bus object in the Hierarchy Pane displays the object's elements in the Contents pane. In the previous figure, the elements of bus object `control`, `valve1` and `valve2`, appear. Each element's properties appear to the right of the element's name. These properties are editable, and you can edit the properties of multiple elements in one operation, as described in "Editing in the Contents Pane" on page 30-28.

Dialog Pane

When a bus object is selected in the Hierarchy pane, or a bus object or element is selected in the Contents pane, the properties of the selected item appear in the Dialog pane. In the previous figure, `valve1` is selected in the Contents pane, so the Dialog pane shows its properties. These properties are editable, and changes can be reverted or applied using the buttons below the Dialog pane, as described in "Editing in the Dialog Pane" on page 30-29.

Filter Boxes

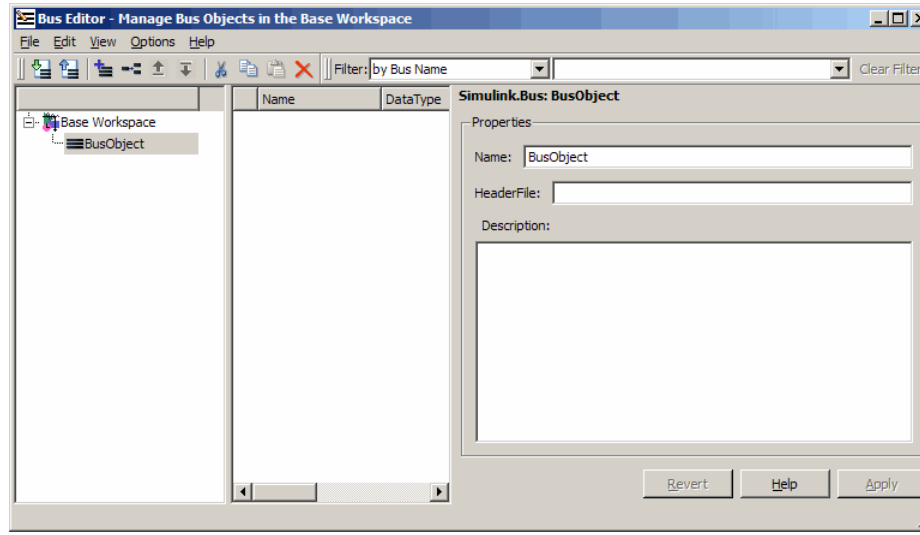
By default, the Bus Editor displays all bus objects that exist in the base workspace. Where a model contains large numbers of bus objects, seeing them all at the same time can be inconvenient. To facilitate working efficiently with large collections of bus objects, you can use the **Filter** boxes, to the right of the iconic tools in the toolbar, to show a selected subset of bus objects. See "Filtering Displayed Bus Objects" on page 30-35 for details.

Creating Bus Objects

To use the Bus Editor to create a new bus object in the base workspace:

1. Choose **File > Add Bus**.

   A new bus object with a default name and properties is created immediately in the base workspace. The object appears in the Hierarchy pane, and its default properties appear in the Dialog pane:



2 To specify the bus object name and other properties, in the Dialog pane:

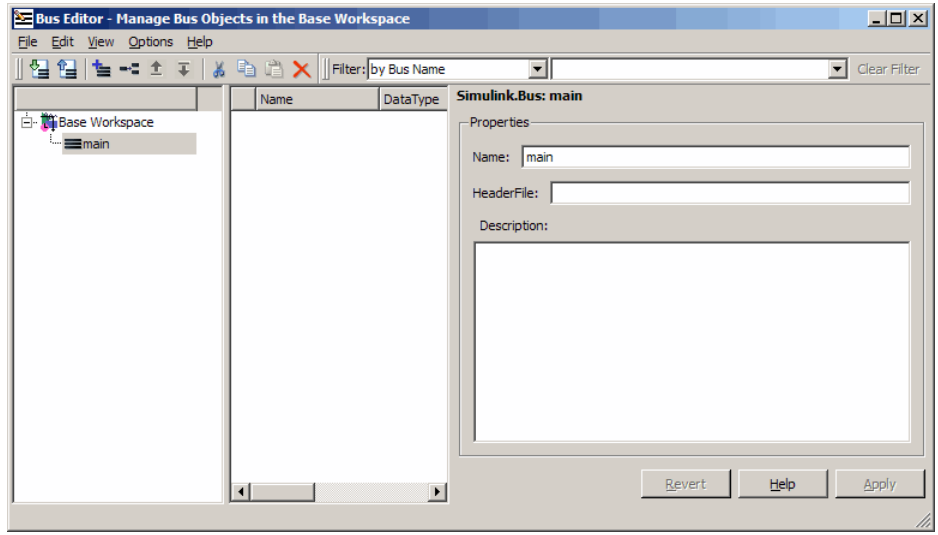
a Specify the **Name** of the of the new bus object (or you can retain the default name). The name must be unique in the base workspace. See "Naming Signals" on page 29-3 for guidelines for signal names.

b Optionally, specify a C **Header file** that defines a user-defined type corresponding to this bus object. This header file has no effect on Simulink simulation; it is used only by Real-Time Workshop software to generate code.

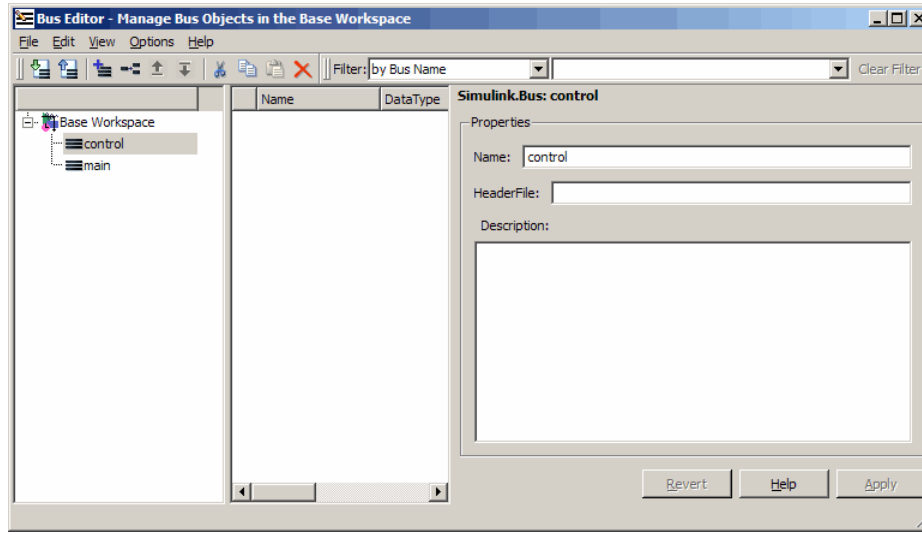
c Optionally, specify a **Description** that provides information about the bus object to human readers. This description has no effect on Simulink simulation; it exists only for human convenience.

3 Click **Apply**.

The properties of the bus object on the base workspace change as specified. If you rename `BusObject` to `main`, the Bus Editor looks like this:



You can use **Add Bus** at any time to create a new bus object in the base workspace, then set the name and properties of the object as needed. You can intersperse creating bus objects and specifying their properties in any order. The hierarchy pane reorders as needed to display all bus objects in alphabetical order. If you add an additional bus object named `control`, the Bus Editor looks like this:



You can also use capabilities outside the Bus Editor to create new bus objects. Such objects do not appear in the Bus Editor until the next time its window is selected.

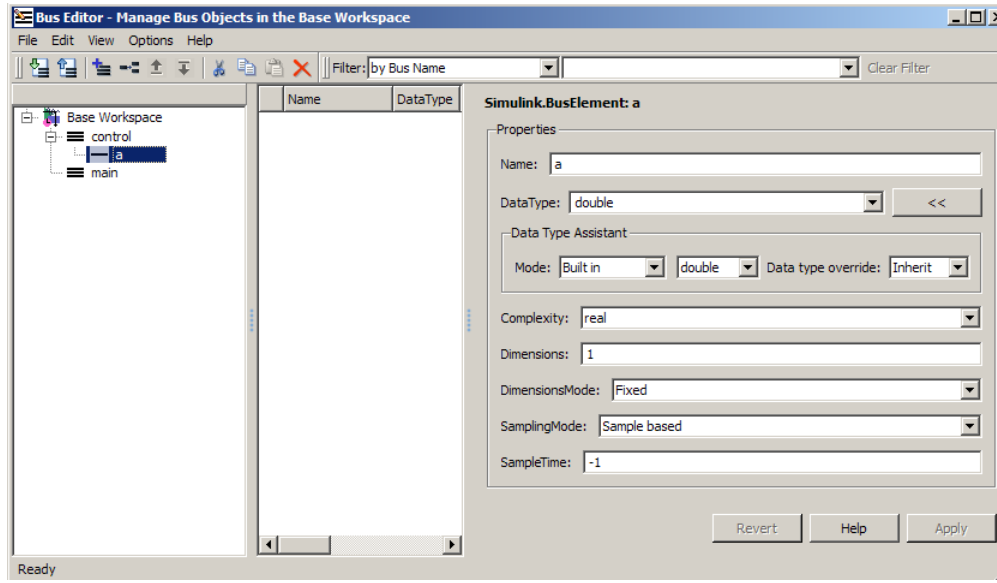
Creating Bus Elements

Every bus element belongs to a specific bus. To create a new bus element:

1. In the Hierarchy pane, select the entity below which to create the new element. The entity can be a bus or a bus element. The new element will belong to the selected bus object, or to the bus object that contains the selected element. The previous figure shows the `control` bus object selected.

2. Choose **File > Add/Insert BusElement**.

   A new bus element with a default name and properties is created immediately in the applicable bus object. The object appears in the Hierarchy pane immediately below the previously selected entity, and its default properties appear in the Dialog pane:



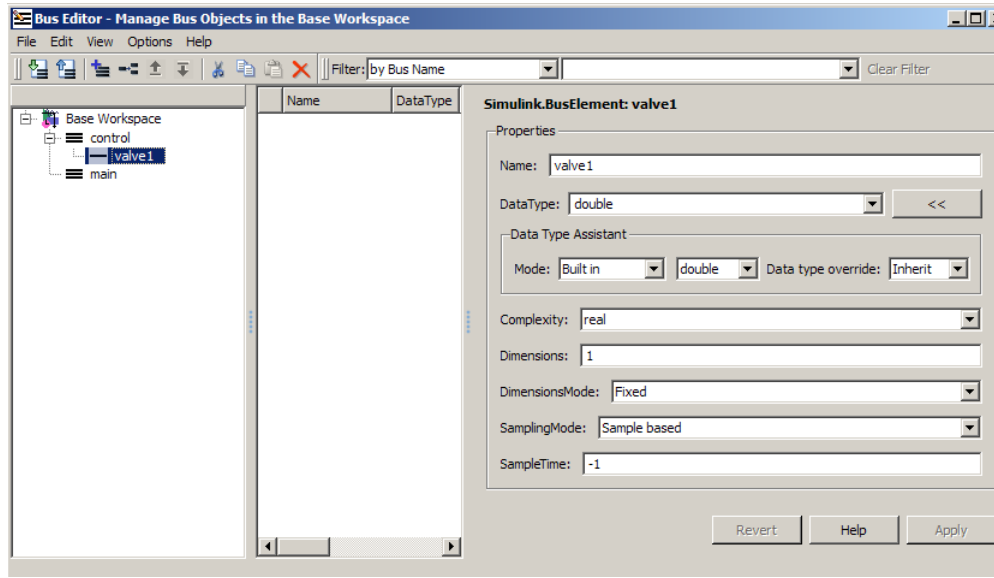
3 To specify the bus element name and other properties, in the Dialog pane:

a Specify the **Name** of the of the new bus element (or you can retain the default name). The name must be unique among the elements of the bus object. See "Naming Signals" on page 29-3 for guidelines for signal names.

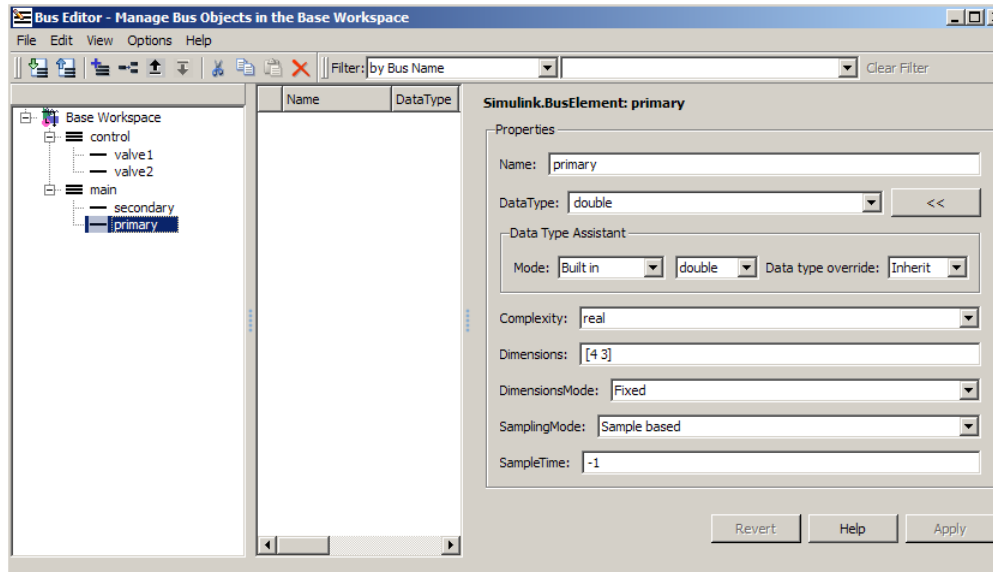
b Specify the other properties of the element. The properties must match the properties of the corresponding signal within the bus exactly, and can be anything that a legal signal might have. The Data Type Assistant appears in the Dialog pane to help specify the element's data type. You can specify any available data type, including a user-defined data type.

4 Click **Apply**.

The properties of the bus element of the bus object in the base workspace change as specified. If you rename the new element `a` to `valve1`, the Bus Editor looks like this:



You can use **Add/Insert BusElement** at any time to create a new bus element in any bus object. You can intersperse creating bus objects and specifying their properties in any order. The order of the other bus elements in the bus object does not change when a new element is added. If you add element `valve2` to `control`, and `secondary` and `primary` to `main`, the Bus Editor looks like this:



You can also use capabilities outside the Bus Editor to add new bus elements to a bus object. Such an addition changes an existing bus object, so any new bus element appears immediately in the Bus Editor.

Nesting Bus Definitions

As described in "Nesting Buses" on page 30-9, any signal in a bus can be another bus, which can in turn contain subordinate buses, and so on to any depth. Describing nested buses with bus objects requires nesting the bus definitions that the objects provide.

Every bus object inherently defines a data type whose properties are those specified by the object. To nest one bus definition in another, you assign to an element of one bus object a data type that is defined by another bus object. The element then represents a nested bus whose structure is given by the bus object that provides its data type.

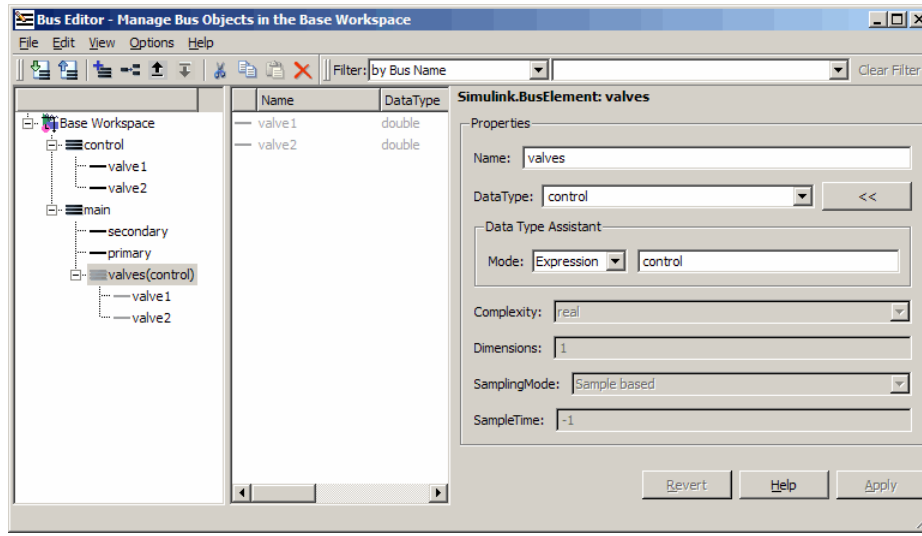
A data type defined by a bus object is called a *bus type*. Nesting buses by assigning bus types to elements, rather than by subordinating the bus objects that define the types, allows the same bus definition to be used conveniently

in multiple contexts without unwanted interactions. To specify that an element of a bus object represents a nested bus definition:

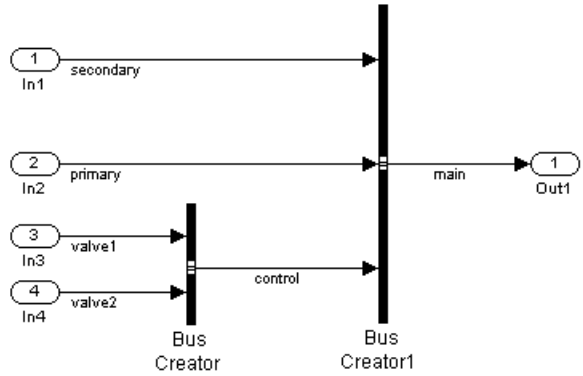
1. Create a bus element to represent the nested bus definition, in the appropriate position under the containing bus object, and give the element the desired name. (You can also use an existing element.)

2. Use the Dialog pane to set the data type of the element to the name of a bus object. The Data Type Assistant shows the names of all available bus types. (You can also specify a nonexistent bus type and define the object later.)

In the preceding figure, if you add to bus object `main` a third element named `valves`, set the data type of `valves` to be `control` (the name of the other defined bus object) and expand the new element `valves`, the Bus Editor looks like this:



The bus object `main` shown in the Bus Editor now defines the same structure used by the bus signal `main` in the next figure:



The distinction between a bus object and the bus type that it defines can be useful for initially understanding how nested bus objects work and how the Bus Editor handles them. In other contexts, the distinction is mostly an implementation detail, and describing bus objects themselves as being nested is more convenient. The rest of this chapter follows that convention.

You can nest a bus object in as many different bus objects as desired, and as many times in the same bus object as desired. You can nest bus objects to any depth, but you cannot define a circular structure by directly or indirectly nesting a bus object within itself.

If you try to define a circular structure, the Bus Editor posts a warning and sets the data type of the element that would have completed the cycle to `double`. Click **OK** to dismiss the Notice and continue using the editor.

You can use the Hierarchy pane to explore nested bus objects by expanding the objects, but you cannot change any property of a bus object anywhere that it appears in nested form. To change the properties of a nested bus object, you must change the source object, which is accessible at the top level in the Hierarchy pane. You can jump from a nested bus object to its source object by selecting the nested object and choosing **Go to '*`element`*'** from its Context menu.

Changing Bus Entities

You can use the Bus Editor to change and delete existing bus objects and elements at any time. All three panes allow you to change the entities that

they display. Changes that create, reorder, or delete entities take effect immediately in the base workspace. Changes to properties take effect when you apply them, or can be canceled, leaving the properties unchanged. The Bus Editor does not provide an Undo capability.

The Bus Editor provides comprehensive GUI capabilities for changing bus entities. You can Cut, Copy, and Paste within and between panes in any way that has a legal result. The Hierarchy and Dialog panes provide a Context menu for the current selection. Pasting a Copied entity always creates a copy, as distinct from a pointer to the original. The Bus Editor automatically changes names when needed to avoid duplication.

Changes made outside the bus editor can affect the information on display within it. Any change to an existing bus object or bus element is visible immediately in the editor. Any change that creates or deletes a bus object becomes visible in the bus editor next time its window is selected.

Editing in the Hierarchy pane

You can select the root node **Base Workspace** and perform various operations, like export, cut, copy, paste, and delete. The operation simultaneously affects all bus objects displayed in the Hierarchy pane, but does not affect any that are invisible because a filter is in effect. See "Filtering Displayed Bus Objects" on page 30-35 for details.

As you use the Bus Editor, the Hierarchy pane automatically reorders the bus objects it displays to maintain alphabetical order. This behavior cannot be changed. However, the elements under a bus object can appear in any order. To change that order, cut and paste elements as needed, or move elements up and down as follows:

1. Select the element to be moved.
2. Choose **Edit > Move Element Up** or **Edit > Move Element Down**.

You cannot Paste one bus object under another to create a nested bus object specification. To specify a nested bus, you must change the data type of a bus element to be the type of an existing bus object, as described in "Nesting Buses" on page 30-9.

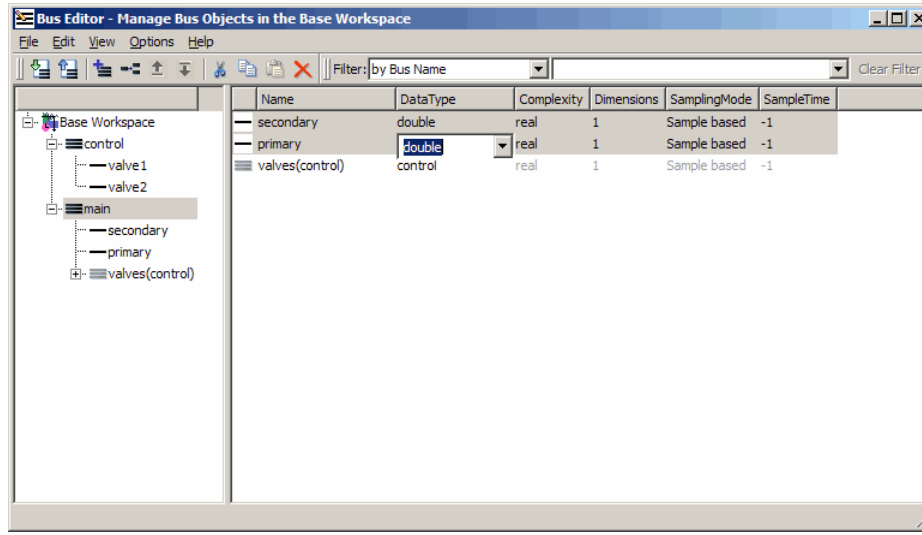
Editing in the Contents Pane

Selecting any top-level bus object in the Hierarchy Pane displays the object's elements in the Contents pane. Each element's properties appear to the right of the element's name, and can be edited. To change a property displayed in the Contents pane, click the value, enter a new value, then press Return.

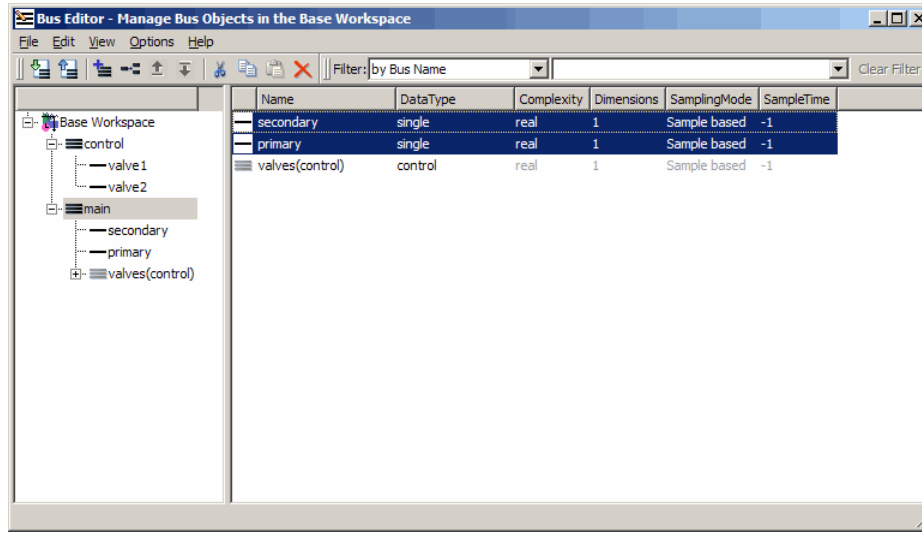
Choose **View > Dialog View** to hide the Dialog pane to provide more room to display properties in the Contents pane. Choose the command again to redisplay the Dialog pane.

You can use the mouse and keyboard to select multiple elements in the Contents pane. The selected entities need not be contiguous. You can then perform any operation that you could on a single entity selected in the pane, including operations performed with the Context menu. Clicking and editing a value in any selected element changes that value in them all.

The next figure shows the Bus Editor with **Dialog View** enabled, two elements selected in the Contents pane, and the **DataType** property selected for editing in the second element:

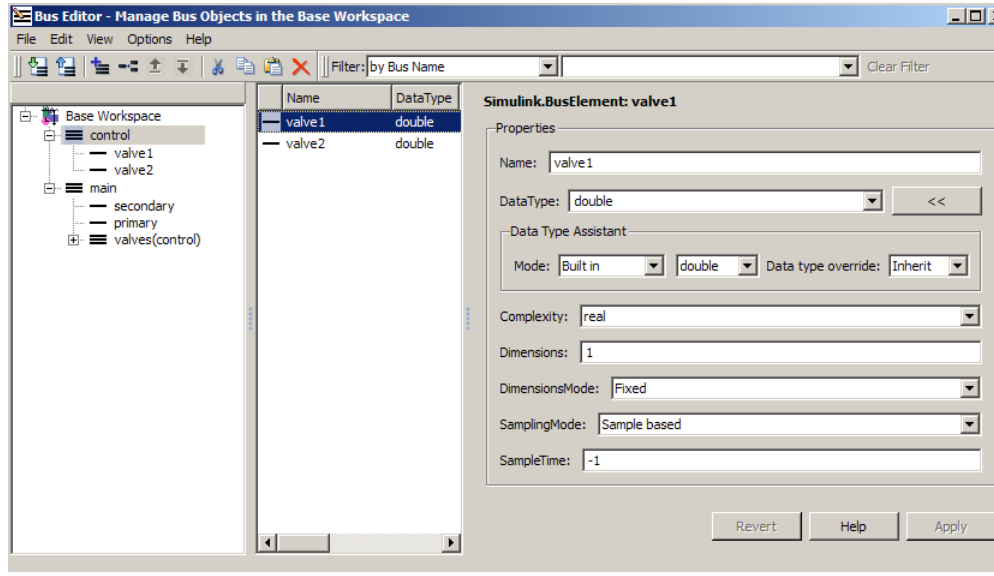


If you change the value of **DataType** to `single` and press Return, the value changes for both elements. The effect is the same no matter which element you edit in a multiple selection:

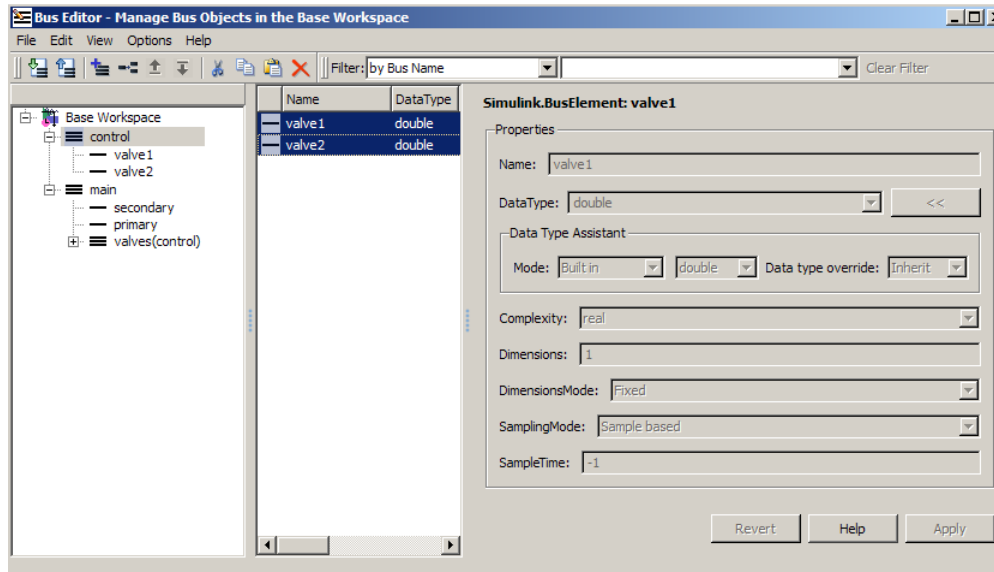


Editing in the Dialog Pane

When a bus object is selected in the Hierarchy pane, or a bus object or element is selected in the Contents pane, the properties of the selected item appear in the Dialog pane. In the next figure, `valve1` is selected in the Contents pane, so the Dialog pane shows its properties:



The properties shown in the Dialog pane are editable, and the pane includes the Data Type Assistant. Click **Apply** to save changes, or **Revert** to cancel them and restore the values that existed before any unapplied changes. You can edit only one element at a time in the Dialog pane. If multiple entities are selected in the Contents pane, all fields in the Dialog pane are grayed out:



If you use the Dialog pane to change any property of a bus entity, then navigate elsewhere without clicking either **Apply** or **Revert**, a query box appears by default. The query box asks whether to apply changes, ignore changes, or continue as if the navigation had not been tried. You can suppress this query for future operations by checking **Never ask me again** in the box, or by selecting **Options > Auto Apply/Ignore Dialog Changes**.

