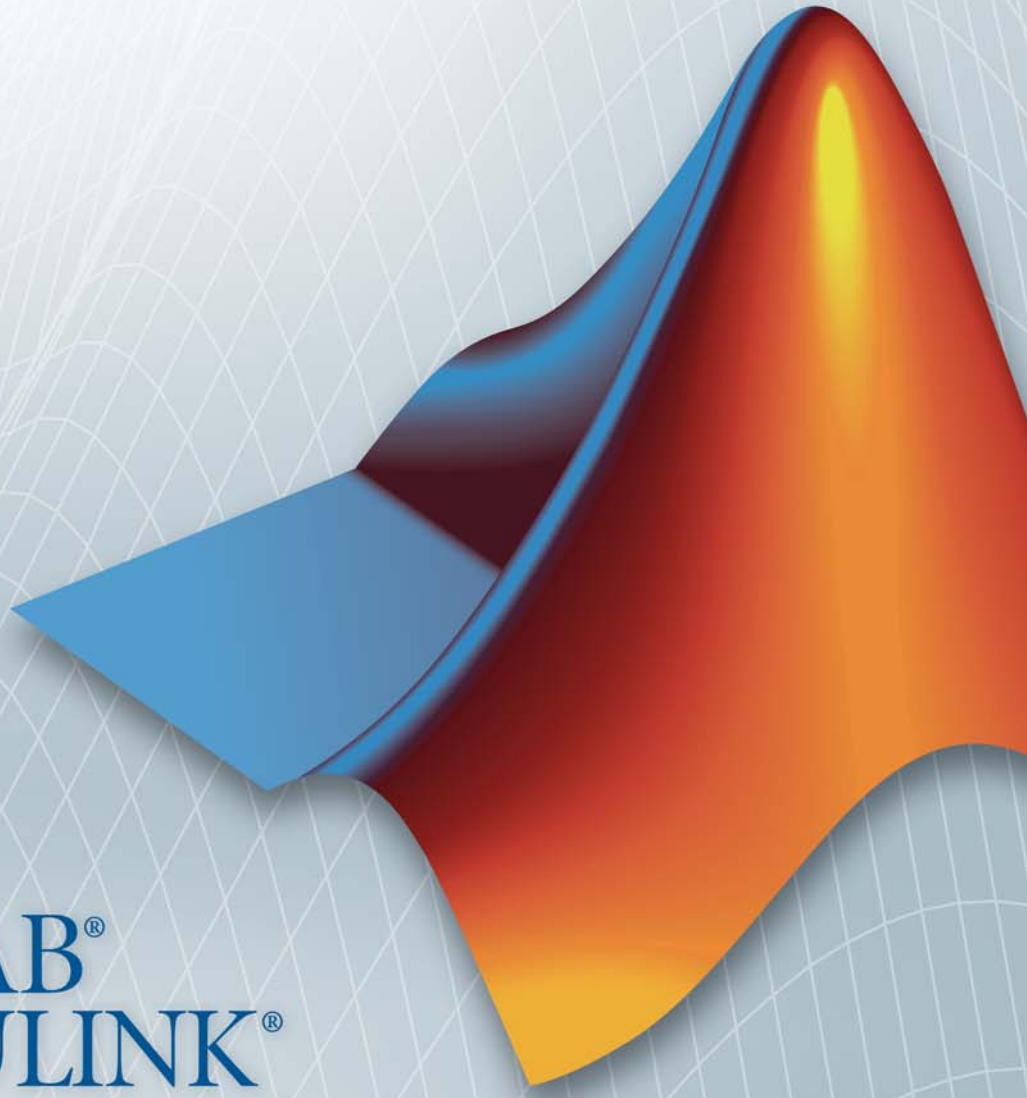
Simulink®

User's Guide

R2012b



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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.

Start the Simulink Software

Open the MATLAB Software

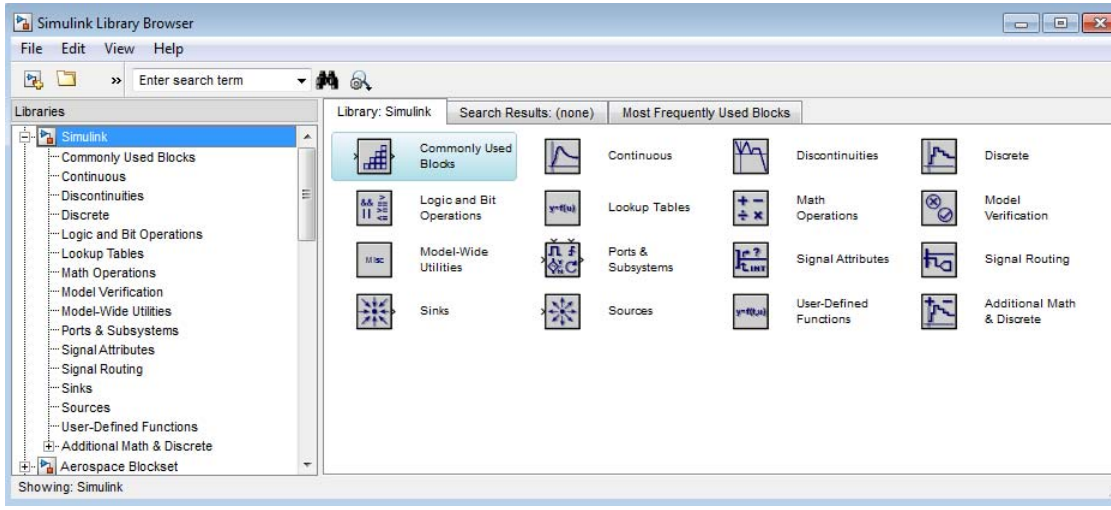
To start the Simulink software, first start the MATLAB® technical computing environment. For details about starting MATLAB, see "Starting and Exiting the MATLAB Program".

Open the Library Browser

To start Simulink Library Browser from MATLAB, use one of these approaches:

- On the MATLAB toolbar, click the Simulink button ( ).
- At the MATLAB prompt, enter the `simulink` command.

The Library Browser opens. It displays a tree-structured view of the Simulink block libraries installed on your system. The Simulink library window displays icons representing the pre-installed block libraries.



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.

To create models, copy blocks from the Library Browser into a model window in the Simulink Editor.

Open the Simulink Editor

Use *one* of the following approaches to open the Simulink Editor:

- Open an existing model. For example, at the MATLAB prompt, enter the name of a model. For details, see "Open an Existing Model" on page 1-4.
- In the Library Browser, select **File > Open**. Choose a model or enter the file name of the model.
- At the MATLAB prompt, use the `open_system` command. For example, to open a model named `vdp`:

  ```
  open_system('vdp')
  ```

Note To have the Simulink Editor display properly, use 32-bit color mode.

Typically, remote desktop connections (for example, a VNC connection) use a default color mode of 16-bits or less.

Open a Model

In this section...

What Happens When You Open a Model

Opening a model brings the model into memory and displays the model graphically in the Simulink Editor.

You can also bring a model into memory without displaying it, as described in "Load a Model" on page 1-7.

Open an Existing Model

To open an existing model, use *one* of these approaches:

- (Windows operating systems only) On the Library Browser toolbar, click the **Open** button.
- In the Library Browser or the Simulink Editor, select **File > Open**. Choose a model or enter the file name of the model.
- At the MATLAB command prompt, enter the name of the model, without the file extension (e.g., `.slx`) . 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, first use the later version to save the model in a format compatible with the earlier version. Then open the model in the earlier version. For details, see "Export a Model to a Previous Simulink Version" on page 1-14.

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`), Simulink displays a warning for SLX files. For MDL files, you might see a warning or an error message, depending on whether it can encode the model, using the current character encoding. The warning or error message specifies the encoding of the current session and the encoding used to create the model. To display the model's text correctly:

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 edit and save the model.

Simulink can check if models contain characters unsupported in the current locale. For more details, see "Check file for foreign characters" and "Saving Models with Different Character Encodings" on page 1-13.

Avoid Initial Model Open Delay

The first model that you open in a MATLAB session takes longer to open than do subsequent models. This is because MATLAB does not load the Simulink product into memory until the first time that you open a Simulink model. This just-in-time loading of the Simulink product reduces the MATLAB startup time and avoids unnecessary consumption of system memory.

To avoid the initial model opening delay, you can have MATLAB load the Simulink software when the MATLAB product starts up. You can issue the command to load Simulink at MATLAB startup from one of two places:

- The `-r` command line option
- The MATLAB `startup.m` file

Use one of these commands:

- `load_simulink` — loads the Simulink product
- `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 Macintosh and Linux® computers:

```
matlab -r load_simulink
```

Load a Model

Loading a model brings it into memory but does not display it graphically.

Tip To both bring a model into memory and display it graphically, open the model as described in "Open a Model" on page 1-4.

After you load a model (as distinct from opening it), you can work with the model programmatically as if it were visible. However, you cannot use the Simulink Editor to edit the model unless you open the model.

You cannot load a model using the Simulink Editor or Library Browser.

To load a model programmatically, at the MATLAB command prompt, enter the `load_system` command. Specify the model to be loaded. For example, to load the `vdp` model:

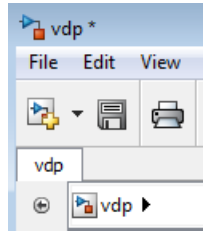
```
load_system('vdp')
```

Save a Model

In this section...

How to Tell If a Model Needs Saving

To tell whether a model needs saving, look at the title bar in the Simulink Editor. If the model needs saving, an asterisk appears next to the model name in the title bar.



To determine programmatically whether a model needs saving, use the model parameter `Dirty`. For example:

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

Save a Model for the First Time

To save a model for the first time, in the Simulink Editor, select **File > Save**. Provide a location and name for the model file.

Model Names

Model file names must start with a letter and can contain letters, numbers, and underscores. The file name must not be the same as that of a MATLAB software command.

The total number of characters must not be greater than a certain maximum, usually 63 characters. To find out whether the maximum for your system is greater than 63 characters, use the MATLAB `namelengthmax` command.

Save a Previously Saved Model

If you are saving a model whose model file was previously saved:

- To *replace* the file contents, in the Simulink Editor, select **File > Save**.
- To save the model with a new name or location, in the Simulink Editor, select **File > Save As**.

Note See also "Upgrade Models to SLX" on page 1-10.

What Happens When You Save a Model?

Simulink saves the model by generating a specially formatted file called the *model file* that contains the block diagram and block properties. The Simulink software follows this process while saving a model:

1. If the model file already exists, Simulink renames the model file as a temporary file.
2. All block `PreSaveFcn` callback routines execute first, then the block diagram `PreSaveFcn` callback routine executes.
3. Simulink writes the model file to a new file using the same name and, by default, an extension of `.slx`.

4. All block `PostSaveFcn` callback routines execute, then the block diagram `PostSaveFcn` callback routine executes.

5. Simulink deletes the temporary file.

If an error occurs during this process, Simulink:

- 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
- Issues an error message

If an error occurs in Step 2 of the save process, then Step 3 is omitted and Steps 4 and 5 are performed.

Saving Models in the SLX File Format

Save New Models as SLX

You save new models and libraries in the SLX format by default, with file extension `.slx`. SLX is a compressed package that conforms to the Open Packaging Conventions (OPC) interoperability standard. SLX stores model information using Unicode UTF-8 in XML and other international formats. Saving Simulink models in the SLX format:

- Typically reduces file size compared to MDL. The file size reduction between MDL and SLX varies depending on the model.
- Solves some problems in previous releases with loading and saving MDL files containing Korean and Chinese characters.

You can specify your file format for saving new models and libraries with the Simulink preference “File format for new models and libraries”.

Upgrade Models to SLX

If you upgrade an MDL file to SLX file format, the file contains the same information as the MDL file, and you always have a backup file. All functionality and APIs that currently exist for working with models, such as the `get_param` and `set_param` commands, are also available when using

the SLX file format. If you upgrade an MDL file to SLX file format without changing the model name or location, then Simulink creates a backup file by renaming (if writable) and Simulink does not remove the MDL file.

If you save an existing MDL file using **File > Save**, Simulink respects the file's current format and saves your model in MDL format.

To save an existing MDL file in the SLX file format,

1. Select **File > Save As**.
2. Leave the default **Save as type** as SLX, and click **Save**.

   Simulink saves your model in SLX format, and creates a backup file by renaming the MDL (if writable) to `mymodel.mdl.`*`releasename`*, e.g., `mymodel.mdl.R2010b`.

Alternatively, use `save_system`:

```
save_system mymodel mymodel.slx
```

This command creates `mymodel.slx`, and if the existing file `mymodel.mdl` is writable it is renamed `mymodel.mdl.`*`releasename`*.

SLX files take precedence over MDL files, so if both exist with the same name and you do not specify a file extension, you load the SLX file.

Simulink Projects can help you migrate files to SLX. For an example, see "Upgrade Model Files to SLX and Preserve Revision History" on page 13-15.

Caution If you use third-party source control tools, be sure to register the model file extension `.slx` as a binary file format. If you do not, these third-party tools might corrupt SLX files when you submit them.

Operations with Possible Compatibility Considerations when using SLX	What Happens	Action
Hard-coded references to file names with extension `.mdl`.	Scripts cannot find or process models saved with new file extension `.slx`.	Make your code work with both the `.mdl` and `.slx`extension. Use functions like `which` and `what` instead
Third-party source control tools that assume a text format by default.	Binary format of SLX files can cause third-party tools to corrupt the files when you submit them.	Register `.slx` as a binary file format with third-party source control tools. Also recommended for `.mdl` files. See "Register Model Files with Source Control Tools" on page 13-70.
Changing character encodings.	Some cases are improved, e.g., SLX solves some problems in previous releases with loading and saving MDL files containing Korean and Chinese characters. However, sharing models between different locales remains problematic.	See "SLX Files and Character Encodings" on page 1-14.

The format of content within MDL and SLX files is subject to change. To operate on model data, use documented APIs (such as `get_param`, `find_system`and Simulink.MDLInfo.

Saving Models with Different Character Encodings

Differences in Character Encodings

When you save a model, the current character encoding is used to encode the text stored in the model file. This can lead to model corruption if you save a model whose original encoding differs from current encoding.

If you change character encoding, it is possible to introduce characters that cannot be represented in the current encoding. If this is the case, the model is saved as **`model`**`.err`, where **`model`** is the model name, leaving the original model file unchanged. Simulink 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, either:

- Save the model in SLX format (see "Saving Models in the SLX File Format" on page 1-10).
- Use the following procedure to locate and remove characters one by one.

  1 Use a text editor to find the character in the `.err` file at the position specified by the save error message.

  2 Find and delete the corresponding character in the open model and resave the model.

  3 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.

SLX Files and Character Encodings

Saving Simulink models in the SLX format typically reduces file size and solves some problems in previous releases with loading and saving MDL files containing Korean and Chinese characters.

Considerations for choosing a model file format:

- Use SLX if you are loading and saving models with Korean or Chinese characters
- Use SLX if you would benefit from a compressed model file
- Whether you use SLX or MDL, Simulink can detect and warn if models contain characters unsupported in the current locale. For SLX, you can use the Model Advisor to help you, see “Check file for foreign characters”.

Export a Model to a Previous Simulink Version

You can export (save) a model created with the latest version of the Simulink software in a format used by an earlier version, such as Simulink 7.0 (R2007b). For example, you might want to perform such an export to make a model available to colleagues who only have access to a previous version of the Simulink product.

To export a model in an earlier format:

1. In the Simulink Editor, select **File > Save**. This saves a copy in the latest version of Simulink. This step avoids compatibility problems.
2. Simulink Editor, select **File > Export > Export Model To Previous Version**.

   The Export To Previous Version dialog box appears.
3. In the dialog box, from the **Save as type** list, select the previous version to which to export the model.

4 Click the **Save** button.

When you export a model to a previous 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 you run it in the earlier version of Simulink software. In addition, Simulink converts blocks that postdate an earlier version into yellow empty masked Subsystem blocks. For example, if you export a model to Release R2007b, and the model contains Polynomial blocks, Simulink converts the Polynomial blocks into yellow empty masked Subsystem blocks. Simulink also removes any unsupported functionality from the model.

Save from One Earlier Simulink Version to Another

You can open a model created in an earlier version of Simulink and export that model to 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 earlier version.

1 Use the current version of Simulink to open the model created with the earlier version.

2 Before you make any changes, save the model in the current version by selecting **File > Save**.

   After saving the model in the current version, you can change and resave it as needed.

3 Save the model in the earlier version of Simulink by selecting **File > Export > Export Model To Previous Version**.

4 Start the earlier Simulink version and use it to open the model that you exported to that earlier version.

5 Save the model in the earlier version by selecting **File > Save**.

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

See also the Simulink preferences that can help you work with models from earlier versions:

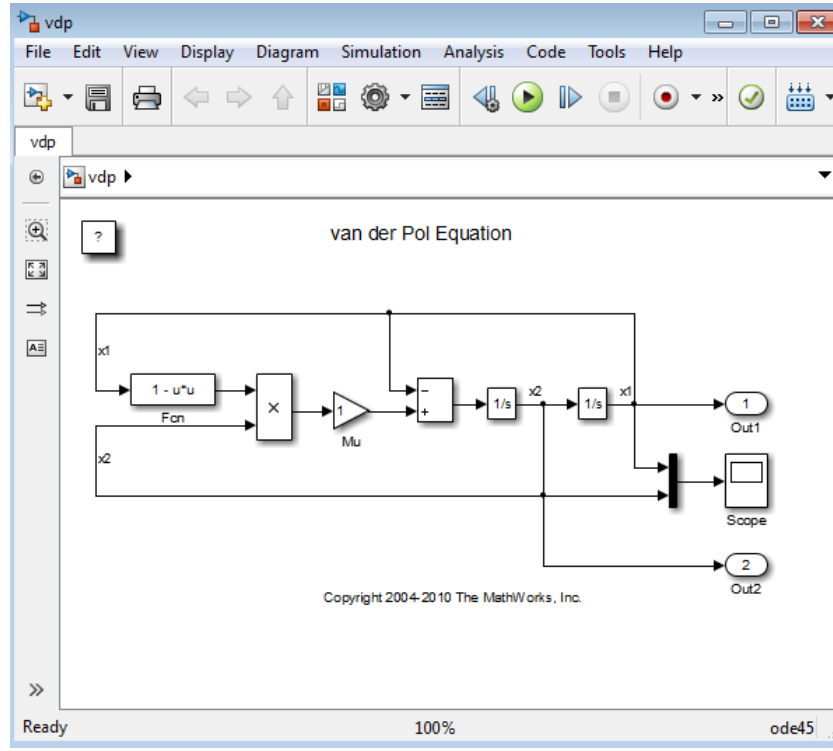
- “Do not load models created with a newer version of Simulink”
- “Save backup when overwriting a file created in an older version of Simulink”

Simulink Editor

In this section...

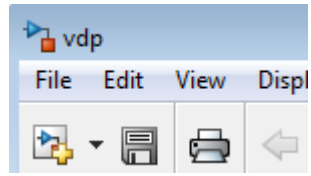
Editor Layout

Opening a Simulink model or library displays the model or library in the Simulink Editor. For more information, see "Open the Simulink Editor" on page 1-3.



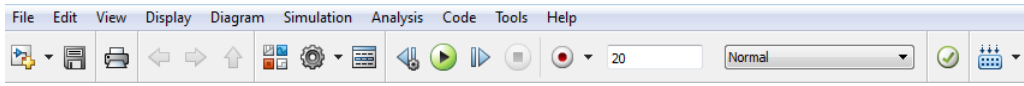
The Simulink Editor has the following major sections:

- **Title bar**



  In the top left corner, the title bar displays the name of the model or subsystem that is open in the model window.

- **Menu bar** and **toolbar**



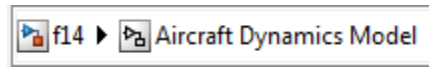
  At the top of the Simulink Editor, you can access commands to work with models. Several buttons in the toolbar provide quick access to commonly used Simulink Editor menu options. Other buttons in the toolbar open other Simulink tools, such as the Model Explorer (for details, see "Open Simulink Tools from the Toolbar" on page 1-20).

- **Palette**

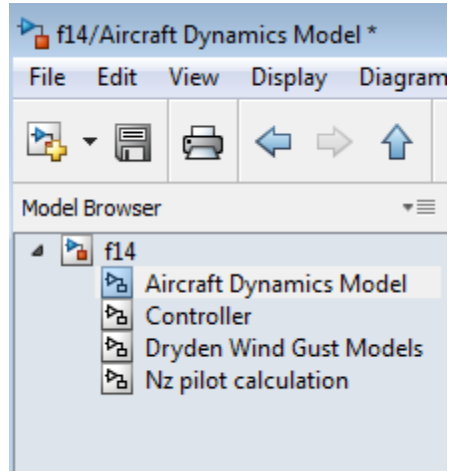
  The icons in the vertical bar on the right side of the Simulink Editor perform very common tasks, such as adding an annotation.

- **Explorer bar**

The breadcrumb shows the systems that you have open in the editor. Select a system in the breadcrumb to open that system in the model window. If you click in the Explorer bar whitespace, you can edit the hierarchy. Also, the down arrow at the right side of the Explorer bar provides a history.



- **Model Browser**



Click the double arrows » in the bottom left corner of the Simulink Editor to open or close a tree-structured view of the model in the editor.

- **Canvas** — The canvas is area where you edit the block diagram. You can use the mouse and keyboard to create and connect blocks, select and move blocks, edit block labels, display block dialog boxes, and so on.

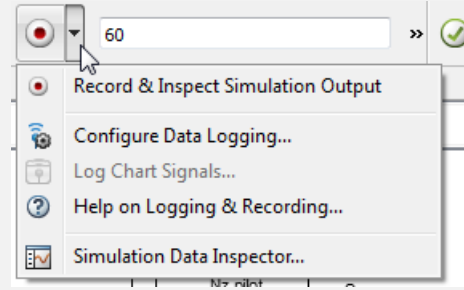
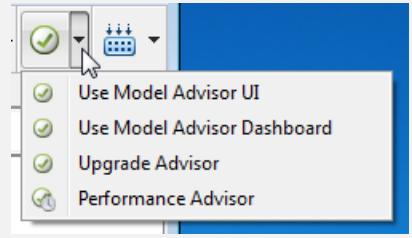
  To display *context menus* specific to a particular model object in the canvas, such as a block, right-click the object.

- **Status information** — Near the top of the editor, you can see (and reset) the simulation time and the simulation mode. The bottom status line shows the status of Simulink processing, the zoom factor, and the solver.