If you suppress the query, and thereafter navigate away from a change without clicking **Apply** or **Revert**, the Bus Editor automatically applies or discards changes, depending on which action you most recently chose in the box. You can re-enable the query box for future operations by deselecting **Options > Auto Apply/Ignore Dialog Changes**.

Exporting Bus Objects

Like all base workspace objects, bus objects are not saved with a model that uses them, but exist separately in a MATLAB code file or MAT-file. You can use the Bus Editor to export some or all bus objects to either type of file.

- If you export bus objects to a MATLAB code file, the Bus Editor asks whether to store them in object format or cell format (the default). Specify the desired format.
- If exporting would overwrite an existing MATLAB code file or MAT-file, a confirmation dialog box appears. Confirm the export or cancel it and try a different filename.

To export all bus objects from the base workspace to a file:

1. Choose **File > Export to File**.

   The Export dialog box appears.

2. Specify the desired name and format of the export file.

3. Click **Save**.

   All bus objects, and nothing else, are exported to the specified file in the specified format.

To export only selected bus objects from the base workspace to a file:

1. Select a bus object in the Hierarchy pane, or one or more bus objects in the Contents pane.

2. Right-click to display the Context menu.

3. Choose **Export to File** to export only the selected bus objects, or **Export with Related Bus Objects to File** to also export any nested bus objects used by the selected objects.

4. Use the Export dialog box to export the selected bus object(s).

Clicking the **Export** icon in the toolbar is equivalent to choosing **File > Export**, which exports all bus objects whether or not any are selected.

Customizing Bus Object Export

You can customize bus object export by providing a custom function that writes the exported objects to something other than the default destination, a MATLAB code file or MAT-file stored in the file system. For example, the

exported bus objects could be saved as records in a corporate database. See "Customizing Bus Object Import and Export" on page 30-41 for details.

Importing Bus Objects

You can use the Bus Editor to import the definitions in a MATLAB code file or MAT-file to the base workspace. Importing the file imports the complete contents of the file, not just any bus objects that it contains. If you import a file not exported by the Bus Editor, be careful that it does not contain unwanted definitions previously exported from the base workspace or created programmatically.

To import bus objects from a file to the base workspace:

1. Choose **File > Import into Base Workspace**.
2. Use the Open File dialog box to navigate to and import the desired file.

Before importing the file, the Bus Editor posts a warning that importing the file will overwrite any variable in the base workspace that has the same name as an entity in the file. Click **Yes** or **No** as appropriate. The imported bus objects appear immediately in the editor. You can also use capabilities outside the Bus Editor to import bus objects. Such objects do not appear in the Bus Editor until the next time its window becomes the current window.

Customizing Bus Object Import

You can customize bus object import by providing a custom function that imports the objects from something other than the default source, a MATLAB code file or MAT-file stored in the file system. For example, the bus objects could be retrieved from records in a corporate database. See "Customizing Bus Object Import and Export" on page 30-41 for details.

Closing the Bus Editor

To close the Bus Editor, choose **File > Close**. Closing the Bus Editor neither saves nor discards changes to bus objects, which remain unaffected in the base workspace. However, if you also close MATLAB without saving changes to bus objects, the changes will be lost. To save bus objects without saving other base workspace contents, use the techniques described in "Exporting

Bus Objects" on page 30-31. You can also save bus objects using any MATLAB technique that saves the contents of the base workspace, but the resulting file will contain everything in the base workspace, not just bus objects.

You can configure the Bus Editor so that closing it posts a reminder to save bus objects. To enable the reminder, select **Options > Always Warn Before Closing**. When this option is selected and you try to close the Bus Editor, a reminder appears that asks whether the editor should save bus objects before closing. Click **Yes** to save bus objects and close, **No** to close without saving bus objects, or **Cancel** to dismiss the reminder and continue in the Bus Editor. You can disable the reminder by deselecting **Options > Always Warn Before Closing**.

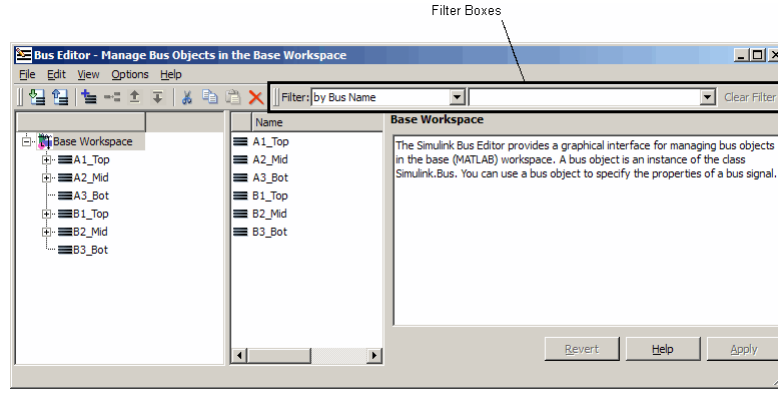
Filtering Displayed Bus Objects

In this section...

By default, the Bus Editor displays all bus objects that exist in the base workspace, always in alphabetical order. When a model contains large numbers of bus objects, seeing them all at the same time can be inconvenient. To facilitate working efficiently with large collections of bus objects, you can set the Bus Editor to display only bus objects that:

- Have names that match a given string or regular expression
- Have a specified relationship to a bus object specified by name

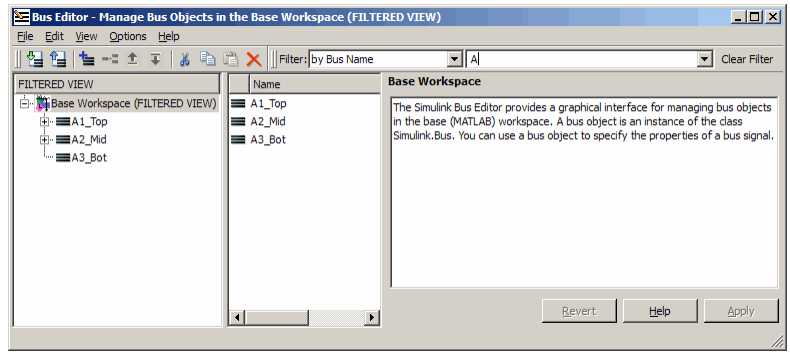
To set a filter, you specify values in the **Filter** boxes to the right of the tools in the toolbar. The left **Filter** box specifies the type of filtering. This box always appears, and is called the **Filter Type** box. Depending on the specified type of filtering, one or two boxes appear to the right of the **Filter Type** box. The next figure indicates the **Filter** boxes and shows that six bus objects exist in the Base Workspace:



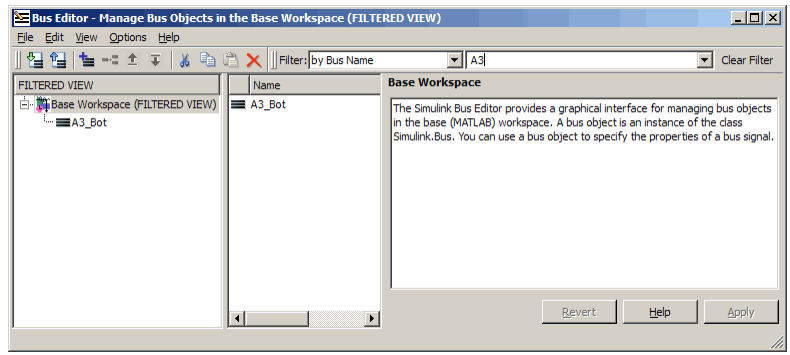
The bus objects shown form two disjoint hierarchies. `A1_Top` is the parent of `A2_Mid`, which is the parent of `A3_Bot`. Similarly, `B1_Top` > `B2_Mid` > `B3_Bot`. See "Nesting Buses" on page 30-9 for information about bus object hierarchies.

Filtering by Name

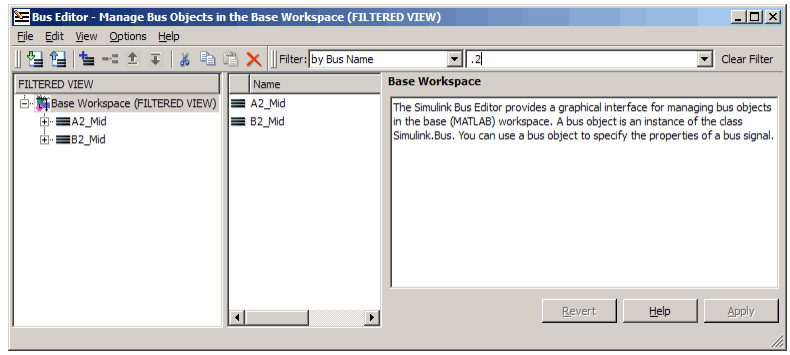
To filter bus objects by name, set the **Filter Type** box to `by Bus Name` (which is the default). The right **Filter** box is the **Object Name** box. Type any MATLAB regular expression (which can just be a string) into the **Object Name** box. As you type, the Bus Editor updates dynamically to show only bus objects whose names match the expression you have typed. The comparison is case-sensitive. For example, entering `A` displays:



Note that **FILTERED VIEW** appears in three locations, as shown in the preceding figure. This indicator appears whenever any filter is in effect. Entering the additional character `3` into the **Object Name** box displays:



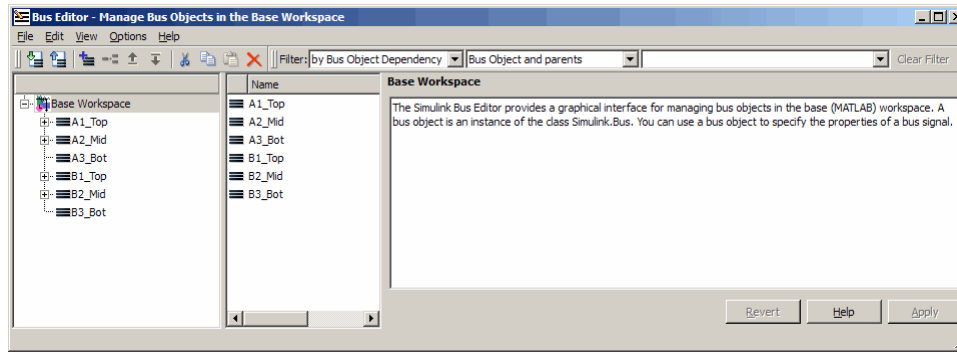
In a MATLAB regular expression, the metacharacter `dot` (.) matches any character, so entering `.2` displays:



See “Regular Expressions” for complete information about MATLAB regular expression syntax.

Filtering by Relationship

To filter bus objects by relationship, set the **Filter Type** box to `by Bus Object Dependency`. A third **Filter** box, called the **Relationship** box, appears between the **Filter Type** box and the **Object Name** box. You may have to widen the Bus Editor to see all three boxes:



In the **Relationship** box, select the type of relationship to display. The options are:

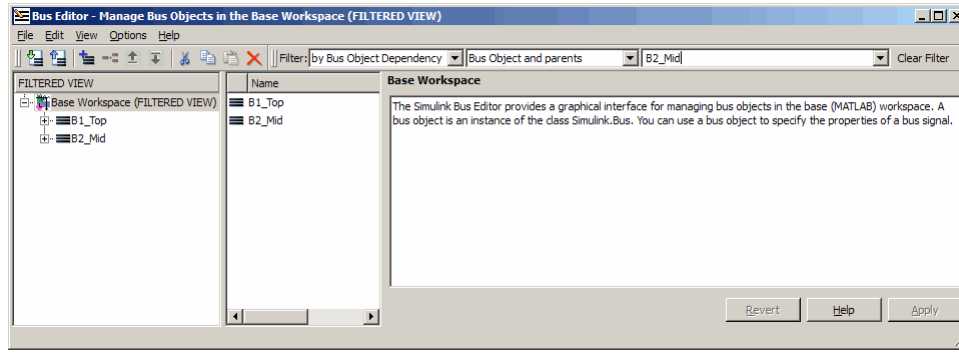
- `Bus Object and Parents` — Show a specified bus object and all superior bus objects in the hierarchy (default)
- `Bus Object and Dependents` — Show a specified bus object and all subordinate bus objects in the hierarchy
- `Bus Object and Related Objects` — Show a specified bus object and all superior and subordinate bus objects

In the **Object Name** box, specify a bus object by name. You can use the list to select any existing bus object name, or you can type a name. As you type, the editor:

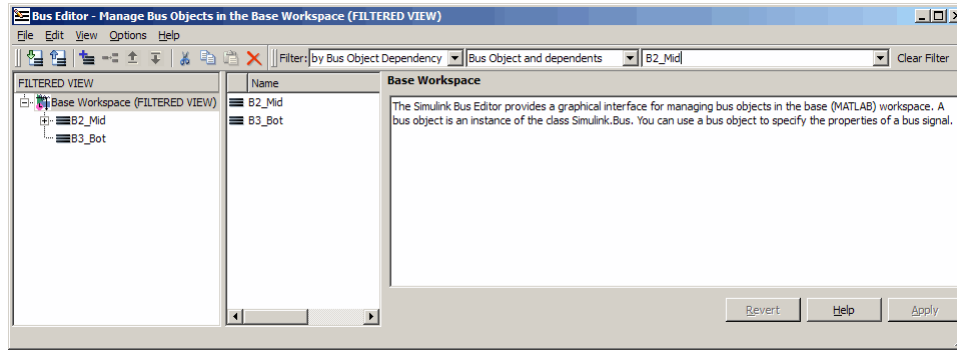
- Dynamically completes the field to indicate the first bus object that alphabetically matches what you have typed.
- Updates the display panes to show only that object and any objects that have the specified relationship to it.

When filtering by relationship, you must enter a string, not a regular expression, in the **Object Name** box. The match is case-sensitive. For example, assuming that `A1_Top` is the parent of `A2_Mid`, which is the parent of `A3_Bot` (as previously described) if you enter `B2` (or any leftmost substring that matches only `B2_Mid`) in the **Object Name** box, the Bus Editor displays the following for each of the three choices of relationship type:

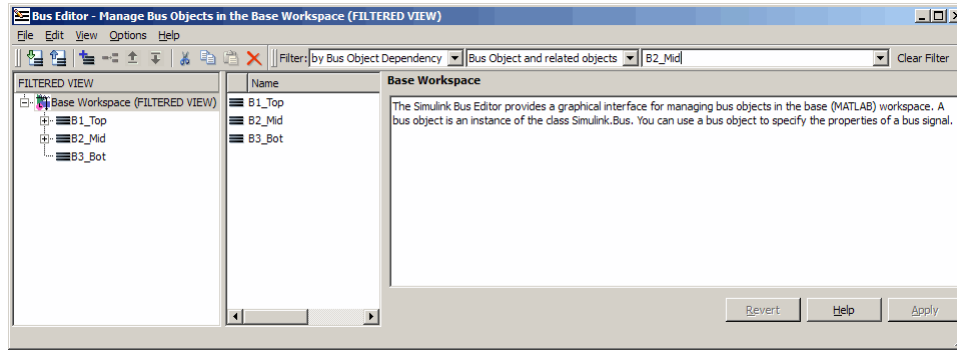
Bus Object and Parents



Bus Object and Dependents



Bus Object and Related Objects



Note that **FILTERED VIEW** appears in each the preceding figures, as it does when any filter is in effect.

Changing Filtered Objects

You can work with any bus object that is visible in a filtered display exactly as you could in an unfiltered display. If you change the name or dependency of an object so that it no longer passes the current filter, the object vanishes from the display. Conversely, if some activity outside the Bus Editor changes a filtered object so that it passes the current filter, the object immediately becomes visible.

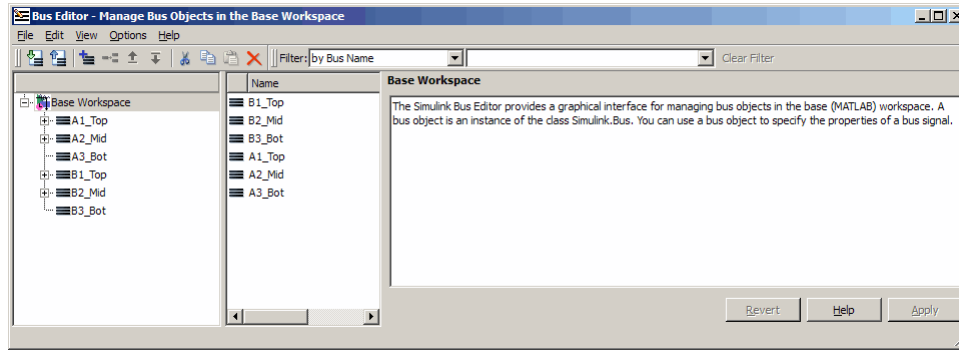
A new bus object created within the Bus Editor with a filter in effect may or may not appear, depending on the filter. If you create a new bus object but do

not see it in the editor, check the filter. The new object (whose name always begins with `BusObject`) may exist but be invisible. Bus objects created or imported using capabilities outside the Bus Editor are not visible until the Bus Editor window is next selected, regardless of whether a filter is in effect.

Operations performed on the root node **Base Workspace** in the Hierarchy pane, such as exporting bus objects, affect only visible objects. An object that is invisible because a filter is in effect is unaffected by the operation. If you want to export all existing bus objects, be sure to clear any filter that may be in effect before performing the export.

Clearing the Filter

To clear any filter currently in effect, click the **Clear Filter** button at the right of the Filter subpane, or press the **F5** key. The subpane reverts to its default state, in which all bus objects appear:



If you jump from a nested bus object to its source object by selecting the nested object and choosing **Go to '*`element`*'** from its Context menu, and the source object is invisible due to a filter, the Bus Editor automatically clears the filter and selects the source object. Jumping to an object that is already visible leaves the filter unchanged.

Customizing Bus Object Import and Export

In this section...

You can use the Bus Editor to import bus objects to the base workspace, as described in "Importing Bus Objects" on page 30-33, and to export bus objects from the base workspace, as described in "Exporting Bus Objects" on page 30-31. By default, the Bus Editor can import bus objects only from a MATLAB code file or MAT-file, and can export bus objects only to a MATLAB code file or MAT-file, with the files stored somewhere that is accessible using an ordinary **Open** or **Save** dialog.

Alternatively, you can customize the Bus Editor's import and export commands by writing MATLAB functions that provide the desired capabilities, and registering these functions using the Simulink Customization Manager. When a custom bus object import or export function exists, and you use the Bus Editor to import or export bus objects, the editor calls the custom import or export function rather than using its default capabilities.

A customized import or export function can have any desired effect and use any available technique. For example, rather than storing bus objects in MATLAB code files or MAT-files in the file system, you could provide customized functions that store the objects as records in a corporate database, perhaps in a format that also meets other corporate data management requirements.

This section describes techniques for designing and implementing a custom bus object import or export function, and for using the Simulink Customization Manager to register such a custom function. The registration process establishes the custom import and export functions as callbacks for the Bus Editor **Import to Base Workspace** and **Export to File** commands, replacing the default capabilities of the editor.

Customizing the Bus Editor's import and export capabilities has no effect on any MATLAB or Simulink API function: it affects only the behavior of the Bus Editor. You can customize bus object import, export, or both. You can establish, change, and cancel import or export customization at any time. Canceling import or export customization restores the default Bus Editor capabilities for that operation without affecting the other.

Prerequisites for Customization

To perform bus object import or export customization, you must understand:

- The MATLAB language and programming techniques that you will need. See *MATLAB Programming Fundamentals* and related MATLAB documentation for information about MATLAB programming.
- Simulink bus object syntax. See "About Bus Objects" on page 30-12, `Simulink.Bus`, `Simulink.BusElement`, and "Nesting Bus Definitions" on page 30-24.
- The proprietary format into which you will translate bus objects, and all techniques necessary to access the facility that stores the objects.
- Any platform-specific techniques needed to obtain data from the user, such as the name of the location in which to store or access bus objects.

The rest of the information that you will need, including all necessary information about the Simulink Customization Manager appears in this section. For complete information about the Customization Manager, see Chapter 32, "Customizing the Simulink User Interface".

Writing a Bus Object Import Function

A callback function that customizes bus import can use any MATLAB programming construct or technique. The function can take zero or more arguments, which can be anything that the function needs to perform its task. You can use functions, global variables, or any other MATLAB technique to provide argument values. The function can also poll the user for information, such as a designation of where to obtain bus object information. The general algorithm of a custom bus object import function is:

1. Obtain bus object information from the local repository.

2 Translate each bus object definition to a Simulink bus object.

3 Save each bus object to the MATLAB base workspace.

An example of the syntactic shell of an import callback function is:

```
function myImportCallBack
disp('Custom import was called!');
```

Although this function does not import any bus objects, it is syntactically valid and could be registered with the Simulink Customization Manager. A real import function would somehow obtain a designation of where to obtain the bus object(s) to import; convert each one to a Simulink bus object; and store the object in the base workspace. The additional logic needed is enterprise-specific.

Writing a Bus Object Export Function

A callback function that customizes bus export can use any MATLAB programming construct or technique. The function must take one argument, and can take zero or more additional arguments, which can be anything that the function needs to perform its task. When the Bus Editor calls the function, the value of the first argument is a cell array containing the names of all bus objects selected within the editor to be exported. You can use functions, global variables, or any other MATLAB technique to provide values for any additional arguments. The general algorithm of a customized export function is:

1 Iterate over the list of object names in the first argument.

2 Obtain the bus object corresponding to each name.

3 Translate the bus object to the proprietary syntax.

4 Save the translated bus object in the local repository.

An example of the syntactic shell of such an export callback function is:

```
function myExportCallBack(selectedBusObjects)
disp('Custom export was called!');
for idx = 1:length(selectedBusObjects)
```

```
    disp([selectedBusObjects{idx} ' was selected for export.']);
end
```

Although this function does not export any bus objects, it is syntactically valid and could be registered. It accepts a cell array of bus object names, iterates over them, and prints each name. A real export function would use each name to retrieve the corresponding bus object from the base workspace; convert the object to proprietary format; and store the converted object somewhere. The additional logic needed is enterprise-specific.

Registering Customizations

To customize bus object import or export, you provide a *customization registration function* that inputs and configures the Customization Manager whenever you start the Simulink software or subsequently refresh Simulink customizations. The steps for using a customization registration function are:

1. Create a file named `sl_customization.m` to contain the customization registration function (or use an existing customization file).
2. At the top of the file, create a function named `sl_customization` that takes a single argument (or use the customization function in an existing file). When the function is invoked, the value of this argument will be the Customization Manager.
3. Configure the `sl_customization` function to set `importCallbackFcn` and `exportCallbackFcn` to be function handles that specify your customized bus object import and export functions.
4. If `sl_customization.m` is a new customization file, put it anywhere on the MATLAB search path. Two frequently-used locations are `matlabroot` and the current working directory; or you may want to extend the search path.

A simple example of a customization registration function is:

```
function sl_customization(cm)
disp('My customization file was loaded.');
cm.BusEditorCustomizer.importCallbackFcn = @myImportCallBack;
cm.BusEditorCustomizer.exportCallbackFcn = @(x)myExportCallBack(x);
```

When the Simulink software starts up, it traverses the MATLAB search path looking for files named `sl_customization.m`. The software loads each such file that it finds (not just the first file) and executes the `sl_customization` function at its top, establishing the customizations that the function specifies.

Executing the previous customization function will display a message (which an actual function probably would not) and establish that the Bus Editor uses a function named `myImportCallBack()` to import bus objects, and a function named `myImportCallBack(x)` to export bus objects.

The function corresponding to a handle that appears in a callback registration need not be defined when the registration occurs, but it must be defined when the Bus Editor later calls the function. The same latitude and requirement applies to any functions or global variables used to provide the values of any additional arguments.

Other functions can also exist in the `sl_customization.m` file. However, the Simulink software ignores files named `sl_customization.m` except when it starts up or refreshes customizations, so any changes to functions in the customization file will be ignored until one of those events occurs. By contrast, changes to other MATLAB code files on the MATLAB path take effect immediately.

Changing Customizations

You can change the handles established in the `sl_customization` function by changing the function to specify the changed handles, saving the function, then refreshing customizations by executing:

```
sl_refresh_customizations
```

The Simulink software then traverses the MATLAB path and reloads all `sl_customization.m` files that it finds, executing the first function in each one, just as it did on Simulink startup.

You can revert to default import or export behavior by setting the appropriate `BusEditorCustomizer` element to `[]` in the `sl_customization` function, then refreshing customizations. Alternatively, you can eliminate both customizations in one operation by executing:

```
cm.BusEditorCustomizer.clear
```

where `cm` was previously set to a customization mananager object (see "Registering Customizations" on page 30-44).

Changes to the import and export callback functions themselves, as distinct from changes to the handles that register them as customizations, take effect immediately unless they are in the `sl_customization.m` file itself, in which case they take effect next time you refresh customizations. Keeping the callback functions in separate files usually provides more flexible and modular results.

Using the Bus Object API

The Simulink software provides all Bus Editor capabilities programmatically. Many of these capabilities, like importing and exporting MATLAB code files and MAT-files, are not specific to bus objects, and are described elsewhere in the MATLAB and Simulink documentation.

The classes that implement bus objects are:

`Simulink.Bus`
: Specify the properties of a signal bus

`Simulink.BusElement`
: Describe an element of a signal bus

The functions that create and save bus objects are:

`Simulink.Bus.createObject`
: Create bus objects for blocks, optionally saving them in a MATLAB file in a specified format

`Simulink.Bus.cellToObject`
: Convert a cell array containing bus information to bus objects in the base workspace

`Simulink.Bus.objectToCell`
: Convert bus objects in the base workspace to a cell array containing bus information

`Simulink.Bus.save`
: Export specified bus objects or all bus objects from the base workspace to a MATLAB file in a specified format

`Simulink.Bus.createMATLABStruct`
: Create MATLAB structure with same hierarchy, names, and attributes as the bus signal

In addition, when you use `Simulink.SubSystem.convertToModelReference` to convert an atomic subsystem to a referenced model, you can save any bus objects created during the conversion to a MATLAB file.

Virtual and Nonvirtual Buses

In this section...

Introduction

A bus signal can be *virtual*, meaning that it is just a graphical convenience that has no functional effect, or *nonvirtual*, meaning that the signal occupies its own storage. During simulation, a block connected to a virtual bus reads inputs and writes outputs by accessing the memory allocated to the component signals. These signals are typically noncontiguous, and no intermediate memory exists. Simulation results and generated code are exactly the same as if the bus did not exist, which functionally it does not.

By contrast, a block connected to a nonvirtual bus reads inputs and writes outputs by accessing copies of the component signals. The copies are maintained in a contiguous area of memory allocated to the bus. Such a bus is represented by a structure in generated code, which can be helpful when tracing the correspondence between the model and the code.

Compared with nonvirtual buses, virtual buses reduce memory requirements because they do not require a separate contiguous storage block, and execute faster because they do not require copying data to and from that block. Not all blocks can accept buses. See "Bus-Capable Blocks" on page 30-11 for more about which blocks can handle which types of buses. Virtual buses are the default except where nonvirtual buses are explicitly required. See "Connecting Buses to Inports and Outports" on page 30-51 for more information.

Creating Nonvirtual Buses

Bus signals do not specify whether they are virtual or nonvirtual; they inherit that specification from the block in which they originate. Every block that

creates or requires a nonvirtual bus must have an associated bus object. Those blocks are:

- Bus Creator
- Inport
- Outport

To specify that a bus is nonvirtual:

1. Associate the block with a bus object, as described in "Associating Bus Objects with Simulink Blocks" on page 30-13.
2. Open the **Block Parameters** dialog of the Bus Creator, Inport, or Outport block.
3. Set **Data type** to `Bus: <object name>` and replace `<object name>` with the bus object name.
4. Click **OK** or **Apply**.

The **Signal Attributes** parameter is applicable only to root Inport and Outport blocks, and does not appear in the parameters of a subsystem Inport or Outport block. In a root Outport block, setting **Signal Attributes > Output as nonvirtual bus in parent model** specifies that the bus emerging in the parent model is nonvirtual. The bus that is input to the root Outport can be virtual or nonvirtual.

Nonvirtual Bus Sample Times

All signals in a nonvirtual bus must have the same sample time, even if the elements of the associated bus object specify inherited sample times. Any bus operation that would result in a nonvirtual bus that violates this requirement generates an error.

All buses and signals input to a Bus Creator block that outputs a nonvirtual bus must therefore have the same sample time. You can use a Rate Transition block to change the sample time of an individual signal, or of all signals in a bus, to allow the signal or bus to be included in a nonvirtual bus.

Automatic Bus Conversion

When updating a diagram prior to simulation or code generation, the Simulink software automatically converts virtual buses to nonvirtual buses where the conversion is possible and prevents an error. For example, referenced models and Stateflow charts require any bus connected to them to be nonvirtual.

The conversion consists of inserting hidden Signal Conversion blocks into the model where needed. You can eliminate the need for the automatic conversion by specifying a nonvirtual bus in the block where the bus originates, or by inserting explicit Signal Conversion blocks. The latter is generally unnecessary, but can be useful to clarify the model.

The source block of any virtual bus that is converted to a nonvirtual bus, whether explicitly or automatically, must specify a bus object, as described in "Using Bus Objects" on page 30-12. Conversion to a nonvirtual bus fails if no bus object is specified, and the Simulink software posts an error message describing the problem.

Connecting Buses to Inports and Outports

In this section...

Connecting Buses to Root Level Inports

If you want a root level Inport of a model to produce a bus signal, in the Inport block parameters dialog box, set **Data type** to `Bus: <object name>` and replace `<object name>` with the name of the bus object name that defines the bus that the Inport produces. See "Using Bus Objects" on page 30-12 for more information.

Connecting Buses to Root Level Outports

A root level Outport of a model can accept a virtual bus only if all elements of the bus have the same data type. The Outport block automatically unifies the bus to a vector having the same number of elements as the bus, and outputs that vector.

If you want a root level Outport of a model to accept a bus signal that contains mixed types, in the Outport block parameters dialog box, set **Data type** to `Bus: <object name>` and replace `<object name>` with the name of the bus object name that defines the bus that the Inport produces. If the bus signal is virtual, it will be converted to nonvirtual, as described in "Automatic Bus Conversion" on page 30-50. See "Using Bus Objects" on page 30-12 more information.

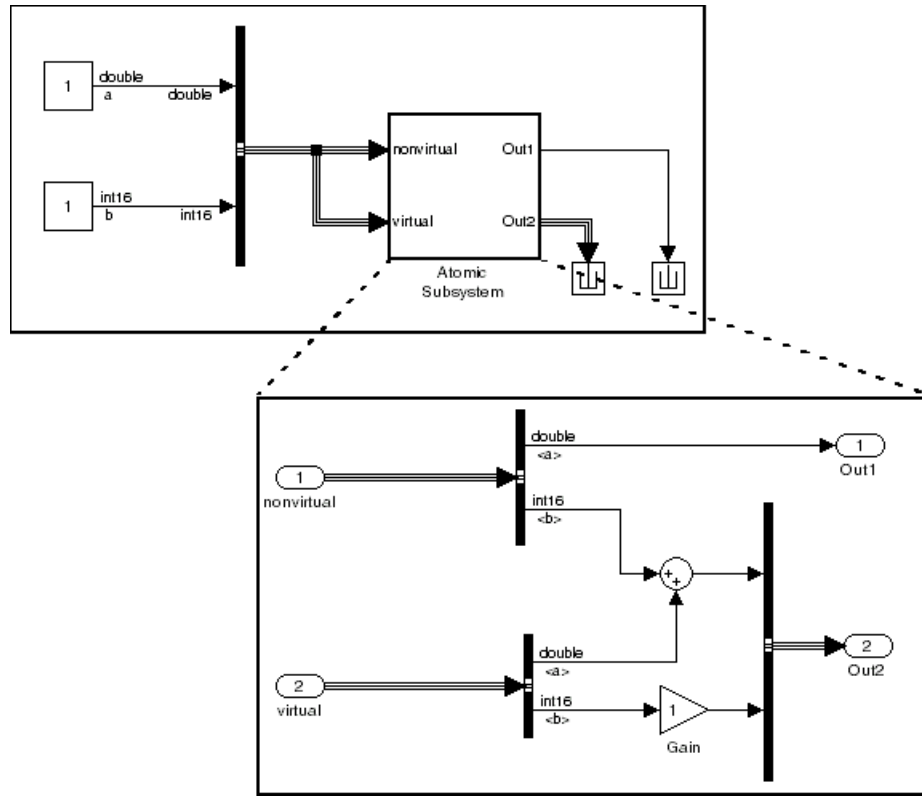
An Outport in a conditionally executed subsystem that is connected to a bus that contains mixed data types cannot be configured to reset and have initial values specified.

Connecting Buses to Nonvirtual Inports

By default, an Inport block is a virtual block and accepts a bus as input. However, an Inport block is nonvirtual if it resides in a conditionally executed or atomic subsystem, or a referenced model, and it or any of its components is directly connected to an output of the subsystem or model. In such a case, the Inport block can accept a bus only if all elements of the bus have the same data type.

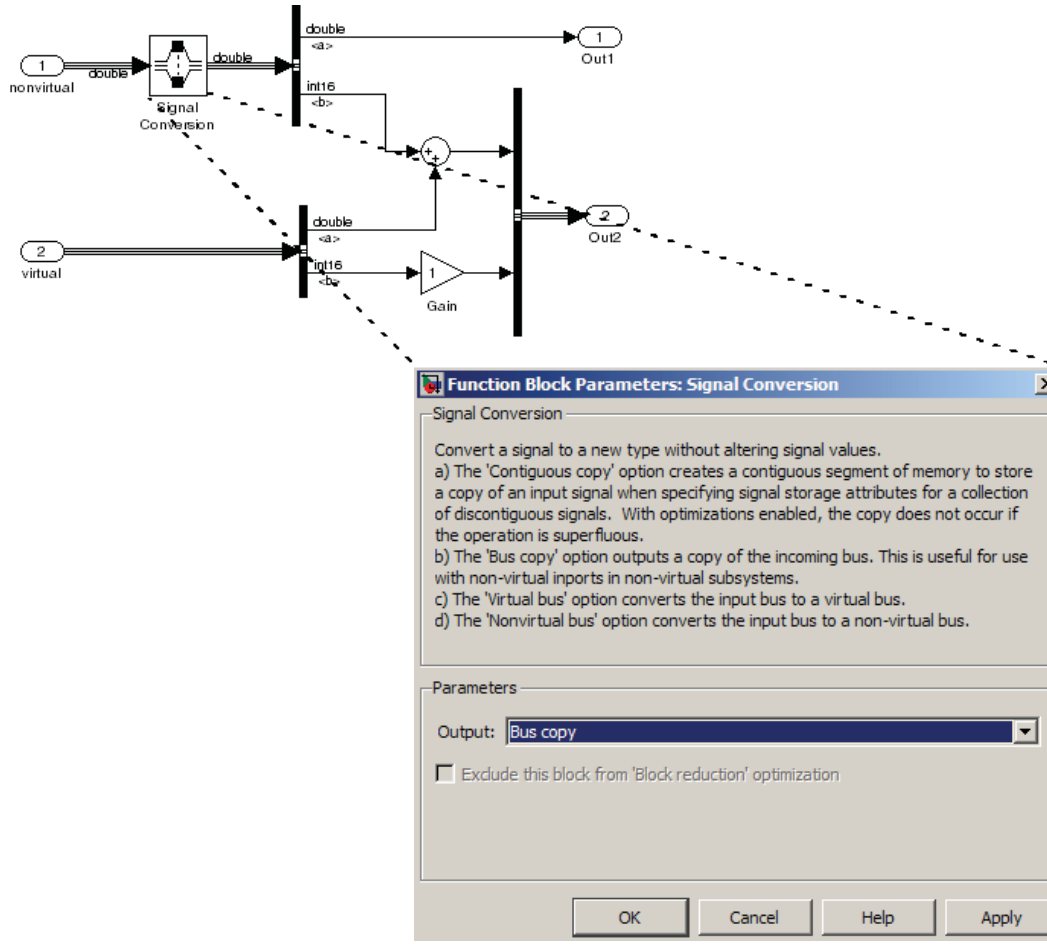
If the components are of differing data types, attempting to simulate the model causes the Simulink software to halt the simulation and display an error message. You can avoid this problem, without changing the semantics of your model, by inserting a Signal Conversion block between the Inport block and the Outport block to which it was originally connected.

For example, consider the following model:



In this model, the Inport labeled `nonvirtual` is nonvirtual because it resides in an atomic subsystem and one of its components (labeled `a`) is directly connected to one of the subsystem's outputs. Further, the bus connected to the subsystem's inputs has components of differing data types. As a result, this model cannot be simulated.

Inserting a Signal Conversion block with the `bus copy`option selected breaks the direct connection to the subsystem's output and thereby enables the Simulink software to simulate the model.



Connecting Buses to Model, Stateflow, and Embedded MATLAB Blocks

Referenced models, Stateflow charts, and Embedded MATLAB blocks require any bus connected to them to be nonvirtual. To provide for this requirement, where possible the Simulink software automatically converts any virtual bus connected to a Model block or Stateflow chart to a nonvirtual bus. See “Automatic Bus Conversion” on page 30-50 for details.

Connecting Multi-Rate Buses to Referenced Models

In a model that uses a fixed-rate solver, referenced models can input only single-rate buses. However, you can input the signals in a multi-rate bus to a referenced model by inserting blocks into the parent and referenced model as follows:

1. **In the parent model:** Insert a Rate Transition block to convert the multi-rate bus to a single-rate bus. The Rate Transition block must specify a rate in its **Block Parameters > Output port sample time** field unless one of the following is true:
   - The **Configuration Parameters > Solver** pane specifies a rate:
     - **Periodic sample time constraint** is `Specified`
     - **Sample time properties** contains the specified rate.
   - The Inport that accepts the bus in the referenced model specifies a rate in its **Block Properties > Signal Attributes > Sample time** field.
2. **In the referenced model:** Use a Bus Selector block to pick out signals of interest, and use Rate Transition blocks to convert the signals to the desired rates.

Specifying Initial Conditions for Bus Signals

In this section...

Bus Signal Initialization

Bus signal initialization is a special kind of signal initialization. For general information about initializing signals, see "Initializing Signals and Discrete States" on page 29-54.

Bus signal initialization specifies the bus element values that Simulink uses for the first execution of a block that uses that bus signal. By default, the initial value for a bus element is the ground value (represented by `0`). Bus initialization, as described in this section, involves specifying nonzero initial conditions (ICs).

You can use bus signal initialization features to:

- Specify initial conditions for signals that have different data types
- Apply a different initial condition for each signal in the bus
- Specify initial conditions for a subset of signals in a bus without specifying initial conditions for all the signals
- Use the same initial conditions for multiple blocks, signals, or models

Blocks that Support Bus Signal Initialization

You can initialize bus signal values that input to a block, if that block meets both of these conditions:

- It has an initial value or initial condition block parameter
- It supports bus signals

The following blocks support bus signal initialization:

- Memory
- Merge
- Outport (when the block is inside a conditionally executed context)
- Rate Transition
- Unit Delay

For example, the Unit Delay block is a bus-capable block and the Block Parameters dialog box for the Unit Delay block has an **Initial conditions** parameter.

Initialization Is Not Supported for Bus Signals with Variable-Size or Frame-Based Elements

You cannot initialize a bus that has:

- Variable-size signals
- Frame-based signals

Workflow for Initializing Bus Signals Using Initial Condition Structures

You need to set up your model properly to use initial condition structures to initialize bus signals. The general workflow involves the tasks listed in the following table. You can vary the order of the tasks, but before you update the diagram or run a simulation, you need to ensure your model is set up properly.

Task	Documentation
Define an IC structure	"Creating Initial Condition (IC) Structures" on page 30-58
Use an IC structure to specify a nonzero initial condition.	"Three Ways to Initialize Bus Signals Using Block Parameters" on page 30-62
Set Configuration Parameters dialog box diagnostics	"Setting Diagnostics to Support Bus Signal Initialization" on page 30-65

Creating Initial Condition (IC) Structures

You can create partial or full IC structures to represent initial values for a bus signal. Create an IC structure by either:

- Defining a MATLAB structure in the MATLAB base or Simulink model workspace
- Specifying an expression that evaluates to a structure for the initial condition parameter in the Block Parameters dialog box for a block that supports bus signal initialization

See "Structures" in the MATLAB documentation for information about defining MATLAB structures.

Full and Partial IC Structures

A full IC structure provides an initial value for every element of a bus signal. This IC structure mirrors the bus hierarchy and reflects the attributes of the bus elements.

A partial IC structure provides initial values for a subset of the elements of a bus signal. If you use a partial IC structure, during simulation, Simulink creates a full IC structure to represent all of the bus signal elements, assigning the respective ground value to each element for which the partial IC structure does not explicitly assign a value.

Specifying partial structures for block parameter values can be useful during the iterative process of creating a model. Partial structures enable you to focus on a subset of signals in a bus. When you use partial structures, Simulink initializes unspecified signals implicitly.

Specifying full structures during code generation offers these advantages:

- Generates more readable code
- Supports a modeling style that explicitly initializes all signals

Match IC Structure Values to Corresponding Bus Element Data Characteristics

The field that you specify in an IC structure must match the following data attributes of the bus element exactly:

- Name
- Data type
- Dimension
- Complexity

For example, if you define a bus element to be a real [2x2] double array, then in the IC structure, define the value to initialize that bus element to be a real [2x2] double array.

You must explicitly specify fields in the IC structure for every bus element that has an enumerated (`enum`) data type.

When you define a partial IC structure:

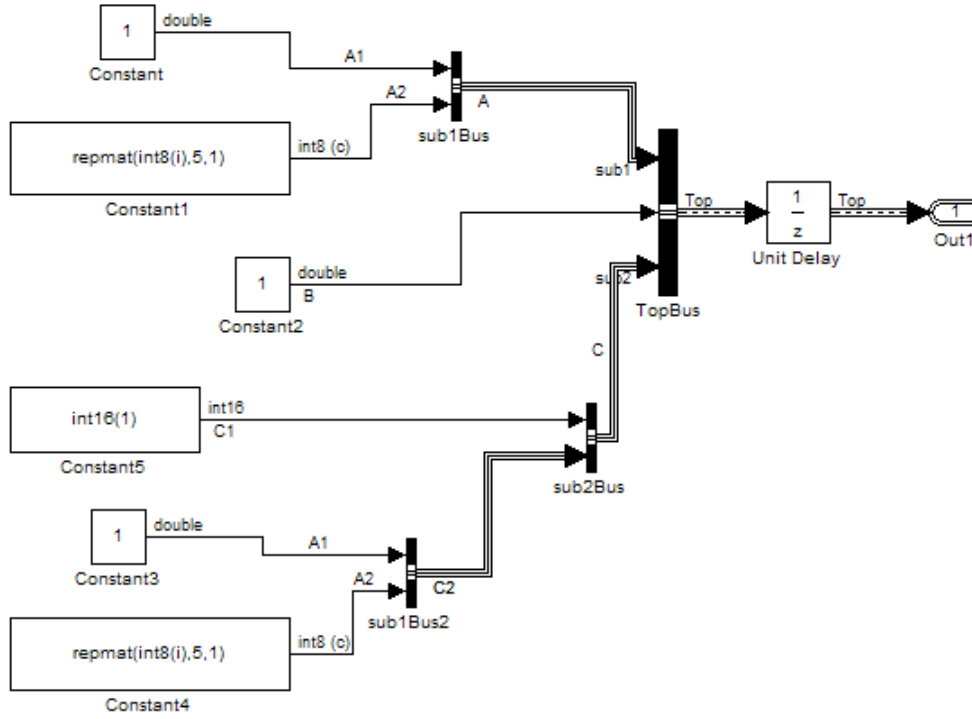
- Include only fields that are in the bus.
- You can omit fields that are in the bus.
- Make the field in the IC structure correspond to the nesting level of the bus element.
- Within the same nesting level in both the structure and the bus, you can specify the structure fields in a different order than the order of the elements in the bus.

Examples of Partial Structures

Suppose you have a bus, `Top`, composed of three elements: `A`, `B`, and `C`, with these characteristics:

- `A` is a nested bus, with two signal elements.
- `B` is a single signal.
- `C` is a nested bus that includes bus `A` as a nested bus.

The following model, `busic_example` includes the nested `Top` bus. The screen capture below shows the model after it has been updated.



The following diagram summarizes the `Top` bus hierarchy and the data type, dimension, and complexity of the bus elements .

```
Top
   A (sub1)
      A1 (double)
      A2 (int8, 5x1, complex)
   B (double)
   C (sub2)
      C1 (int16)
      C2 (sub1)
         A1 (double)
         A2 (int8, 5x1, complex)
```

Valid partial IC structures. In the following examples, `K` is an IC structure specified for the initial value of the Unit Delay block. The IC structure corresponds to the `Top` bus in the `busic_example` model discussed in the preceding section.

These three initial condition specifications are valid:

`K.A.A1 = 3`
Bus element `Top.A.A1` is double; the corresponding structure field is `3`, which is a double.

`K = struct('C',struct('C1',int16(4)))`
Matching data types can require you to cast types. Bus element `Top.C.C1` is `int16`. The corresponding structure field explicitly specifies `int16(4)`.

`K = struct('B',3,'A',struct('A1',4))`
Bus element `Top.B` and `Top.A` are at the same nesting level in the bus. For bus elements at the same nesting level, the order of corresponding structure fields does not matter.

Invalid partial IC structures. In the following examples, `K` is an IC structure specified for the initial value of the Unit Delay block. The IC structure corresponds to the `Top` bus in the `busic_example` model discussed in the preceding section.

These three initial condition specifications are *not* valid:

`K.A.A2 = 3`
Value data type, dimension, and complexity do not match. `Top.A.A2` is an `int8`, but `K.A.A2` is a double; `Top.A.A2` is `5x1`, but `K.A.A2` is `1x1`; `Top.A.A2` is complex, but `K.A.A2` is real.

`K.C.C2 = 3`
You cannot use a scalar to initialize IC substructures.

```
K = struct('B',3,'X',4)
```

You cannot specify fields that are not in the bus (`X` does not exist in the bus).

Creating Full IC Structures Using Simulink.Bus.createMATLABStruct

Use the `Simulink.Bus.createMATLABStruct` function to streamline the process of creating a full MATLAB initial condition structure with the same hierarchy, names, and data attributes as a bus signal. This function fills all the elements that you do not specify with the ground values for those elements.

You can use several different kinds of input with the `Simulink.Bus.createMATLABStruct` function, including

- A bus object name
- An array of port handles

See the `Simulink.Bus.createMATLABStruct` documentation for details.

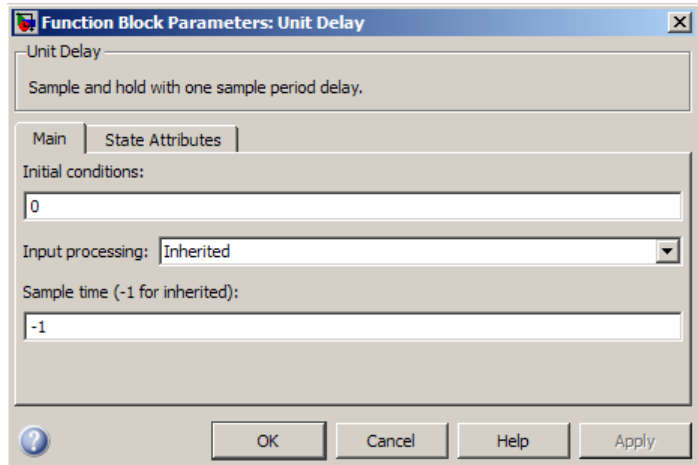
Using Model Advisor to Check for Partial Structures

To detect when structure parameters are not consistent in shape (hierarchy and names) with the associated bus signal, in the Model Editor, use the **Tools > Model Advisor > By Product > Simulink** "Check for partial structure parameter usage with bus signals" check. This check identifies partial IC structures.

Three Ways to Initialize Bus Signals Using Block Parameters

You initialize a bus signal by setting the initial condition parameter for a block that receive a bus signal as input and that supports bus initialization (see "Blocks that Support Bus Signal Initialization" on page 30-56).

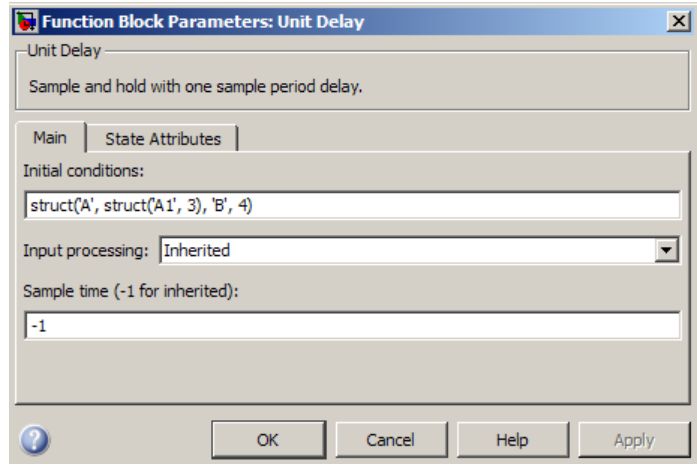
For example, the Block Parameters dialog box for the Unit Delay block has an **Initial conditions** parameter.



For a block that supports bus signal initialization, you can replace the default value of `0` with:

- A MATLAB structure that explicitly defines the initial conditions for the bus signal.

  For example, in the **Initial conditions** parameter of the Unit Delay block, you could type in a structure such as shown below:

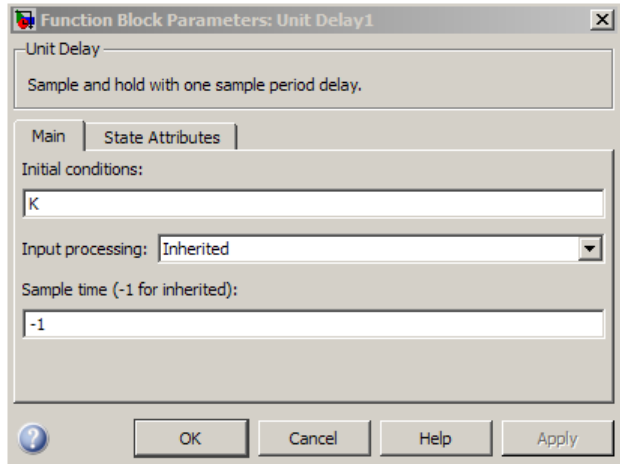


- A MATLAB variable that you define as an IC structure with the appropriate values.

  For example, you could define the following partial structure in the base workspace:

  ```
  K = struct('A', struct('A1', 3), 'B', 4);
  ```

  You can then specify the `K` structure as the **Initial conditions** parameter of the Unit Delay block:

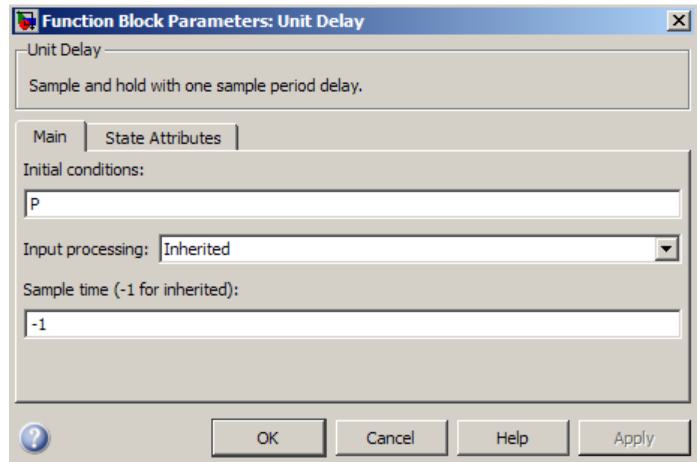


- A `Simulink.Parameter` object that uses an IC structure for the `Value` property

  For example, you could define the partial structure `P` in the base workspace (reflecting the `busic` model discussed in the previous section):

  ```
  P = Simulink.Parameter;
  P.Datatype = 'Bus: Top';
  P.Value = Simulink.Bus.createMATLABStruct('Top');
  P.Value.A.A1 = 3;
  P.Value.B = 5;
  ```

  You can then specify the `P` structure as the **Initial conditions** parameter of the Unit Delay block:



All three approaches require that you define an IC structure (see "Creating Initial Condition (IC) Structures" on page 30-58). You cannot specify a nonzero scalar value or any other type of value other than `0`, an IC structure, or `Simulink.Parameter` object to initialize a bus signal.

Defining an IC structure as a MATLAB variable, rather than specifying the IC structure directly in the block parameters dialog box offers several advantages, including:

- Reuse of the IC structure for multiple blocks
- Using the IC structure as a tunable parameter during simulation

You can tune the value of a `Simulink.Parameter` object during simulation.

Setting Diagnostics to Support Bus Signal Initialization

To enable bus signal initialization, before you start a simulation, set the following two Configuration Parameter diagnostics as indicated:

- In the **Configuration Parameters > Diagnostics > Connectivity** pane, set "Mux blocks used to create bus signals" to `error`.

- **Configuration Parameters > Diagnostics > Data Validity** pane, set "Underspecified initialization detection" to `simplified`.

The documentation for these diagnostics explains how convert your model to handle error messages the diagnostics generate.

Combining Buses into an Array of Buses

In this section...

What Is an Array of Buses?

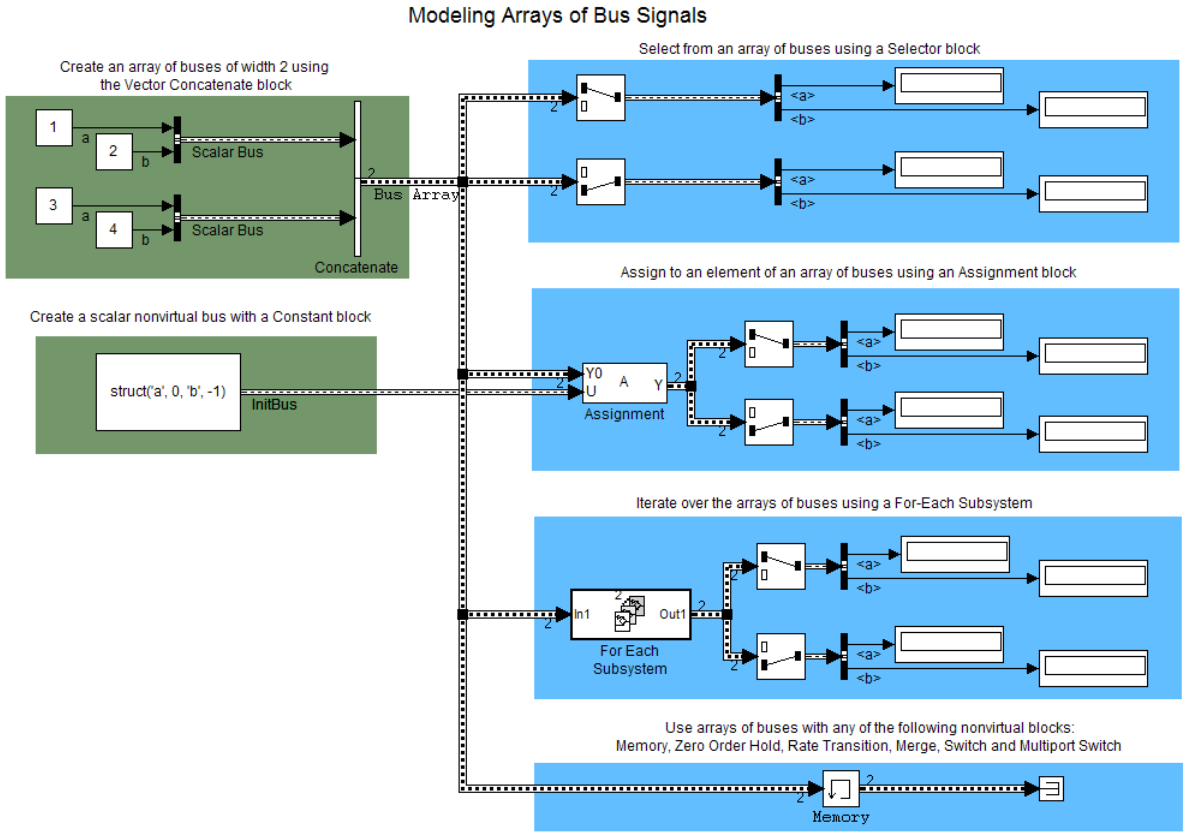
An array of buses is an array whose elements are buses. Each element in an array of buses must be nonvirtual and must have the same bus type. (That is, each bus object has the same signal name, hierarchy, and attributes for its bus elements).