Open Simulink Tools from the Toolbar

The Simulink Editor toolbar provides several buttons for quick access to other Simulink tools.

For buttons that have associated menu options, clicking the button invokes the first menu option.

Tools	Buttons and Associated Menus
Library Browser	
Model Explorer	
Simulation Stepper	Next Step  Previous Step 
Simulation Data Inspector	
Advisor Tools	

Undoing Commands

You can cancel the effects of up to 101 consecutive operations. To undo commands, select **Edit > Undo**. Repeat until you get to the command that you want to undo. You can undo operations such as:

- 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" on page 4-39 for more information)

To reverse the effects of an **Undo** command, select **Edit > Redo**.

Window Management

One Simulink Editor Per Model

When you open a model, that model appears in its own Simulink Editor window. For example, if you have one model already open, and then you open a second model, the second model appears in a second Simulink Editor.

To open the same model in two separate Simulink Editor windows, at the MATLAB command prompt, enter the `open_system` command, using the `window` argument. For example, if you already have the `vdp` model open, then to open another instance of the `vdp` model in a separate Simulink Editor, enter:

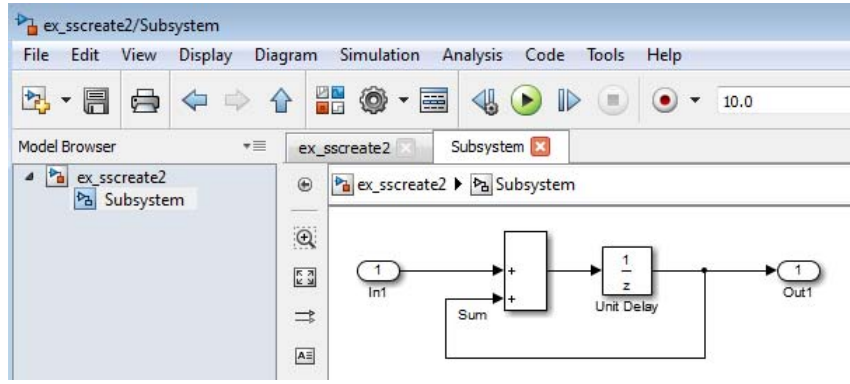
```
open_system ('vdp', 'window')
```

Open a Subsystem

The Simulink Editor displays only one active window at a time. By default, if you open a Subsystem block, the opened subsystem replaces (in terms of being displayed in the model window) the model from which you opened the subsystem.

You can use tabs in the Simulink Editor to make it easier to navigate between model windows for the top model and subsystems. To open a subsystem in a separate tab:

1. Right-click the Subsystem block.
2. From the context-menu, select **Open In New Tab**. In the example below, there are separate tabs for the `ex_sscreate2` model and for the `Subsystem`.



Navigate between the top model and subsystems by clicking the appropriate tab. Or, choose an option following options from the **View > Navigate** menu, such as **Back**, **Back to Parent**, or **Previous Tab**.

For more information about opening subsystems, see "Navigate Model Hierarchy" on page 4-39.

Open a Referenced Model

If you open a Model block, the referenced model opens in a separate Simulink Editor.

Bring the MATLAB Desktop Forward

Simulink Editor windows open on top of the MATLAB desktop. To bring the MATLAB desktop back to the top of your screen, in the Simulink Editor, select **View > MATLAB Desktop**.

Zoom and Pan Block Diagrams

You can enlarge or shrink the view of the block diagram in the current Simulink Editor window.

Goal of Zoom or Pan	What You Do
Enlarge the model diagram incrementally	Select **View > Zoom In** or press **Ctrl++**.
Enlarge the model diagram dynamically	Roll the mouse scroll wheel forward.
Zoom by a factor of two, displaying the selected model object	**1** In the palette, drag the zoom button () to the object that you want to include in the enlarged view. **2** Press the left mouse button.
Zoom until the whole model diagram just fits in the current window	Select **View > Fit to View** or press **Spacebar**.
Zoom and pan	**1** Roll the mouse scroll wheel forward. **2** Release the scroll wheel. **3** Hold the scroll wheel down and pan to the desired positioning by moving the mouse. **4** Release the scroll wheel. To disable the zoom and pan behavior for the scroll wheel, clear the **File > Simulink Preferences > Editor Defaults > Scroll wheel controls zooming** preference.
Pan with the mouse	Hold down **p** or **q** and drag mouse.
Shrink the model diagram incrementally	Select **View > Zoom Out**.

Goal of Zoom or Pan	What You Do
Shrink the model diagram dynamically	Roll the mouse scroll wheel backward.
Restore the model diagram to 100%	Select **View > Normal View (100%)** or press **Alt+1**.
Go back in pan/zoom history	**b**
Go forward in pan/zoom history	**t**

To disable the zoom and pan behavior for the scroll wheel, clear the **File > Simulink Preferences > Editor Defaults > Scroll wheel controls zooming** preference. If you hold the **CRTL** key and use the scroll wheel, the scroll wheel behavior is the opposite of how the preference is set.

Update a Block Diagram

Updating the Diagram

You can leave many attributes of a block diagram, such as signal data types and sample times, unspecified. The Simulink software then infers the values of block diagram attributes, based on the block connectivity and attributes that you specify. The process that Simulink uses is known as *updating the diagram*.

Simulink attempts to infer the most appropriate values for attributes that you do not specify. If Simulink cannot infer an attribute, it halts the update and displays an error dialog box.

Simulation Updates the Diagram

Simulink updates the block diagram at the start of a simulation. The updated diagram provides the simulation with the results of the latest changes that you have made to a model.

Update Diagram at Edit Time

As you create a model, at any point you can have Simulink update the diagram. Updating the diagram periodically can help you to identify and fix potential simulation issues as you develop the model. This approach can make it easier to identify the sources of problems by focusing on a set of recent changes. Also, the update diagram processing takes less time than performing a simulation, so you can identify issues more efficiently.

To update the diagram at edit time, use one of these approaches:

- In the Simulink Editor, select **Simulation > Update Diagram**.
- Press **Ctrl-D**.

For example:

1 Create the following model.

2 In the Simulink Editor, select **Display > Signals & Ports > Port Data Types**.

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 In the Constant block parameters dialog box, set **Output data type** to `single`.

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

4 In the Simulink Editor, select **Simulation > Update Diagram**.

The updated block diagram reflects the change that you made previously.

In this example, Simulink infers a data type for the output of the Gain block. This is because you did not specify a data type for the block. The inferred 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 input is `single`.

Copy Models to Third-Party Applications

On a computer running the Microsoft Windows operating system, you can:

1. Copy a Simulink product model to the Windows operating system clipboard.
2. Paste the model from the clipboard to a third-party application, such as word processing software.

You can 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. For a description of how to set up the figure settings and save a figure to the clipboard on a Windows platform, see "Exporting to the Windows or Macintosh Clipboard".

Print a Block Diagram

In this section...

Print Interactively or Programmatically

You can print a block diagram:

- Interactively in the Simulink Editor, by selecting **File > Print**.
- Programmatically, by using the MATLAB `print` command.

To control some additional aspects of printing a block diagram, use the `param_set` command with model parameters.

Systems to Print

From the Simulink Editor

To specify what systems in a block diagram that you want to print:

1. In the Simulink Editor, select **File > Print > Print**.

   The Print Model dialog box appears.

2. In the Options section, select one of the following:
   - **Current system** — The current system only

- **Current system and above** — The current system and all systems above it in the model hierarchy
- **Current system and below** — 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** — All systems in the model, with the option of looking into the contents of masked and library blocks

To print the contents of masked subsystems that are at or below the level of the current block, select the **Look under mask dialog** check box. When you print all systems, the top-level system is the current block, so Simulink looks under all masked blocks.

To print the contents of library blocks that are systems, in the Print Model dialog box, select the **Expand unique library links** check box. Only one copy is printed, regardless of how many copies of the block that the model contains.

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

With the 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. Precede the system name with the `-s` switch identifier. The name of the system is the only required argument. The system 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.

The `print` command prints only the system that you specify. The command does not have options to specify the scope of the systems to be printed (for example, current system and below). To specify the scope of the systems to be printed, use the Simulink Editor.

This example shows how to print the currently selected subsystem (`Controller`).

```
open_system('f14');
open_system('f14/Controller');
print(['-s', gcs])
```

This example shows how to print the contents of a subsystem named `Controller` in the current system.

```
open_system('f14');
print -sController
```

This example shows how to print the contents of a subsystem named `Aircraft Dynamics Model`.

```
open_system('sldemo_clutch');
print (['-sAircraft Dynamics Model'])
```

To print a system whose name appears on multiple lines, assign the newline character to a variable and use that variable in the `print` command. This example shows how to print a subsystem whose name, `Aircraft Dynamics Model`, appears on three lines.

```
open_system('f14');
cr = sprintf('\n');
print (['-sAircraft' cr 'Dynamics' cr 'Model'])
```

The *`device`* specifies the device type. For a list of device types, see the documentation for the `print` function.

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

Title Block Print Frame

A title block print frame is a border that contains information relevant to the block diagram, such as the name of the block diagram. After you create a print frame, you can print a block diagram with a print frame:

1. In the Simulink Editor, select **File > Print > Print**.

   The Print Model dialog box appears.

2. Select the **Frame** check box.

3. In the adjacent edit box, enter the path to the title block frame.

To create a customized title block frame, use the MATLAB frame editor. For information about using the frame editor to create title block frames, see "Custom Print Frames".

Paper Size and Orientation

On Windows platforms, you can use the Simulink Editor to specify the type and orientation of the paper for printing a model.

1. Select **File > Print > Page Setup**.

   The Print Setup dialog box appears.

2. In the Paper and Orientations section, set the fields for paper size and orientation.

On all platforms, you can set the paper orientation alone, using the MATLAB `orient` command.

On all platforms, you can also set the paper type and orientation by using the `set_param` command with the model's `PaperType` and`PaperOrientation` properties, respectively (see "Model Parameters").

Diagram Positioning and Sizing

To position and size the model diagram on the printed page, use the `set_param` command with a model's `PaperPositionMode` and `PaperPosition` parameters.

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.

If you set the `PaperPositionMode` parameter to `manual`, Simulink positions (and scales, if necessary) the model diagram to fit inside the specified print rectangle. If `PaperPositionMode` is `auto`, Simulink centers the model diagram on the printed page, scaling the diagram, if necessary, to fit the page.

For example, these commands print the block diagram of the `vdp` model in the lower-left corner of a U.S. letter-size page in landscape orientation.

```
open_system('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
```

Tiled Printing

By default, each block diagram is scaled during the printing process so 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 Simulink prints the block diagram, and hence, the total size of the printed diagram.

Also, you can set different tiled-print settings 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 use tiled printing.

Enable Tiled Printing

To enable tiled printing for a model or subsystem, use one of these approaches:

- In the Simulink Editor, select **File > Print > Enable Tiled Printing**.
- At the MATLAB command prompt:

1. Use the `set_param` command to set the `PaperPositionMode` parameter to `tiled` (see).
2. Use the `print` command with the `-tileall` argument.

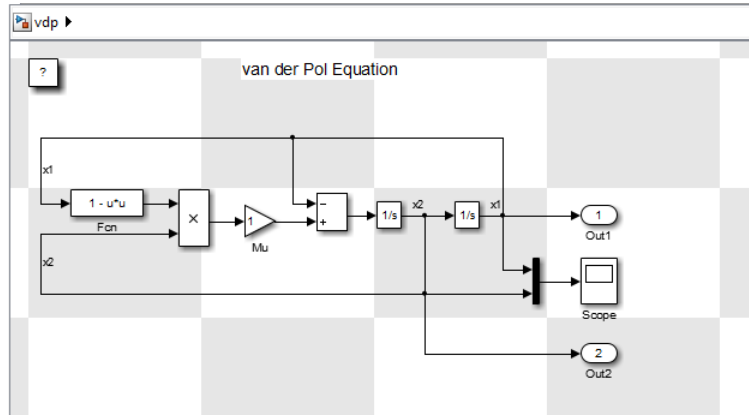
For example, to open the `f14` model and enable tiled printing for the `Controller` subsystem, enter:

```
open_system('f14');
set_param('f14/Controller', 'PaperPositionMode', 'tiled');
print('-sf14/Controller', '-tileall')
```

Display Page Boundaries

Displaying the page boundaries in the Simulink Editor can help you to visualize the model size and layout with respect to the page. To make the page boundaries visible, select **File > Print > Show Page Boundaries**.

Simulink renders the page boundaries on the Simulink Editor canvas. If tiled printing is enabled, Simulink represents page boundaries with a checkerboard pattern. Each checkerboard square indicates the extent of a separate page.



If tiled printing is disabled, only a single page appears on the canvas.

To display the page boundaries programmatically, use the `set_param` command, with the system's `ShowPageBoundaries` parameter set to `on` (see "Model Parameters"). For example:

```
open_system('vdp');
set_param('vdp', 'ShowPageBoundaries', 'on')
```

Scaling and Margins

To scale the block diagram so that more or less of it appears on a single tiled page, use the `set_param` command with the `TiledPageScale` parameter. 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.

To specify the margin sizes associated with tiled pages, use the `set_param` command with 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 determines the margin's 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.

Range of Tiled Pages

By default, Simulink prints all of a system's tiled pages.

On a Microsoft Windows platform, to specify a range of tiled page numbers to print, you can use the Simulink Editor.

1. In the Simulink Editor, select **File > Print > Print**.

   The Print Model dialog box appears.

2. In the Options section, select **Current system** and **Enable tiled printing for all systems**.

3. In the Print range section in the middle of the dialog box, select **Pages** and enter a page range.

To specify a range of tiled page numbers programmatically, use the `print` command with the `-tileall` argument and the `-pages` argument. Append to `-pages` a two-element vector that specified the range.

Note Simulink 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, and so on.

For example, to print the second, third, and fourth pages:

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

Print Sample Time Legend

You can print a legend that contains sample time information for your entire system, including any subsystems. The legend appears on a separate page from the model. To print a sample time legend:

- In the Simulink Editor, select **File > Print > Print**.

  The Print Model dialog box appears.

- In the Options section select, select **Print Sample Time Legend**.

For more information about the contents and the settings of the legend, see “View Sample Time Information” on page 5-9.

Generate a Model Report

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

Tip If you have the SimulinkReport Generator™ installed, you can generate a detailed report about a system. To do so, in the Simulink Editor, select **File > Reports > System Design Description**. For more information, see "System Design Description".

To generate a model report for the current model:

1. In the Simulink Editor, select **File > Print > Print Details**.

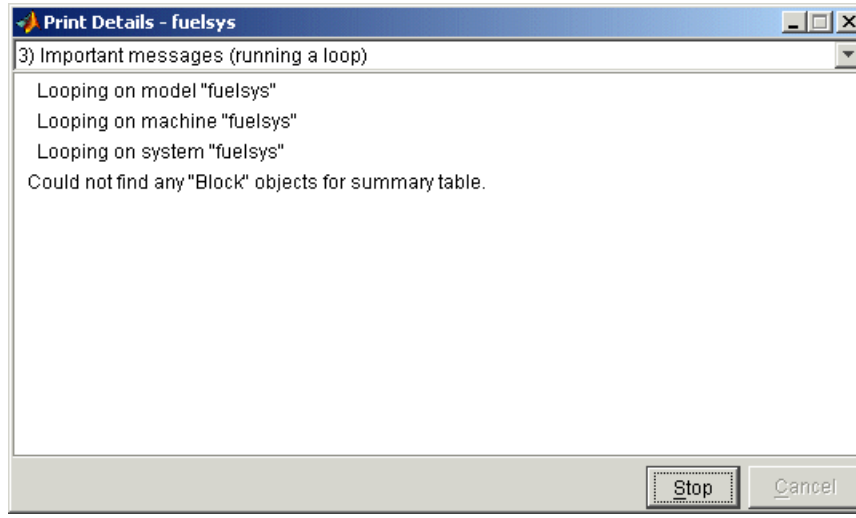
   The Print Details dialog box appears.

2. Select the desired report options. For details, see "Model Report Options" on page 1-37.

3. Select **Print**.

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

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



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 changes to a **Stop** button. To terminate the report generation, press **Stop**. 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

Use the Print Details dialog box allows you to specify 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.

Printing Limitations

Printing Properties (Windows)

On Windows platforms, the **File > Print > Print** dialog box includes:

- Printing options, such as the printer to use, the print range, the number of copies, and which systems to print.

- A **Properties** button, which displays additional printing properties, such as paper orientation and resizing options. In R2012b, Simulink ignores the settings for these additional printing properties. Simulink only uses the settings in the main Print dialog box.

Printer Name (Mac)

On Mac platforms, the printer name that you specify in the **File > Print > Print** dialog box must:

- Use only alphanumeric characters (letters and numbers), and not special characters such as an underscore or ampersand (&)
- Include no blank spaces

End a Simulink Session

To terminate a Simulink software session, close all Simulink windows.

To terminate a MATLAB software session, choose 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**

Keyboard and Mouse Shortcuts for Simulink

In this section...

Model Viewing Shortcuts

The following table lists keyboard shortcuts for viewing models.

Task	Shortcut
Zoom in	**Ctrl++**
Zoom out	**Ctrl+-**
Zoom to normal (100%)	**Alt+1**
Pan	Hold the mouse scroll wheel down and drag the mouse
Fit diagram to screen	**Spacebar**
Pan with mouse	Hold down **p** or **q** and drag mouse
Go back in pan/zoom history	**b**
Go forward in pan/zoom history	**t**
Delete selection	**Delete** or **Backspace**
Move selection	Make selection and use arrow keys

Block Editing Shortcuts

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

Task	Shortcut
Select one block	Left mouse button (LMB)
Select multiple blocks	**Shift** + LMB
Copy block from another window	Drag block
Move block	Drag block
Rotate block clockwise	**Ctrl+R** or **Ctrl+Y**
Rotate block counterclockwise	**Ctrl+Shift+R**
Flip block	**Ctrl+I**
Duplicate block	**Ctrl+C**, then **Ctrl+V**
Connect blocks	Select output port, hover over input port, and press **Ctrl** + LMB
Disconnect block	**Shift** + drag block
Create subsystem from selected blocks	**Ctrl+G**
Open selected subsystem	**Enter**
Go to parent of selected subsystem	**Esc**
Look under a block mask	**Ctrl + U**

Line Editing Shortcuts

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

Task	Shortcut
Select one line	Left mouse button (LMB)
Select multiple lines	**Shift** + LMB
Draw branch line	**Ctrl** + drag line; or RMB and drag line
Route lines around blocks	**Shift** + draw line segments
Move line segment	Drag segment
Move vertex	Drag vertex

Signal Label Editing Shortcuts

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

Action	Shortcut
Create signal label	Double-click line, then enter label
Copy signal label	**Ctrl** + drag label
Move signal label	LMB + drag label
Edit signal label	Click in label, then edit

Annotation Editing Shortcuts

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

Action	Shortuct
Create annotation	Double-click in diagram, then enter text
Copy annotation	**Ctrl+C** then **Ctrl+V**
Move annotation	Drag annotation
Edit annotation	Click in text, then edit

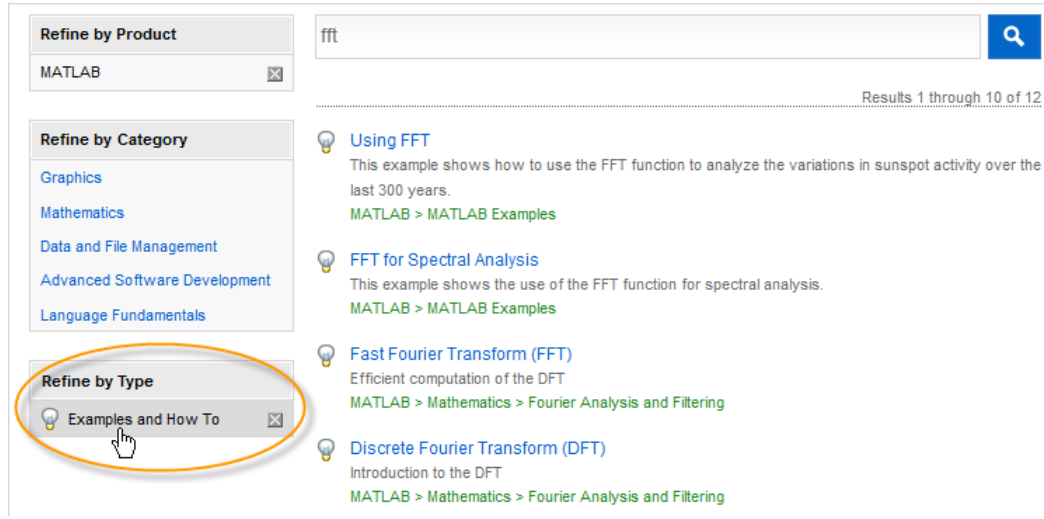
Simulink Demos Are Now Called Examples

Starting in R2012b, Simulink models and videos that were previously called *demos* are now called *examples*. There are two ways to access these examples from the Help browser:

- At the top of the product landing page, click **Examples**.

- On any documentation page, click the Table of Contents button  , and then select **Examples**.

You can filter documentation search results to display only examples.



For more information about changes to the Help browser, see the R2012b MATLAB Release Notes.

2

Simulation Stepping

Simulation Stepping

In this section...

About Simulation Stepping

The Simulation Stepper steps through the major time steps of a simulation without changing the course of a simulation. The Simulation Stepper is available from the Simulink Editor toolbar:

With Simulation Stepper, you can:

- Start and stop simulation of Simulink models
- Step forward and backward through a simulation
- Change from stepping backward to running with the **Play** button
- Change from running to paused (**Pause** button) or step backward (if backward stepping is enabled)
- Add conditional breakpoints
- Add breakpoints at simulation time

You can use the stepping capabilities to perform actions such as analyze plotted data at a particular moment in simulation time.

The stepping backward capability requires capturing simulation snapshots. A simulation snapshot at a particular simulation time captures all the information required to continue a simulation from that point. A simulation snapshot contains simulation state (SimState) and possibly information related to logged data and visualization blocks.

The Simulink software can store simulation state only when it is stepping forward through a simulation. When stepping backward, the software uses the simulation snapshot, stored as SimState, to restore the previous state of the simulation.

Stepping backward does not mean that the model is simulating backward. Stepping backward involves loading a previously captured snapshot of the model. When stepping forward again, the model is simulated from that point and new snapshots are captured.

Simulation Stepper Versus Simulink Debugger

The Simulation Stepper and the Simulink Debugger both enable you to start, stop, and step through a model simulation. Both allow you to use breakpoints as part of a debugging session. However, Simulation Stepper and Simulink Debugger are very different in their intended use. Simulation Stepper lets you see all the data in between major steps. Simulink Debugger lets you enter a major step.

Use the following table as a guideline:

Action	Simulation Stepper	Simulink Debugger
Look at state of system after executing a major time step.	X	X
Observe dynamics of the entire model from step to step.	X	
Step simulation backward.	X	
Pause across major steps.	X	
Control a Stateflow® debugging session.	X	
Step through simulation by major steps.	X	

Action	Simulation Stepper	Simulink Debugger
Monitor single block dynamics (for example, output, update, and so forth) during a single major time step.		X
Look at state of system while executing a major time step.		X
Observe solver dynamics during a single major step.		X
Show various stages of Simulink simulation.		X
Pause within a major step.		X
Step through a simulation block-by-block.		X
Command-line interface.		X

To better understand the difference between Simulation Stepper and Simulink Debugger, you need a good understand of the simulation process. (For more information, see “How S-Functions Work”.)

In particular, use Simulink Debugger for advanced debugging scenarios that involve custom blocks (such as S-functions). In this case, the Simulink Debugger can help you analyze the issues with a particular block method. Simulink Debugger also gives you finer control on breakpoints. It also gives you finer control to step from one method to another block method within a time step. For more information on the debugger, see “Introduction to the Debugger” on page 21-2.

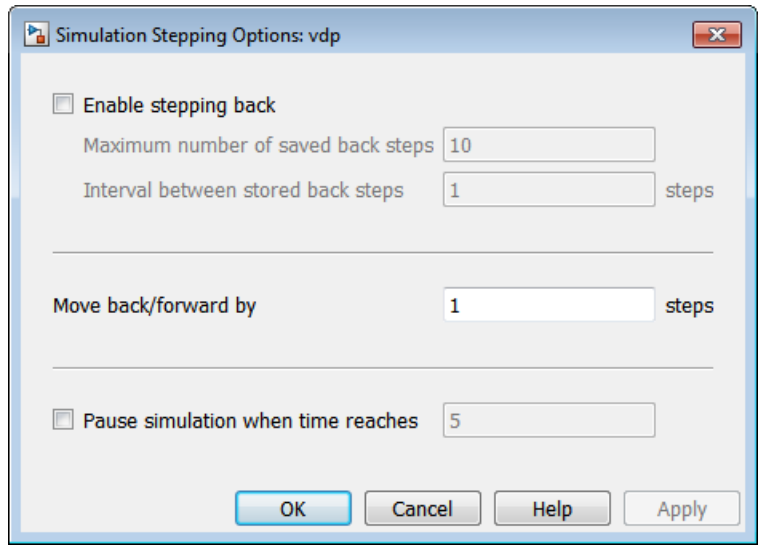
Simulation Stepper Graphical Cues

Simulation Stepper Toolbar Icons

Icon	Action
	Displays the Simulation Stepping Options dialog box, which affect Simulation Stepper performance. You can configure stepping options such as pausing after a specific simulation time and enabling stepping backward. This button is available until you enable previous stepping in the dialog box and start the simulation. To access this dialog box again, select **Simulation > Simulation Stepping Options**. In conjunction with enabling the step back capability, you must also simulate the model or step it forward to save snapshots for the step backward capability. **Tip** Snapshots for stepping backward are available only within the duration of a simulation. The Simulation Stepper does not save the steps for step backward across simulations.
	Steps the simulation to a previously captured simulation snapshot. Stepping to the final step ends the simulation.
	Starts/pauses/continues simulation.
	Steps the simulation forward.
	Stops the simulation.

Simulation Stepping Options Dialog Box

Click the Simulation Stepping Options icon () to display the Simulation Stepping Options dialog box.



Use this dialog box to specify how you want to step through a simulation. When you enable stepping backward and start the simulation, the icon changes to  , so that you can step backward.

If you enter an invalid value, the dialog box reverts all settings to the values that were last applied.

Note When the icon changes to  , you cannot access this dialog box from the toolbar. To access this dialog box again, select **Simulation > Simulation Stepping Options**.

When the simulation is running and there are no saved back steps (but stepping back is enabled), the icon changes to  (disabled state).

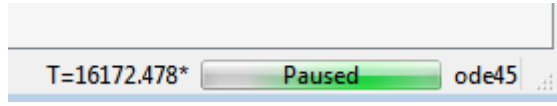
The Simulation Stepping Options dialog box contains the following parameters. For any setting, you can change the value while the simulation is running or paused.

Parameter	Operation
Enable stepping back	Select check box to enable backward stepping.
Maximum number of saved back steps	Enter maximum number of snapshots that the software can capture. A snapshot at a particular simulation time captures all the information required to continue a simulation from that point. For more information, see "Simulation Snapshots" on page 2-14.
Interval between stored back steps	Enter the number of major time steps to take between capturing simulation snapshots. For more information, see "Simulation Snapshots" on page 2-14.
Move back/forward by	Enter the number of major time steps for a single call to step forward or backward. For more information, see "Simulation Snapshots" on page 2-14.
Pause simulation when time reaches	Select check box to pause simulation when time reaches the specified time(s). This value can be a scalar value, or a vector of times. Specifying a vector of pause times is equivalent to specifying multiple separate pause times for a single simulation. You can specify pause times as variables in the model or MATLAB workspace.

Parameter	Operation
	Note The stepper does not alter the course of the simulation. As a consequence, specifying a value for a pause time does not necessarily pause the simulation at exactly that time. Instead, the simulation pauses at whatever simulation time is closest to the requested pause time, without going below it.

Simulation Stepper Pause Status

The status bar at the bottom of the Simulink Editor displays the simulation time of the last completed simulation step. While a simulation is running, the editor updates the time display to indicate where the simulation is. This display is an approximation because the status bar is not updated at every simulation time step. When you pause a simulation, the status bar display time catches up to the actual time of the last completed step.



When you use Simulation Stepper to step through a simulation, the time on the status bar updates at every major time step of the simulation. The value that is displayed (the time of the last completed step) might not always be the same as the time of the solver. This event occurs because of the difference in the way that different solvers propagate the simulation time in a single iteration of the simulation loop. Simulation Stepper pauses at a single position within the simulation loop. However, some solvers perform their time advance before the stepper pauses and others perform their time advance after the stepper pauses, which then becomes part of the next step. As result, for some solvers, the solver time is always one major step ahead of the time of the last model output. When this condition occurs, and the simulation is paused, the status bar time displays an asterisk next to it. The asterisk indicates that

the solver in this simulation has already advanced past the displayed time (which is the time of the last completed simulation step). Continuous and variable step discrete solvers exhibit this behavior. Other solvers do not cause the asterisk to be displayed because the times are synchronized.

Current Limitations

- There is no command-line interface for the Simulation Stepper.
- Simulation stepping (forward and backward) is available for only Normal and Accelerator modes.
- The step back capability relies on SimState ("Save and Restore Simulation State as SimState" on page 14-32) technology for saving and restoring the state of a simulation. As a result, the step back capability is available only for models that support SimState.
- Some blocks do not support backwards stepping for reasons other than SimState support. Overall, the presence of any of the following blocks in a model prevents the model from being enabled for backward stepping:
  - S-functions that have P-work vectors but do not declare their SimState compliance level, or declare it to be unknown or disallowed (see "S-Function Compliance with the `SimState`").
  - SimMechanics™ First Generation blocks
  - Model blocks configured for Accelerator mode.
  - SimEvents® blocks
- MATLAB Function blocks generally support stepping backward. However, use of certain constructs in the MATLAB code of this block might prevent this block from supporting backward stepping. The following scenarios prevent the MATLAB Function from being fully supported or stepping backward:
  - Persistent variables of opaque data type. Attempts to step back under this condition result in an error message based on the specific variable type.
  - Extrinsic functions calls that might contain state (such as properties of objects or persistent data of functions). No warnings or error messages are displayed, but the result will likely be incorrect.

  - Calls to custom C code (through MEX function calls) that might not contain static variables. No warnings or error messages are displayed, but the result will likely be incorrect.

- Some visualization blocks do not support stepping backward. Because these blocks are not critical to the state of the simulation, there are no errors or warnings issued when back stepping is performed on a model that contains these blocks:

  - `XY Graph`
  - `Floating Scope`
  - `Signal Viewer`
  - `Auto Correlator`
  - `Cross Correlator`
  - `Spectrum Analyzer`
  - `Averaging Spectrum Analyzer`
  - `Power Spectral Density`
  - `Averaging Power Spectral Density`
  - `Floating Bar Plot`
  - `3Dof Animation`
  - `MATLAB Animation`
  - `VR Sink`
  - Any blocks that implement custom visualization in their output method (for example, an S-function that outputs to a MATLAB figure) are not fully compliant with backward stepping because the block method `Output` is not executed during backward stepping. While the state of such blocks remain consistent with the simulation time (if the blocks comply with SimState) the visualization component will be inconsistent until the next step forward of the simulation.

  Because these block do not affect the numerical result of a simulation, the back stepping is not disabled for these blocks. Note that the values these blocks output are inaccurate until the simulation is stepped forward again.

- Port values displays do not always update when stepping backward. Upon stepping backward, if the port value is unavailable, the `unavailable` label is displayed.
- Simulation Stepper steps through the major time steps of a simulation without changing the course of a simulation. Choosing a refine factor greater than unity produces loggable outputs at times in between of the major time steps of the solver. These times are not major time steps, and stepping to a model state at those times is not possible.
- You cannot add conditional breakpoints on inputs to, outputs from, or signals inside variant subsystems.

If the simulation is run with the **Enable stepping back** check box selected, the Simulink software checks the capability of the model to step back. As a result, it might display a warning at the MATLAB command prompt. In some cases, the step backward capability might not be supported for that simulation. The step back capability is then disabled for the duration of that simulation (until the model is terminated, at which point the setting resets to the originally requested value).

Step Through a Simulation

In this section...

Configure Simulation Stepping

To control aspects of the simulation stepping operations, such as to enable stepping backward or limiting how many simulation snapshots to capture, use the Simulation Stepping Options dialog box. You can access this dialog box in one of the following ways:

- In the Simulation toolbar, click the  button, the **Next** icon.
- If the  button is no longer available, or if you prefer to use the menu bar, select **Simulation > Simulation Stepping Options**.

For a description of the options, see "Simulation Stepping Options Dialog Box" on page 2-6.

Forward and Backward Stepping

This topic describes how to step forward and backward through a simulation.

1. In the MATLAB Command Window, type

   ```
   vdp
   ```

   The model and its associated scope are displayed.

2. In the Simulation toolbar, click  . The

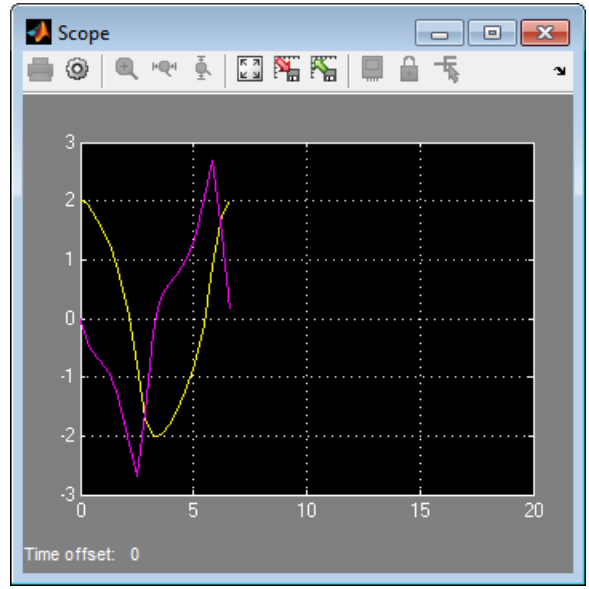
   Simulation Stepping Options dialog box is displayed.

3 Click the **Enable previous stepping** check box, then click **OK**.

4 In the Simulation toolbar, click  .

The simulation simulates one step. At the same time, the software stores the simulation snapshot for that step.

5 Repeatedly click the **Next** button to continue stepping forward and storing simulation data. For example, 25 clicks plots data that looks like:



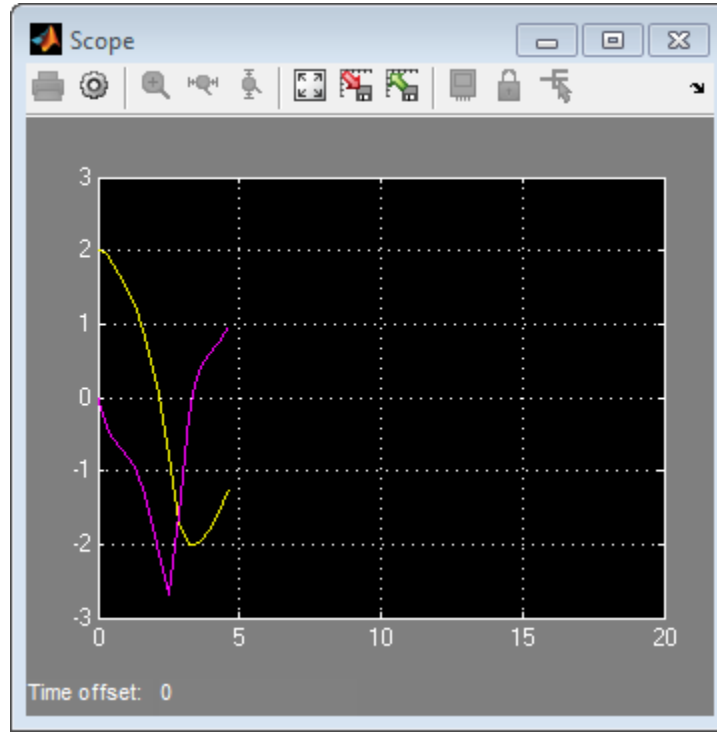
If you clear the **Enable previous stepping** check box, the software clears the stored snapshot cache.

Note You must step forward before you can step backward to create the simulation state that the step backward operation requires.

---

6 In the Simulation toolbar, click  one or more times to step backward to the previously stepped simulation snapshot.

The scope updates to show that data has been removed from the scope.



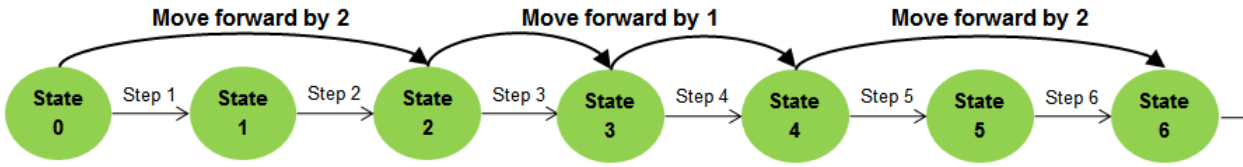
Simulation Snapshots

In the Simulation Stepping Options dialog box, you can specify options for snapshot capturing:

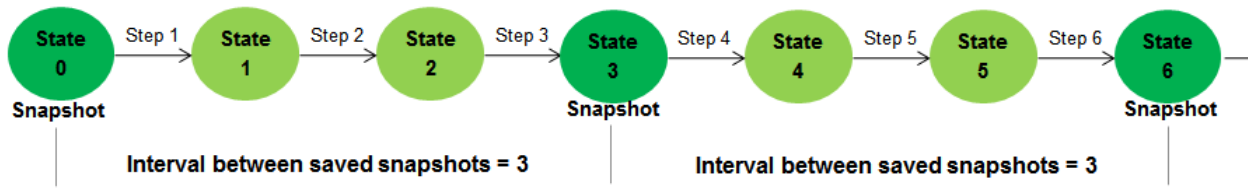
- The maximum number of snapshots to capture while simulating forward. The greater the number of steps, the more memory the simulation will occupy. This number can impact simulation speed.
- The number of steps to skip between snapshots. This capability enables you to create snapshots of simulation state at periodic intervals, such

as every three steps. This interval is independent of the number of steps taken in either the forward or backward direction. Because taking simulation snapshots affects simulation speed, saving snapshots at larger intervals can improve simulation speed (compared to setting this interval to a smaller number).

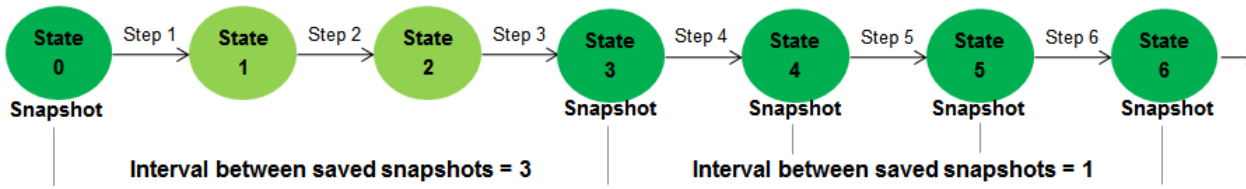
The following figure illustrates how the stepper can move along the steps of a simulation. In this case, the stepper first pauses the simulation after two major steps, then again after two consecutive single major steps, and the again after two major steps. The number of simulation steps between stepper pauses is the **Move back/forward by** setting in the stepper options dialog box. You can change this setting during simulation as shown in the following figure.



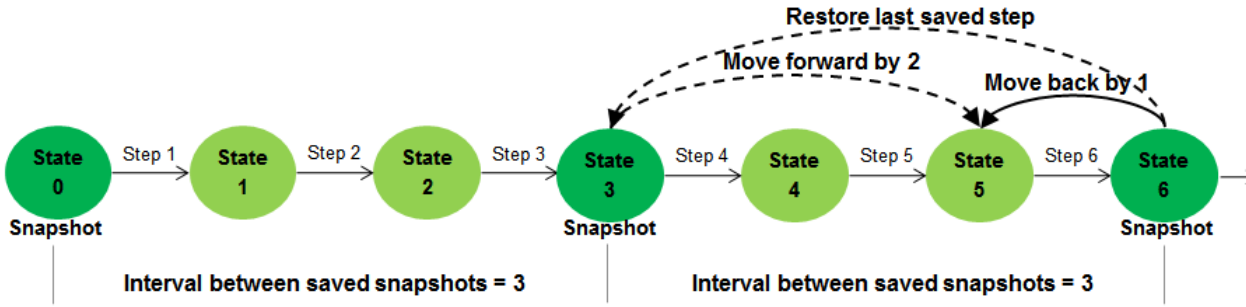
The following figure illustrates snapshot captures where the interval between stored snapshots is three.



In the following figure, the number of steps to skip between snapshots is three at first, but after the fourth step, the number of steps changes to one. This example illustrates the flexibility of the stepper, which allows you to change the stepping options while stepping forward. In this example, at the fourth step, the Simulation Stepping Options dialog box was used to change the snapshot steps from three to one. This capability is most useful when you want to capture more snapshots around a simulation time of interest.



The following figure illustrates how the snapshots settings of the stepper can change the action for stepping backward. For example, suppose that the interval between snapshots is set to 3 (simulation steps), and starting at a certain simulation time (corresponding to state 6 in the following figure), the stepper **Move back/forward by** setting is set to 1. To accomplish this task, the stepper first restores the simulation state to the last saved snapshot (state 3), and then simulates for two major times steps to arrive at the desired state (5). This capability is helpful for memory usage and simulation performance.



Stepping to the final step ends the simulation. This means that stepping backward after reaching the end of simulation is not possible unless you restart the simulation.

Tune Parameters

While using the stepper, if the simulation is in a paused state, you can change tunable parameters, including some solver settings.

Although you can change tunable parameters when a simulation is paused (as part of stepping or by using the **Pause** button), changes to the solver step size

take effect when the solver advances the simulation time. For some solvers, this occurs after the next simulation step is taken.

The Simulation Stepper takes into account the size of a movement (**Move back/forward by**) and the frequency of saving backward steps (**Interval between stored back steps**). If you specify a frequency that is larger than the step size, the stepper first steps back to the last saved step, then simulates forward until the total step count difference reaches the size of the step. Note that new tunable parameters are applied when simulating forward. For this reason, in a scenario like this, if you change tunable parameters before stepping back, the resulting simulation output might not match the previous simulation output at that step.

For example, assume a snapshot save frequency of 3 and a step size of 1 (see the previous figure). The stepper first steps back to the last saved step, up to three steps, then simulates forward until the total step count difference reaches one. If you change tunable parameters before stepping back, the resulting simulation output might not match the previous simulation output at that step.

Referenced Models

When using the stepper and Model block, the referenced model uses the stepping options of the top model for the duration of a simulation. In addition, the stepper dialog box of the referenced model serves as a direct link to the settings of the top model. As a result, changing the stepper settings through the referenced model during simulation also changes the stepper settings of the top model. When the simulation ends, the stepper settings of the referenced model revert to the original values.

This table illustrates this behavior for the **Move back/forward by** parameter (number of steps):

Simulation Off		Simulation On	Changed Referenced Model Setting	Simulation Off
Top Model	Original top model number of steps (*OrgTopModel*)	Number of steps = *OrgTopModel*	New number of steps (*NewRefModel*) copied from referenced model	Keeps value *NewRefModel*
Referenced Model	Original referenced model number of steps (*OrgRefModel*)	Number of steps = *OrgTopModel*	New number of steps = *NewRefModel*	Reverts to original referenced model number of steps *OrgRefModel*

Simulation Stepper and Stateflow Debugger

When you debug a Stateflow chart (for example, when the simulation stops at a Stateflow breakpoint), Simulation Stepper changes to contain additional buttons to control the Stateflow debugging session. When the Stateflow debugging session ends, the default Simulation Stepper interface is reinstated. For more information about controlling the Stateflow debugger through the Simulink Editor toolbar, see "Control Chart Execution in the Debugger".

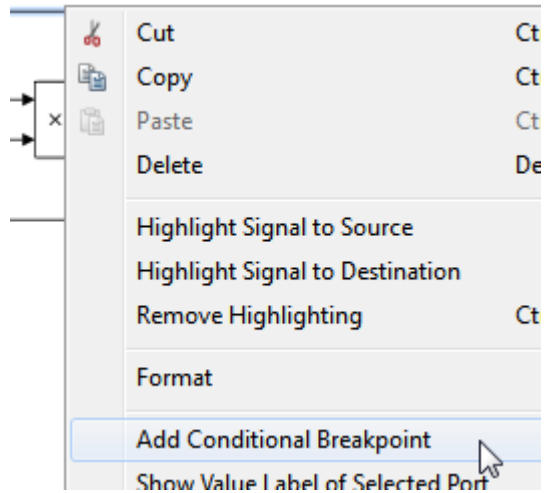
Conditional Breakpoints

The Simulation Stepper allows you to set conditional breakpoints for scalar signals. A conditional breakpoint is a breakpoint that is triggered based on a certain expression evaluated on a signal. When the breakpoint is triggered, the corresponding simulation pauses.