An example of using an array of buses is to model a multi-channel communication system. You can model all the channels using the same bus object, although each of channels could have a different value.

Using arrays of buses involves:

- Using a bus object as a data type (See "Specifying a Bus Object Data Type" on page 25-27.)
- Working with arrays (See "More About Matrices and Arrays"

To see an example of a model that uses an array of buses, open the `sldemo_bus_arrays` demo. In this demo, the nonvirtual bus input signals connect to a Concatenate block that creates an array of bus signals. When you update the diagram, the demo model looks like the following figure:



The model uses the array of buses with:

- An Assignment block, to assign a bus in the array
- A For Each Subsystem block, to perform iterative processing over each bus in the array
- A Memory block, to output the array of buses input from the previous time step

For additional background about when to use arrays of buses, see:

- “Benefits an Array of Buses” on page 30-69
- “Blocks That Support Arrays of Buses” on page 30-70

For details about working with an array of buses, see:

For information about converting an existing model to use an array of buses, see "Converting a Model to Use an Array of Buses" on page 30-79.

Benefits an Array of Buses

Using an array of buses allows you to replace buses of arrays and buses of identical buses. Using an array of buses provides these benefits:

- Represents structured data compactly
  - Reduces model complexity
  - Reduces maintenance by centralizing algorithms used for processing multiple buses
- Streamlines iterative processing of multiple buses of the same type, for example, by using a For Each Subsystem with the array of buses
- Makes it easier for you to change the number of buses, without your having to restructure the rest of the model or make updates in multiple places in the model
- Allows models to use built-in blocks, such as the Assignment or Selector blocks, to manipulate arrays of buses just like arrays of any other type, rather than your creating custom S-functions to manage packing and unpacking structure signals
- Supports using the combined bus data across subsystem boundaries, model reference boundaries, and into or out of an Embedded MATLAB Function block
- Allows you to keep all the logic in the Simulink model, rather than splitting the logic between C code and the Simulink model

  - Supports integrated consistency and correctness checking, maintaining metadata in the model, and avoids your keeping track of model components in two different environments
- Generated code has an array of C structures that you can integrate with legacy C code that uses arrays of structures:
  - Makes it easier to index into an array for Simulink computations, using a `for` loop on indexed structures

Blocks That Support Arrays of Buses

The following blocks support arrays of buses:

- Virtual blocks (see "Virtual Blocks" on page 18-2)
- These bus-related blocks:
  - Bus Assignment
  - Bus Creator
  - Bus Selector
- These nonvirtual blocks:
  - Merge
  - Multiport Switch
  - Rate Transition
  - Switch
  - Zero-Order Hold
- Assignment
- Embedded MATLAB Function
- Matrix Concatenate
- Selector
- Vector Concatenate
- Width
- Two-Way Connection (a SimscapeSimscape block)

For requirements for using some of these blocks with arrays of buses, see "Block Limitations" on page 30-72.

Array of Buses Limitations

Bus Limitations

The buses that you combine into an array must all:

- Be nonvirtual
- Have the same bus type (that is, same name, hierarchies, and attributes for the bus elements)
- Have no variable-size signals or frame-based signals

Structure Parameter Limitations

The following limitations apply to using structure parameters with an array of buses.

You can use:

- `0` as an initial condition for an array of buses
- A scalar `struct` that represents the same hierarchy and names as the array of buses

You *cannot* use:

- Partial structures
- An array of structures
- A structure parameter for an array of buses that has an element that is an array of buses

For more information, see "Specifying Initial Conditions for Bus Signals" on page 30-56.

Set Strict Bus Handling Diagnostic to Error

Before you run simulation on a model that uses an array of buses, in the **Configuration Parameters > Diagnostics > Connectivity** pane, set **Mux blocks used to create bus signals** to `error`.

Block Limitations

The following table describes the block parameter setting limitations for blocks that support arrays of buses. This information is also in the reference pages for each of these blocks.

Block	Block Parameters Limitations
Memory	**Initial condition** — Only this parameter (which may be, but does not have to be, a structure) is scalar-expanded to match the dimensions of the array of buses.
Merge	• **Allow unequal port widths** — Clear this parameter. • **Number of inputs** — Set to a value of 2 or greater. • **Initial condition** — Only this parameter (which may be, but does not have to be, a structure) is scalar-expanded to match the dimensions of the array.
Multiport Switch	**Number of data ports** — Set to a value of 2 or greater.
Signal Conversion	**Output** — Set to `Bus copy`.
Switch	**Threshold** — Specify a scalar threshold.

Simulink Feature Limitations

You cannot:

- Log an array of buses signal
- Import data from or export data to an array of buses.

Stateflow Limitations

Stateflow action language does not support arrays of buses.

Defining an Array of Buses

For information about the kinds of buses that you can combine into an array of buses, see "Bus Limitations" on page 30-71.

Using a Concatenate Block to Define an Array of Buses

To define an array of buses, use a Concatenate block. The table describes the array of buses input requirements and output for each of the Vector Concatenate and the Matrix Concatenate versions of the Concatenate block.

Block	Bus Signal Input Requirement	Output
Vector Concatenate	Vectors, row vectors, or columns vectors	If any of the inputs are row or column vectors, row or column vector
Matrix Concatenate	Signals of any dimensionality (scalars, vectors, and matrices)	Trailing dimensions are assumed to be 1 for lower dimensionality inputs. Concatenation is on the dimension that you specify with the **Concatenate dimension** parameter.

To use a Concatenate block to define an array of buses, see "How to Define an Array of Buses" on page 30-74.

Note Do not use a Mux block or a Bus Creator block to define an array of buses. Instead, use a Bus Creator block to create scalar bus signals.

How to Define an Array of Buses

1. Define one bus object to use for all the bus signals that you want to combine into an array of buses. For information about defining bus objects, see "Creating Bus Objects" on page 30-18.

   The `sldemo_bus_arrays` demo defines an `sldemo_bus_arrays_busobject` bus object, which the Bus Creator blocks use for the input bus signals (`Scalar Bus`) for the array of buses.

2. Add a Vector Concatenate or Matrix Concatenate block to the model and open the block parameters dialog box for the block.

   The `sldemo_bus_arrays_busobject` demo uses a Vector Concatenate block, because the inputs are scalars.

3. Set the **Number of inputs** parameter to be the number of buses that you want to be in the array of buses.

   The block icon displays the number of input ports that you specify.

4. Set the **Mode** parameter to match the type of the input bus data.

   In the `sldemo_bus_arrays` demo, the input bus data is scalar, so the **Mode** setting is `Vector`.

5. If you use a Matrix Concatenation block, set the **Concatenate dimension** parameter to specify the output dimension along which to concatenate the input arrays. Enter one of the following values:

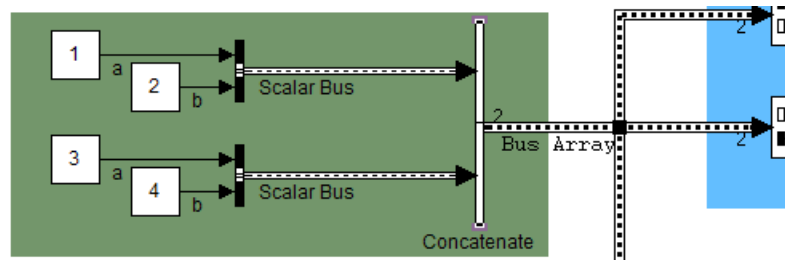
   - `1` to concatenate input arrays vertically
   - `2` to concatenate input arrays horizontally
   - A higher dimension than 2, to perform multidimensional concatenation on the inputs

6. Connect the buses that you want to be in the array of buses to the Concatenate block.

Signal Line Style for an Array of Buses

After you create an array of buses and update the diagram, the line style for the array of buses signal is a thicker version of the signal line style for a nonvirtual bus signal.

For example, in the `sldemo_bus_arrays` demo, the `Scalar Bus` signal is a nonvirtual bus signal, and the `Bus Array` output signal of the Concatenate block is an array of buses signal.



Using an Array of Buses in a Model

A General Workflow for Using an Array of Buses in a Model

Setting up a model to use an array of buses usually involves basic tasks similar to these:

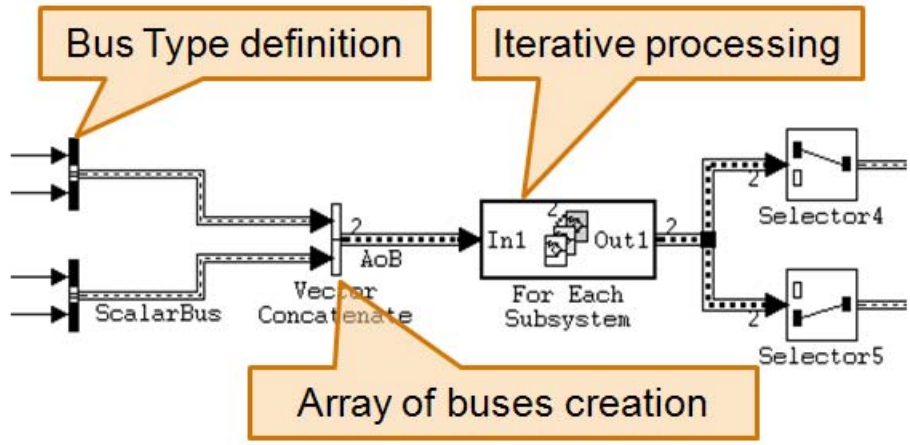
1. Define the array of buses, as described in "Defining an Array of Buses" on page 30-73.

2. Add a subsystem for performing iterative processing on each element of the array of buses. For example, use a For Each Subsystem block or an Iterator block. See "Performing Iterative Processing with an Array of Buses" on page 30-76.

3. Connect the array of buses signal from the Concatenate block to the iterative processing subsystem that you set up in step 2.

4. Model your scalar algorithm within the iterative processing subsystem (for example, a For Each subsystem) and use Bus Selector and Bus Assignment blocks to select from, and assign to, the scalar bus within the subsystem.

This simplified picture reflects the general workflow described above.



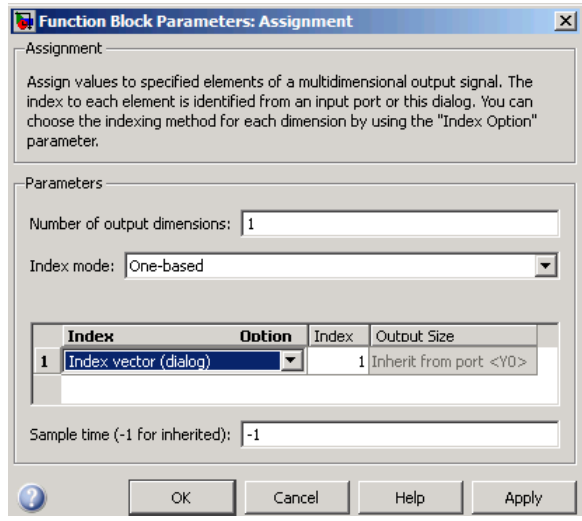
Performing Iterative Processing with an Array of Buses

You can perform iterative processing on the bus signal data of an array of buses using blocks such as a For Each Subsystem block, a While Iterator Subsystem block, or a For Iterator Subsystem block. You can use one of these blocks to perform the same kind of processing on each bus in the array of buses, or a selected subset of buses in the array of buses.

Assigning Into an Array of Buses

Use an Assignment block to assign values to specified elements in a bus array.

For example, in the `sldemo_bus_arrays` demo, the Assignment block assigns the value to the first element of the array of buses. The block parameters dialog box looks like the following graphic:



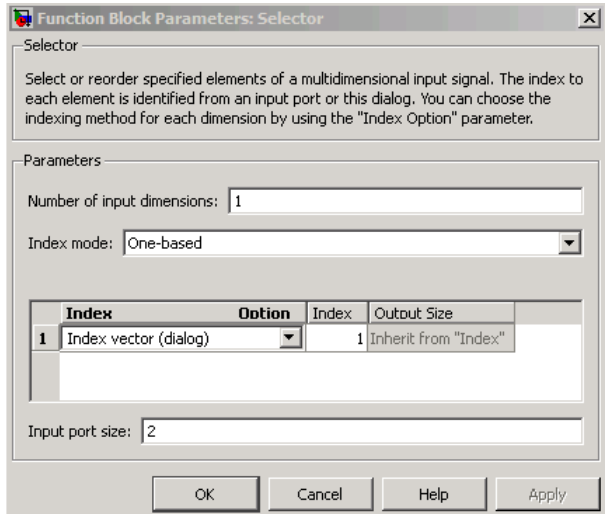
To assign bus elements within a bus signal, use the Bus Assignment block. The input for the Bus Assignment block must be a scalar bus signal.

Selecting Bus Elements from an Array of Buses

Use a Selector block to select elements of an array of buses. The input array of buses can be of any dimensionality.

The output bus signal of the Selector block is a selected or reordered set of elements from the input array of buses.

For example, the `sldemo_bus_arrays` demo uses Selector blocks to select elements from the array of buses signal that the Assignment and For Each Subsystem blocks outputs. The block parameters dialog box for the Selector block that selects the first element looks like the following graphic:



To select bus elements within a bus signal, use the Bus Selector block. The input for the Bus Selector block must be a scalar bus signal.

Generated Code for an Array of Buses

When you generate code for a model that includes an array of buses, a `typedef` that represents the underlying bus type appears in the `*_types.h` file.

Code generation produces an array of C structures that you can integrate with legacy C code that uses arrays of structures. As necessary, code for bus variables (arrays) are generated in the following structures:

- Block IO
- States
- External inputs
- External outputs

Here is a simplified example of some generated code for an array of buses.

```
typedef struct {
  real_T a;
  real_T b;
} BusObject;
```

```
/* Block signals (auto storage) */
typedef struct {
  BusObject ForEachSubsystem_IterInp_0[2];
} BlockIO_aob1;
```

Converting a Model to Use an Array of Buses

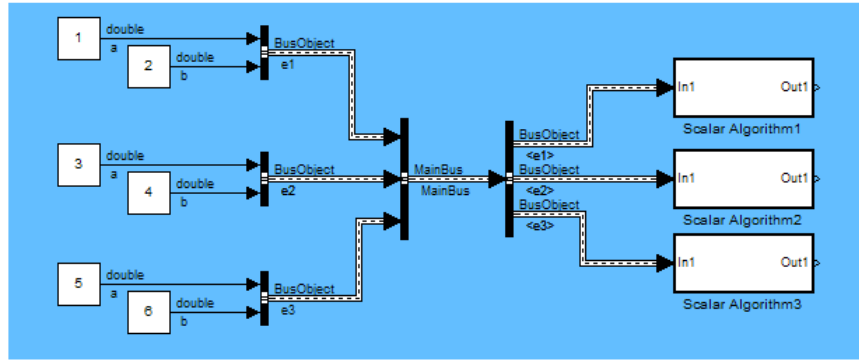
There are several reasons to convert a model to use an array of buses (see "Benefits an Array of Buses" on page 30-69). For example:

- The model was developed before Simulink supported arrays of buses (introduced in R2010b), and the model contains many subsystems that perform the same kind of processing.
- The model that has grown in complexity.

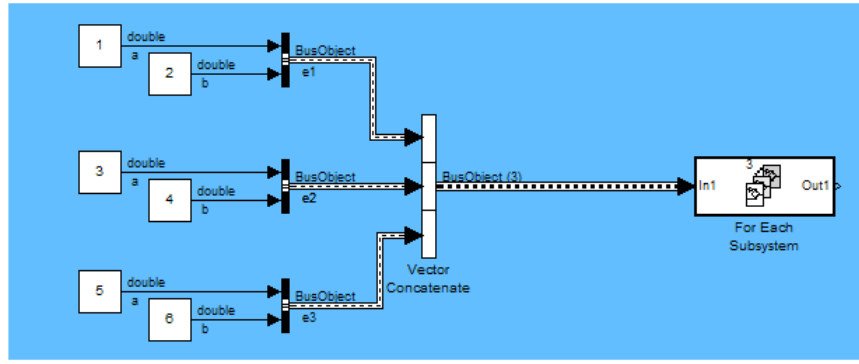
General Workflow for Converting a Model to Use an Array of Buses

This section presents a general guide to converting a model that contains buses to a model that uses an array of buses. The method that you use depends on your model. For details about these techniques, see "Combining Buses into an Array of Buses" on page 30-67.

This workflow refers to a stylized example model. The example shows the original modeling pattern and a new modeling pattern that uses an array of buses.



Original modeling pattern



New modeling pattern

In the original modeling pattern:

- The target bus signal to be converted is named `MainBus`, and it has three elements, each of type `BusObject`.
- The `ScalarAlgorithm1`, `ScalarAlgorithm2`, and `ScalarAlgorithm3` subsystems encapsulate the algorithms that operate on each of the bus elements. The subsystems all have the same content.
- A Bus Selector block picks out each element of `MainBus` to drive the subsystems.

The construction in the original modeling pattern is inefficient for two reasons:

- A copy of the subsystem that encapsulates the algorithm is made for each element of the bus that is to be processed.
- Adding another element to `MainBus` involves changing the bus object definition and the Bus Selector block, and adding a new subsystem. Each of these changes is a potential source of error.

To convert the original modeling pattern to use an array of buses:

1. Identify the target bus and associated algorithm that you want to convert. Typically, the target bus signal is a bus of buses, where each element bus signal is of the same type.
   - The bus that you convert must be a nonvirtual bus. You can convert a virtual bus to a nonvirtual bus if all elements of the target bus have the same sample time (or if the sample time is inherited).
   - The target bus cannot have variable-dimensioned and frame-based elements.
2. Use a Vector Concatenate or Matrix Concatenate block to convert the original bus of buses signal to an array of buses.

   In the example, the new modeling pattern uses a Vector Concatenate block to replace the Bus Creator block that creates the `MainBus` signal. The output of the Vector Concatenate block is an array of buses, where the type of the bus signal is `BusObject`. The new model eliminates the wrapper bus signal (`MainBus`).
3. Replace all identical copies of the algorithm subsystem with a single For-Each subsystem that encapsulates the scalar algorithm. Connect the array of buses signal to the For-Each subsystem.

   The new model eliminates the Bus Selector blocks that separate out the elements of the `MainBus` signal in the original model.
4. Configure the For Each Subsystem block to iterate over the input array of buses signal and concatenate the output bus signal.

For limitations, see the For Each Subsystem block documentation; for example, the scalar algorithm within the For-Each subsystem cannot have continuous states.

Buses and Libraries

When you define a library block, the block can input, process, and output buses just as an ordinary subsystem can. MathWorks recommends not using Bus Selector blocks in library blocks, because such use complicates changing the library blocks and increases the likelihood of errors. When a Bus Selector block appears in a library block, the following considerations and recommendations apply:

- You cannot change a Bus Selector block directly within a library. To change the Bus Selector block, copy the library block that uses it to a model, edit the Bus Selector block within the context of the model, then copy the changed library block back to the library.
- The Inport that feeds the Bus Selector block should have an associated bus object, as described in "Using Bus Objects" on page 30-12. This bus object must be stored in a MATLAB code file or MAT-file, and imported into the base workspace of any model that subsequently uses the library block.
- Any model that uses the library block containing the Bus Selector should set **Configuration Parameters > Connectivity > Element name mismatch** to `error`. This setting minimizes the possibility of consistency errors at the interface to the library block.

See Chapter 23, "Working with Block Libraries" for information about creating block libraries and copying library blocks to and from them.

Avoiding Mux/Bus Mixtures

In this section...

Introduction

You can use muxes and virtual buses interchangeably in a model if all constituent signals have the same attributes and the model has no nested buses. You can implement such a signal as either a mux or a virtual bus, and the Simulink software by default automatically converts between the two formats as needed. See "Mux Signals" on page 29-16 for information about muxes.

Do not mix muxes and buses in new applications.

One way that such a mux/bus mixture occurs is when you use a Mux block to create a virtual bus, such as a Mux block that outputs to a Bus Selector. This kind of mixture does not support strong type checking and increases the likelihood of run-time errors. MathWorks discourages treating muxes and buses interchangeably. Mux/bus mixtures may become unsupported in the future. Simulink generates a warning for this kind of mux/bus mixture when you load a model created in a release prior to R2010a. For new models, Simulink generates an error. Do not create such mux/bus mixtures in new applications, and consider upgrading existing applications to avoid such mixtures. The **Configuration Parameters > Diagnostics > Connectivity** pane provides diagnostics that report cases where muxes and virtual buses are used interchangeably, and includes capabilities that you can use to upgrade a model to eliminate such mixtures. See "Using Diagnostics for Mux/Bus Mixtures" on page 30-85 and "Using the Model Advisor for Mux/Bus Mixtures" on page 30-89 for details.

Another way for a mux/bus mixture to occur is when a virtual bus signal is treated as a mux, such as a bus signal that inputs directly to a Gain block. To detect such mixtures, in the **Configuration Parameters > Diagnostics > Connectivity** pane, set the **Bus signal treated as vector** diagnostic to `warning` or `error`.

Note Do not confuse muxes used as bus elements, which is legal and causes no problems, with mux/bus mixtures. A mux/bus mixture occurs only when some blocks treat a signal as a mux, while other blocks treat that same signal as a bus.

Using Diagnostics for Mux/Bus Mixtures

The **Configuration Parameters > Diagnostics > Connectivity** pane provides the following diagnostics to detect mux/bus mixtures.

Diagnostic	Description
Mux blocks used to create bus signals	Detect and correct muxes that are used as buses
Bus signal treated as vector	Detect and correct buses that are used as muxes (vectors)
Non-bus signals treated as bus signals	Detect when Simulink implicitly converts a non-bus signal to a bus signal

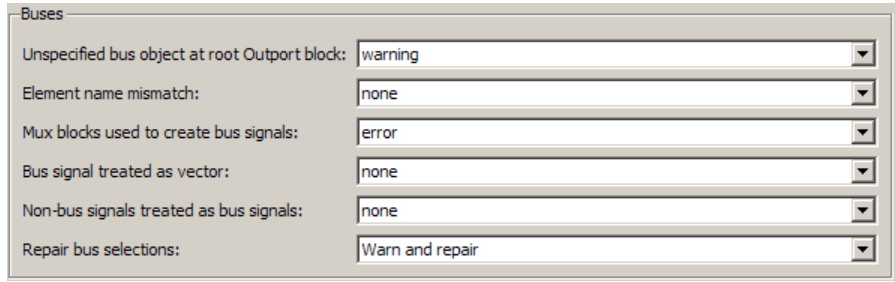
You can use these diagnostics as described in this section, or you can use the Model Advisor to perform the some of these checks and also to obtain advice about corrections, as described in "Consulting the Model Advisor" on page 3-80. For complete information about the **Connectivity** pane, see "Connectivity Diagnostics Overview".

Mux blocks used to create bus signals

To detect and correct muxes that are used as buses, in the **Configuration Parameters > Diagnostics > Connectivity** pane:

1. Set **Mux blocks used to create bus signals** to `warning` or `error`.

2 Set **Bus signal treated as vector** to `none`.



3 Click **OK** or **Apply**.

4 Build the model.

5 Replace blocks as needed to correct any cases of Mux blocks used to create buses. You can use the `slreplace_mux` function to replace all such Mux blocks in a single operation.

For complete information about this option, see the reference documentation for "Mux blocks used to create bus signals".

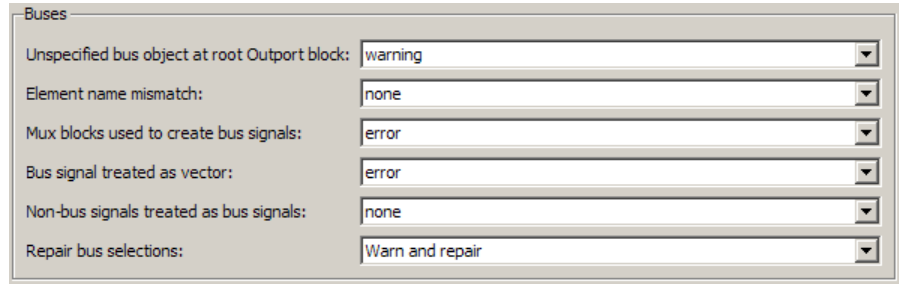
Bus signal treated as vector

To detect and correct buses that are used as if they were muxes (vectors):

1 Correct any cases of Mux blocks used to create buses as described in "Mux blocks used to create bus signals" on page 30-85.

2 In the **Configuration Parameters > Diagnostics > Connectivity** pane, set **Mux blocks used to create bus signals** to `error`.

3 In the same pane, set **Bus signal treated as vector** to `warning` or `error`.



4 Click **OK** or **Apply**.

5 Build the model.

6 Correct the model where needed as described under "Correcting Buses Used as Muxes" on page 30-90.

For complete information about this option, see the reference documentation for "Bus signal treated as vector".

Note **Bus signal treated as vector** is disabled unless you set **Mux blocks used to create bus signals** to `error`. Setting **Bus signal treated as vector** to `error` has no effect unless you have previously corrected all cases of Mux blocks used to create buses.

Equivalent Parameter Values

Due to the requirement that **Mux blocks used to create bus signals** be `error` before **Bus signal treated as vector** is enabled, one parameter, `StrictBusMsg`, can specify all permutations of the two controls. The parameter can have one of five values. The following table shows these values and the equivalent GUI control settings:

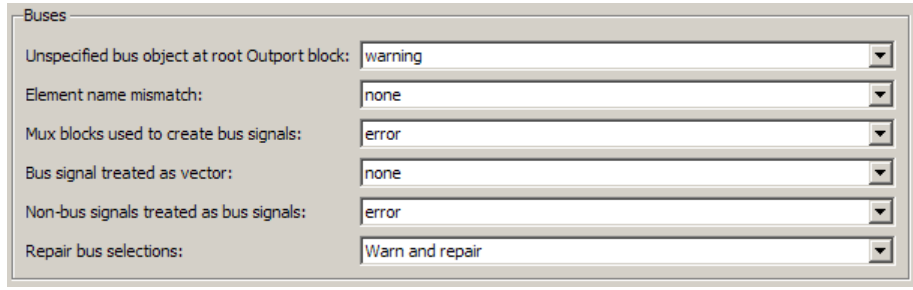
Value of `StrictBusMsg` (API)	Mux blocks used to create bus signals (GUI)	Bus signal treated as vector (GUI)
`None`	`none`	`none`
`Warning`	`warning`	`none`

Value of `StrictBusMsg` (API)	Mux blocks used to create bus signals (GUI)	Bus signal treated as vector (GUI)
`ErrorLevel1`	`error`	`none`
`WarnOnBusTreatedAsVector`	`error`	`warning`
`ErrorOnBusTreatedAsVector`	`error`	`error`

Non-bus signals treated as bus signals

Detect when Simulink implicitly converts a non-bus signal to a bus signal:

1. Correct any cases of Mux blocks used to create buses as described in "Mux blocks used to create bus signals" on page 30-85.
2. In the **Configuration Parameters > Diagnostics > Connectivity** pane, set **Mux blocks used to create bus signals** to `error`.
3. In the same pane, set **Non-bus signals treated as bus signals** to `warning` or `error`.



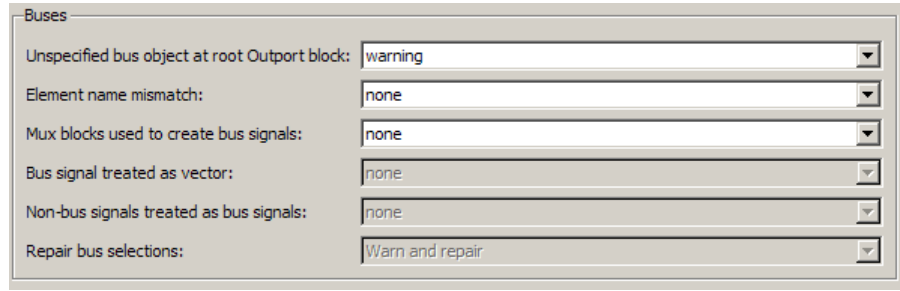
4. Click **OK** or **Apply**.
5. Build the model.
6. Correct the model where needed as described under "Correcting Buses Used as Muxes" on page 30-90.

For complete information about this option, see the reference documentation for "Non-bus signals treated as bus signals".

Using the Model Advisor for Mux/Bus Mixtures

The Model Advisor provides a convenient way to both run the diagnostics for mux/bus mixtures and obtain advice about corrections. To use the Model Advisor to detect and correct mux/bus mixtures:

1. Set **Configuration Parameters > Diagnostics > Connectivity > Buses > Mux blocks used to create bus signals** to `none`.