Note When simulation arrives at a conditional breakpoint, simulation does not stop immediately when the block is executed. Instead, simulation stops only after the current simulation step completes.

To set a conditional breakpoint for a signal:

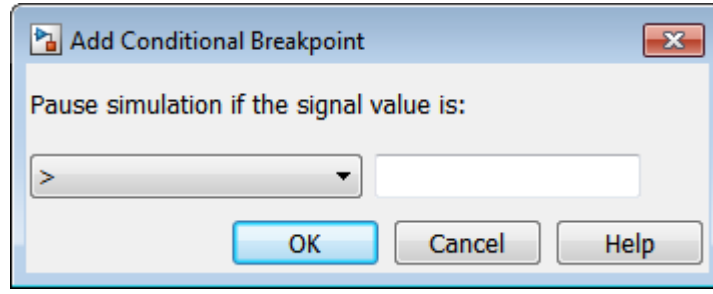
1 Right-click that signal and select **Add Conditional Breakpoint**.



Alternatively, select the signal then, from the menu bar, select **Simulation > Debug > Add Conditional Breakpoint**.

Note You cannot add conditional breakpoints on inputs to, outputs from, or signals inside variant subsystems.

This action displays the Add Conditional Breakpoint dialog box.



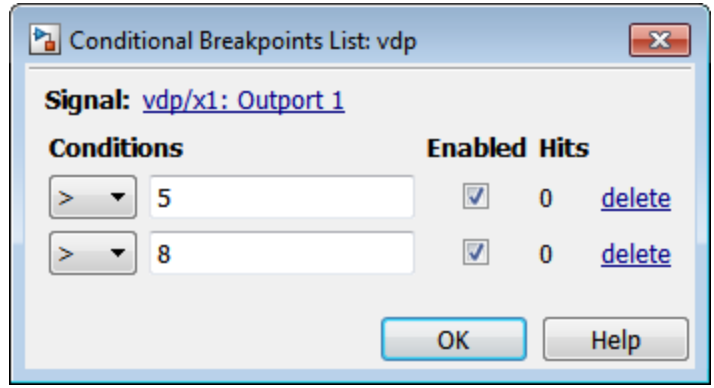
2 From the drop-down list, select the condition for this signal:

Condition	Pause simulation if the signal value is...
>	Greater than the specified value.
>=	Greater than or equal to the specified value.
=	Equal to the specified value.
~=	Not equal to the specified value.
<=	Less than or equal to the specified value.
<	Less than the specified value.

3 Enter the signal value at which you want simulation to pause. The affected signal line is updated with a conditional breakpoint icon like the following,  .

You can add multiple conditional breakpoints to a signal line.

4 To view a summary of the conditional breakpoints and edit them, left-click the conditional breakpoint icon. (Alternatively, from the menu bar, select **Simulation > Debug > Conditional Breakpoints List**.) A Conditional Breakpoints List dialog box like the following is displayed. If the conditional breakpoints list is empty, a message pops up to warn you that there are no conditional breakpoints.



In this dialog box, you can:

- Change the condition for the signal value.

- Change the value of the signal.
- Disable and enable the conditional breakpoint.
- Delete the condition.

Condition values:

- Must be numeric. They cannot be expressions.
- Cannot be `NaN`.

5 Click **OK** when done and simulate the model.

3

How Simulink Works

How Simulink Works

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.

For more information on this process, see:

- "Modeling Dynamic Systems" on page 3-3
- "Simulating Dynamic Systems" on page 3-18

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 "Connect Blocks" on page 4-12) selected from libraries of block types (see "Block Libraries") 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.

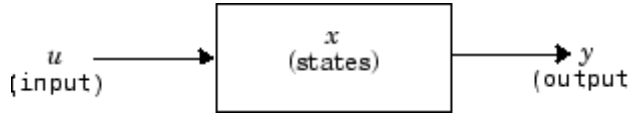
States

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 "Debugging").
- The **Data Import/Export** pane of a model's Configuration Parameters dialog box (see "Import and Export States" on page 45-113) 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 model 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,

`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, do not use 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 “Block Parameters” on page 3-9 and “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 3-18 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.

When you change the value of a tunable parameter, the change takes effect at the start of the next time step. See “Block Parameters” on page 3-9 and “Tunable Parameters” on page 24-13 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 "View Sample Time Information" on page 5-9). 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 "View Sample Time Information" on page 5-9).

For a more detailed discussion of sample times, see "Sample Time"

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 "S-Function Basics"). 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 "Block Creation" 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, which are drawn with a bold border, 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 precondition—such as a trigger, an enable, a function-call, or an action—occurs (see "Conditional Subsystems"). Simulink always computes all inputs used during the execution of a nonvirtual subsystem before executing the subsystem. 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 enable port is greater than zero. To create an enabled subsystem, place an Enable Port block within a Subsystem block. You can configure an enabled subsystem to hold or reset the states of blocks within the enabled subsystem prior to a subsystem enabling action. Simply select the **States when enabling** parameter of the Enable Port block. Similarly, you can configure each output port of an enabled subsystem to hold or reset its output prior to the subsystem disabling action. Select the **Output when disabled** parameter in the Outport block.

Triggered subsystems. You create a triggered subsystem by placing a trigger port block within a subsystem. The resulting 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. A Stateflow chart can also have a trigger port which is defined by using the Stateflow editor. Simulink does not distinguish between a triggered subsystem and a triggered chart.

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 and update 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 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 `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 noninherited sample time or inherited (-1) sample time. All blocks that specify a noninherited sample time must specify the same sample time, that is, 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 and triggered subsystems. You can create an enabled and triggered subsystem by placing a Trigger Port block and an Enable Port block within a Subsystem block. The resulting 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. Because the contents of a triggered subsystem execute in an aperiodic fashion, Simulink limits the types of blocks placed in an enabled and triggered subsystem to blocks that do not have explicit sample times. In other words, blocks within the subsystem must have a sample time of `-1`).

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 a single 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 Switch Case 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 block. The subsystem icon will automatically adapt to the type of block (i.e., If or Switch Case 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 at 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 as compared to function-call subsystems. This restriction also means that you can control how the states and outputs behave.

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

A while iterator subsystem is very similar to a function-call subsystem in that it can run for any number of iterations at a given time step. The while iterator subsystem differs from a function-call subsystem in that there is no separate initiator (e.g., a Stateflow Chart). In addition, a while iterator subsystem has access to the current iteration number optionally produced by the While Iterator block. A while iterator 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 iterator subsystems. A for iterator subsystem will run a fixed number of iterations at each model time step. The number of iterations can be an external input to the for iterator subsystem or specified internally on the For Iterator block. A for iterator subsystem is created by placing a For Iterator block within a subsystem block.

A for iterator subsystem has access to the current iteration number that is optionally produced by the For Iterator block. A for iterator 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 iterator subsystem is very similar to a while iterator subsystem with the restriction that the number of iterations during any given time step is fixed.

For each subsystems. The for each subsystem allows you to repeat an algorithm for individual elements (or subarrays) of an input signal. Here, the algorithm is represented by the set of blocks in the subsystem and is applied to a single element (or subarray) of the signal. You can configure the decomposition of the subsystem inputs into elements (or subarrays) using the For Each block, which resides in the subsystem. The For Each block also allows you to configure the concatenation of individual results into output signals. An advantage of this subsystem is that it maintains separate sets of states for each element or subarray that it processes. In addition, for certain models, the for each subsystem improves the code reuse of the code generated by Simulink Coder™.

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 "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 the system's model is open and you simulate the model. In the Simulink Editor, select **Simulation > Run**. Running the simulation 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 3-21).
- Determines the block sorted order (see "Control and Displaying the Sorted Order" on page 23-35 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 5-29).

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 "Assign Block Priorities" on page 23-47). 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 3-21) used to compute the system's continuous states, the system's fundamental sample time (see "Sample Times in Systems" on page 5-22), and whether the system's continuous states have discontinuities (see "Zero-Crossing Detection" on page 3-23).

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 3-21).

   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 3-23 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 14-10).

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 14-10).

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 "Sample Times in Systems" on page 5-22 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, you can obtain a more accurate integration results by including the derivative input information at each time step. To do so, enable the **Model Configuration Parameters > Solver > Shape Preservation** option.

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.

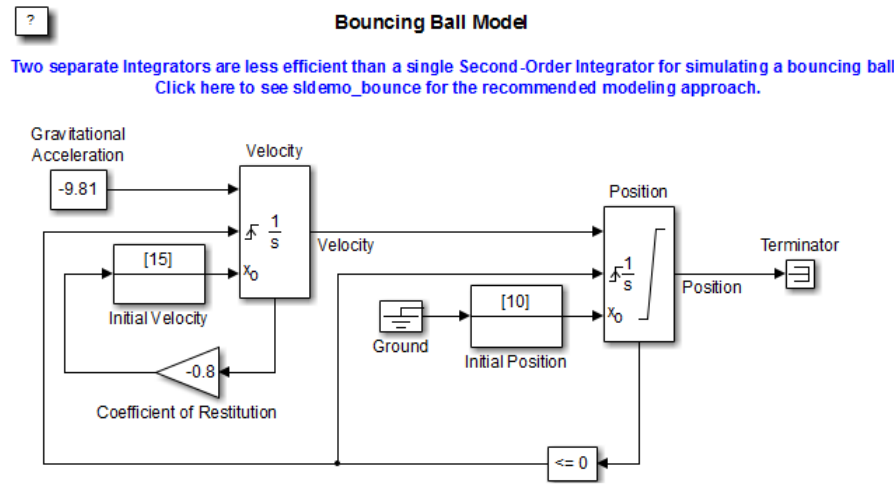
Two algorithms are provided in the Simulink software: Nonadaptive and Adaptive. For information about these techniques, see "Zero-Crossing Algorithms" on page 3-33.

Demonstrating Effects of Excessive Zero-Crossing Detection

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

- The `sldemo_bounce_two_integrators` model 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` model uses a better model design than `sldemo_bounce_two_integrators`.
- The `sldemo_doublebounce` model demonstrates how the adaptive algorithm successfully solves a complex system with two distinct zero-crossing requirements.

The Bounce Model with Two Integrators.



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

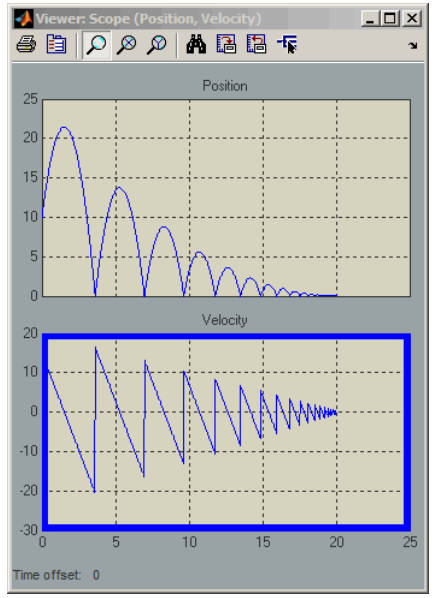
2 Once the block diagram appears, set the **Model Configuration Parameters > Solver > Algorithm** parameter to `Nonadaptive`.

3 Also in the **Solver** pane, set the **Stop time** parameter to 20 s.

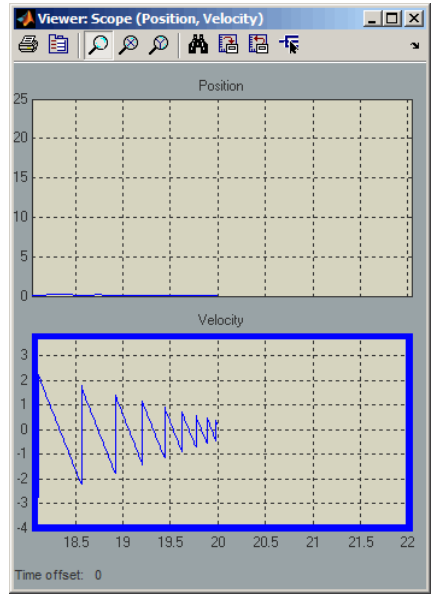
4 Run the model. In the Simulink Editor, select **Simulation > Run**.

5 After the simulation completes, click the Scope block 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** edit box in the Simulink Editor toolbar to 25 seconds, and run the simulation again.

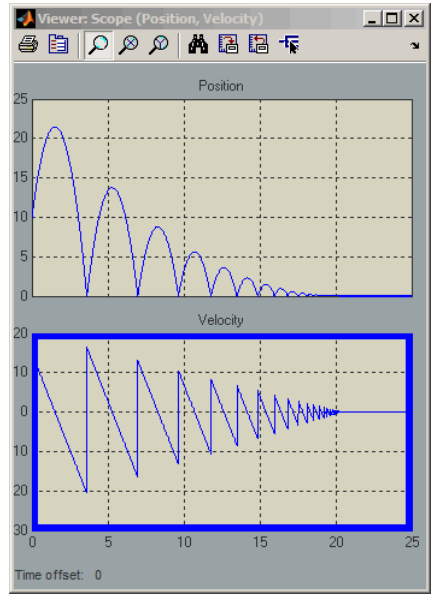
8 This time the simulation halts with an error shortly after it passes the simulated 20 second time point.

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 you can increase this limit by adjusting the **Model Configuration Parameters > Solver > Number of consecutive zero crossings** parameter. In this case, making that change does not allow the simulation to simulate for 25 seconds.

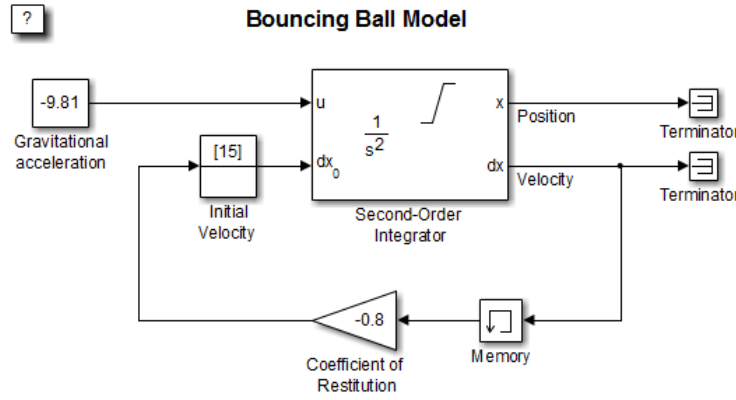
9 Also in the **Solver** pane, from the **Algorithm** pull down menu, select the **Adaptive** algorithm.

10 Run the simulation again.

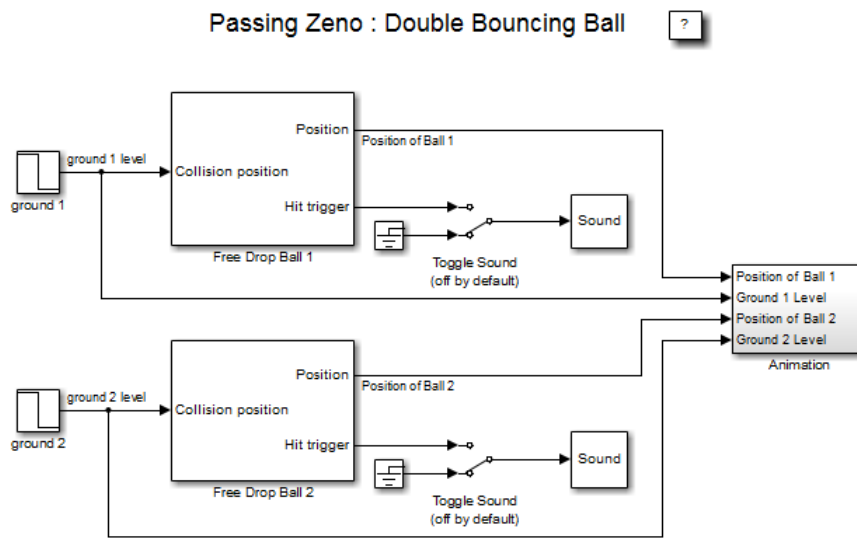
11 This time the simulation runs to completion because the adaptive algorithm prevented an excessive number of zero crossings from occurring.



Bounce Model with a Second-Order Integrator.



The Double-Bounce Model.



1 At the MATLAB command prompt, type `sldemo_doublebounce` to load the example. 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 example 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.

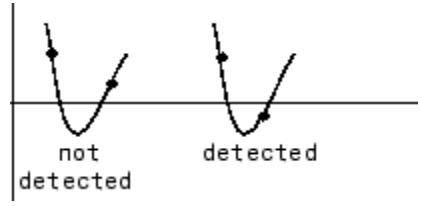
7 Notice that this time the simulation runs to completion, even after the ground shifts out from underneath the ball on the left at 20 seconds.

How the Simulator Can Miss Zero-Crossing Events

The bounce and double-bounce models 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...	Rationale 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...	Rationale 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...	Rationale 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:

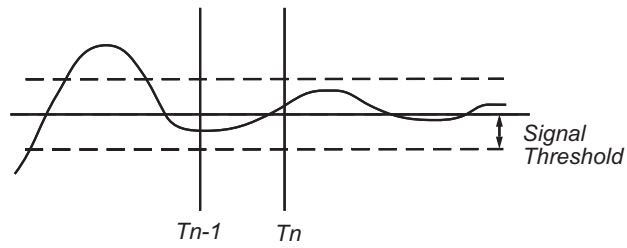
- The zero crossing error is exceeded. This is determined by the value specified in the **Signal threshold** option in the Solver pane of the Configuration Parameters dialog box. This can also be set with the `ZCThreshold` command. The default is `Auto`, but you can enter any real number greater than 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 7-4.
From File	One: to detect when the input signal has a discontinuity in either the rising or falling direction
From Workspace	One: to detect when the input signal has a discontinuity in either the rising or falling direction

Block	Description of Zero Crossing
If	One: to detect when the If condition is met.
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 7-20.
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 7-24

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 3-35 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 a signal loop exists with only direct feedthrough blocks within the loop. *Direct feedthrough* means that the block output depends on the value of an input port; the value of the input directly controls the value of the output. *Non-direct-feedthrough* blocks maintain a State variable. Two examples are the Integrator or Unit Delay block.

Some Simulink blocks have input ports with direct feedthrough. The software cannot compute the output of these blocks without knowing the values of the signals entering the blocks at these input ports at the current time step.

Some examples of blocks with direct feedthrough inputs are:

- Math Function block
- Gain block

- 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

Tip To determine if a block has direct feedthrough:

1. Double-click the block.

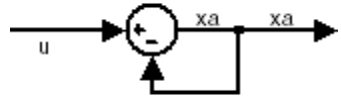
   The block parameter dialog box opens.

2. Click the **Help** button in the block parameter dialog box.

   The block reference page opens.

3. Scroll to the **Characteristics** section of the block reference page, which lists whether or not that block has direct feedthrough.

An example of an algebraic loop is the following simple loop. Note that this is *not* a recommended modeling pattern.



Mathematically, this loop implies that the output of the Sum block is an algebraic variable 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:

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

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 of the state vector. Such systems are *differential algebraic equations (DAEs)*, not ODEs.

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

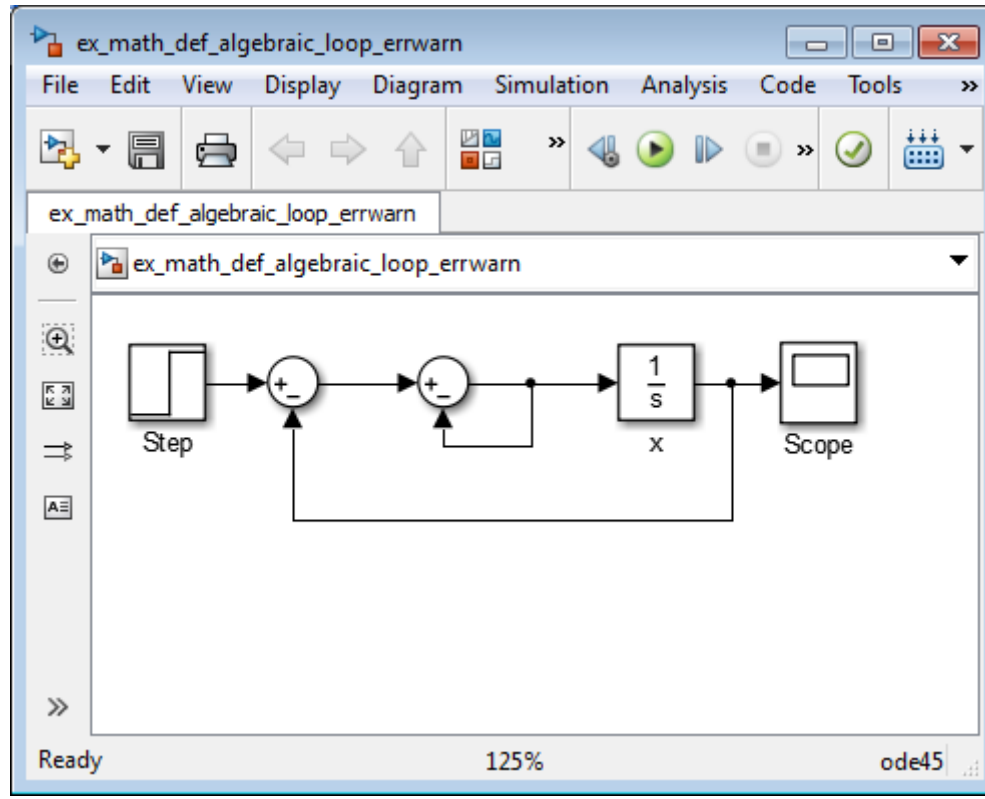
$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}, \mathbf{x_a}, t)$$
$$0 = \mathbf{g}(\mathbf{x}, \mathbf{x_a}, t),$$

- **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 $\dot{x}$.

Meaning of Algebraic Loops in Physical Systems. Algebraic constraints can occur when modeling physical systems, often due to conservation laws, such as conservation 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 3-51, to produce an ordinary differential equation (ODE). However, this technique may be too time consuming if you have a large, complex model.

MathWorks® offers the Simscape™ software that extends Simulink by providing tools to model systems that span mechanical, electrical, hydraulic, and other physical domains as physical networks.

Simscape software automatically constructs the differential algebraic equations (DAEs) that characterize the behavior of a Simulink model. These equations are integrated with the rest of the model, and the Simscape software solves the DAEs directly. The variables for the components in the different physical domains are solved simultaneously, thereby avoiding problems with algebraic loops.

Problems Caused by Algebraic Loops

If your model contains an algebraic loop:

- You cannot generate code for the model.
- The Simulink algebraic loop solver might not be able to solve the algebraic loop.
- While Simulink is trying to solve the algebraic loop, the simulation might execute slowly.

  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.

Identifying Algebraic Loops in Your Model

- "Algebraic Loop Diagnostic" on page 3-43
- "Highlighting Algebraic Loops Using the Algebraic Loop Diagnostic" on page 3-44
- "Highlighting Algebraic Loops Using the ashow Debugger Command" on page 3-45

Algebraic Loop Diagnostic. Simulink detects algebraic loops during simulation initialization, for example, when you update your diagram. You can 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 main **Diagnostics** pane, set the **Algebraic loop** parameter as follows.

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

If you want Simulink to try to solve the loop, select `none` or `warning`. If you want to review the loop before Simulink tries to solve the loop, select `error`.

Highlighting Algebraic Loops Using the Algebraic Loop Diagnostic. To highlight algebraic loops in the Simulink Editor when updating or simulating a model:

1. Open the `sldemo_hydcyl` model:

   ```
   sldemo_hydcyl
   ```

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

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

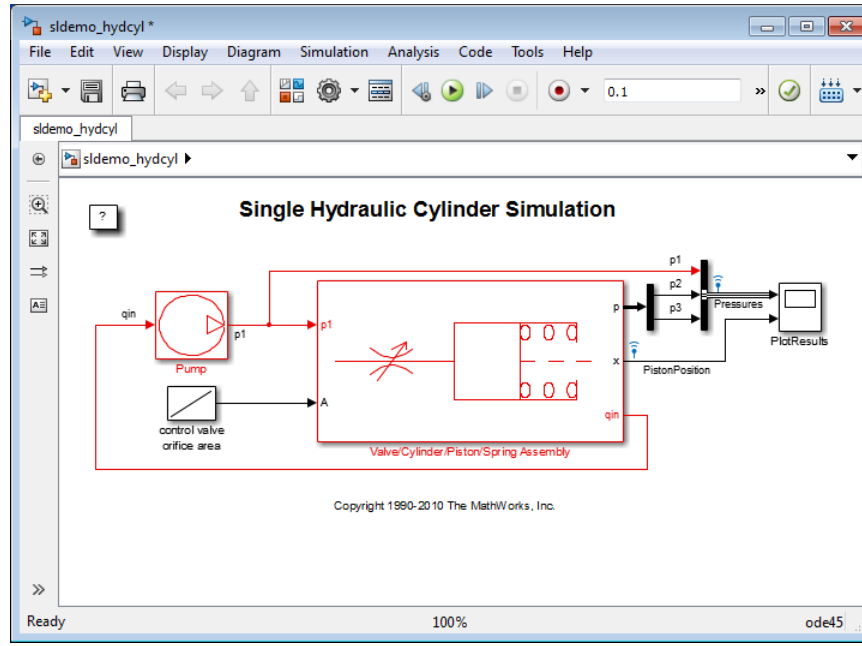
   If the Simulink software finds an algebraic loop in the model, it should stop the simulation and report an error.

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

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

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

In the Simulink 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 Using the ashow Debugger Command.

The Simulink debugger allows you to step through a model simulation. To use the `ashow` command to highlight algebraic loops:

1 Open the `sldemo_hydcyl` model.

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

2. Start the Simulink debugger. In the Simulink Editor, select **Simulation > Debug > Debug Model**.

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 algebraic 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, in the MATLAB Command Window, enter the following command:

   ```
   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:

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

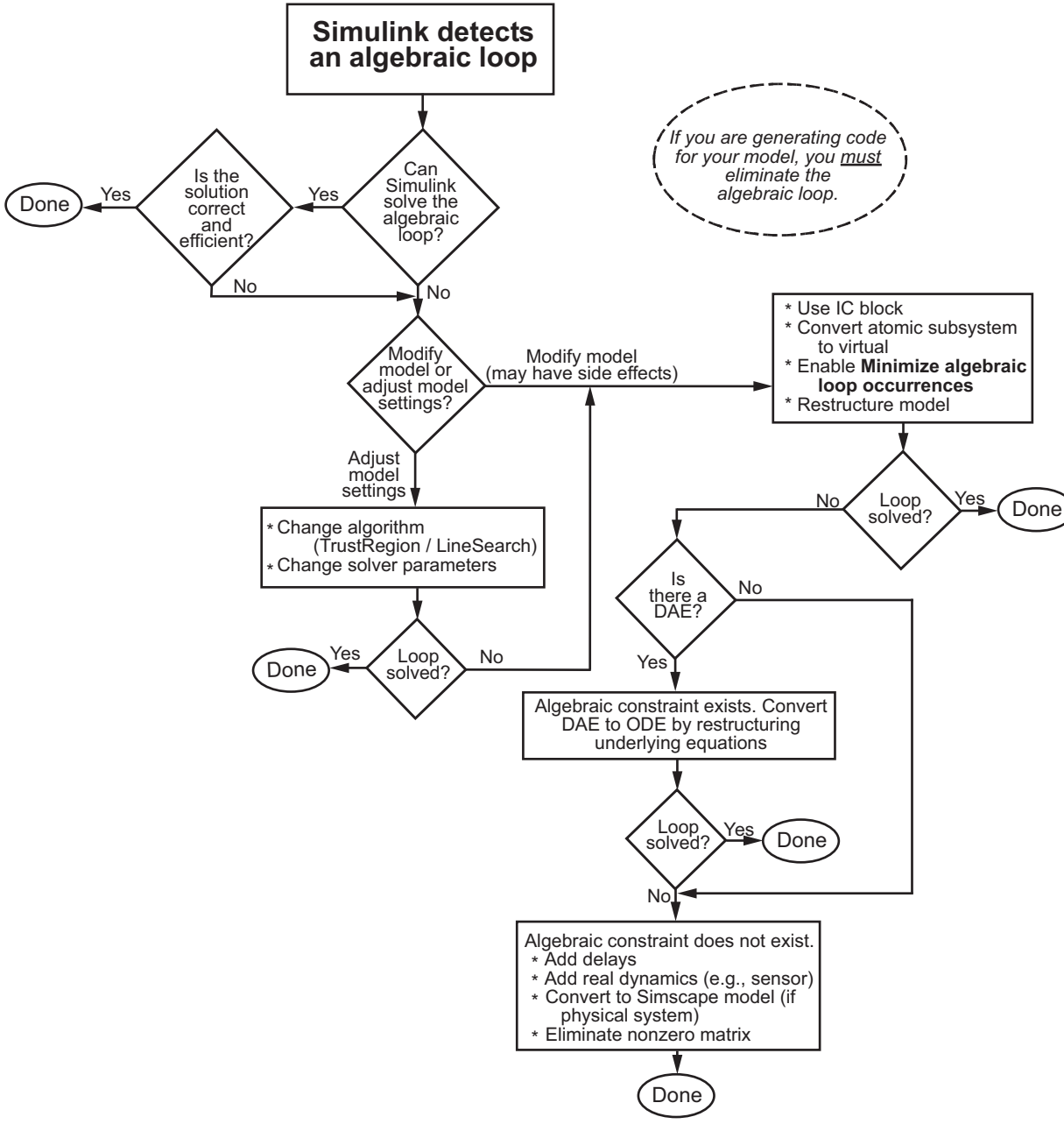
6. In the Simulink debugger, click **Close**.

7. At the MATLAB command prompt, press **Enter** to restore the default MATLAB command prompt.

What If I Have an Algebraic Loop in My Model?

If Simulink reports an algebraic loop in your model, the algebraic loop solver might be able to solve the loop. If Simulink cannot solve the loop, there are several techniques to eliminate the loop.

The following workflow helps you evaluate what techniques to try to eliminate an algebraic loop. Some of those techniques are described in the following sections.


Simulink detects an algebraic loop
Can Simulink solve the algebraic loop?
Yes
Is the solution correct and efficient?
Yes
Done
No
No
If you are generating code for your model, you must eliminate the algebraic loop.
Modify model or adjust model settings?
Modify model (may have side effects)
* Use IC block
* Convert atomic subsystem to virtual
* Enable Minimize algebraic loop occurrences
* Restructure model
Loop solved?
No
Yes
Done
Adjust model settings
* Change algorithm (TrustRegion / LineSearch)
* Change solver parameters
Loop solved?
Yes
Done
No
Is there a DAE?
No
Yes
Algebraic constraint exists. Convert DAE to ODE by restructuring underlying equations
Loop solved?
Yes
Done
No
Algebraic constraint does not exist.
* Add delays
* Add real dynamics (e.g., sensor)
* Convert to Simscape model (if physical system)
* Eliminate nonzero matrix
Done

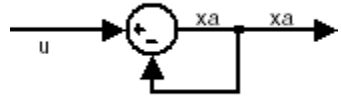
Simulink Algebraic Loop Solver

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 more slowly than models without algebraic loops.

The algebraic loop solver requires:

- One block where the loop solver can break the loop and attempt to solve the loop
- Real double signals
- The underlying algebraic constraint must be a smooth function

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

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

The algebraic loop solver uses a gradient-based search method, which requires continuous first derivatives of the algebraic constraint that correspond to the algebraic loop. As a result, if the algebraic loop contains discontinuities, the algebraic loop solver might fail.

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 with the trust-region algorithm, try simulating the model using the line-search algorithm.

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

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

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

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

For more information, see:

- "Trust-Region Methods for Nonlinear Minimization" in the Optimization Toolbox™ documentation.
- "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 is 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
- Discontinuities

- Stateflow charts

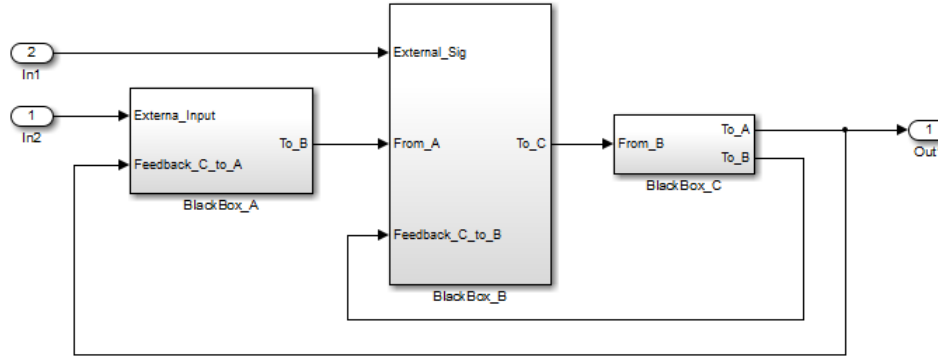
Removing Algebraic Loops

Introducing a Delay.

Algebraic loops can occur in large models when atomic subsystems create feedback loops.

In the following generic model, there are two algebraic loops that involve subsystems.

- BlackBox_A —> BlackBox_B —> BlackBox_C —> BlackBox_A
- BlackBox_B —> BlackBox_C —> BlackBox_B



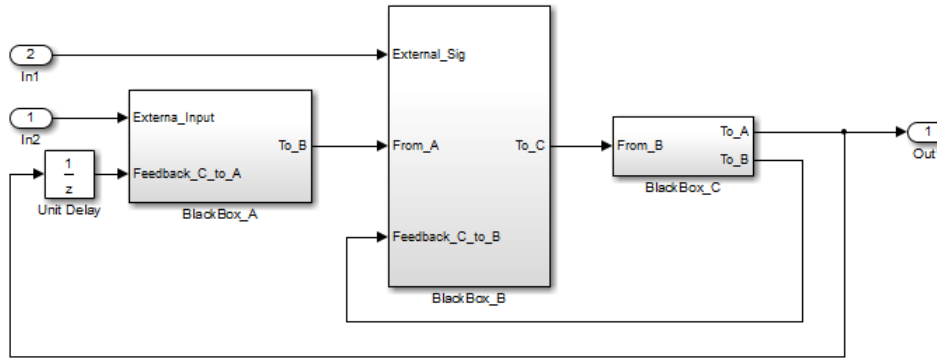
When you update this model, Simulink detects the loop BlackBox_A —> BlackBox_B —> BlackBox_C —> BlackBox_A.

Since you do not know the contents of these subsystems, you must break the loops by adding a Unit Delay block outside the subsystems. There are three ways to use the Unit Delay to break these loops:

- Add a unit delay between BlackBox_A and BlackBox_C
- Add a unit delay between BlackBox_B and BlackBox_C
- Add unit delays to both algebraic loops

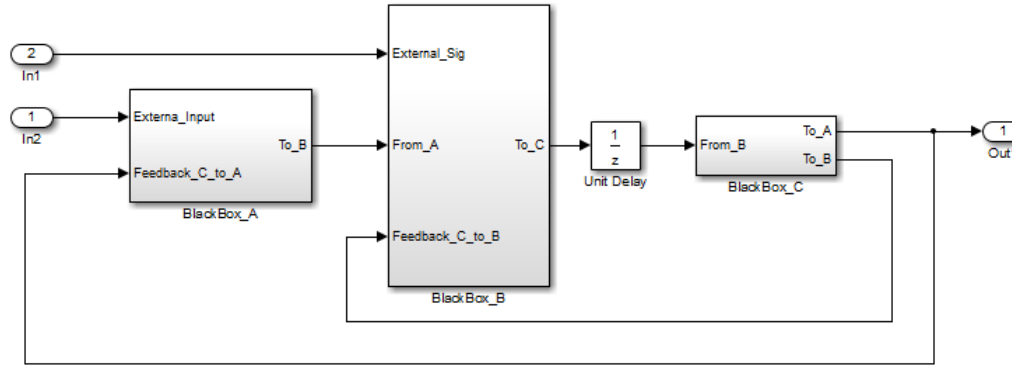
Add a unit delay between BlackBox_A and BlackBox_C

If you add a unit delay on the feedback signal between the subsystems BlackBox_A and BlackBox_C, you introduce the minimum number of unit delays (1) to the system. By introducing the delay before BlackBox_A, BlackBox_B and BlackBox_C use data from the current time step.



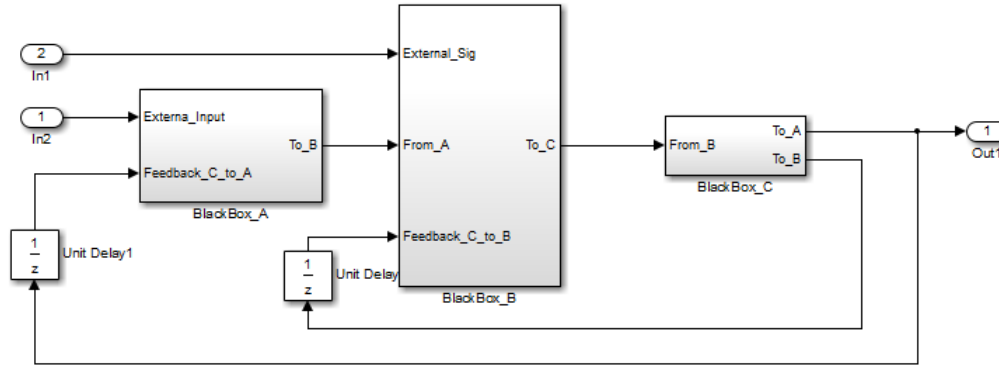
Add a unit delay between BlackBox_B and BlackBox_C

If you add a unit delay between the subsystems BlackBox_B and BlackBox_C, you break the algebraic loop between BlackBox_B and BlackBox_C. In addition, you break the loop between BlackBox_A and BlackBox_C, because that signal completes the algebraic loop. By inserting the Unit Delay block before BlackBox_C, BlackBox_C now works with data from the previous time step only.



Add unit delays to both algebraic loops

In the following example, you insert Unit Delay blocks to break both algebraic loops. In this model, BlackBox_A and BlackBox_B use data from the previous time step. BlackBox_C uses data from the current time step.



Additional Techniques to Help the Algebraic Loop Solver

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, use one of the following techniques to solve the loop manually:

- Restructure the underlying DAEs using techniques such as differentiation or change of coordinates. These techniques put the DAEs in a form that is easier for the algebraic loop solver to solve.
- Convert the DAEs to ODEs, which eliminates any algebraic loops.
- "Create Initial Guesses Using the IC and Algebraic Constraint Blocks" on page 3-54

Create 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, but use this technique only when you think the loop is legitimate.

There are two ways to specify an initial guess:

- Place an IC block in the algebraic loop.
- Specify an initial guess for a signal in an algebraic loop using an Algebraic Constraint block.

Changing Block Priorities Does Not Remove Algebraic Loops

During the updating phase of simulation, Simulink determines the order in which to execute the block methods during simulation. This block invocation ordering is the *sorted order*.

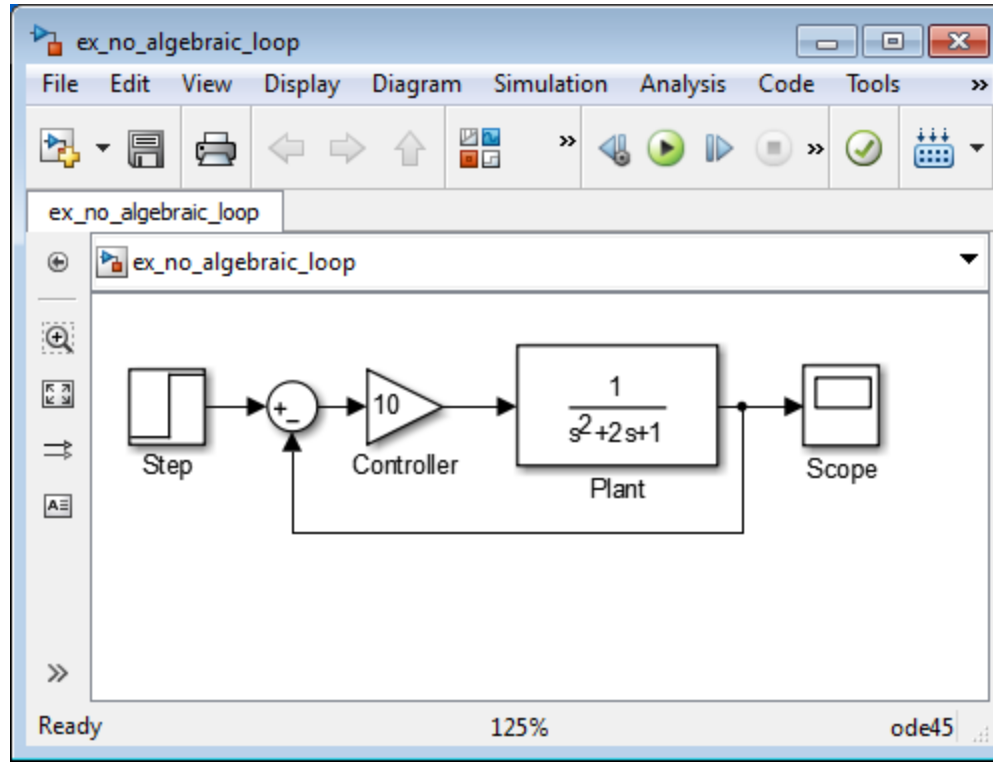
If you assign priorities to nonvirtual blocks to indicate to Simulink their execution order relative to other blocks, the algebraic loop solver does not honor these priorities when attempting to solve any algebraic loops.

Artificial Algebraic Loops

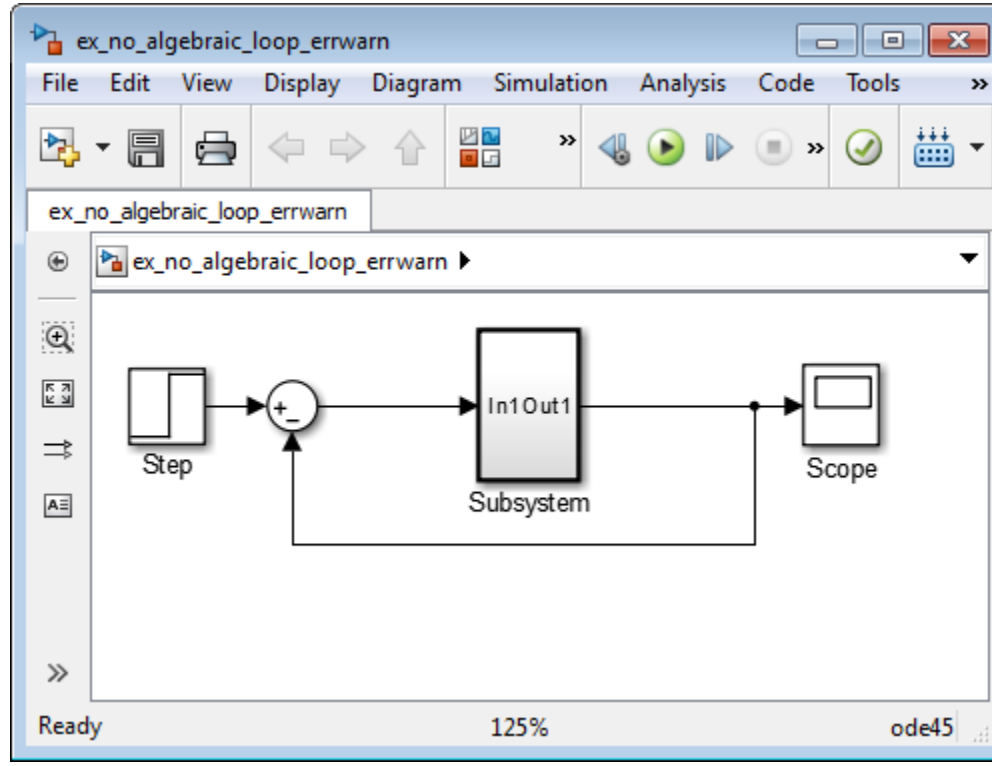
- "What Is an Artificial Algebraic Loop?" on page 3-55
- "Eliminating Artificial Algebraic Loops Caused by Atomic Subsystems" on page 3-57
- "Bundled Signals That Create Artificial Algebraic Loops" on page 3-57
- "Model and Block Parameters for Diagnosing and Eliminating Artificial Algebraic Loops" on page 3-62

What Is an Artificial Algebraic Loop?. An *artificial algebraic loop* occurs when an atomic subsystem or Model block causes Simulink to detect an algebraic loop, even though the contents of the subsystem do not contain an algebraic constraint. When you create an atomic subsystem, all Inport blocks are direct feedthrough, resulting in an algebraic loop.

The following model does not contain an algebraic loop. The model simulates without error.



Suppose you enclose the Controller and Plant blocks in a subsystem and, in the Subsystem Parameters dialog box, select **Treat as atomic unit** to make the subsystem atomic.



When simulating this model, Simulink detects an algebraic loop because the subsystem is direct feedthrough, even though the path within the atomic subsystem is not direct feedthrough.

In the Configuration Parameters dialog box, on the main Diagnostics pane, if you set the **Algebraic loop** parameter to `error`, Simulink stops the simulation with an algebraic loop error.

Eliminating Artificial Algebraic Loops Caused by Atomic Subsystems. One way to eliminate an artificial algebraic loop caused by an atomic subsystem is to convert the atomic subsystem to a virtual subsystem. Doing so has no effect on the behavior of the model.

When the subsystem is atomic and you simulate the model, Simulink invokes the algebraic loop solver. The algebraic loop solver terminates after one iteration. The algebraic loop is automatically solved because there is no algebraic constant. After you make the subsystem virtual, during simulation, Simulink does not invoke the algebraic loop solver.

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.

If you replace the atomic subsystem with a virtual subsystem and the simulation still fails with an algebraic loop error, you probably have one of the following elsewhere in your model:

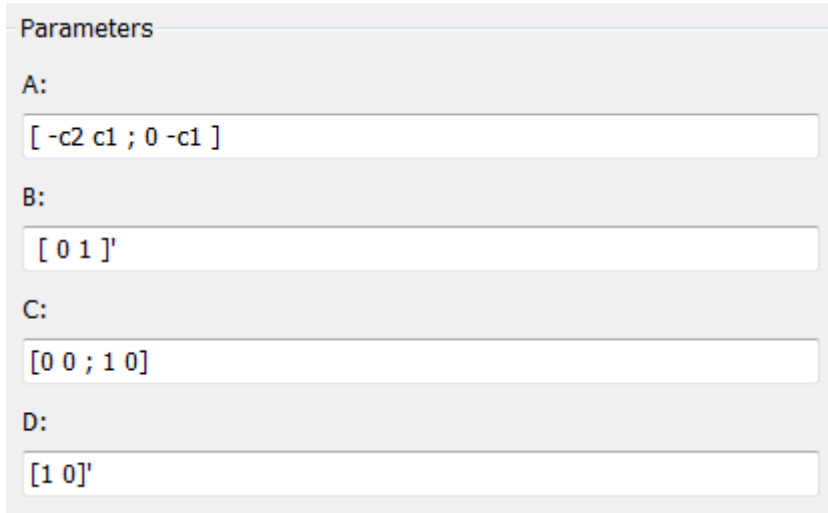
- An algebraic constraint
- An artificial algebraic loop not caused by this atomic subsystem

Examine your model, try to identify the location of the algebraic loop, and use some of the techniques described in this section to solve the loop.

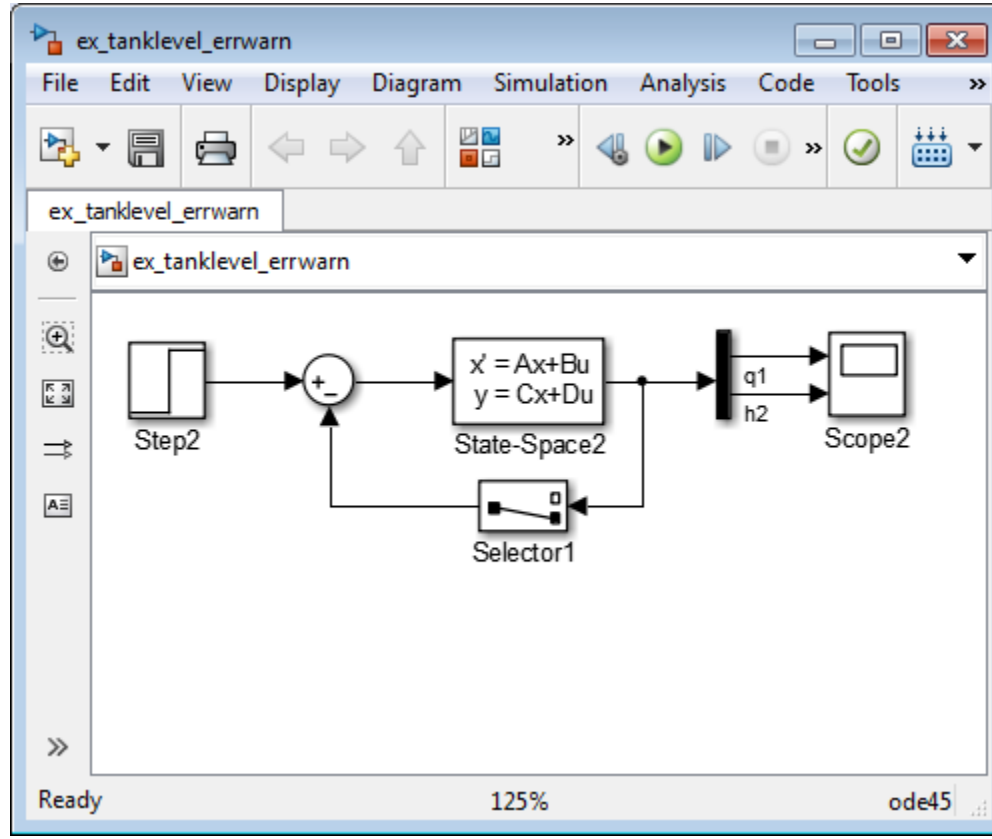
Bundled Signals That Create Artificial Algebraic Loops. Some models bundle signals together. This bundling might cause Simulink to detect an algebraic loop, even when an algebraic constraint does not exist. If you redirect one or more signals, you might remove the artificial algebraic loop.

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

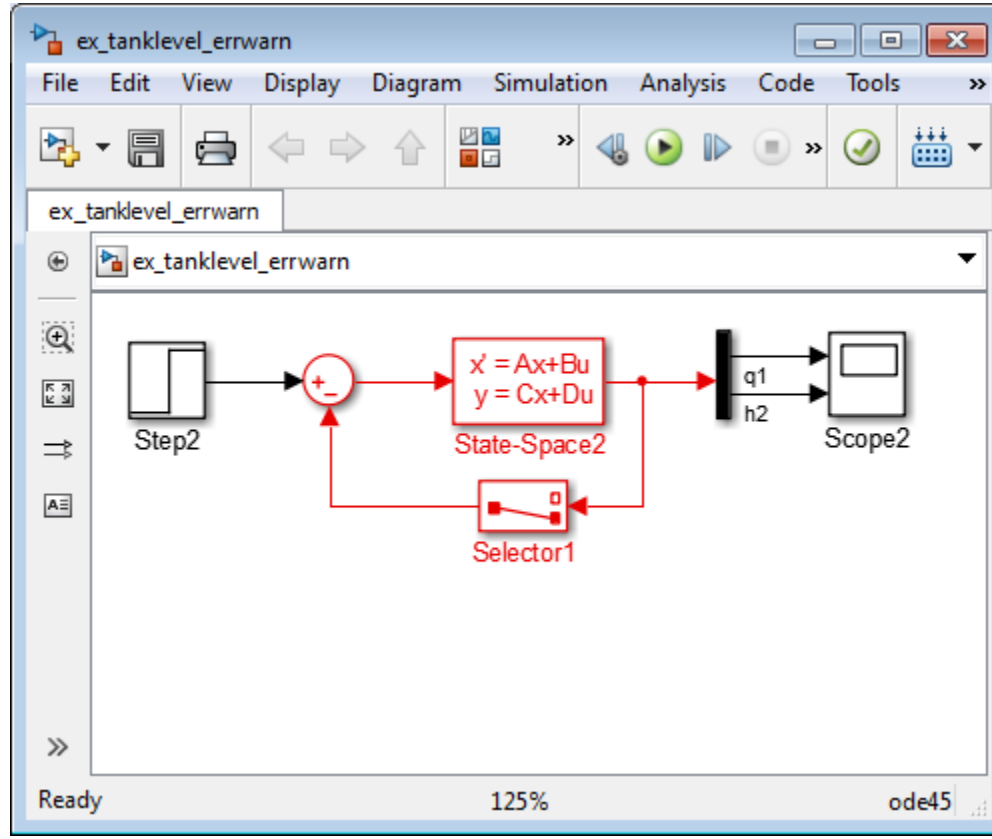
- Output `q1` is the rate of the fluid flow into the tank from the pump.
- Output `h2` is the height of the fluid in the second tank.
- The State-Space block defines the dynamic response of the tank system to the pump operation:



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

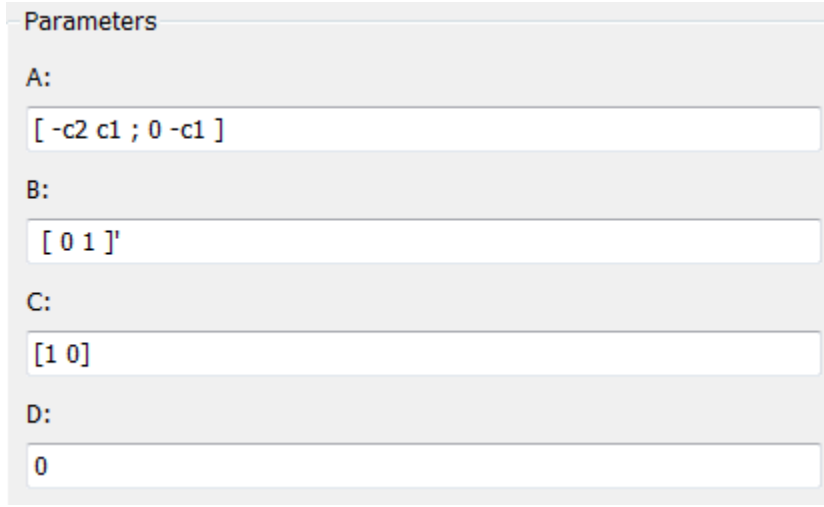


If you simulate this model with the **Algebraic loop** parameter set to `warn` or `error`, Simulink identifies the algebraic loop.



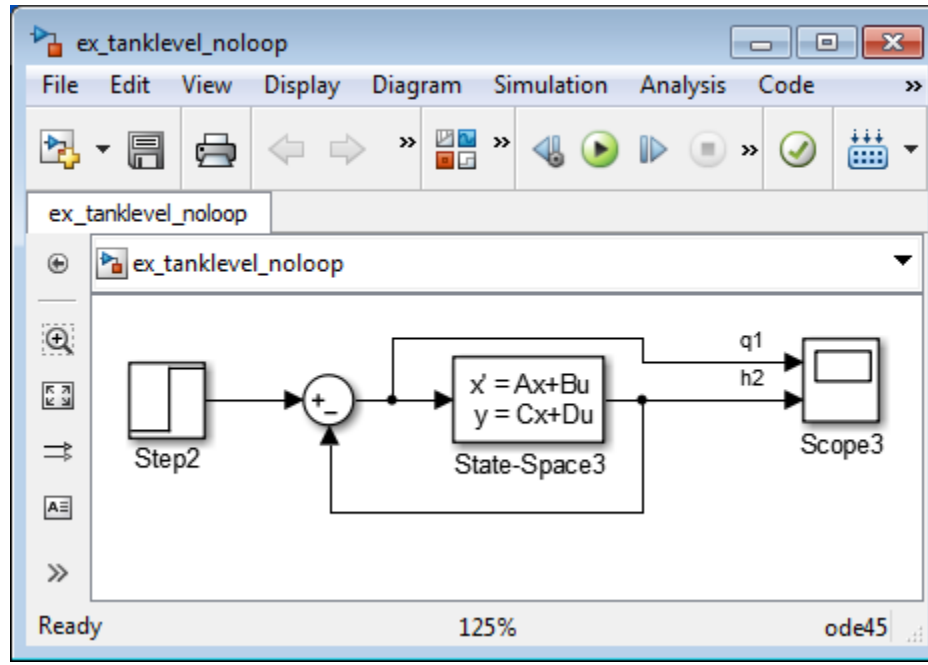
To eliminate this algebraic loop:

1 Change the `C` and `D` matrices as follows:



2 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. The feedback signal has only one element now, so the Selector block is no longer necessary, as you can see in the following model.



Model and Block Parameters for Diagnosing and Eliminating Artificial Algebraic Loops. There are two parameters to consider when you think that your model has an artificial algebraic loop:

- **Minimize algebraic loop occurrences** parameter — Specify that Simulink try to eliminate any artificial algebraic loops for:
  - Atomic subsystems — In the Subsystem Parameters dialog box, select **Minimize algebraic loop occurrences**.
  - Model blocks — For the referenced model, in the Configuration Parameters dialog box, on the **Model Referencing** pane, select **Minimize algebraic loop occurrences**
- **Minimize algebraic loop** parameter — If the **Minimize algebraic loop occurrences** parameter has no effect, specifies what diagnostic action Simulink takes.

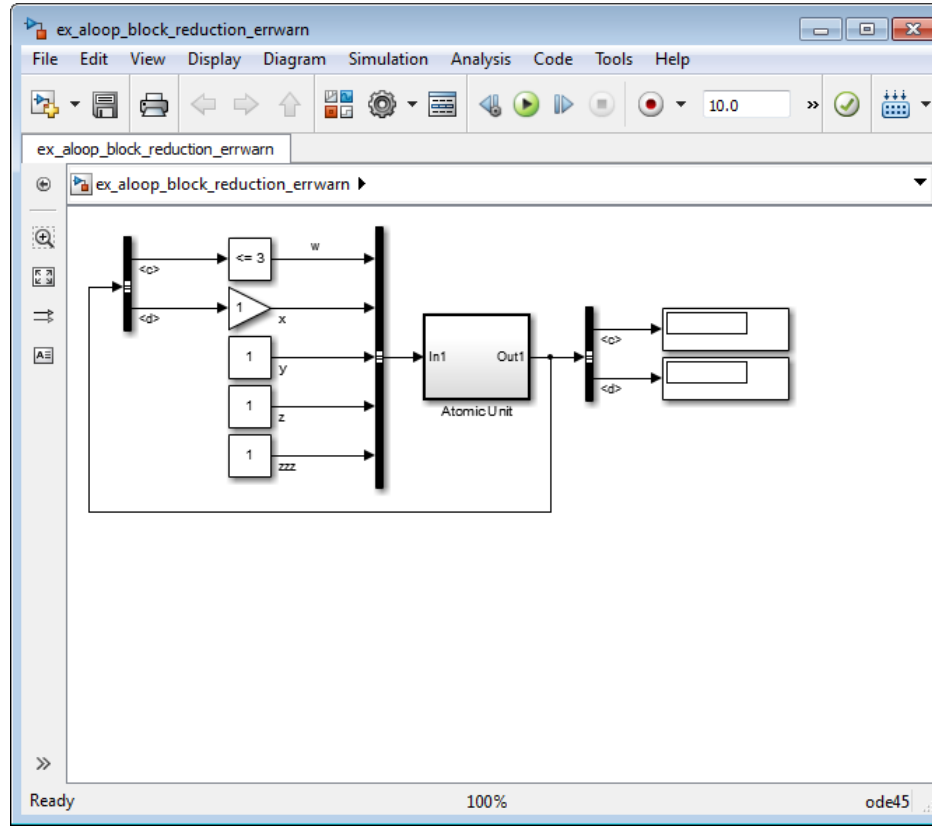
The **Minimize algebraic loop** parameter is in the Configuration Parameters dialog box, on the main **Diagnostics** pane. The diagnostic actions for this parameter are:

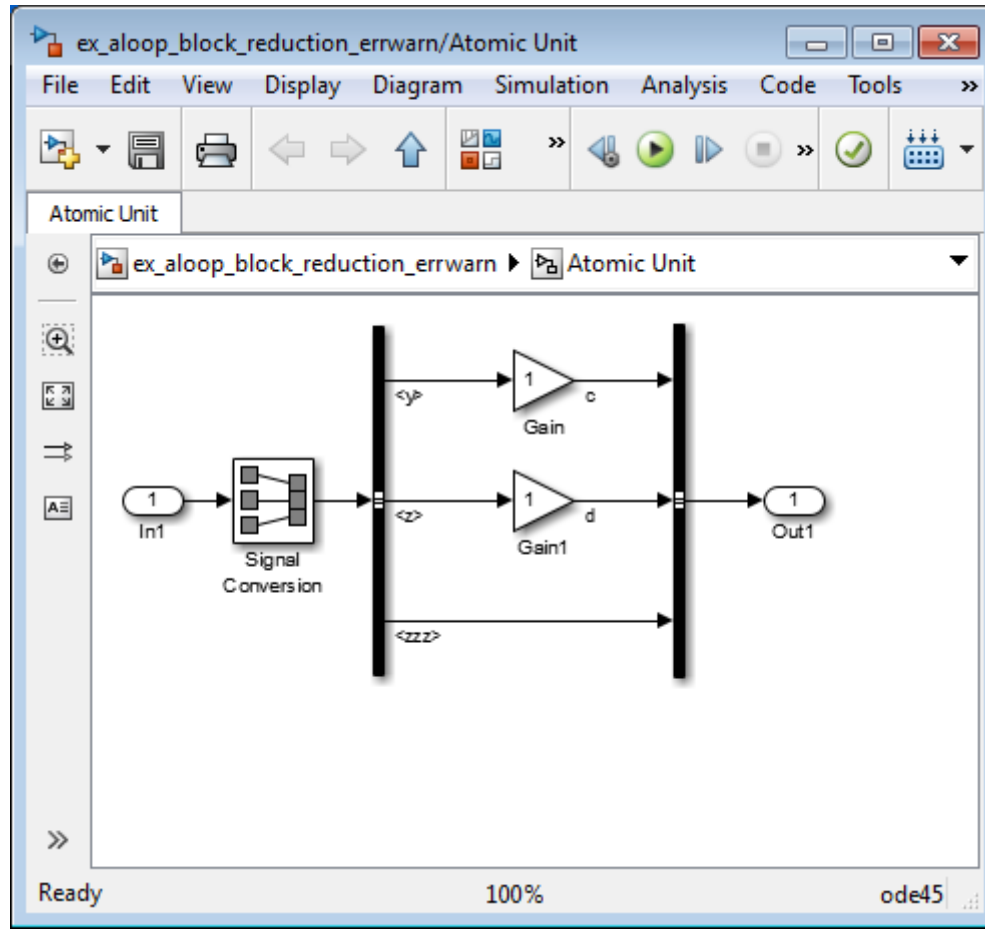
Setting	Simulation Response
`none`	Simulink takes no action.
`warning`	Simulink displays a warning that the **Minimize algebraic loop occurrences** parameter has no effect.
`error`	Simulink terminates the simulation and displays an error that the **Minimize algebraic loop occurrences** parameter has no effect.

Block Reduction and Artificial Algebraic Loops. When you enable the **Block reduction** optimization in the Configuration Parameters dialog box, Simulink collapses certain groups of blocks into a single, more efficient block, or removes them entirely. Enabling block reduction results in faster execution during model simulation and in generated code.

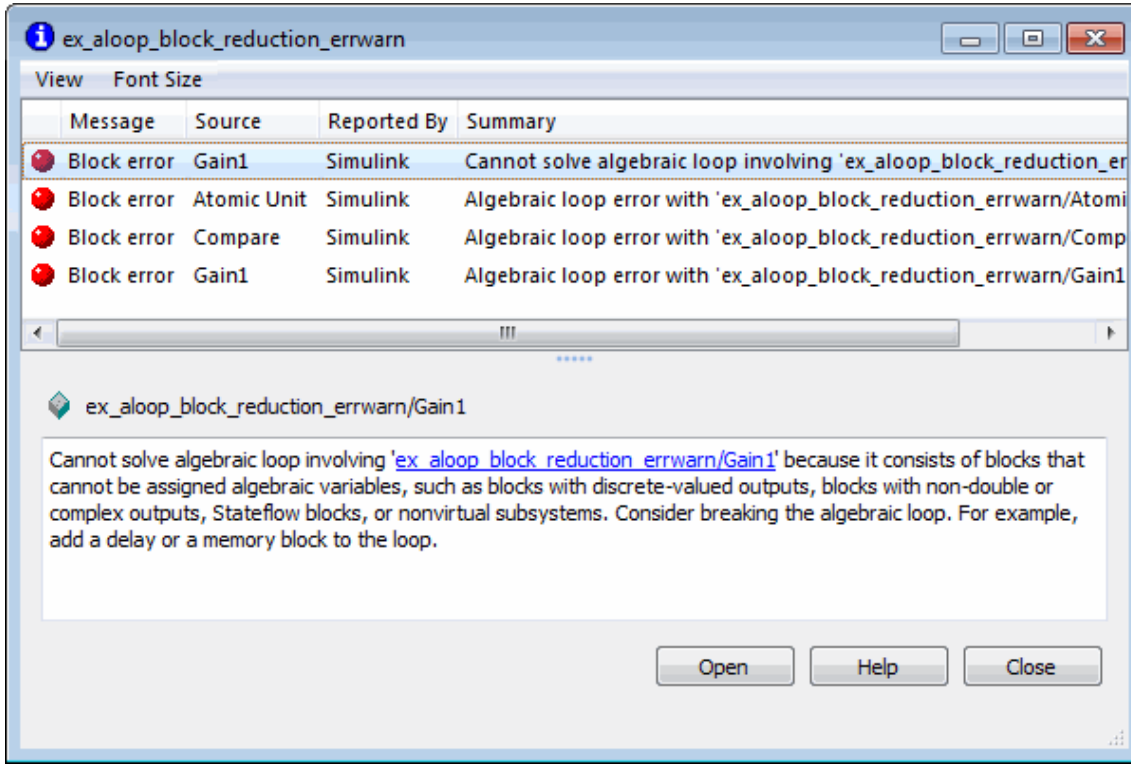
Enabling block reduction may also help Simulink solve artificial algebraic loops.

Consider the following example model.

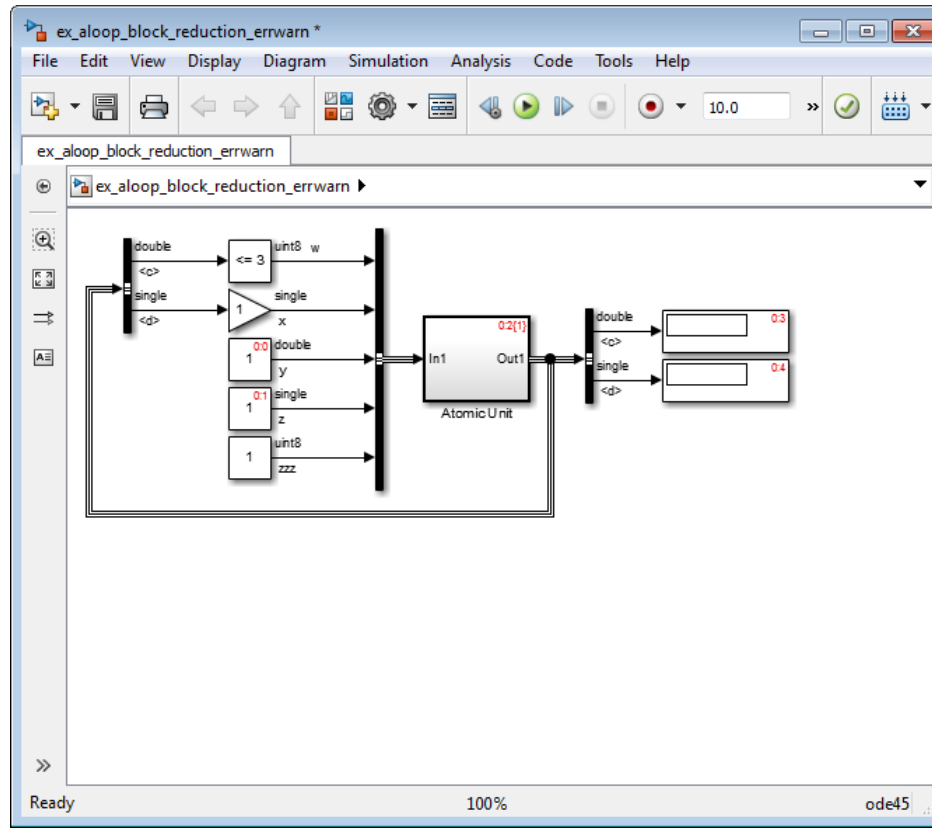

ex_aloop_block_reduction_errwarn
File Edit View Display Diagram Simulation Analysis Code Tools Help
10.0
ex_aloop_block_reduction_errwarn
ex_aloop_block_reduction_errwarn
<c>
<d>
<= 3
w
1
x
1
y
1
z
1
zzz
In1
Out1
Atomic Unit
<c>
<d>
Ready
100%
ode45



Initially, block reduction is turned off. When you simulate this model, the Atomic Unit subsystem and Gain and Compare to Constant blocks are part of an algebraic loop that Simulink cannot solve.



If you enable block reduction and sorted order, and resimulate the model, Simulink does not display the sorted order for blocks that have been reduced. You can now quickly see which blocks have been reduced.

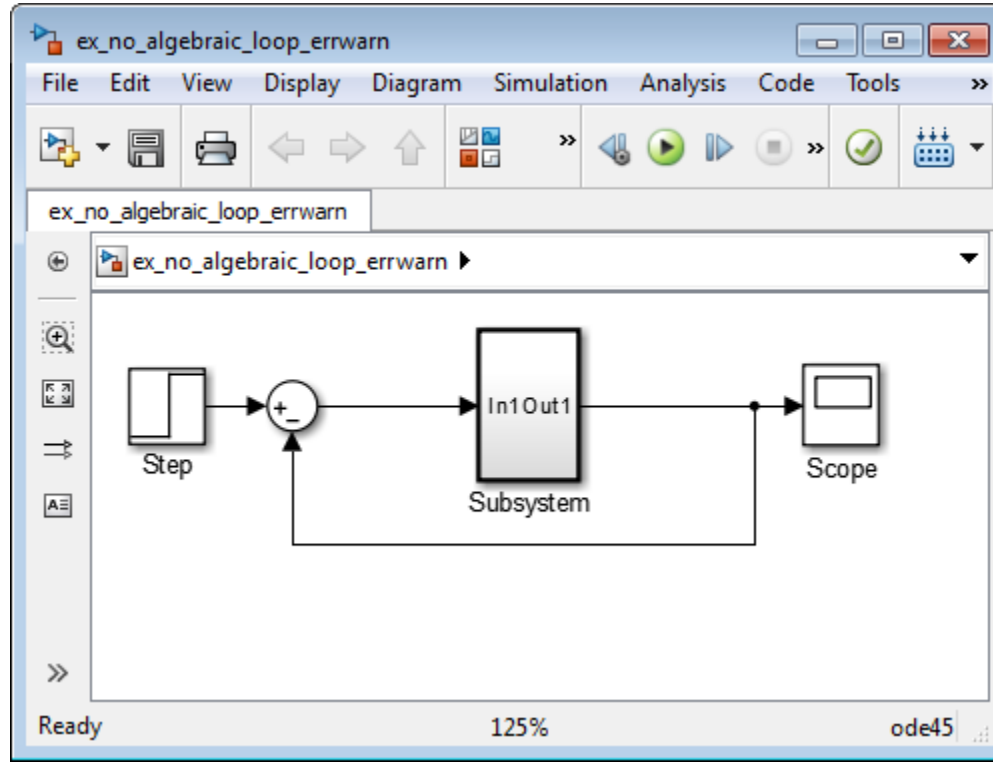


The Compare to Constant and Gain blocks have been eliminated from the model, so they no longer generate an algebraic loop error. The Atomic Unit subsystem generates a warning:

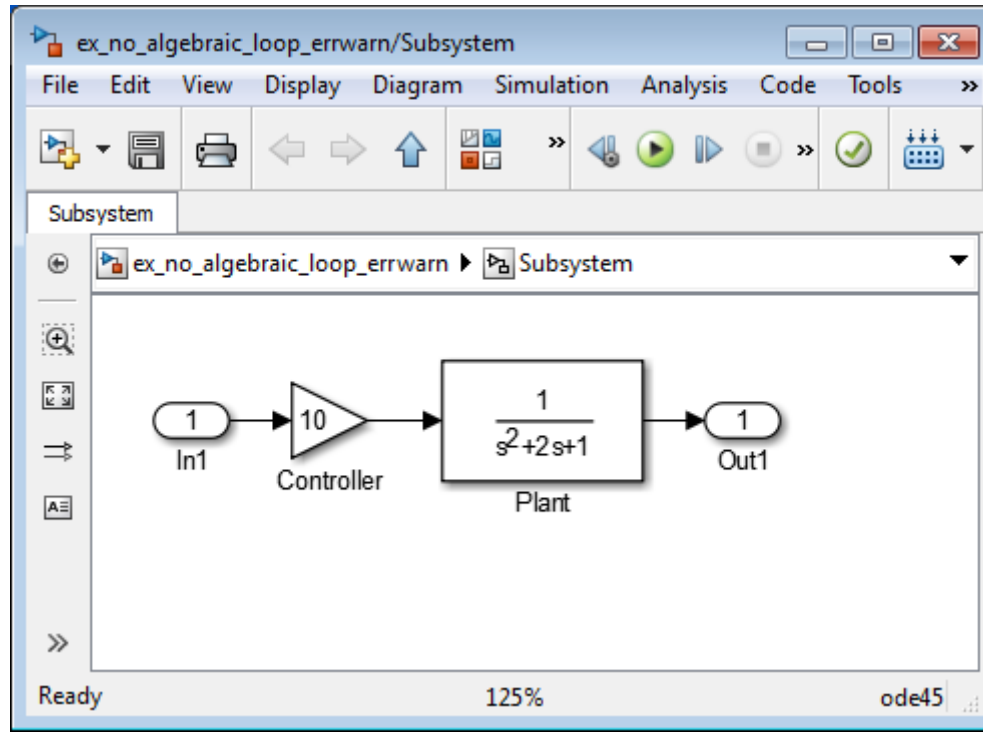
```
Warning: If the inport 'ex_aloop_block_reduction_errwarn/
Atomic Unit/In1' of subsystem 'ex_aloop_block_reduction_errwarn/
Atomic Unit' involves direct feedback, then an algebraic loop
exists, which Simulink cannot remove. Consider clearing the
'Minimize algebraic loop occurrences' parameter to avoid this
warning.
```

Tip Use Bus Selector blocks to pass only the required signals into atomic subsystems.

How Simulink Eliminates Artificial Algebraic Loops. When you enable **Minimize algebraic loop occurrences**, Simulink tries to eliminate artificial algebraic loops. This section describes this process, using this model, which from contains an atomic subsystem that causes an artificial algebraic loop.



The contents of the atomic subsystem are not direct feedthrough, but Simulink identifies the atomic subsystem as direct feedthrough.



If the **Algebraic loop** diagnostic is set to `error`, simulating the model results in an error because the model contains an artificial algebraic loop involving its atomic subsystem.

To see how Simulink tries to eliminate this algebraic loop, follow these steps:

1. Create the model from the preceding graphics, with the atomic subsystem that causes the artificial algebraic loop.
2. Select **Simulation > Model Configuration Parameters**.
3. In the Configuration Parameters dialog box, on the main **Diagnostics** pane, set the **Algebraic loop** parameter to `warning` or `none`.

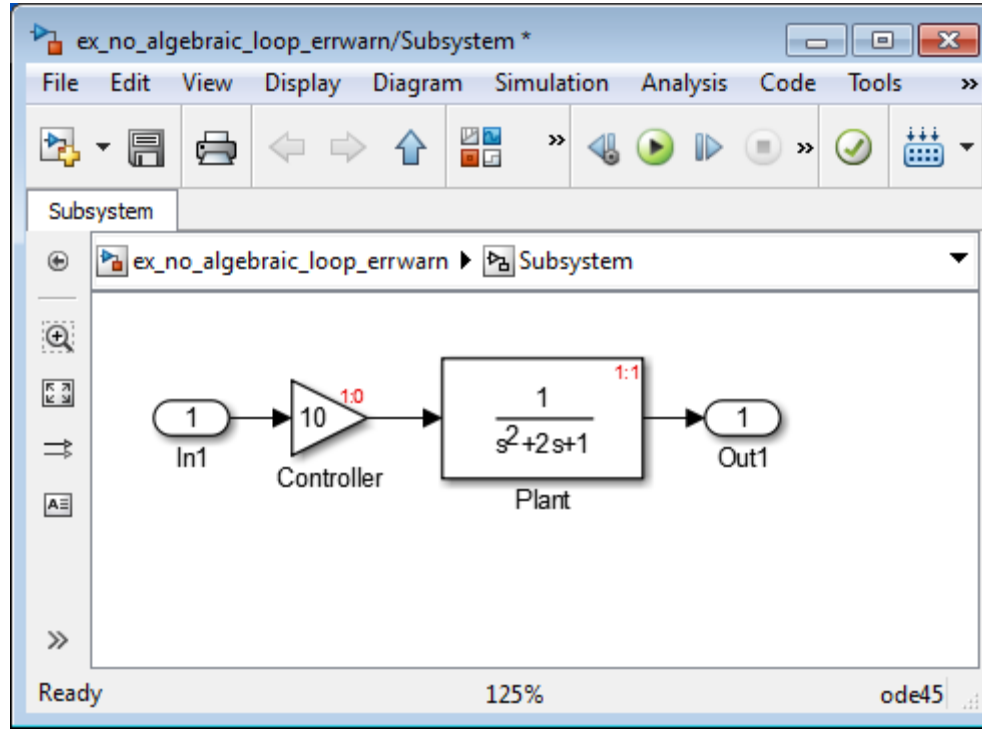
4 On the **Data Import/Export** pane, make sure the **Signal logging** parameter is disabled. If signal logging is enabled, Simulink cannot eliminate artificial algebraic loops.

5 Click **OK**.

6 To display the sorted order for this model and the atomic subsystem, select **Format > Block Displays > Sorted Order**.

Reviewing the sorted order might help you understand how to eliminate the artificial algebraic loop.

All the blocks in the subsystem execute at the same level: 1. (0 is the lowest level, indicating the first blocks to execute.)



Note For more information about sorted order, see "Control and Displaying the Sorted Order" on page 23-35.

7. In the top-level model, right-click the subsystem and select **Subsystem Parameters**.

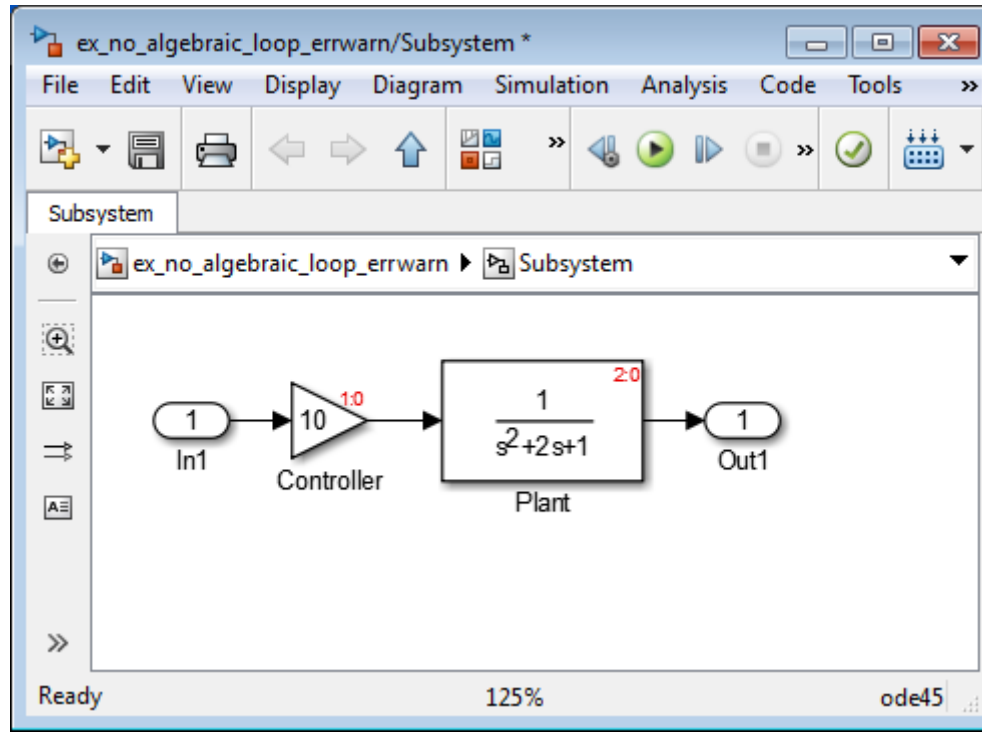
8. Select **Minimize algebraic loop occurrences**.

   This parameter indicates to Simulink to try to eliminate the algebraic loop that contains the atomic subsystem when it simulates the model.

9. Click **OK**.

10. Click **Simulation > Update Diagram** to recalculate the sorted order.

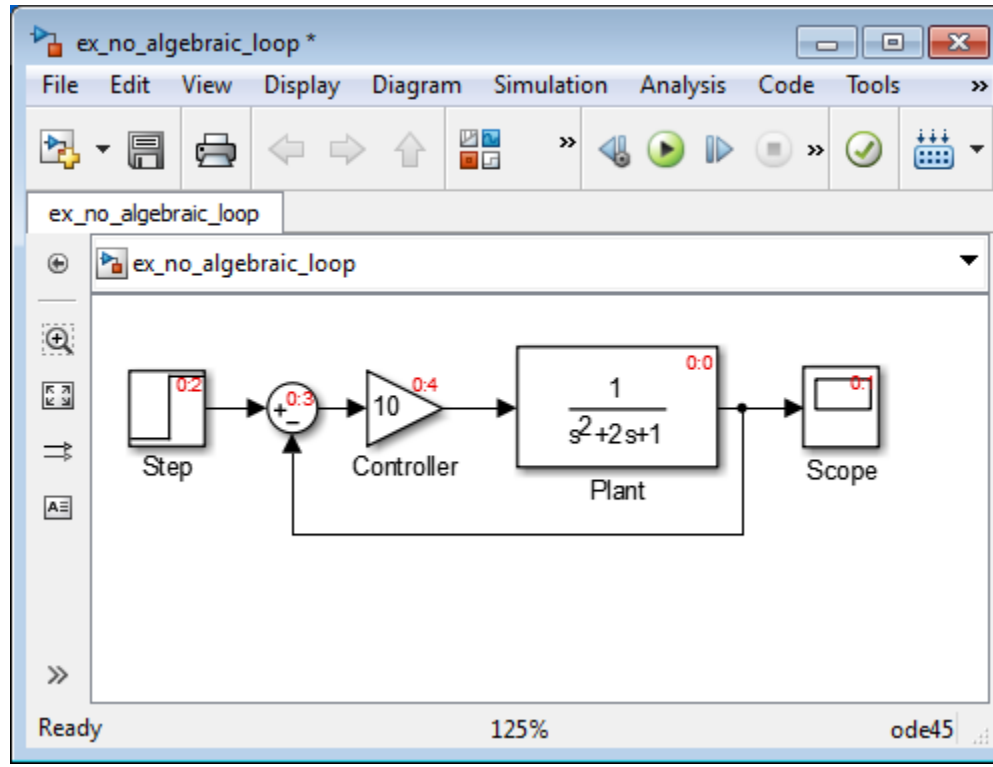
    Now there are two levels of sorted order inside the subsystem: 1 and 2.



To eliminate the artificial algebraic loop, Simulink tries to make the input of the subsystem or referenced model non-direct feedthrough.

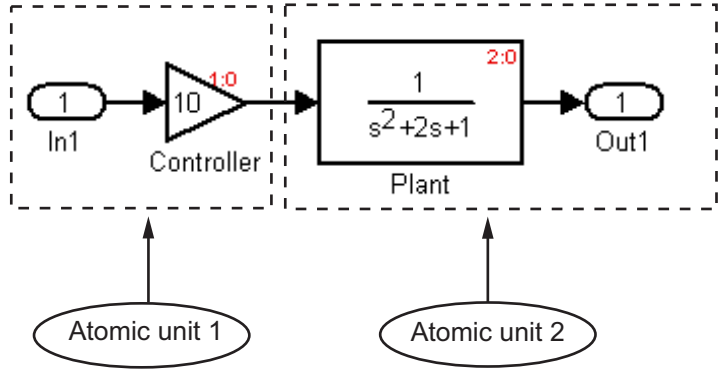
When you simulate a model, all the blocks first execute their `mdlOutputs` method, and then their `mdlDerivatives` and `mdlUpdate` methods.

In the original version of this model, the execution of the `mdlOutputs` method starts with the Plant block because the Plant block is non-direct feedthrough. The execution finishes with the Controller block.



Note For more information about these methods, see “Block Methods” on page 3-16.

If you enable the **Minimize algebraic loop occurrences** parameter for the atomic subsystem, Simulink divides the subsystem into two atomic units.



The following conditions are true:

- Atomic unit 2 is not direct feedthrough.
- Atomic unit 1 has only a `mdlOutputs` method.

The output of Atomic unit 1 is needed only by the `mdlDerivatives` or `mdlUpdate` methods of Atomic unit 2. Simulink can execute what normally would have been executed during the `mdlOutput` method of Atomic unit 1 in the `mdlDerivatives` methods of Atomic unit 2.

The new execution order for the model is:

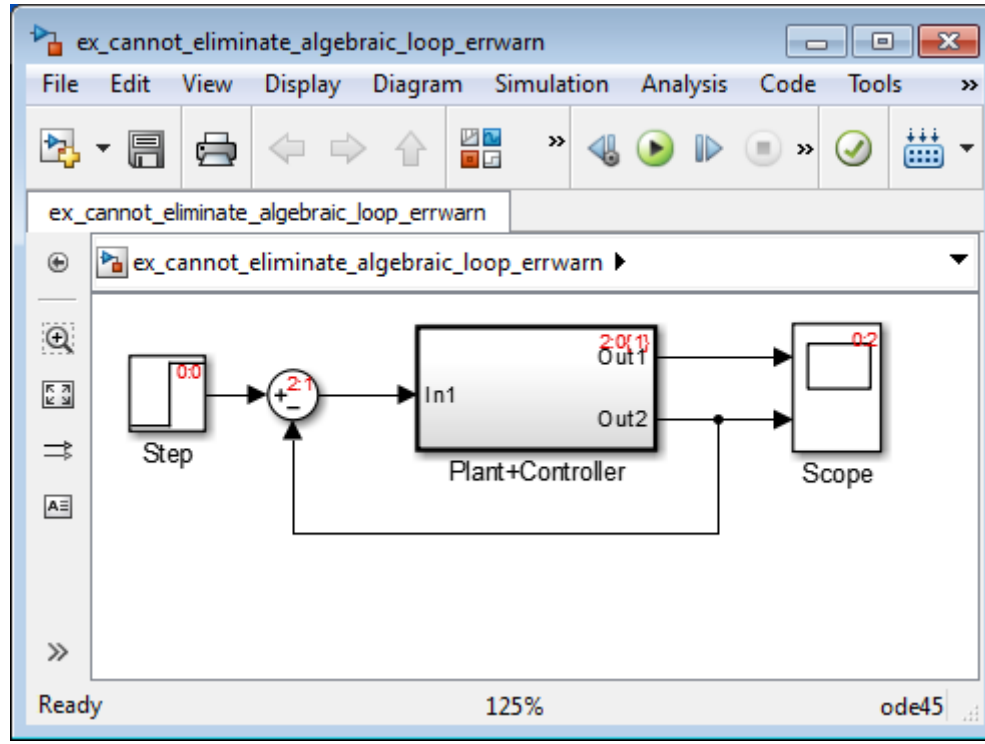
- `mdlOutputs` method of model
  - `mdlOutputs` method of Atomic unit 2
  - `mdlOutputs` methods of other blocks
- `mdlDerivatives` method of model
  - `mdlOutputs` method of Atomic unit 1
  - `mdlDerivatives` method of Atomic unit 2
  - `mdlDerivatives` method of other blocks

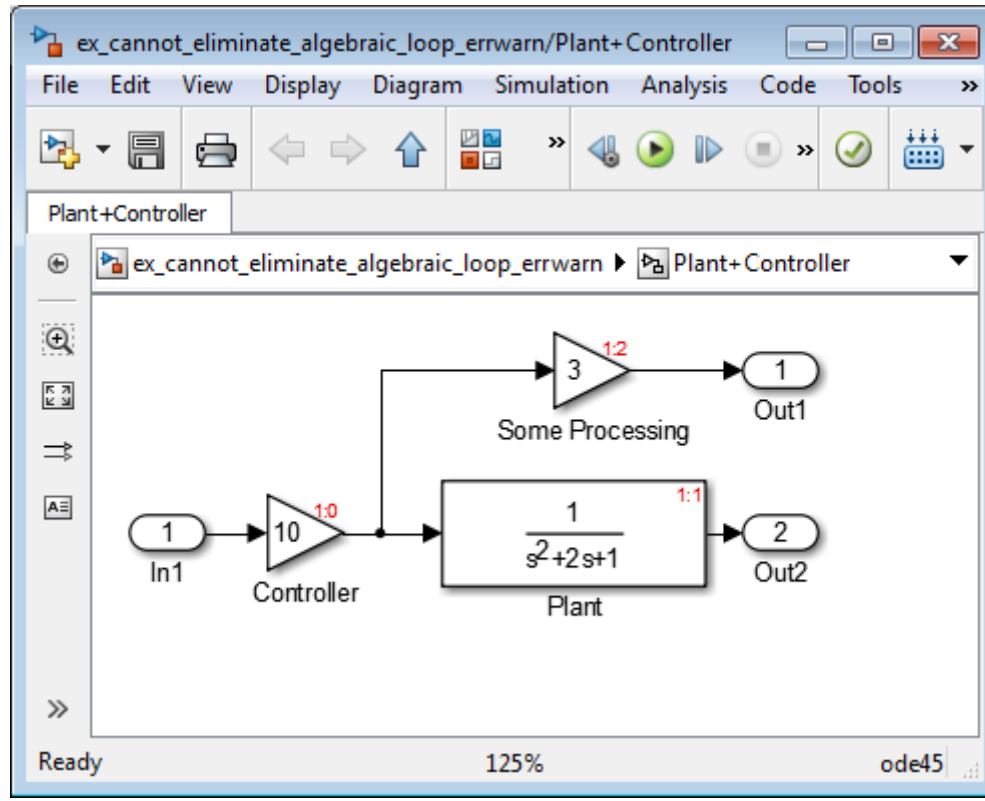
For the **Minimize algebraic loop occurrences** technique to be successful, the subsystem or referenced model must have a non-direct-feedthrough block connected directly to an Inport. Simulink can then set the `DirectFeedthrough`

property of the block Inport to `false` to indicate that the input port does not have direct feedthrough.

When Simulink Cannot Eliminate Artificial Algebraic Loops. Setting the **Minimize algebraic loop occurrences** parameter does not always work. Simulink cannot change the `DirectFeedthrough` property of an Inport for an atomic subsystem if the Inport is connected to an Outport only through direct-feedthrough blocks.

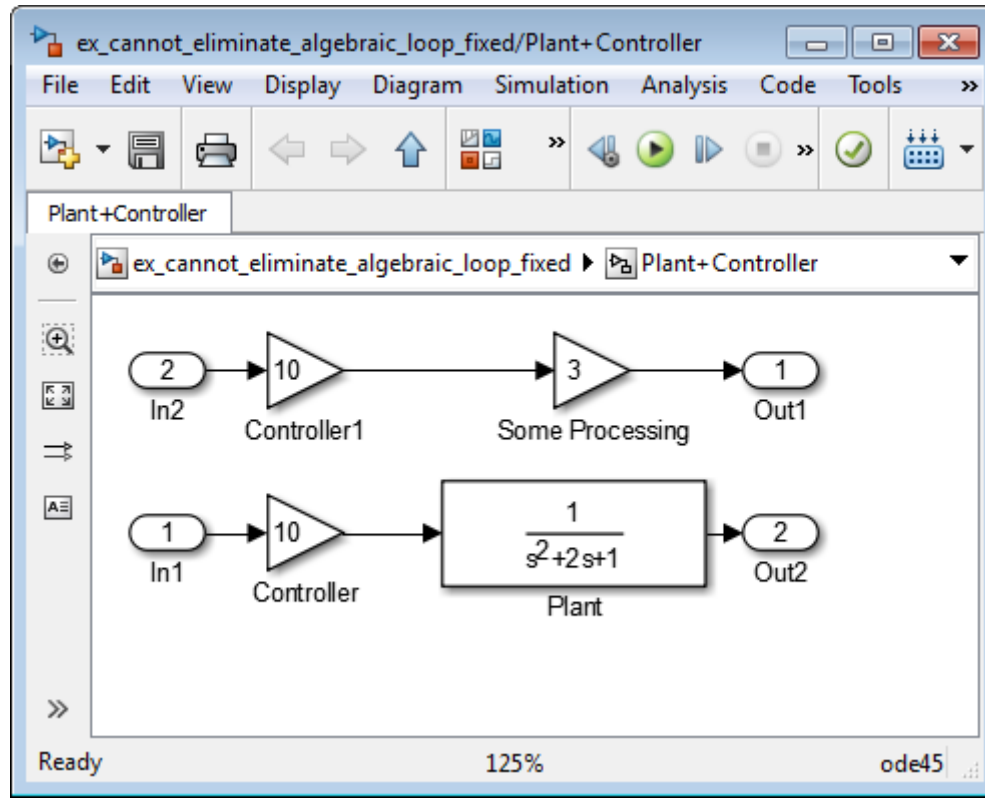
Consider the following model. The subsystem Plant+Controller causes an algebraic loop, but it has an extra Gain block and an extra output.





Simulink cannot move the `mdlOutputs` method of the Controller block to the `mdlDerivative` method of an Atomic unit 1 because the output of the atomic subsystem depends on the output of the Controller block. You cannot make the subsystem non-direct-feedthrough.

You can modify this model to eliminate the artificial algebraic loop by redefining the atomic subsystem by adding additional Inport and Gain blocks, as you can see in the following model. Doing so makes In1 non-direct-feedthrough and In2 direct feedthrough, breaking the algebraic loop.



Managing Large Models with Artificial Algebraic Loops. For large models with algebraic loops, MathWorks recommends the following techniques:

- Avoid creating loops that contain discontinuities or nondouble data types. The Simulink algebraic loop solver is gradient-based and must solve algebraic constraints to high precision.
- Develop a scheme for clearly identifying atomic subsystems as direct feedthrough or not direct feedthrough. Use a visual scheme such as coloring the blocks or defining a block-naming convention.
- If you plan to generate code for your model, enable the **Minimize algebraic loop occurrences** parameter for all atomic subsystems. When

possible, make sure that the input ports for the atomic subsystems are connected directly to non-direct-feedthrough blocks.

- Avoid combining non-direct-feedthrough and direct-feedthrough paths using the Bus Creator or Mux blocks. Simulink might not be able to eliminate any resulting artificial algebraic loops. Instead, consider clustering the non-direct-feedthrough and direct-feedthrough objects in separate subsystems.

  Use Bus Selector blocks to pass only the required signals into atomic subsystems.

Modeling Dynamic Systems

4

Creating a Model

Create an Empty Model

To create an empty model:

1. Open the Library Browser, by typing `simulink` at the MATLAB command line.
2. In the Library Browser, select **File > New > Model** or click the **New model** button ().

The Simulink software creates an empty model in memory and displays the empty model in a Simulink Editor window.

Create 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, use the Simulink model construction functions listed in "Modeling Basics" to write a function that creates a model with the defaults that you prefer. For example, the following function creates a model that has a green canvas 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');

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

Populate a Model

In this section...

Copy Blocks to Your Model

Use the Simulink Library Browser as the source for populating your model. In the Library Browser, browse and search blocks from built-in and user libraries. Copy blocks from the Library Browser to your model in the Simulink Editor.

To open the Library Browser, at the MATLAB command line, enter:

```
simulink
```

For details, see “Open the Simulink Library Browser”.

For information about creating your own libraries and adding them to the Library Browser, see “Block Libraries”.

Browse Block Libraries

The **Libraries** pane on the left displays a tree-structured folder of the block libraries 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 browse the libraries on your system and the blocks that the libraries contain.

The contents of the library that you select 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. An icon and a name identifies each member of the selected library.

To open a sublibrary, use *one* of the following approaches:

- Select the library in the **Libraries** pane.
- Double-click the library in the **Library** tab.

To get help for a block:

1. Right-click the block.
2. From the context menu, select **Help**.

The help text and the context menu are the same as what appear when you right-click an instance of that block in a model.

Search Block Libraries

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

1. In the Library Browser, in **Search** text field, enter the search character string.
2. Press `Return` or click **Search**.

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

By default, the search finds any substring and is not case-sensitive. To change these defaults or to enable use of MATLAB regular expressions in the **Search** field, click the **Library Browser Options** button and select the appropriate commands. Work with blocks that you find by searching just as you do with blocks that you find by selecting a library.

Copy 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 that you select.

The resulting block retains a link to its source library. Updates to the source library automatically propagate to all of its linked copies. See “Libraries” for information about library links.

Select Modeling Objects

In this section...

Select an Object

To select a modeling object (for example, a block or line), click it. When you place the cursor on a block, small black square handles appear at the corners of the block. Placing the cursor on a line highlights part of the line in blue.

Clicking a block or line highlights the whole object in blue. For example, the figure below shows a selected Sine Wave block.

Selecting an object by clicking it deselects any other selected objects.

Select Multiple Objects

To select more than one object, use *one* of these approaches:

- Select objects one at a time.
- Use a bounding box to select objects located near each other.
- Select the entire model.

Select 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 that you want to select.

To deselect a selected object, click the object again while holding down the **Shift** key.

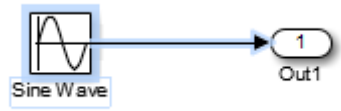
Select Multiple Objects Using a Bounding Box

To select more than one object in the same area of the window, draw a bounding box around the objects. This type of selection is also known as "marquee selection" and "drag selection."

1 Define the starting corner of a bounding box. Position the cursor (pointer) at one corner of the box, then press and hold the left mouse button.

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

3 Release the mouse button. Simulink selects all blocks and lines that are at least partially enclosed by the bounding box. For example, in the figure below, the bounding box enclosed at least part of the Sine Wave and the line from the Sine Wave block.



Select All Objects

To select all objects in the active window, select **Edit > Select All**.

Note To create a subsystem, you cannot select all blocks and signals . For more information, see "Create a Subsystem" on page 4-36.

Specify Block Diagram Colors

In this section...

Set Block Diagram Colors Interactively

You can specify the foreground and background colors of any block or annotation in a diagram, as well as the background color of the diagram.

Type of Color	How to Set
Block diagram background	Select **Diagram > Format > Canvas Color**.
Block or annotation background	**1** Select the blocks and annotations. **2** Select **Diagram > Format > Background Color**
Block or annotation foreground	**1** Select the blocks and annotations. **2** Select **Diagram > Format > Foreground Color**

In all cases, you see a menu of color choices. 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 changes to the selected color.

Platform Differences for Custom Colors

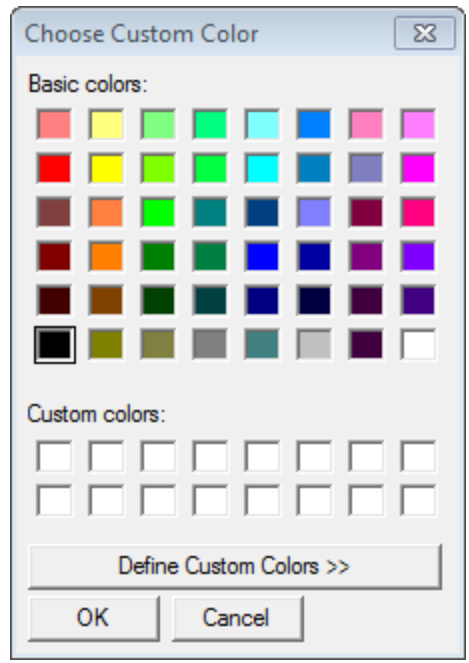
On Mac platforms, choosing **Custom** invokes the Mac color picker interface. Use the color picker to choose and define custom colors.

On Windows and Linux platforms, use the Simulink interface, as described in:

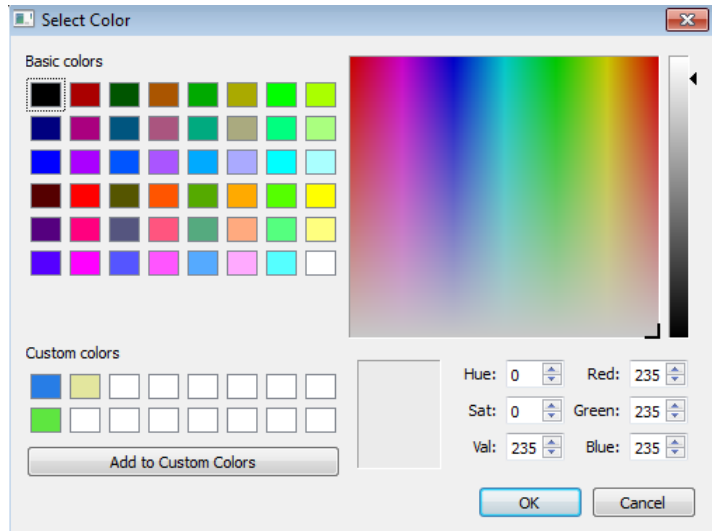
- "Choose a Custom Color" on page 4-9
- "Define a Custom Color" on page 4-10

Choose a Custom Color

If you choose **Custom**, and there are no custom colors already defined, Simulink displays the Choose Custom Color dialog box.



If you choose **Custom**, and there are custom colors already defined, Simulink displays the Select Color dialog box.



The Select Color dialog box displays a palette of basic colors and a palette of already defined custom colors. To choose a color from either palette, click the color and then click **OK**.

Define a Custom Color

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

The dialog box expands to display the Select Color dialog box. To define a custom color:

1. Specify the color using *one* of these approaches:
   - Enter the red, green, and blue components of the color as values between 0 (darkest) and 255 (brightest).
   - Enter hue, saturation, and luminescence components of the color as values in the range 0 to 255.
   - Move 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.

2. Adjust the values until the color in the box to the right of the custom colors palette is the custom color that you want.

3. Click the **Add to Custom Colors** button.

To replace an existing custom color, select the custom color in the custom color palette before defining the new custom color.

Specify 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
Block diagram background	`ScreenColor`
Block and annotation background	`BackgroundColor`
Block and annotation foreground	`ForegroundColor`

Set the color parameter to either a named color or an RGB value.

- Named color: `'black'`, `'white'`, `'red'`, `'green'`, `'blue'`, `'cyan'`, `'magenta'`, `'yellow'`, `'gray'`, `'lightBlue'`, `'orange'`, `'darkGreen'`
- RBG value: `'[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]')
```