2. Click **OK** or **Apply**.

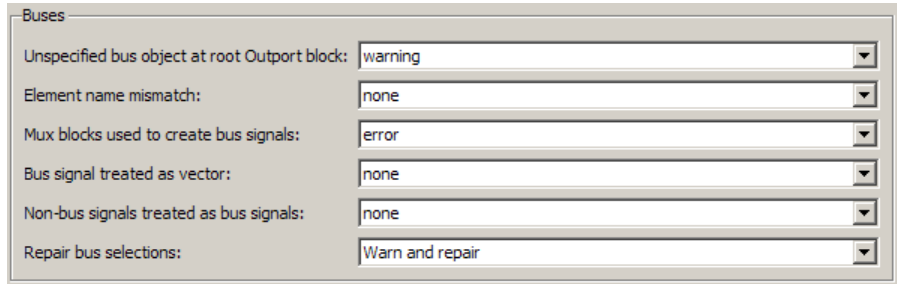
3. Select and run the Model Advisor check **Simulink > Check for proper bus usage**.

   The Model Advisor reports any cases of Mux blocks used to create bus signals.

4. Follow the Model Advisor's suggestions to correct any errors reported by the check. You can use the `slreplace_mux` function to replace all such errors in a single operation.

5. Set **Configuration Parameters > Diagnostics > Connectivity > Buses > Mux blocks used to create bus signals** to `error`.

6. Set **Configuration Parameters > Diagnostics > Connectivity > Bus signal treated as vector** to `none`.



7 Click **OK** or **Apply**.

8 Again run the Model Advisor check **Simulink > Check for proper bus usage**.

The Model Advisor reports any cases of bus signals treated as muxes (vectors).

9 Follow the Model Advisor's suggestions and the information in "Correcting Buses Used as Muxes" on page 30-90 to correct any errors discovered by the check.

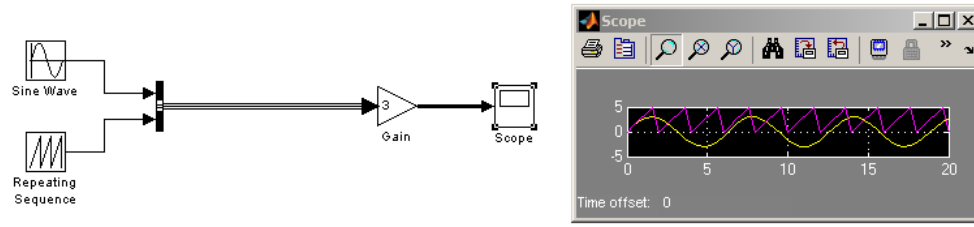
Instructions for using the Model Advisor appear in "Consulting the Model Advisor" on page 3-80.

Correcting Buses Used as Muxes

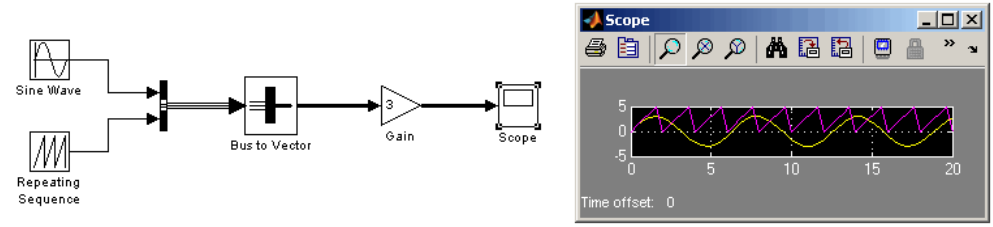
When you discover a bus signal used as a mux, one answer is to reorganize the model by replacing blocks so that the mixture no longer occurs. Where that is undesirable or unfeasible, the Simulink software provides two capabilities to address the problem:

- The Bus to Vector block (Signal Attributes library), which you can insert into any bus used implicitly as a mux to explicitly convert the bus to a mux (vector).
- The `Simulink.BlockDiagram.addBusToVector` function, which automatically inserts Bus to Vector blocks wherever needed.

For example, this figure shows a model that uses a bus as a mux by inputting the bus to a Gain block.



This figure shows the same model, rebuilt after inserting a Bus to Vector block into the bus.



Note that the results of simulation are the same in either case. The Bus to Vector block is virtual, and never affects simulation results, code generation, or performance. For more information, see the reference documentation for the Bus to Vector block and the `Simulink.BlockDiagram.addBusToVector` function.

Bus to Vector Block Compatibility Issues

If you use **Save As** to save a model in a version of the Simulink product before R2007a (V6.6), the following is done:

- Set the `StrictBusMsg` parameter to `error` if its value is `WarnOnBusTreatedAsVector` or `ErrorOnBusTreatedAsVector`.
- Replace each Bus to Vector block in the model with a null subsystem that outputs nothing.

The resulting model specifies strong type checking for Mux blocks used to create buses. Before you can use the model, you must reconnect or otherwise correct each signal that contained a Bus to Vector block but is now interrupted by a null subsystem.

In R2010a, if you load a model created in a prior release, you may get warning messages that you did not get before. To avoid getting Mux block-related warnings for existing models that you want to load in R2010a, use the `slreplace_mux` function to substitute Bus Creator blocks for any Mux blocks used to create buses signals.

Avoiding Mux/Bus Mixtures When Developing Models

MathWorks discourages the use of mux/bus mixtures, and may cease to support them at some future time. MathWorks, therefore, recommends upgrading existing models to eliminate any mux/bus mixtures, and permanently setting **Mux blocks used to create bus signals** and **Bus signal treated as vector** to `error` in all new models and all existing models that may undergo further development.

Note The Bus to Vector block is intended only for use in existing models to facilitate the elimination of implicit conversion of buses into muxes. New models and new parts of existing models should avoid mux/bus mixtures, and should not use Bus to Vector blocks for any purpose.

Buses in Generated Code

The various techniques for defining buses are essentially equivalent for simulation, but the techniques used can make a significant difference in the efficiency, size, and readability of generated code. For example, a nonvirtual bus appears as a structure in generated code, and only one copy exists of any algorithm that uses the bus. A virtual bus does not appear as a structure or any other coherent unit in generated code, and a separate copy of any algorithm that manipulates the bus exists for each element. Using buses properly results in efficient code and visually clean models. If you intend to generate production code for a model that uses buses, see "Optimizing Buses for Code Generation" for information about the best techniques to use.

Composite Signal Limitations

- Simulink and Real-Time Workshop both support using arrays as elements of a bus. However, neither product supports using buses as elements of an array. The that capabilities that of an array of buses can often be emulated by using a bus whose elements are arrays.
- Buses that contain signals of enumerated data types cannot pass through a block that requires an initial value, like a Unit Delay block. See for instructions on how to work around this limitation.
- Root level bus outputs cannot be logged using the **Configuration Parameters > Data Import/Export > Save to Workspace > Output** option. Use standard signal logging instead, as described in "Logging Signals" on page 27-3.

Working with Variable-Size Signals

Variable-Size Signal Basics

In this section...

About Variable-Size Signals

A Simulink signal can be a scalar, vector (1-D), matrix (2-D), or N-D. For information about these types of signals, see "Signal Basics" on page 29-2 in the *Simulink User's Guide*.

A Simulink variable-size signal is a signal whose size (the number of elements in a dimension), in addition to its values, can change during a model simulation. However, during a simulation, the number of dimensions cannot change. This capability allows you to model systems with varying resources, constraints, and environments.

Creating Variable-Size Signals

You can create variable-size signals in your Simulink model by using:

- Switch or Multiport Switch blocks with different input ports having fixed-size signals with different sizes. The output is a variable-size signal.
- A selector block and the `Starting and ending indices (port)` indexing option. The index port signal can specify different subregions of the input data signal which produce an output signal of variable size as the simulation progresses.
- The S-function block with the output port configured for a variable-size signal. The output includes not only the values but also the dimension of the signal.

How Variable-Size Signals Propagate

In the Simulink environment, variable-size signals can change their size during model execution in one of two ways:

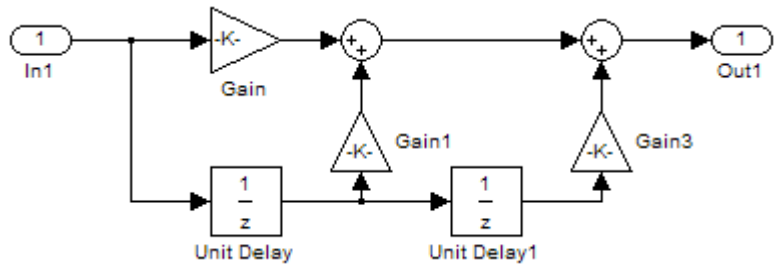
- **At every step of model execution.**

  Various blocks in the model modify the sizes of the signals during execution of the output method.

- **Only during initialization of conditionally executed subsystems.**

  Size changes occur during distinct mode-switching events in subsystems such as Action, Enable, and Function-Call subsystems.

You can see the key difference by considering a Discrete 2-Tap Filter block with states.



Discrete 2-Tap Filter

Assume that the input signal dimension to this filter changes from 4 to 1 during simulation. It is ambiguous when and how the states of the Unit Delay blocks should adapt from 4 to 1 to continue processing the input. To ensure consistency, both Unit Delay blocks must change their state behavior synchronously. To prevent ambiguity, Simulink generally disallows blocks whose number of states depends on input signal sizes in contexts where signal sizes change at any point during execution.

In contrast, consider the same Discrete 2-Tap Filter block in a Function-Call subsystem. Assume that this subsystem is using the second way to propagate variable-size signals. In this case, the size of the input signal changes from 4 to 1 only at the initialization of the subsystem. At initialization, the subsystem resets all of its states (including the states of the two Unit Delay

blocks) to their initial values. Resetting the subsystem ensures no ambiguity on the assignment of states to the input signal of the filter.

"Demo of Mode-Dependent Variable-Size Signals" on page 31-13 shows how you can use the two ways of propagating variable-size signals in a complementary fashion to model complex systems.

Empty Signals

An empty signal is a signal with a length of `0`. For example, signals with size `[0]`, `[0x3]`, `[2x0]`, and `[2x0x3]` are all empty signals. Simulink allows empty signals with variable-size signals and supports most element-wise operations. However, Simulink does not support empty signals for blocks that modify signal dimensions. Unsupported blocks include Reshape, Permute, and Sum along a specified dimension.

Subsystem Initialization of Variable-Size Signals

The initial signal size from an Outport block in a conditionally executed subsystem varies depending on the parameters you select.

If you set the **Propagate sizes of variable-size signals** parameter in the parent subsystem to `During execution`, the **Initial output** parameter for the Output block must not exceed the maximum size of the input port. If the **Initial output** parameter value is:

Initial output parameter	Initial output signal size
A nonscalar matrix	The initial output signal size is the size of the **Initial output** parameter.
A scalar	The initial output signal size is a scalar.
The default []	The initial output size is an empty signal (dimensions are all zeros).

If you set the **Propagate sizes of variable-size signals** parameter in the parent subsystem to `Only when enabling`, the **Initial output** parameter for the Output block must be a scalar value.

- When size is repropagated for the input of the Outport block, the initial output value is set using scalar expansion from the scalar parameter value.
- If the **Initial output** parameter is the default value `[]`, Simulink treats the initial output as a grounded value.
- If the model does not activate the parent subsystem at start time (`t = 0`), the current size of the subsystem output corresponding to the Outport block is set to maximum size.
- When its parent subsystem repropagates signal sizes, the values of the subsystem variable-size output signals are also reset to their initial output parameter values.

Simulink Models Using Variable-Size Signals

In this section...

Demo of Variable-Size Signal Generation and Operations

This demo model shows how to create a variable-size signal from multiple fixed-size signals and from a single data signal. It also shows some of the operations you can apply to variable-size signals.

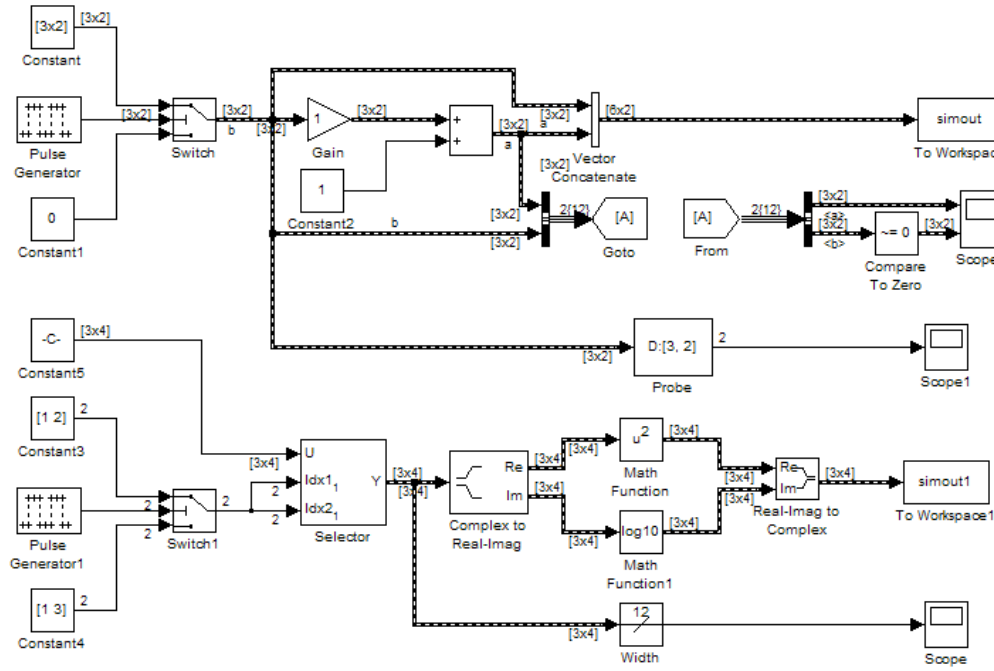
For a complete list of blocks that support variable-size signals, see "Simulink Block Support for Variable-Size Signals" on page 31-22.

1. In the MATLAB Command Window, type

   ```
   sldemo_varsize_basic
   ```

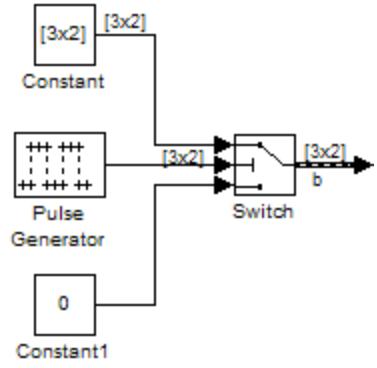
2. From the **Format** menu, point to **Port/Signal Displays**, and then click **Signal Dimensions**. Run a simulation or press `Ctrl-D`.

   The Simulink editor displays the signal dimensions and line styles. See "Signal Basics" on page 29-2 for an interpretation of signal line styles.



Creating a Variable-Size Signal from Fixed-Size Signals

One way to create a variable-size signal is to use the Switch block. The input signals to the Switch block can differ in their number of dimensions and in their size.



Output from the Switch block is a 2-D variable-size signal with a maximum size of `3x2`. When you select the **Allow different data input sizes** parameter on the Switch block, Simulink does not expand the scalar value from the Constant1 block.

Saving Variable-Size Signal Data

You could add a To Workspace block to the output from the Switch block. Since the model already has a To Workspace block, the second To Workspace block would save data to a signal array named `simout2` The `values` field logs the actual signal values. If logged signal data is smaller than the maximum size, values are padded with NaNs or appropriate values. To obtain these signal values, type:

```
simout2.signals.values

ans(:,:,1) =

     1    -1
    -2     2
    -3     3


ans(:,:,2) =

     1    -1
    -2     2
    -3     3


ans(:,:,3) =

     0   NaN
   NaN   NaN
   NaN   NaN
```

The `valueDimensions` field logs the dimensions of a variable-size signal. To obtain the dimensions, type:

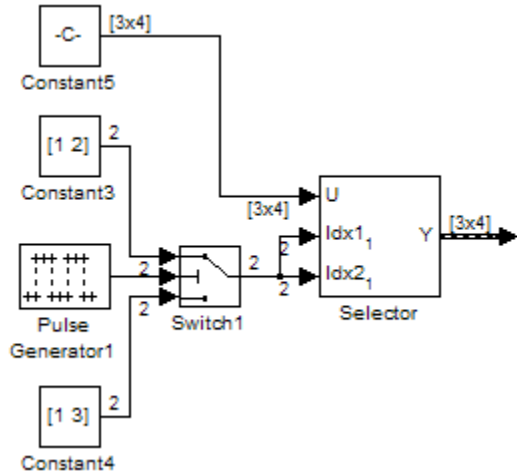
```
simout2.signals.valueDimensions
```

The signal dimensions for the first three time steps are shown.

```
ans =

     3     2
     3     2
     1     1
```

Creating a Variable-Size Signal from a Single Data Signal

The data signal (Constant5) is a `3x4` matrix. The Pulse Generator represents a control signal that selects a starting and ending index value (`[1 2]` or `[1 3]`). The Selector block then uses the index values to select different parts of the data signal at each time step and output a variable-size signal.



Viewing Changes in Signal Size

The output from the Selector block is either a `2x2` or `3x3` matrix. Because the maximum dimension for a variable-size signal is the `3x4` matrix from the data signal, the logged output signals are padded with NaNs.

Use the Probe or Width blocks to inspect the current dimensions and width of a variable-size signal. In addition, you can display variable-size signals

on Scope blocks and save variable-size signals to the workspace using the To Workspace block.

Processing Variable-Size Signals

The remainder of the model demonstrates various operations that are possible with variable-size signals. Operations include using the Gain block, the Sum block, the Math Function block, the Matrix Concatenate block. You can connect variable-size signals with the From, Goto, Bus Assignment, Bus Creator, and Bus Selector blocks.

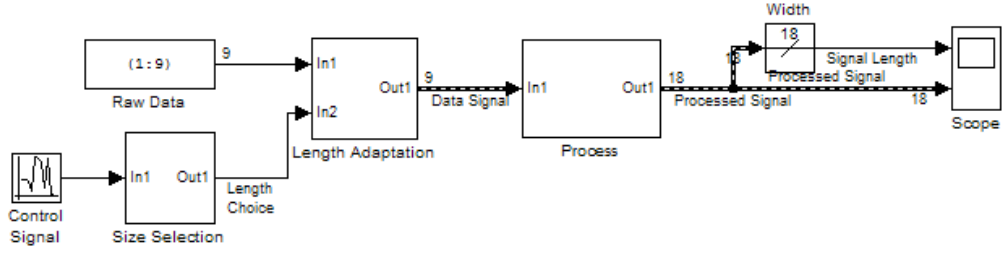
Demo of Variable-Size Signal Length Adaptation

This demo model corresponds to a hypothetical system where the model adapts the length of a signal over time. Length adaptation is based on the value of a control signal. When the control signal falls within one of three predefined ranges, the fixed-size raw data signal changes to a variable-size data signal.

The variable-size signal connects to a processing block, where blocks that support variable-size signals operate on it. An Embedded MATLAB Function block with both input and output signals of variable size allow more flexibility than other blocks supporting variable-size signals. See “Simulink Block Support for Variable-Size Signals” on page 31-22.

To open the demo model, in the MATLAB® Command Window, type:

```
sldemo_varsize_dataLengthAdapt
```

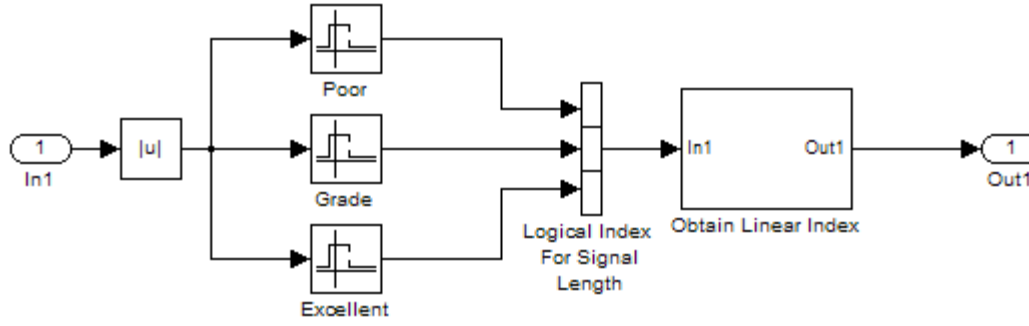


Creating a Variable-Size Signal by Adapting the Length of a Data Signal

This model generates a data signal and converts the signal to a variable-size signal. The size of the signal depends on the value of a control signal. The raw data signal is a column vector with values from 1 to 9.

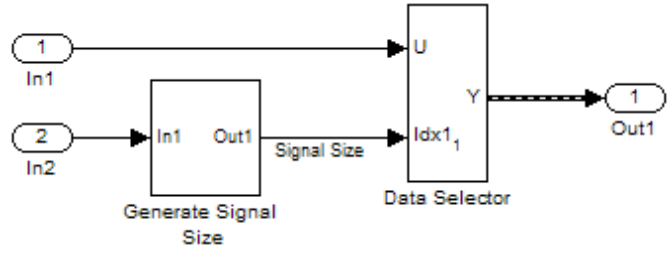
```
[1:9].'

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

The Size Selection subsystem determines the quality of the data signal and outputs a quality value (1, 2, or 3). This value helps to select the length of the data signal in the Length Adaptation subsystem.



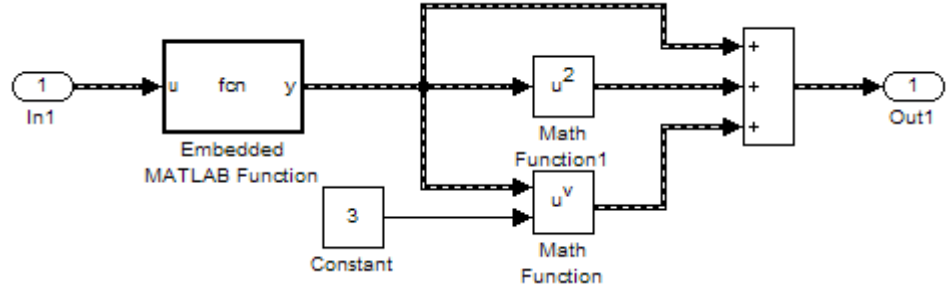
In the Length Adaptation subsystem, the Signal Size subsystem generates an index based on the quality value from the Size Selection subsystem (In2). The

Data Selector block uses the starting and ending indices to adapt the length of the data signal (In1) and output a variable-size signal.



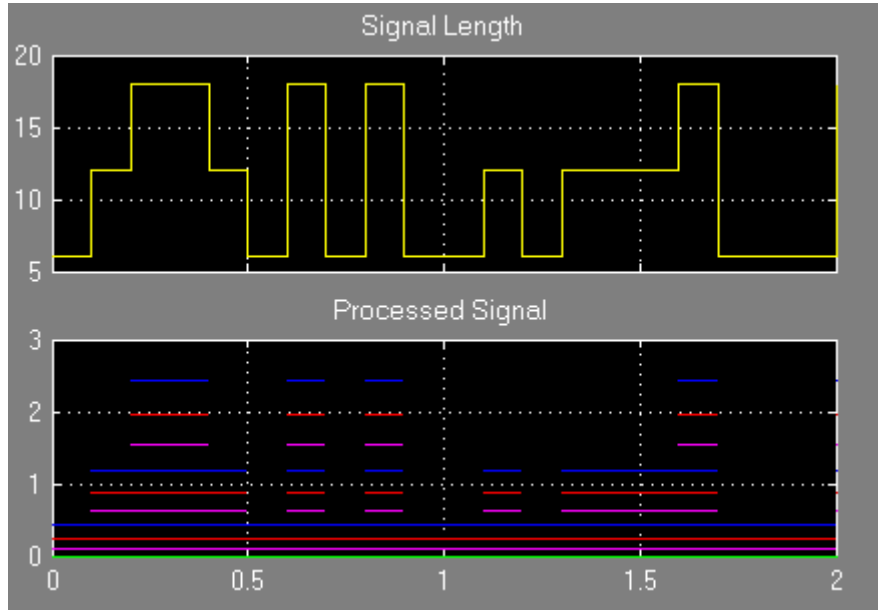
Processing a Variable-Size Signal

The center section of the model processes the variable-size signal. The Embedded MATLAB Function block adds zeros between the data values in a way that is similar to upsampling a signal. The dimension of the signal changes from `9` to `18`. The Math Function blocks demonstrate various manipulations you can do with variable-size signals.



Visualizing a Variable-Size Signal

The right section of the model determines the signal width (size) and uses a scope to visualize the width and the processed data signal.



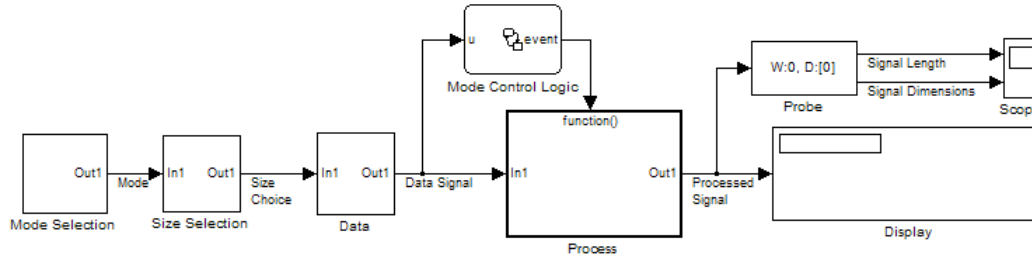
Demo of Mode-Dependent Variable-Size Signals

This demo model represents a system that has three operation modes. For each mode, the data signal to process has a different size.

The Process subsystem in this model receives a variable-size signal where the size of the signal depends on the operation mode of the system. For each mode change, the Stateflow chart, Mode Control Logic, detects when the data signal size changes. It then generates a function call to reset the blocks in the Process subsystem.

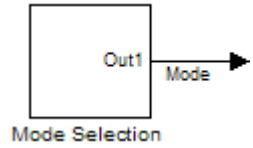
To open the model, In the MATLAB Command Window, type:

```
sldemo_varsize_multimode
```

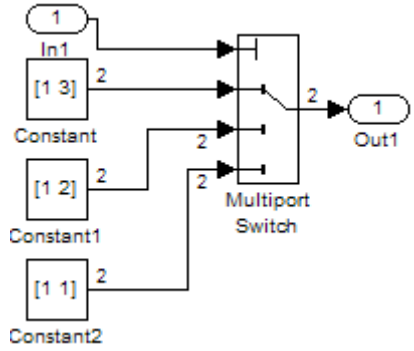


Creating a Variable-Size Signal Based on Mode

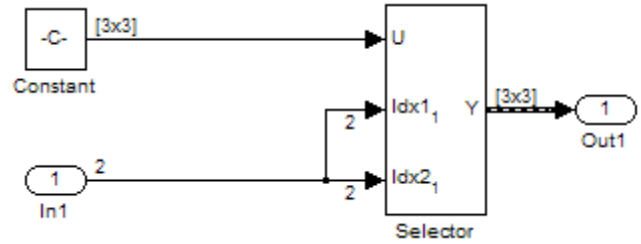
The Mode Selection subsystem determines the mode for processing a data signal and outputs a mode value (1, 2, or 3). This value helps to select the length of the data signal using the Size Selection and Data subsystems.



The Size Selection subsystem creates an index value from the mode value. In this example, the index values are `[1 3]`, `[1 2]`, and `[1 1]`.



The Data subsystem takes a data signal (Constant block) and selects part of the data signal dependent on the mode. The output is a variable-size signal with a matrix size of `3x3`, `2x2`, and `1x1`.



The dimensions of the raw data signal (Constant block) is a `3x3`. After connecting a To Workspace block to a signal line, you can view the signal in the MATLAB Command Window by typing:

```
simout.signals.values

ans(:,:,1) =

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

The variable-size signal generated from the Data subsystem is also a `3x3` matrix. For shorter signals, the matrix is padded with NaNs.

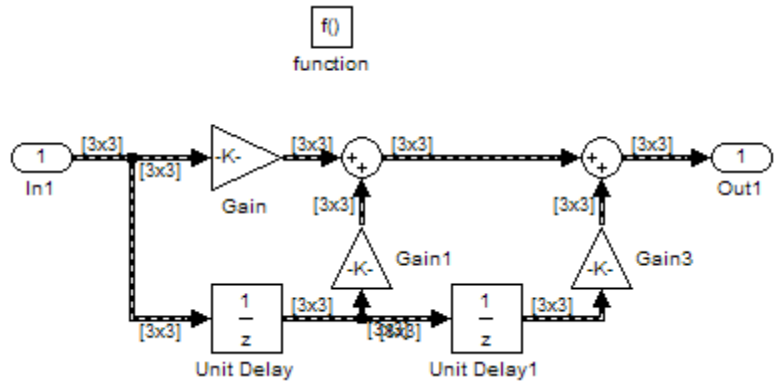
```
simout.signals.values

ans(:,:,1) =

     1   NaN   NaN
   NaN   NaN   NaN
   NaN   NaN   NaN


ans(:,:,2) =

     1     4   NaN
     2     5   NaN
   NaN   NaN   NaN
```

```
ans(:,:,3) =

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

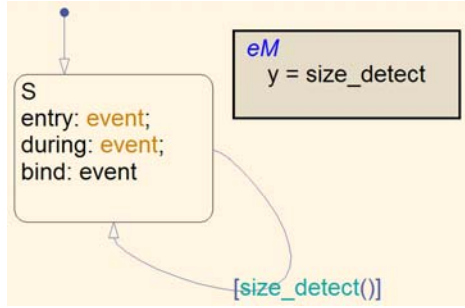
Processing a Variable-Size Signal with a Conditionally Executed Subsystem

Because the Process subsystem contains a Delay block, the subsystem resets and repropagates the signal at each time step. This model uses a Stateflow chart to detect a signal size change and reset the Process subsystem.

In the function block dialog, and from the **Propagate sizes of variable-size signals** list, choose `Only when enabling`. When the model enables this subsystem, selecting this option directs the Simulink software to propagate sizes for variable-size signals inside the conditionally executed subsystem. Signal sizes can change only when they transition from disabled to enabled. For an explanation of handling signal-size changes with blocks containing states, see "How Variable-Size Signals Propagate" on page 31-3.

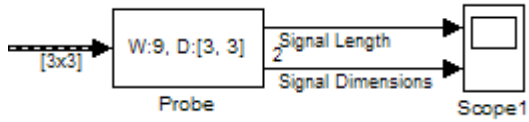


The Stateflow chart determines if there is a change in the size of the signal. The function `size_detect` calculates the width of the variable-size signal at each time step, and compares the current width to the previous width. If there is a change in signal size, the chart outputs a function-call output event that resets and repropagates the signal sizes within the Process subsystem.

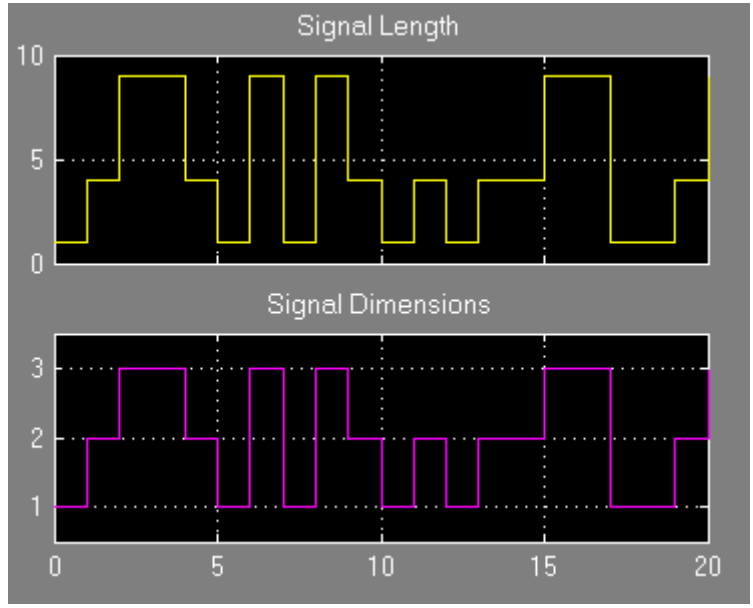


Visualizing Data

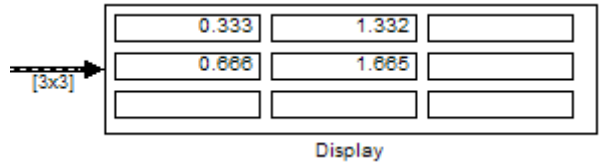
Use the Probe block to visualize signal size and signal dimension.



Since the signals are `n x n` matrices, the signal dimension lines overlap in the Scope display.



You can use a Display block and the Simulink Debugger to visualize signal values at each time step.



S-Functions Using Variable-Size Signals

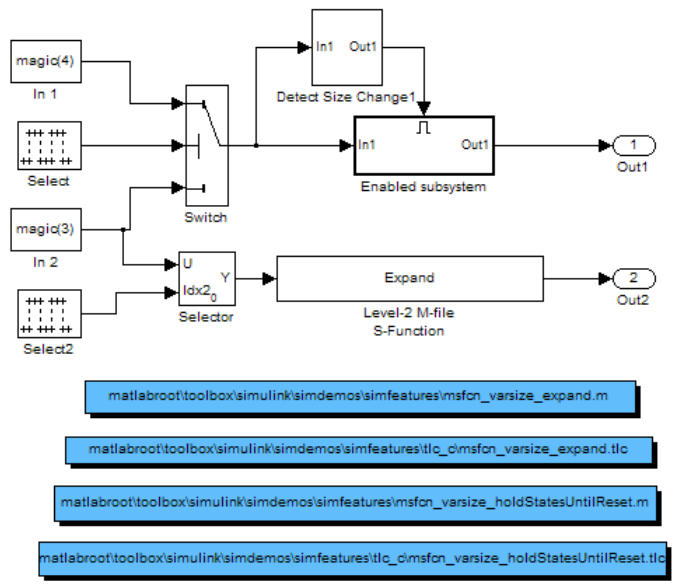
In this section...

Demo of Level-2 MATLAB S-Function with Variable-Size Signals

Both Level-2 MATLAB S-Functions and C S-Functions support variable-size signals when you set the **DimensionMode** for the output port to `Variable`. You also need to consider the current dimension of the input and output signals in the input and output update methods.

To open this demo model, in the MATLAB Command Window, type:

```
msfcndemo_varsize
```



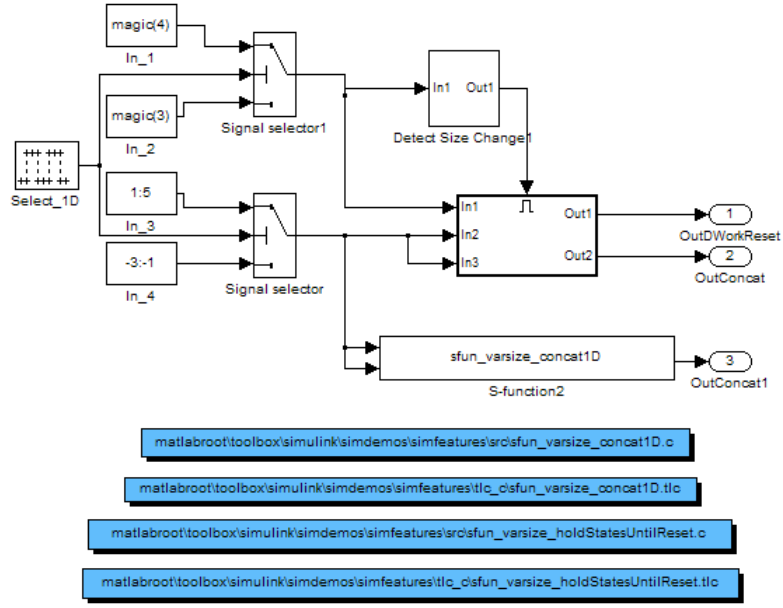
The Enabled subsystem includes a Level-2 MATLAB S-Function which demonstrates how to implement a block that holds its states until reset. Because this block contains states and delays the input signal, the input size can change only when a reset occurs.

The Expand block is a Level-2 MATLAB S-Function that takes a scalar input and outputs a vector of length indicated by its input value. The output is by `1:n` where `n` is the input value.

Demo of C S-Function with Variable-Size Signals

To open this demo model, in the MATLAB Command Window, type:

```
sfcndemo_varsize
```



The enabled subsystems have two S-Functions:

- sfun_varsize_holdStatesUntilReset is a C S-Function that has states and requires its DWorks vector to reset whenever the sizes of the input signal changes.
- sfun_varsize_concat1D is a C S-function that implements the concatenation of two unoriented vectors. You can use this function within an enabled subsystem by itself.

Simulink Block Support for Variable-Size Signals

In this section...

Simulink Block Data Type Support

The Simulink Block Data Type Support table includes a complete list of blocks that support variable-size signals.

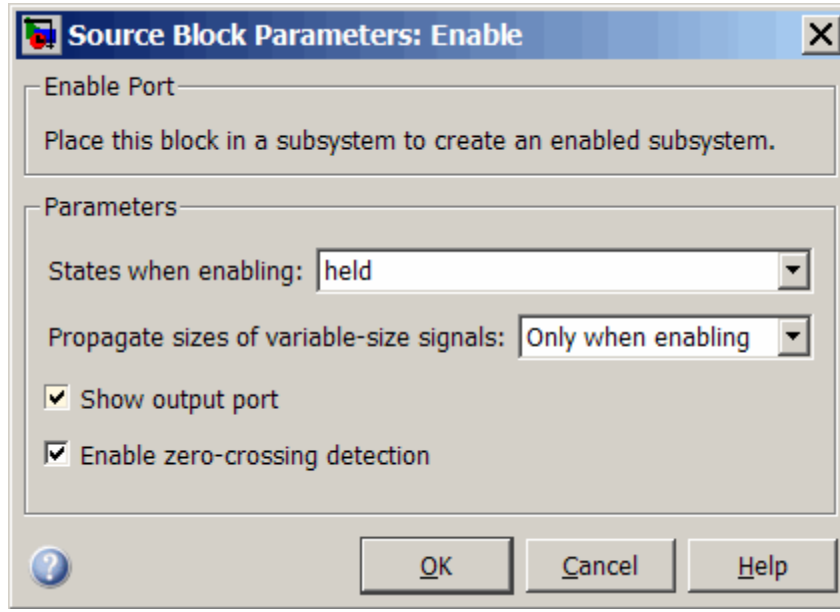
To view the table.

1. Open a Simulink® model window.
2. From the **Help** menu, point to **Block Support Table**, and then click **Simulink**.

An `X` in the Variable-Size Support column indicates support for that block.

Conditionally Executed Subsystem Blocks

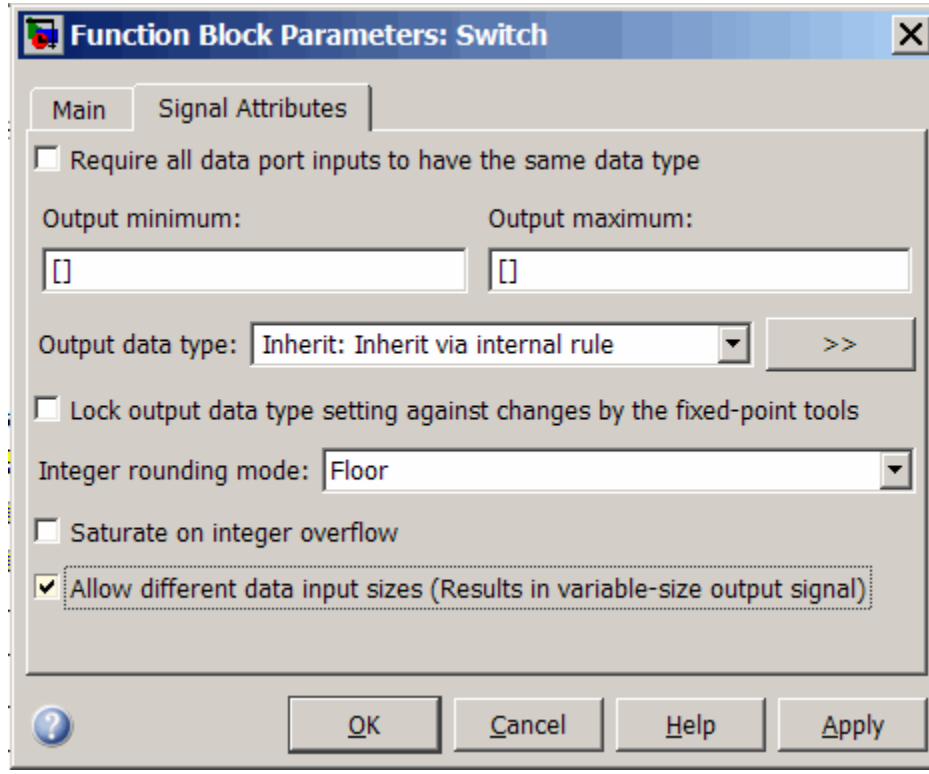
Control port blocks are in conditionally executed subsystems. You can set the **Propagate sizes of variable-size signals** parameter for these blocks to `During exection`, `Only when execution is resumed` (Action Port), and `Only when enabling` (Enable and Trigger or Function-Call).



- Action Port
- Enable
- Trigger — **Trigger type** set to `function-call`

Switching Blocks

Switching blocks support variable-size signals by allowing input signals with different sizes and propagating the size of the input signal to the output signal. You can set the **Allow different data input sizes** parameter for these blocks on the Signal Attributes pane to either on or off.



- Switch
- Multiport Switch
- Manual Switch

Variable-Size Signal Limitations

The following table is a list of known limitations and workarounds.

Limitation	Workaround
Array format logging does not support variable-size signals.	Use a structure or a structure with time format for logging variable-size signals.
Right-click signal logging (time-series format) does not support variable-size signals.	Use a To Workspace block or a root Outport block for logging variable-size signals.
External mode simulation does not support a variable-size signal feeding into a Scope or Display block.	Use the Assignment block to convert a variable-size signal into a fixed-size signal before feeding into Scope or Display blocks for external mode simulation.
A frame-based variable-size signal cannot change the frame length (first dimension size), but it can change the second dimension size (number of channels). Using frame-based signals requires Signal Processing Blockset software.	Use the Frame Conversion block to convert a signal into sample-based signal.
Variable-size signals must have a discrete sample time.	—
A scalar signal (width equals 1) cannot be a variable-size signal because the maximum size is 1.	—

Limitation	Workaround
Real-Time Workshop Embedded Coder™ does not support variable-size signals with ERT S-functions, custom storage classes, function prototype control, the AUTOSAR, C++ interface, and the ERT reusable code interface.	—
Simulink does not support variable-size parameter or DWork vectors.	—

Customizing Simulink Environment and Printed Models

32

Customizing the Simulink User Interface

Adding Items to Model Editor Menus

In this section...

About Adding Items to the Model Editor Menus

You can add commands and submenus to the end of the Simulink model editor menus. Adding an item to the end of a Model Editor menu entails performing the following tasks:

- For each item, create a function, called a *schema function*, that defines the item (see "Defining Menu Items" on page 32-4).
- Register the menu customizations with the Simulink customization manager at startup, e.g., in an `sl_customization.m` file on the MATLAB path (see "Registering Menu Customizations" on page 32-9).
- Create callback functions that implement the commands triggered by the items that you add to the menus.

Note You can use the procedures described in the following sections to customize the Stateflow Chart Editor's menu.

Code Example

The following `sl_customization.m` file adds four items to the editor's **Tools** menu.

```
function sl_customization(cm)

  %% Register custom menu function.
  cm.addCustomMenuFcn('Simulink:ToolsMenu', @getMyMenuItems);
end

%% Define the custom menu function.
function schemaFcns = getMyMenuItems(callbackInfo)
  schemaFcns = {@getItem1,...
      @getItem2,...
      {@getItem3,3}... %% Pass 3 as user data to getItem3.
      @getItem4};
end

%% Define the schema function for first menu item.
function schema = getItem1(callbackInfo)
  schema = sl_action_schema;
  schema.label = 'Item One';
  schema.userdata = 'item one';
  schema.callback = @myCallback1;
end

function myCallback1(callbackInfo)
  disp(['Callback for item ' callbackInfo.userdata ' was called']);
end

function schema = getItem2(callbackInfo)
  % Make a submenu label 'Item Two' with
  % the menu item above three times.
  schema = sl_container_schema;
  schema.label = 'Item Two';
 schema.childrenFcns = {@getItem1, @getItem1, @getItem1};
end

function schema = getItem3(callbackInfo)
  % Create a menu item whose label is
  % 'Item Three: 3', with the 3 being passed
  % from getMyItems above.

  schema = sl_action_schema;
```

```
  schema.label = ['Item Three: ' num2str(callbackInfo.userdata)];
end

function myToggleCallback(callbackInfo)
    if strcmp(get_param(gcs, 'ScreenColor'), 'red') == 0
        set_param(gcs, 'ScreenColor', 'red');
    else
        set_param(gcs, 'ScreenColor', 'white');
    end
end

%% Define the schema function for a toggle menu item.
function schema = getItem4(callbackInfo)
  schema = sl_toggle_schema;
  schema.label = 'Red Screen';
  if strcmp(get_param(gcs, 'ScreenColor'), 'red') == 1
    schema.checked = 'checked';
  else
    schema.checked = 'unchecked';
  end
  schema.callback = @myToggleCallback;
end
```

Defining Menu Items

You define a menu item by creating a function that returns an object, called a *schema* object, that specifies the information needed to create the menu item. The menu item that you define may trigger a custom action or display a custom submenu. See the following sections for more information.

- "Defining Menu Items That Trigger Custom Commands" on page 32-4
- "Defining Custom Submenus" on page 32-7

Defining Menu Items That Trigger Custom Commands

To define an item that triggers a custom command, your schema function must accept a callback info object (see "Callback Info Object" on page 32-10) and create and return an action schema object (see "Action Schema Object" on page 32-5) that specifies the item's label and a function, called a *callback*,

to be invoked when the user selects the item. For example, the following schema function defines a menu item that displays a message when selected by the user.

```
function schema = getItem1(callbackInfo)

  %% Create an instance of an action schema.
  schema = sl_action_schema;

  %% Specify the menu item's label.
  schema.label = 'My Item 1';

  %% Specify the menu item's callback function.
  schema.callback = @myCallback1;

end

function myCallback1(callbackInfo)
  disp(['Callback for item ' callbackInfo.userdata
        ' was called']);
end
```

Action Schema Object. This object specifies information about menu items that trigger commands that you define, including the label that appears on the menu item and the function to be invoked when the user selects the menu item. Use the function `sl_action_schema` to create instances of this object in your schema functions. Its properties include

- `tag`

  Optional string that identifies this action, for example, so that it can be referenced by a filter function.

- `label`

  String specifying the label that appears on a menu item that triggers this action.

- `state`

  String that specifies the state of this action. Valid values are `'Enabled'` (the default), `'Disabled'`, and `'Hidden'`.

- `statustip`

  String specifying text to appear in the editor's status bar when the user selects the menu item that triggers this action.

- `userdata`

  Data that you specify. May be of any type.

- `accelerator`

  String specifying a keyboard shortcut that a user may use to trigger this action. The string must be of the form `'Ctrl+K'`, where *K* is the shortcut key. For example, `'Ctrl+T'` specifies that the user may invoke this action by holding down the **Ctrl** key and pressing the **T** key.

- `callback`

  String specifying a MATLAB expression to be evaluated or a handle to a function to be invoked when a user selects the menu item that triggers this action. This function must accept one argument: a callback info object.

Toggle Schema Object. This object specifies information about a menu item that toggles some object on or off. Use the function `sl_toggle_schema` to create instances of this object in your schema functions. Its properties include

- `tag`

  Optional string that identifies this toggle action, for example, so that it can be referenced by a filter function.

- `label`

  String specifying the label that appears on a menu item that triggers this toggle action.

- `checked`

  This property must be set to one of the following values:

  `'checked'` Menu item displays a check mark.

  `'unchecked'` Menu item does not display a check mark.

- `state`

String that specifies the state of this toggle action. Valid values are `'Enabled'` (the default), `'Disabled'`, and `'Hidden'`.

- `statustip`

  String specifying text to appear in the editor's status bar when the user selects the menu item that triggers this toggle action.

- `userdata`

  Data that you specify. May be of any type.

- `accelerator`

  String specifying a keyboard shortcut that a user may use to trigger this action. The string must be of the form `'Ctrl+K'`, where *K* is the shortcut key. For example, `'Ctrl+T'` specifies that the user may invoke this action by holding down the **Ctrl** key and pressing the **T** key.

- `callback`

  String specifying a MATLAB expression to be evaluated or a handle to a function to be invoked when a user selects the menu item that triggers this action. This function must accept one argument: a callback info object.

Defining Custom Submenus

To define a submenu, create a schema function that accepts a callback info object and returns a container schema object (see "Container Schema Object" on page 32-7) that specifies the schemas that define the items on the submenu. For example, the following schema function defines a submenu that contains three instances of the menu item defined in the example in "Defining Menu Items That Trigger Custom Commands" on page 32-4.

```
function schema = getItem2( callbackInfo )
    schema = sl_container_schema;
    schema.label = 'Item Two';
    schema.childrenFcns = {@getItem1, @getItem1, @getItem1};
end
```

Container Schema Object. A container schema object specifies a submenu's label and its contents. Use the function `sl_container_schema` to create instances of this object in your schema functions. Properties of the object include

- `tag`

  Optional string that identifies this submenu.

- `label`

  String specifying the submenu's label.

- `state`

  String that specifies the state of this submenu. Valid values are `'Enabled'` (the default), `'Disabled'`, and `'Hidden'`.

- `statustip`

  String specifying text to appear in the editor's status bar when the user selects this submenu.

- `userdata`

  Data that you specify. May be of any type.

- `childrenFcns`

  Cell array that specifies the contents of the submenu. Each entry in the cell array can be

  - a pointer to a schema function that defines an item on the submenu (see "Defining Menu Items" on page 32-4)
  - a two-element cell array whose first element is a pointer to a schema function that defines an item entry and whose second element is data to be inserted as user data in the callback info object (see "Callback Info Object" on page 32-10) passed to the schema function
  - `'separator'`, which causes a separator to appear between the item defined by the preceding entry in the cell array and the item defined in the following entry. This case is ignored for this entry, e.g., `'SEPARATOR'` and `'Separator'` are valid entries. A separator is also suppresses if it would appear at the beginning or end of the submenu and combines separators that would appear successively (e.g., as a result of an item being hidden) into a single separator.

  For example, the following cell array specifies two submenu entries:

  ```
  {@getItem1, 'separator', {@getItem2, 1}}
  ```

  In this example, a 1 is passed to `getItem2` via a callback info object.

- `generateFcn`

  Pointer to a function that returns a cell array defining the contents of the submenu. The cell array must have the same format as that specified for the container schema objects `childrenFcns` property.

Note The `generateFcn` property takes precedence over the `childrenFcns` property. If you set both, the `childrenFcns` property is ignored and the cell array returned by the `generateFcn` is used to create the submenu.

Registering Menu Customizations

You must register custom items to be included on a Simulink menu with the customization manager. Use the `sl_customization.m` file for a Simulink installation (see "Registering Customizations" on page 32-24) to perform this task. In particular, for each menu that you want to customize, your system's `sl_customization` function must invoke the customization manager's `addCustomMenuFcn` method (see "Customization Manager" on page 32-24). Each invocation should pass the tag of the menu (see "About Menu Tags" on page 32-10) to be customized and a custom menu function that specifies the items to be added to the menu (see "Creating the Custom Menu Function" on page 32-9) . For example, the following sl_customization function adds custom items to the Simulink Tools menu.

```
function sl_customization(cm)
  %% Register custom menu function.
  cm.addCustomMenuFcn('Simulink:ToolsMenu', @getMyItems);
```

Creating the Custom Menu Function

The custom menu function returns a list of schema functions that define custom items that you want to appear on the model editor menus (see "Defining Menu Items" on page 32-4).

Your custom menu function should accept a callback info object (see "Callback Info Object" on page 32-10) and return a cell array that lists the schema functions. Each element of the cell array can be either a handle to a schema function or a two-element cell array whose first element is a handle to a

schema function and whose second element is user-defined data to be passed to the schema function. For example, the following custom menu function returns a cell array that lists three schema functions.

```
function schemas = getMyItems(callbackInfo)
  schemas = {@getItem1, ...
             @getItem2, ...
               {@getItem3,3} }; % Pass 3 as userdata to getItem3.
end
```

Callback Info Object

Instances of these objects are passed to menu customization functions. Properties of these objects include

- `uiObject`

  Handle to the owner of the menu for which this is the callback. The owner can be the Simulink editor or the Stateflow editor.

- `model`

  Handle to the model being displayed in the editor window.

- `userdata`

  User data. The value of this field can be any type of data.

Debugging Custom Menu Callbacks

On systems using the Microsoft Windows operating system, selecting a custom menu item whose callback contains a breakpoint can cause the mouse to become unresponsive or the menu to remain open and on top of other windows. To fix these problems, use the MATLAB code debugger keyboard commands to continue execution of the callback.

About Menu Tags

A menu tag is a string that identifies a Simulink Model Editor or Stateflow Chart Editor menu bar or menu. You need to know a menu's tag to add

custom items to it (see "Registering Menu Customizations" on page 32-9). You can configure the editor to display all (see "Displaying Menu Tags" on page 32-11) but the following tags:

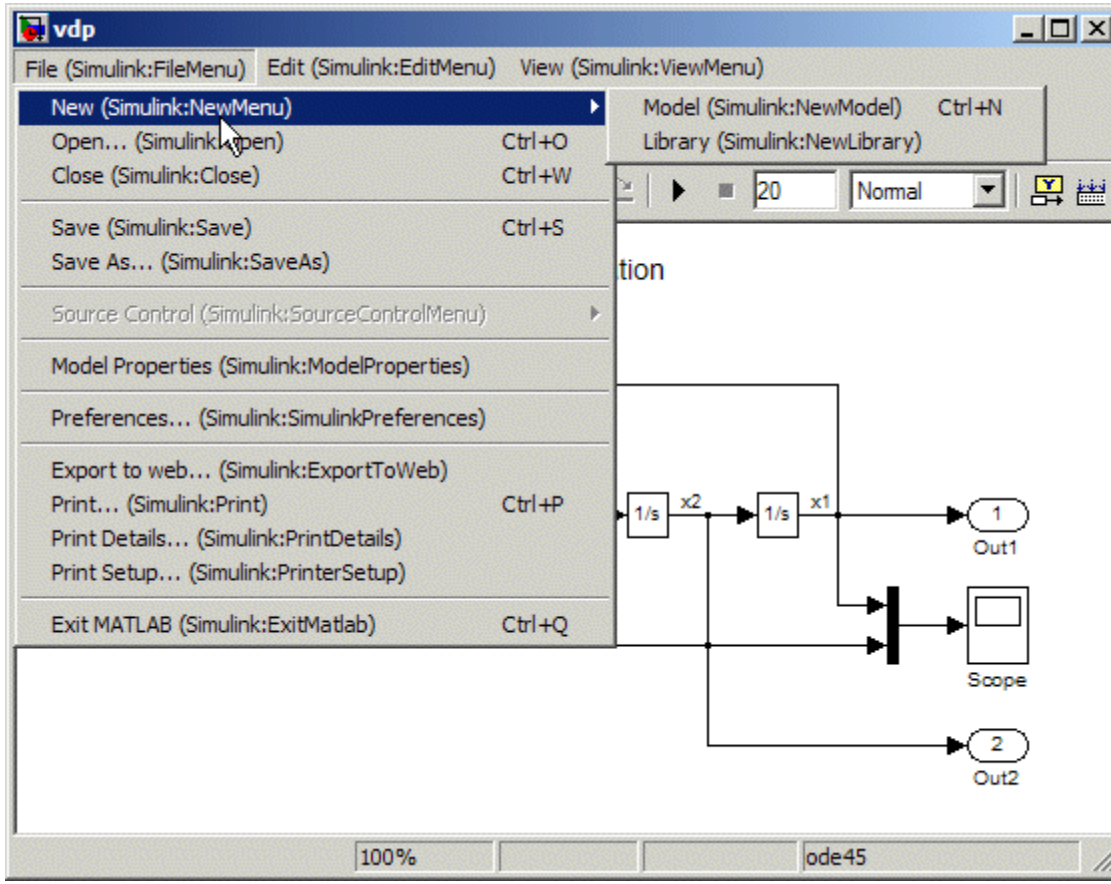
Tag	Usage
Simulink:MenuBar	Add menus to Model Editor's menu bar.
Simulink:ContextMenu	Add items to the end of Model Editor's context menu.
Simulink:PreContextMenu	Add items to the beginning of Model Editor's context menu.
Stateflow:MenuBar	Add menus to Chart Editor's menu bar.
Stateflow:ContextMenu	Add items to the end of Chart Editor's context menu.
Stateflow:PreContextMenu	Add items to the beginning of Chart Editor's context menu.

Displaying Menu Tags

You can configure the Simulink software (and the Stateflow product) to display the tag for a menu item next to the item's label, allowing you to determine at a glance the tag for a menu. To configure the editor to display menu tags, set the customization manager's `showWidgetIdAsToolTip` property to `true`, e.g., by entering the following commands at the command line:

```
cm = sl_customization_manager;
cm.showWidgetIdAsToolTip=true;
```

The tag of each menu item appears next to the item's label on the menu:



To turn off tag display, enter the following command at the command line:

```
cm.showWidgetIdAsToolTip=false;
```

Note Some menu items may not work while menu tag display is enabled. To ensure that all items work, turn off menu tag display before using the menus.

Disabling and Hiding Model Editor Menu Items

In this section...

About Disabling and Hiding Model Editor Menu Items

You can disable or hide items that appear on the Simulink model editor menus. To disable or hide a menu item, you must:

- Create a filter function that disables or hides the menu item (see "Creating a Filter Function" on page 32-13).
- Register the filter function with the customization manager (see "Registering a Filter Function" on page 32-14).

For more information on Model Editor menu items, see:

Example: Disabling the New Model Command on the Simulink Editor's File Menu

```
function sl_customization(cm)
  cm.addCustomFilterFcn('Simulink:NewModel',@myFilter);
end

function state = myFilter(callbackInfo)
  state = 'Disabled';
end
```

Creating a Filter Function

Your filter function must accept a callback info object and return a string that specifies the state that you want to assign to the menu item. Valid states are

- 'Hidden'
- 'Disabled'
- 'Enabled'

Your filter function may have to compete with other filter functions and with Simulink itself to assign a state to an item. Who succeeds depends on the strength of the state that each assigns to the item. 'Hidden' is the strongest state. If any filter function or Simulink assigns 'Hidden' to the item, it is hidden. 'Enabled' is the weakest state. For an item to be enabled, all filter functions and the Simulink or Stateflow products must assign 'Enabled'to the item. The 'Disabled' state is of middling strength. It overrides 'Enabled' but is itself overridden by 'Hidden'. For example, if any filter function or Simulink or Stateflow assigns 'Disabled' to a menu item and none assigns 'Hidden' to the item, the item is disabled.

Note The Simulink software does not allow you to filter some menu items, for example, the **Exit MATLAB** item on the Simulink **File** menu. An error message is displayed if you attempt to filter a menu item that you are not allowed to filter.

Registering a Filter Function

Use the customization manager's addCustomFilterFcn method to register a filter function. The addCustomFilterFcn method takes two arguments: a tag that identifies the menu or menu item to be filtered (see "Displaying Menu Tags" on page 32-11) and a pointer to the filter function itself. For example, the following code registers a filter function for the **New Model** item on the Simulink **File** menu.

```
function sl_customization(cm)
  cm.addCustomFilterFcn('Simulink:NewModel',@myFilter);
end
```

Disabling and Hiding Dialog Box Controls

In this section...

About Disabling and Hiding Controls

The Simulink product includes a customization API that allows you to disable and hide controls (also referred to as *widgets*), such as text fields and buttons, on most of its dialog boxes. The customization API allows you to disable or hide controls on an entire class of dialog boxes, for example, parameter dialog boxes via a single method call.

Before attempting to customize a Simulink dialog box or class of dialog boxes, you must first ensure that the dialog box or class of dialog boxes is customizable. Any dialog box that appears in the dialog pane of Model Explorer is customizable. In addition, any dialog box that has dialog and widget IDs is customizable. To determine whether a standalone dialog box (i.e., one that does not appear in Model Explorer) is customizable, open the dialog box, enable dialog and widget ID display (see "Dialog Box and Widget IDs" on page 32-18), and position the mouse over a widget. If a widget ID appears, the dialog box is customizable.

Once you have determined that a dialog box or class of dialog boxes is customizable, you must write M-code to customize the dialog boxes. This entails writing callback functions that disable or hide controls for a specific dialog box or class of dialog boxes (see "Writing Control Customization Callback Functions" on page 32-17) and registering the callback functions via an object called the customization manager (see "Registering Control Customization Callback Functions" on page 32-19). Simulink then invokes

the callback functions to disable or hide the controls whenever a user opens the dialog boxes.

For more information on Dialog Box controls, see:

Example: Disabling a Button on a Simulink Dialog Box

The following `sl_customization.m` file disables the **Build** button on the **Real-Time Workshop** pane of the Configuration Parameters dialog box for any model whose name contains "engine."

```
function sl_customization(cm)

% Disable for standalone Configuration Parameters dialog box.
cm.addDlgPreOpenFcn('Simulink.ConfigSet',@disableRTWBuildButton)
% Disable for Configuration Parameters dialog box that appears in
% the Model Explorer.
cm.addDlgPreOpenFcn('Simulink.RTWCC',@disableRTWBuildButton)

end

function disableRTWBuildButton(dialogH)
  hSrc   = dialogH.getSource;  % Simulink.RTWCC
  hModel = hSrc.getModel;
  modelName   = get_param(hModel, 'Name');

  if ~isempty(strfind(modelName, 'engine'))
    % Takes a cell array of widget Factory ID.
    dialogH.disableWidgets({'Simulink.RTWCC.Build'})
  end

end
```

To test this customization:

1 Put the preceding `sl_customization.m` file on the path.

2 Register the customization by entering `sl_refresh_customizations` at the command line or by restarting the MATLAB software (see "Registering Customizations" on page 32-24).

3 Open the `sldemo_engine` demo model, for example, by entering the command `sldemo_engine` at the command line.

Writing Control Customization Callback Functions

A callback function for disabling or hiding controls on a dialog box should accept one argument: a handle to the dialog box object that contains the controls you want to disable or hide. The dialog box object provides methods that the callback function can use to disable or hide the controls that the dialog box contains.

The dialog box object also provides access to objects containing information about the current model. Your callback function can use these objects to determine whether to disable or hide controls. For example, the following callback function uses these objects to disable the **Build** button on the **Real-Time Workshop** pane of the Configuration Parameters dialog box displayed in Model Explorer for any model whose name contains "engine."

```
function disableRTWBuildButton(dialogH)

  hSrc   = dialogH.getSource;  % Simulink.RTWCC
  hModel = hSrc.getModel;
  modelName   = get_param(hModel, 'Name');

  if ~isempty(strfind(modelName, 'engine'))
     % Takes a cell array of widget Factory ID.
     dialogH.disableWidgets({'Simulink.RTWCC.Build'})
  end
```

Dialog Box Methods

Dialog box objects provide the following methods for enabling, disabling, and hiding controls:

- `disableWidgets(widgetIDs)`
- `hideWidgets(widgetIDs)`

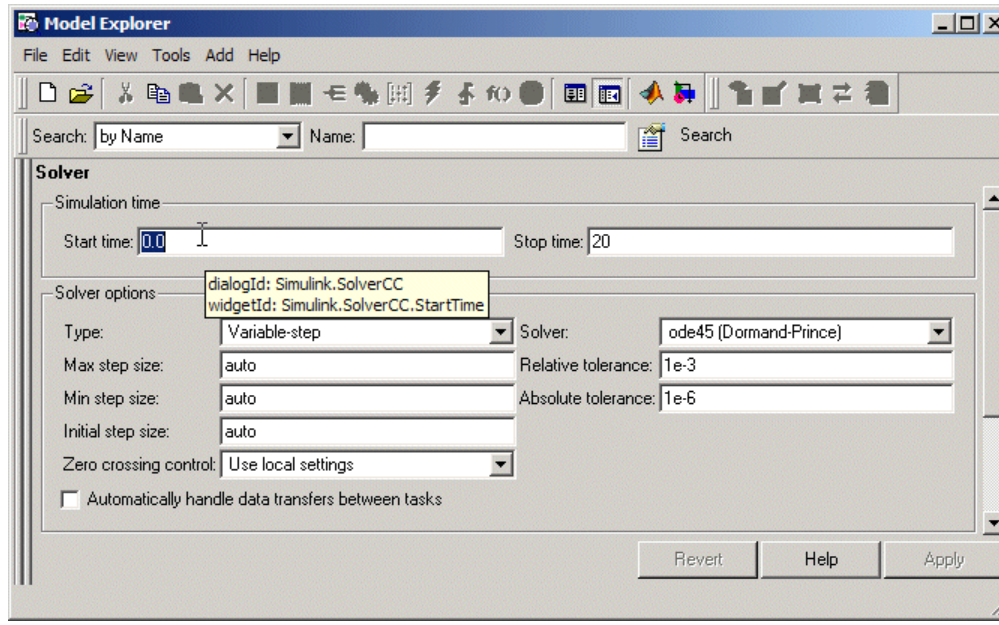
where `widgetIDs` is a cell array of widget identifiers (see "Dialog Box and Widget IDs" on page 32-18) that specify the widgets to be disabled or hidden.

Dialog Box and Widget IDs

Dialog box and widget IDs are strings that identify a control on a Simulink dialog box. To determine the dialog box and widget ID for a particular control, execute the following code at the command line:

```
cm = sl_customization_manager;
cm.showWidgetIdAsToolTip = true
```

Then, open the dialog box that contains the control and move the mouse cursor over the control to display a tooltip listing the dialog box and the widget IDs for the control. For example, moving the cursor over the **Start time** field on the **Solver** pane of the Configuration Parameters dialog box reveals that the dialog box ID for the **Solver** pane is `Simulink.SolverCC` and the widget ID for the **Start time** field is `Simulink.SolverCC.StartTime`.



Note The tooltip displays "not customizable" for controls that are not customizable.

Registering Control Customization Callback Functions

To register control customization callback functions for a particular installation of the Simulink product, include code in the installation's `sl_customization.m` file (see "Registering Customizations" on page 32-24) that invokes the customization manager's `addDlgPreOpenFcn` on the callbacks.

The `addDlgPreOpenFcn` takes two arguments. The first argument is a dialog box ID (see "Dialog Box and Widget IDs" on page 32-18) and the second is a pointer to the callback function to be registered. Invoking this method causes the registered function to be invoked for each dialog box of the type specified by the dialog box ID. The function is invoked before the dialog box is opened, allowing the function to perform the customizations before they become visible to the user.

The following example registers a callback that disables the **Build** button on the **Real-Time Workshop** pane of the Configuration Parameters dialog box (see "Writing Control Customization Callback Functions" on page 32-17).

```
function sl_customization(cm)

  % Disable for standalone Configuration Parameters dialog box.
  cm.addDlgPreOpenFcn('Simulink.ConfigSet',@disableRTWBuildButton)

  % Disable for Configuration Parameters dialog box that appears in
  % the Model Explorer
  cm.addDlgPreOpenFcn('Simulink.RTWCC',@disableRTWBuildButton)

end
```

Note Registering a customization callback causes the Simulink software to invoke the callback for every instance of the class of dialog boxes specified by the method's dialog box ID argument. This allows you to use a single callback to disable or hide a control for an entire class of dialog boxes. In particular, you can use a single callback to disable or hide the control for a parameter that is common to most built-in blocks. This is because most built-in block dialog boxes are instances of the same dialog box super class.

Customizing the Library Browser

In this section...

Reordering Libraries

The order in which a library appears in the Library Browser is determined by its name and its sort priority. Libraries appear in the Library Browser's tree view in ascending order of priority, with all blocks having the same priority sorted alphabetically. The Simulink library has a sort priority of `-1` by default; all other libraries, a sort priority of `0`. This guarantees that the Simulink library is by default the first library displayed in the Library Browser. You can reorder libraries by changing their sort priorities. To change library sort priorities, insert a line of code of the following form in an `sl_customization.m` file (see "Registering Customizations" on page 32-24) on the MATLAB path:

```
cm.LibraryBrowserCustomizer.applyOrder( {'LIBNAME1', PRIORITY1, ...
                                         'LIBNAME2, 'PRIORITY2, ...
                                          .
                                          .
                                         'LIBNAMEN', PRIORITYN} );
```

where `LIBNAMEn` is the name of the library or its `.mdl` file and `PRIORITYn` is an integer indicating the library's sort priority. For example, the following code moves the Simulink Extras library to the top of the Library Browser's tree view.

```
cm.LibraryBrowserCustomizer.applyOrder( {'Simulink Extras', -2} );
```

Disabling and Hiding Libraries

To disable or hide libraries, sublibraries, or library blocks, insert code of the following form in an `sl_customization.m` file (see "Registering Customizations" on page 32-24) on the MATLAB path:

```
cm.LibraryBrowserCustomizer.applyFilter( {'PATH1', 'STATE1', ...
                                          'PATH2', 'STATE2', ...
                                          .
                                          .
                                          'PATHN', 'STATEN'} );
```

where `PATHn` is the path of the library, sublibrary, or block to be disabled or hidden and `'STATEn'` is `'Disabled'` or `'Hidden'`. For example, the following code hides the Simulink Sources sublibrary and disables the Sinks sublibrary.

```
cm.LibraryBrowserCustomizer.applyFilter({'Simulink/Sources','Hidden'});
cm.LibraryBrowserCustomizer.applyFilter({'Simulink/Sinks','Disabled'});
```

Customizing the Library Browser's Menu

You can perform the same kinds of customizations to the Library Browser's menu as you can to the model and Stateflow editor menus. Simply use the corresponding Library Browser menu tags to perform the customizations.

- `LibraryBrowser:FileMenu`
- `LibraryBrowser:EditMenu`
- `LibraryBrowser:ViewMenu`
- `LibraryBrowser:HelpMenu`

For example, the following code adds a menu item to the Library Browser's file menu:

```
%Menu customization:
% Add items to the Library Browser File menu
cm.addCustomMenuFcn('LibraryBrowser:FileMenu',@getMyMenuItems

%% Define the custom menu function.
function schemaFcns = getMyMenuItems(callbackInfo)
schemaFcns = {@myBasic};
end

%% Define the schema function for first menu item.
function schema = myBasic(callbackInfo)
disp('1');
```

```
schema = sl_action_schema;
schema.label = 'Display 1';
schema.userdata = 'item one';
schema.tag = 'LibraryBrowser:ItemOne';
end
```

Registering Customizations

In this section...

About Registering User Interface Customizations

You must register your user interface customizations using a MATLAB function called `sl_customization.m`. This is located on the MATLAB path of the Simulink installation that you want to customize. The `sl_customization` function should accept one argument: a handle to a customization manager object. For example:

```
function sl_customization(cm)
```

The customization manager object includes methods for registering menu and control customizations (see "Customization Manager" on page 32-24). Your instance of the `sl_customization` function should use these methods to register customizations specific to your application. For more information, see the following sections on performing customizations.

- "Adding Items to Model Editor Menus" on page 32-2
- "Disabling and Hiding Model Editor Menu Items" on page 32-13
- "Disabling and Hiding Dialog Box Controls" on page 32-15

The `sl_customization.m` file is read when the Simulink software starts. If you subsequently change the `sl_customization.m` file, you must restart the Simulink software or enter the following command at the command line to effect the changes:

```
sl_refresh_customizations
```

Customization Manager

The customization manager includes the following methods:

- `addCustomMenuFcn(stdMenuTag, menuSpecsFcn)`

  Adds the menus specified by `menuSpecsFcn` to the end of the standard Simulink menu specified by `stdMenuTag`. The `stdMenuTag` argument is a string that specifies the menu to be customized. For example, the `stdMenuTag` for the Simulink editor's **Tools** menu is `'Simulink:ToolsMenu'` (see "Displaying Menu Tags" on page 32-11 for more information). The `menuSpecsFcn` argument is a handle to a function that returns a list of functions that specify the items to be added to the specified menu. See "Adding Items to Model Editor Menus" on page 32-2 for more information.

- `addCustomFilterFcn(stdMenuItemID, filterFcn)`

  Adds a custom filter function specified by `filterFcn` for the standard Simulink model editor menu item specified by `stdMenuItemID`. The `stdMenuItemID` argument is a string that identifies the menu item. For example, the ID for the **New Model** item on the Simulink editor's **File** menu is `'Simulink:NewModel'` (see "Displaying Menu Tags" on page 32-11 for more information) . The `filterFcn` argument is a pointer to a function that hides or disables the specified menu item. See "Disabling and Hiding Model Editor Menu Items" on page 32-13 for more information.

33

PrintFrame Editor

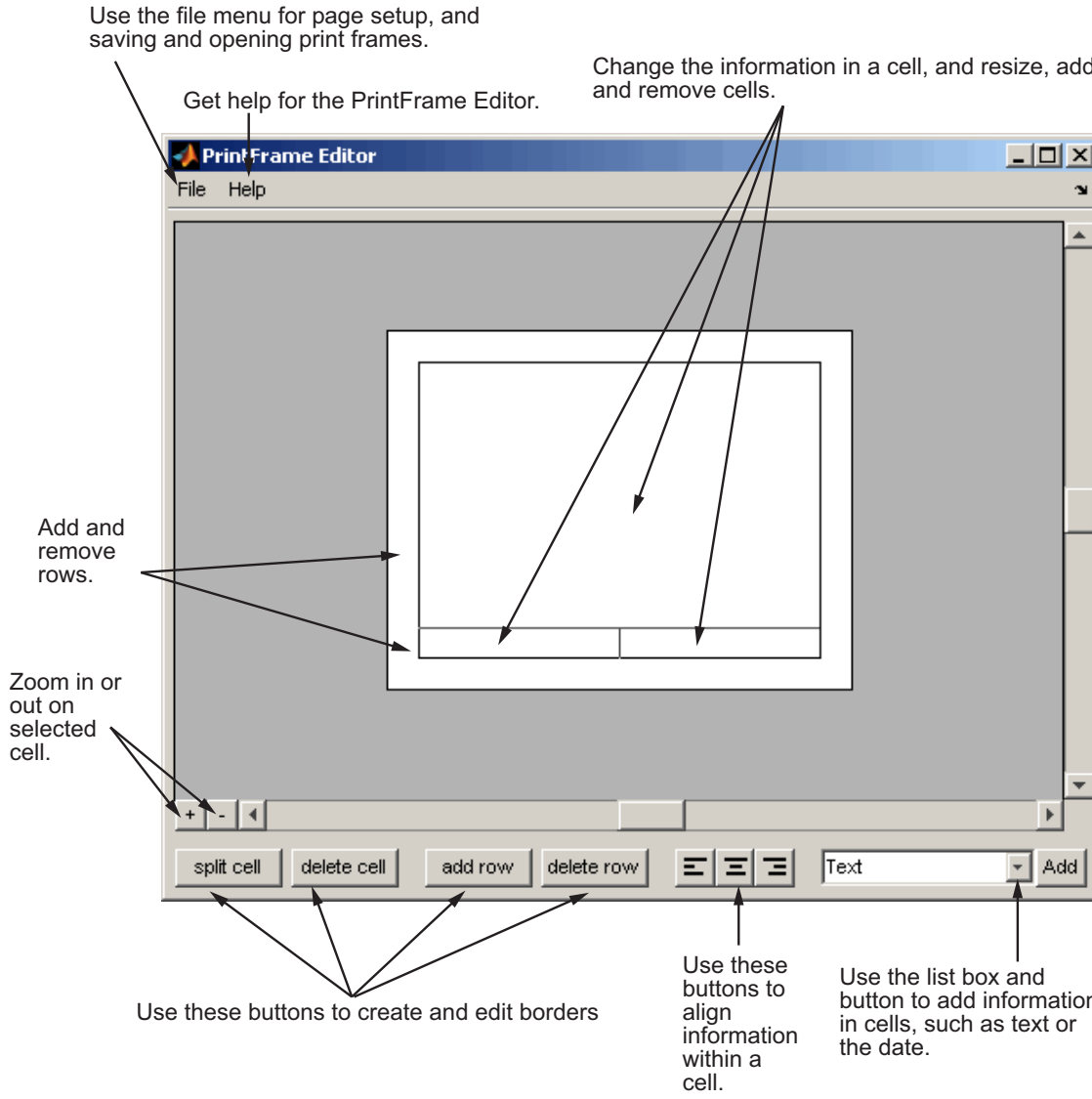
PrintFrame Editor Overview

In this section...

About the Print Frame Editor

The PrintFrame Editor is a graphical user interface you use to create and edit print frames for block diagrams created with the Simulink software and the Stateflow product. This chapter outlines the PrintFrame Editor, accessible with the `frameedit`command.

The following figure describes the general layout of the PrintFrame Editor.

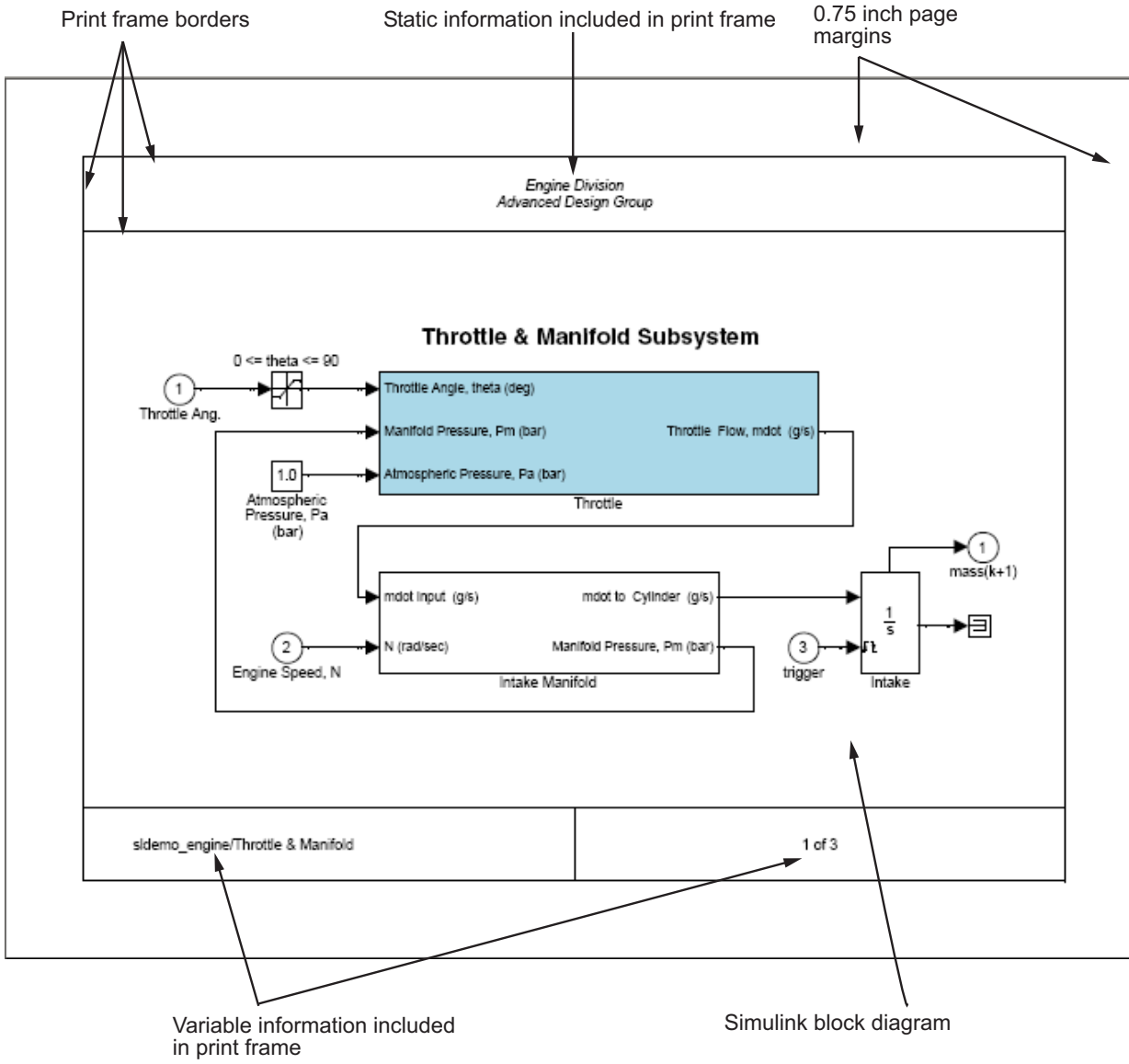


What PrintFrames Are

Print frames are borders containing information relevant to the block diagram, for example, the name of the block diagram. After creating a print

frame, you can use the Simulink software or the Stateflow product to print a block diagram with a print frame.

This illustration shows an example of a print frame with the major elements labeled.



See the "Example" on page 33-26 for specific instructions to create this print frame.

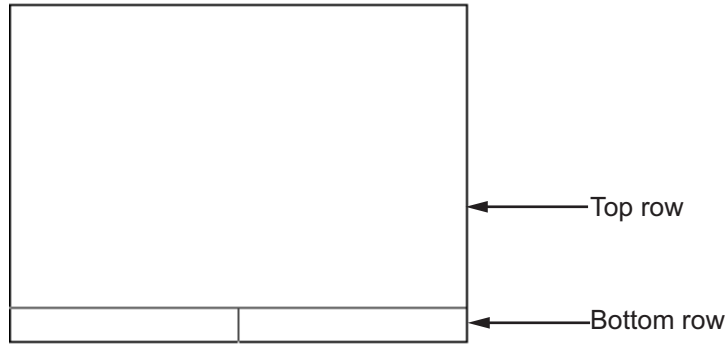
Starting the PrintFrame Editor

Type `frameedit`at the MATLAB prompt. The **PrintFrame Editor** window appears. The **PrintFrame Editor** window opens with the default print frame.

You can use `frameedit filename` to open the **PrintFrame Editor** window with the specified filename, where `filename` is a figure file you previously created and saved using `frameedit`.

Default Print Frame

The default print frame has two rows. The top row consists of one cell and the bottom row has two cells.



You can add information entries to these cells. You can also add new rows and cells and add information in them, or change entries to different ones.

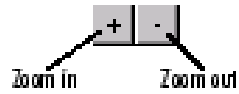
Zooming In and Out

While using the PrintFrame Editor, you might need to zoom in on an area to better see the information or cell.

1. Click in the area you want to zoom in on.

   This selects a cell.

2. Click the zoom in button.



The area is magnified.

3 Click the zoom in button repeatedly to continue zooming in.

To zoom out, reducing magnification in an area, click the zoom out button. Click the zoom out button repeatedly to continue zooming out.

Getting Help for the PrintFrame Editor

Select **PrintFrame Editor Help** from the **Help** menu in the PrintFrame Editor window to access this online help.

Closing the PrintFrame Editor

To close the **PrintFrame Editor** window, click the close box in the upper right corner, or select **Close** from the **File** menu.

Print Frame Process

These are the basic steps for creating and using print frames:

- “Designing the Print Frame” on page 33-8
- “Specifying the Print Frame Page Setup” on page 33-9
- “Creating Borders (Rows and Cells)” on page 33-11
- “Adding Information to Cells” on page 33-14
- “Changing Information in Cells” on page 33-18
- “Saving and Opening Print Frames” on page 33-22
- “Printing Block Diagrams with Print Frames” on page 33-23

See also the “Example” on page 33-26.

Designing the Print Frame

In this section...

Before You Begin

Before you create a print frame using the PrintFrame Editor, consider the type of information you want to include in it and how you want the information to appear. You might want to make a sketch of how you want the print frame to look, and note the wording you want to use.

Variable and Static Information

In a print frame, you can include variable and static information. Variable information is automatically supplied at the time of printing, for example, the date the block diagram is being printed. Static information always prints exactly as you entered it, for example, the name and address of your organization.

Single Use or Multiple Use Print Frames

You can design a print frame for one particular block diagram, or you can design a more generic print frame for printing with different block diagrams.

Specifying the Print Frame Page Setup

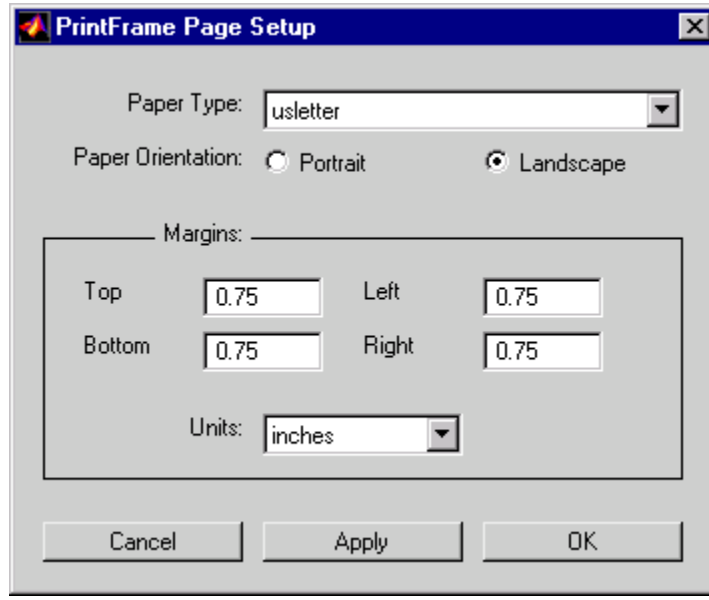
After you have an idea of the design of your print frame, specify the page setup for the print frame.

Note Always begin creating a new print frame with **PrintFrame Page Setup**. If, instead, you begin by creating borders and adding information, and then later change the page setup, you might have to correct the borders and placement of the information. For example, if you add information to cells and then change the page setup paper orientation from landscape to portrait, the information you added might not fit in the cells, given the new orientation.

---

1. In the **PrintFrame Editor** window, select **Page Setup** from the **File** menu.

   The **PrintFrame Page Setup** dialog box appears.



2. In the dialog box, specify:

- **Paper Type** – for example, usletter
- **Paper Orientation** – portrait or landscape
- **Margins** for the print frame and the **Units** in which to specify the margins

3 Click **Apply** to see the effects of the changes you made. Then click **OK** to close the dialog box.

Creating Borders (Rows and Cells)

In this section...

First Steps

Once you have set up the page, use the PrintFrame Editor to specify borders (cells) in which the block diagram and information will be placed.

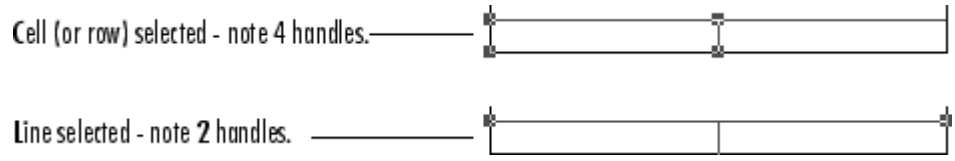
Important Always specify the PrintFrame page setup before creating borders and adding information (see "Specifying the Print Frame Page Setup" on page 33-9). Otherwise, you might have to correct the borders and placement of the information. For example, if you add information to cells and then change the paper orientation from landscape to portrait, the information you added might not fit in the cells, given the new orientation.

Adding and Removing Rows

You can add and remove rows in a print frame.

1. Click within an existing row to select it. If a row consists of multiple cells, click in any of the cells in the row to select that row.

   When a row is selected, handles appear on all four corners. If handles appear on only two corners, you clicked on and only selected the line, not the row.



2 Click the **add row** button to create a new row.

The new row appears above the row you selected.

3 To remove a row, select the row and click the **delete row** button.

Adding and Removing Cells

You can create multiple cells within a row.

1 Select the row in which you want multiple cells.

2 Click the **split cell** button.

The row splits into two cells. If the row already consists of more than one cell, the selected cell splits into two cells.

3 To remove a cell, select the cell and click the **delete cell** button.

Resizing Rows and Cells

You can change the dimensions of a row or cell.

1 Click on the line you want to move.

A handle appears on both ends of the line.

2 Drag the line to the new location.

For example, to make a row taller, click on the top line that forms the row. Then drag the line up and the height of the row increases.

Print Frame Size

Note that the overall size of the print frame is based on the options you specify using the page setup feature. Therefore, when you change the dimensions

of one row or cell, the dimensions of the row or cell next to it change in an inverse direction. For example, if you drag the top line of a row to make it taller, the row above it becomes shorter by the same amount.

To change the overall dimensions of the print frame, use the page setup feature. See “Specifying the Print Frame Page Setup” on page 33-9.

Adding Information to Cells

In this section...

Procedure for Adding Information to Cells

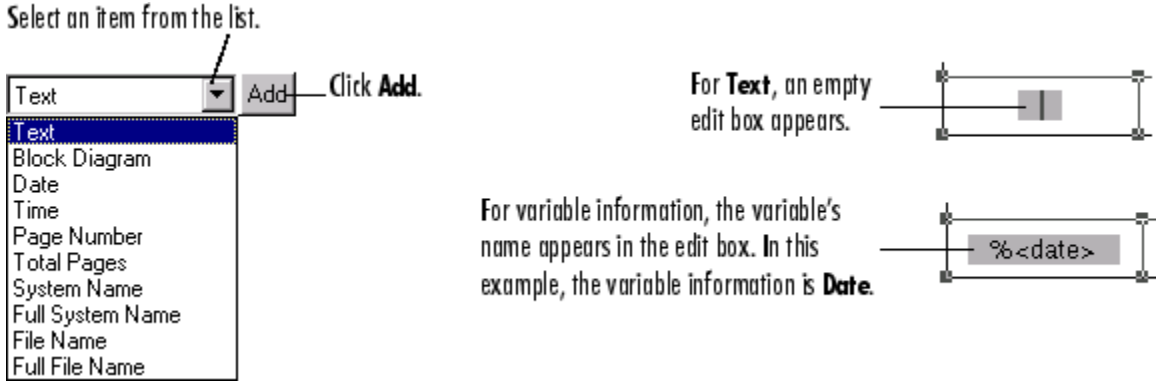
Use the following steps to add information to cells.

1 Select the cell where you want to add information.

2 From the list box, select the type of information you want to add.

3 Click the **Add** button.

An edit box containing that information appears in the cell. (The edit boxes for your platform might look slightly different from those in the figure below.)



4 Click outside of the edit box to end editing mode.

Note If you click the **Add** button and nothing happens, it might be because you did not select a cell first.

Text Information

For **Text**, type the text you want to include in that cell, for example, the name of your organization. Press the **Enter** key if you want to type additional text on a new line. Note that you can type special characters, for example, superscripts and subscripts, Greek letters, and mathematical symbols. For special characters, use embedded TeX sequences (see the `text` command `String` property (in Text Properties of the online documentation) for a list of allowable sequences). Click outside of the edit box when you are finished to end editing mode.

Variable Information

All of the items in the information list box, except for the **Text** item, are for adding variable information, which is supplied at the time of printing. When you print a block diagram with a print frame that contains variable information, the information for that particular block diagram prints in those fields.

Types of Variable Information

The variable entries you can include are:

- **Block Diagram** — This entry indicates where the block diagram is to be printed. **Block Diagram** is a mandatory entry. If **Block Diagram** is not in one of the cells, you cannot save the print frame and therefore cannot print a block diagram with it.
- **Date** — The date that the block diagram and print frame are printed, in `dd-mmm-yyyy` format, for example, `05-Dec.-1997`.
- **Time** — The time that the block diagram and print frame are printed, in `hh:mm` format, for example, `14:22`.
- **Page Number** — The page of the block diagram being printed.
- **Total Pages** — The total number of pages being printed for the block diagram, which depends on the printing options specified.

- **System Name** — The name of the block diagram being printed.
- **Full System Name** — The name of the block diagram being printed, including its position from the root system through the current system, for example, `engine/Throttle & Manifold`.
- **File Name** — The filename of the block diagram, for example, `sldemo_engine.mdl`.
- **Full File Name** — The full path and filename for the block diagram, for example, `\\matlab\toolbox\simulink\simdemos\automotive\sldemo_engine.mdl`.

Note: Adding the system name or filename does not mean that you can then specify a filename for the Simulink software or the StateFlow product in the PrintFrame Editor. It means that when you print a block diagram and specify that it print with a print frame, the system name or filename of the Simulink software or the Stateflow product block diagram is printed in the specified cell of the print frame.

Format for Variable Information

When you add a variable entry, a percent sign, `%`, is automatically included to identify the entry as variable information rather than a text string. In addition, the type of entry, for example, `page`, appears in angle brackets, < >. The entry consists of the entire string, for example, `%<page>`, for **Page Number**.

Multiple Entries in a Cell

You can include multiple entries in one cell.

1. Select the cell.
2. Add another item from the list box.

   The new entry is added after the last entry in that cell.

You can also type descriptive text to any of the variable entries without using the **Text** item in the information list box.

1. Double-click in the cell.

   An edit box appears around the entry.

2. Type text in the edit box before or after the entry.

3. Click anywhere outside of the edit box to end editing mode.

Note You cannot include multiple entries or text in the cell that contains the block diagram entry. `%<blockdiagram>` must be the only information in that cell. If there is any other information in that cell, you cannot save the print frame and therefore cannot print it with a block diagram.

Changing Information in Cells

In this section...

Aligning the Information in a Cell

To align the information within a cell:

1. Click within the cell to select it.
2. Click on one of the **Align** buttons for left, center, or right alignment.

   The information aligns within the cell.

Alignment does not apply to the cell that contains the `%<blockdiagram>` entry. The block diagram is automatically scaled and centered to fit in that cell at the time of printing.

Editing Text Strings

You can change text you typed in a cell:

1. Double-click the information you want to edit.

   An edit box appears around all of the information in that cell.

2. Click at the start of the text you want to change and drag to the end of the text to be changed.

   This highlights the text.

3. Type the replacement text.

It automatically replaces the highlighted text.

4 Click anywhere outside of the edit box to end editing mode.

Note Be careful not to edit the text of a variable entry, because then the variable information will not print. For example, if you accidentally remove the `%` from the `%<page>` entry, the text `<page>` will print instead of the actual page number.

Removing and Copying Entries

You can cut, copy, paste, or delete an entry:

1 Double-click the information you want to remove or copy.

An edit box appears around all of the information in that cell.

2 Click at the start of the entry you want to edit and drag to the end of that entry. This highlights the entry.

For variable information, be sure to include the entire string, for example, `%<page>`.

Note that for computers running the Microsoft Windows operating system, you can select all of the entries in a cell by right-clicking the information and choosing **Select All** from the pop-up menu.

3 Use the standard editing techniques for your platform to cut, copy, or delete the highlighted information.

- For computers running the Microsoft Windows operating system, right-click in the edit box and select **Cut**, **Copy**, or **Delete** from the pop-up menu.
- For UNIX based systems, highlighting the information automatically copies it to the clipboard. If you want to remove it, press the **Delete** key.

If you make a mistake, use your platform's standard undo technique. For example, for computers running the Microsoft Windows operating system, right-click in the edit box and select **Undo** from the pop-up menu.

4 If you cut or copied the information to the clipboard and want to paste it, double-click the entry where you want to paste it and position the cursor at the new location in that edit box. Then use the standard paste technique for your platform.

- For computers running the Microsoft Windows operating system, right-click at the new location and select **Paste** from the pop-up menu.
- For UNIX based systems, click at the new location and then click the middle mouse button.

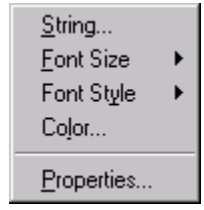
5 Click somewhere outside of the edit box to end editing mode.

Changing the Font Characteristics

You can change the font characteristics for the information in any cell. Specifically, you can specify the font size, style, color, and family.

1 Right-click the information in the cell.

The information in the cell is selected and the pop-up menu for changing font characteristics appears.



If this pop-up menu does not appear, it is because you were in edit mode. To get the font pop-up menu, click somewhere outside of the edit box surrounding the information and then right-click.

2 Select an item from the pop-up menu. Choose **Properties** if you want to change the font family or if you want to change multiple characteristics at once.

Note that you can also select **String** from the pop-up menu, which allows you to edit the text string.

3 Select the new font characteristic(s) for that cell. For example, for **Font Size**, select the new size from its pop-up menu.

Note that changing the font characteristics for the `%<blockdiagram>` entry is not relevant and does nothing.

Saving and Opening Print Frames

In this section...

Saving a Print Frame

You must save a print frame to print a block diagram with that print frame. To save a print frame:

1. Select **Save As** from the **File** menu.

   The **Save As** dialog box appears.

2. Type a name for the print frame in the **File name** edit box.

3. Click the **Save** button.

The print frame is saved as a figure file, which has the `.fig` extension. A figure file is a binary file used for print frames.

Opening a Print Frame

You can open a saved print frame in the PrintFrame Editor, make changes to it, and save it under the same or a different name. To open an existing print frame:

1. Select **Open** from the **File** menu.

2. Select the print frame you want to open.

   All print frames are figure files.

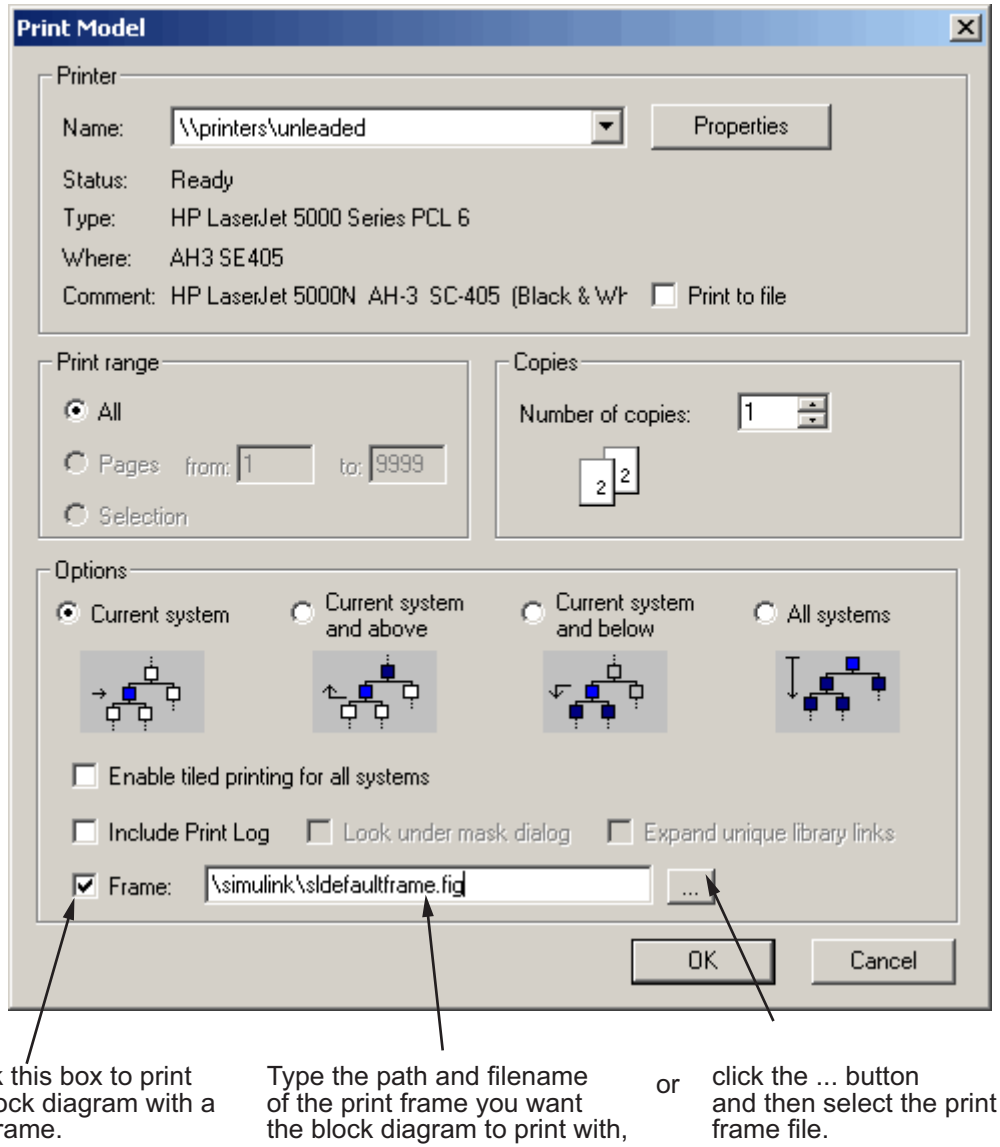
Alternatively, you can open a print frame from the MATLAB prompt. Type `frameedit filename` and the PrintFrame Editor opens with the print frame file you specified.

Printing Block Diagrams with Print Frames

When using the Simulink software or Stateflow product, you can print a block diagram with the print frame.

1 Select **Print** from the **File** menu.

The **Print Model** dialog box appears. The dialog box shown below is for computers running the Microsoft Windows operating system. The dialog box for your platform might look slightly different.



Check this box to print the block diagram with a print frame.

Type the path and filename of the print frame you want the block diagram to print with,

or

click the ... button and then select the print frame file.

In the **Print Model** dialog box:

1 Select the **Frame** check box.

2. Supply the filename for the print frame you want to use. Either type the path and filename directly in the edit box, or click the **...** button and select the print frame file you saved using the PrintFrame Editor.

   Note that the default print frame filename, `sldefaultframe.fig`, appears in the filename edit box until you specify a different filename.

3. Specify other printing options in the **Print** dialog box. For example, for computers running the Microsoft Windows operating system, specify options under **Properties**.

   Note Specify the paper orientation for printing the way you normally would. The paper orientation you specified in the PrintFrame Editor's **PrintFrame Page Setup** dialog box is not the same as the paper orientation used for printing. For example, assume you specified a landscape-oriented print frame in the PrintFrame Editor. If you want the printed page to have a landscape orientation, you must specify that at the time of printing. For example, for computers running the Microsoft Windows operating system, click the **Properties** button in the **Print Model** dialog box, and for **Page Setup**, specify the **Orientation** as **Landscape**.

   ---

4. Click **OK** in the **Print** dialog box.

   The block diagram prints with the print frame you specified.

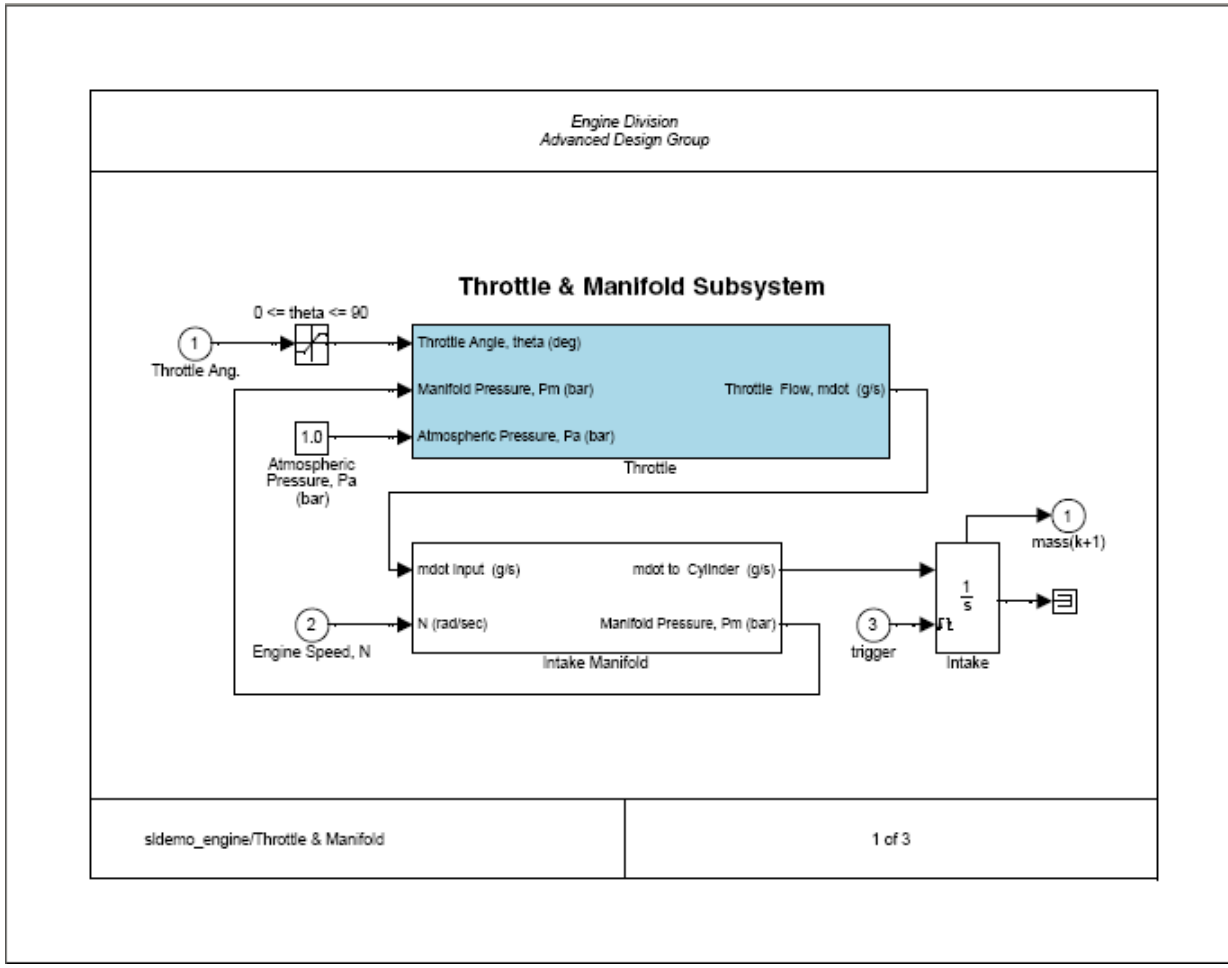
See also the example, "Print the Block Diagram with the Print Frame" on page 33-30.

Example

In this section...

About the Example

This example uses a Simulink software demo engine model. It involves two parts — first creating a print frame, and then printing the engine model with that print frame. The result looks similar to the figure below.



Create the Print Frame

1. At the MATLAB prompt, type `frameedit`.

   The **PrintFrame Editor** window appears.

2. Set up the page:

   a. Select **Page Setup** from the **File** menu.

The **PrintFrame Page Setup** dialog box opens.

b For **Paper Type**, select a size that is appropriate for your printer.

c For this example, keep the **Paper Orientation** as **Landscape** and the **Margins** set to `0.75` **inches**.

d Click the **OK** button.

The dialog box closes. The print frame you see in the **PrintFrame Editor** window will reflect your changes.

3 Add the information entries `%<blockdiagram>`, `%<fullsystem>`, and `%<page>`.

a Click within the upper row in the print frame.

b From the bottom right list box, select `Block Diagram`, then click **Add**. The `%<blockdiagram>` appears in the row.

c Click within the lower left cell in the print frame.

d From the bottom right list box, select `Full System Name`, then click **Add**. The `%<fullsystem>` appears in the cell.

e Click within the lower right cell in the print frame.

f From the bottom right list box, select `Page Number`, then click **Add**. The `%<page>` appears in the cell.

4 Add a row at the top.

a Click within the upper row in the print frame, the row that contains the `%<blockdiagram>` entry.

Be sure that handles appear on all four corners of the row.

b Click the **add row** button.

A new row appears at the top, above the row you selected.

5 Make the new row shorter.

a Click on the horizontal line that separates the top row (the row you just added) from the row beneath it (the row containing the `%<blockdiagram>` entry).

Be sure that only two handles appear, one at each end of the line. If you see four handles in either row, click directly on the horizontal line and the other two handles disappear.

b Drag the line up until the top row is about the same height as the row at the bottom of the print frame.

6 Add information in the top row.

a Click anywhere within the top row (the row you just added).

b Select **Text** from the information list box.

c Click the **Add** button.

An edit box appears in the cell.

d Type `Engine Division`, press the **Enter** key to advance the cursor to the next line, and then type `Advanced Design Group`.

Click the zoom in button if you need to magnify the entry.

e Click outside of the edit box to end editing mode.

7 In the left cell of the bottom row, align the information on the left.

a Click the zoom out button if you need to.

b Click within the left cell of the bottom row to select it.

c Click the left alignment button.

The entry moves to the left.

8 Make the information in the top row appear in italics.

a Right-click on the entry in the row.

b Select **Font Style** from the pop-up menu.

If the pop-up menu for font properties does not appear, you are in editing mode. Click outside of the edit box to end editing mode and then right-click the text to access the pop-up menu.

c From the **Font Style** pop-up menu, select **italic**.

The entry in the cell appears in italics and the information will appear in italics when the print frame is printed with a Simulink diagram.

9 Add the total number of pages to the right cell in the bottom row.

   a Click within the cell to select it.

   b Add the total pages entry: select **Total Pages** from the information list box and click the **Add** button.

      The `%<npages>` entry appears after the `%<page>` entry. If you need to, zoom in to see the entry.

   c Add the text `of` after the page number entry. Click the cursor after the `%<page>` entry, and then type `of` (type a space before and after the word).

   The information in the cell now is: `%<page> of %<npages>`.

10 Save the print frame: select **Save As** from the **File** menu. In the **Save Frame** dialog box, type `engdivl` for the **File name**. Click the **Save** button.

   The print frame is saved as a figure file.

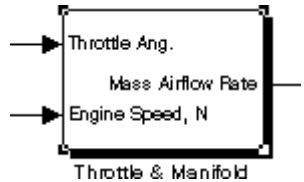
11 You can close the **PrintFrame Editor** window by clicking the close box.

Print the Block Diagram with the Print Frame

1 To view the Simulink engine model, type `sldemo_engine` at the MATLAB prompt.

   The engine model appears in a Simulink window.

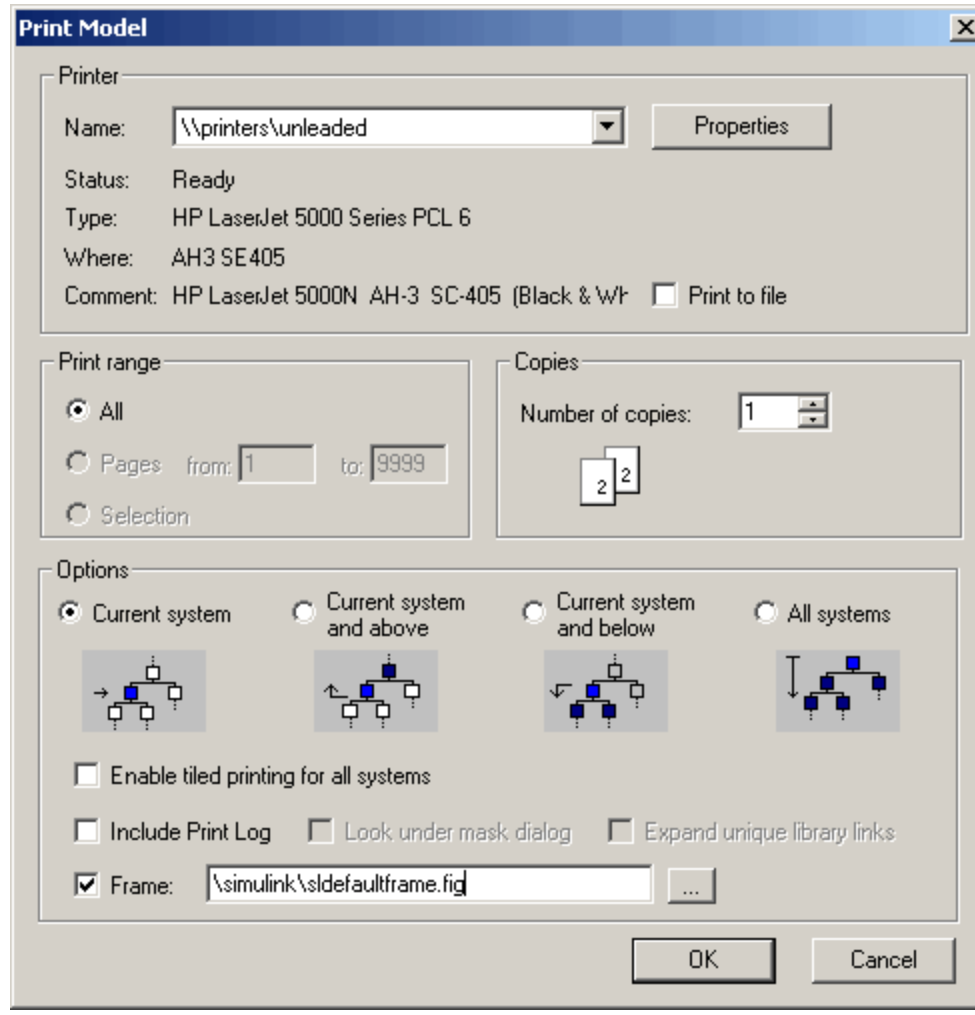
2 Double-click the Throttle & Manifold block.



   The Throttle & Manifold subsystem opens in a new window.

3 In the **Throttle & Manifold** window, select **Print** from the **File** menu.

The **Print Model** dialog box opens with the default settings as shown here.



4 In the **Print Model** dialog box, set the page orientation to landscape. This example uses the techniques for computers running the Microsoft Windows

operating system. Use the methods for your own platform to change the page orientation for printing.

a Click the **Properties** button.

The **Document Properties** dialog box opens.

b Go to the **Page Setup** tab.

c For **Orientation**, select **Landscape**.

d Click **OK**.

The **Document Properties** dialog box closes.

5 In the **Print Model** dialog box, under **Options**, select **Current system and below**.

This specifies that the Throttle & Manifold block diagram and its subsystems will print.

6 Check the **Frame** check box.

7 Specify the print frame to use.

a Click the **...** button.

b In the **Frame File Selection** dialog box, find the filename of the print frame you just created, `engdivl.fig`, and select it.

c Click the **Open** button.

The path and filename appear in the **Frame** edit box.

8 Click **OK** in the **Print Model** dialog box.

The Throttle & Manifold block diagram prints with the print frame; it should look similar to the figure shown at the start of this example.

In addition, the Throttle block diagram and the Intake Manifold block diagram print because you specified printing of the current system and its subsystems. These block diagrams also print with the `engdivl` print frame, but note that their variable information in the print frame is different.

A

Examples

Use this list to find examples in the documentation.

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