Connect Blocks

In this section...

Automatically Connect Blocks

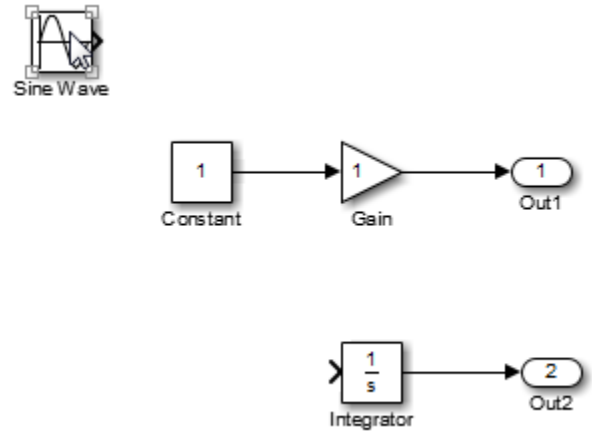
You can have the Simulink software connect blocks automatically. This eliminates the need to draw the connecting lines yourself. When connecting blocks, Simulink routes the lines around intervening blocks to avoid cluttering the diagram.

Autoconnect Two Blocks

When connecting two blocks with multiple ports, Simulink draws as many connections as possible between the two blocks.

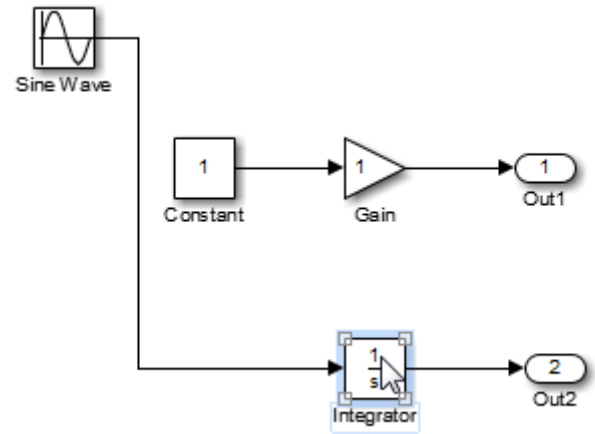
To autoconnect two blocks:

1 Select the source block. In this example, the Sine Wave block is the source block.



2 Hold down **Ctrl** and left-click the destination block. In this example, the Integrator block is the destination block.

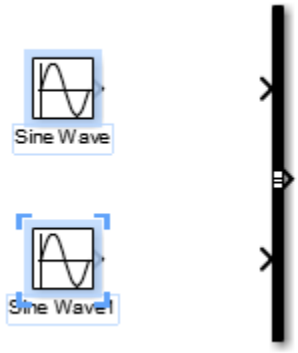
The source block is connected to the destination block, and the lines are routed around intervening blocks if necessary.



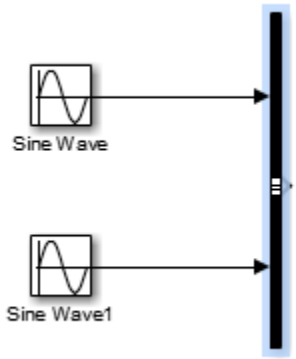
Connect Groups of Blocks

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

1. Select the source blocks.

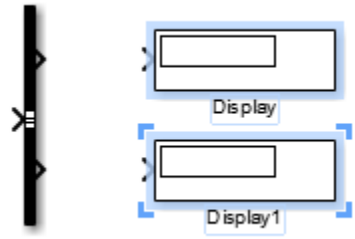


2. Hold down **Ctrl** and left-click the destination block.

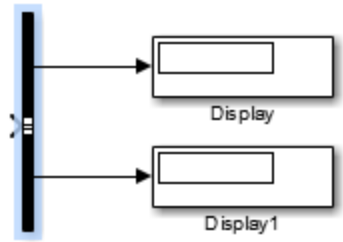


To connect a source block to a group of destination blocks:

1. Select the *destination* blocks.



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



Manually Connect Blocks

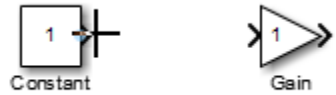
You can draw lines manually between blocks or between lines and blocks. You might want to do this if you need to control the path of the line or to create a branch line.

Draw a Line Between Blocks

You can create lines either from output to input ports, or from input to output ports. For example, to connect the output port of a Constant block to the input port of Gain block:

1 Position the cursor over the output port of the Constant block. You do not need to position the cursor precisely on the port.

The cursor shape changes to crosshairs.

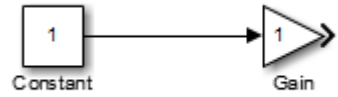


2. Hold down the left mouse button.

3. Drag the cursor to the input port of the Gain block. Position the cursor on or near the port or in the block. If you position the cursor in the block, the line connects to the closest input port.

4. Release the mouse button. A connecting line with an arrow showing the direction of the signal flow replaces the port symbol.

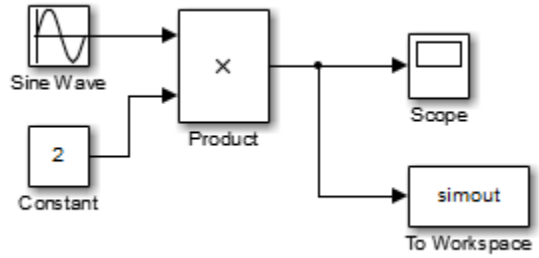
   The arrow appears at the appropriate input port, and the signal is the same.



Draw 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. Use branch lines to connect a signal to more than one block.

This example shows how to connect the Product block output to both the Scope block and the To Workspace block.



To add a branch line:

1. Position the cursor on the line where you want the branch line to start.
2. While holding down the **Ctrl** key, press and hold down the left or right mouse button.
3. Drag the cursor to the input port of the target block, then release the mouse button and the **Ctrl** key.

Draw Line Segments

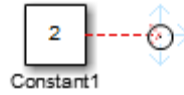
Manually draw line segments when you want to draw:

- Line segments differently than autoconnect feature draws the lines
- A line, before you copy the block to which the line connects

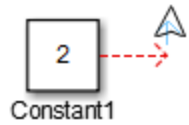
To draw a line segment:

1. Draw a line from the block port to an unoccupied area of the canvas. Release the mouse button where you want the line segment to end.

   The cursor turns into a circle, and blue arrow guides appear.



2 For each additional line segment, position the cursor over the blue arrow guide that points in the direction in which you want to draw a line segment. The cursor turns into an empty arrowhead.



Tip To reroute the whole line instead of extending it, select the end of the line itself when the circle cursor is displayed and drag the line end to a new location.

3 Drag the cursor to draw the second line segment and release the mouse button to finish drawing the line.

Move a Line Segment

To move a line segment:

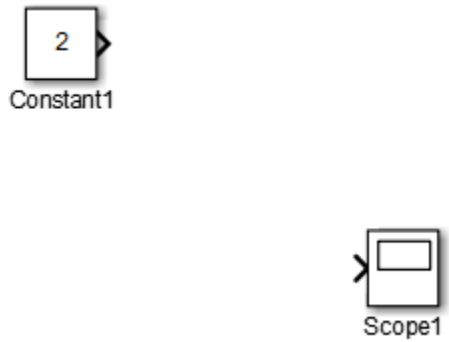
1 Position the cursor on the segment that you want to move.

2 Press and hold down the left mouse button.

3 Drag the cursor to the desired location and release the mouse button.

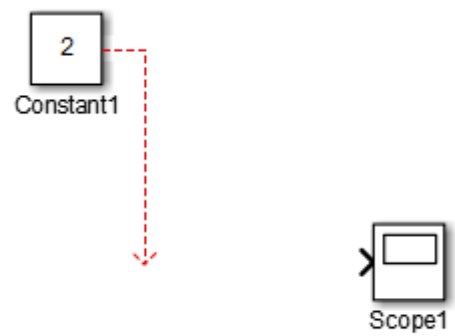
Draw a Diagonal Line

You cannot draw a single diagonal line between two ports. You can draw very short line segments connecting to each port, with a longer diagonal segment in the middle. For example, suppose you position two blocks as shown below:



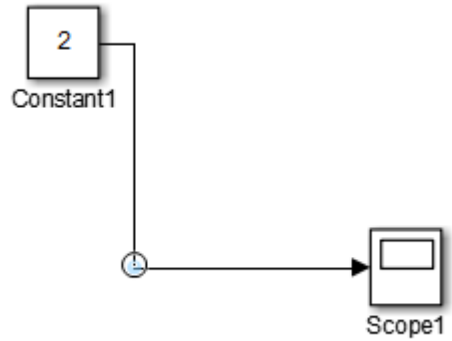
To approximate a diagonal line:

1. Draw a short line segment from the output port of the Constant block.
2. At the end of the first line segment, draw a second line segment.

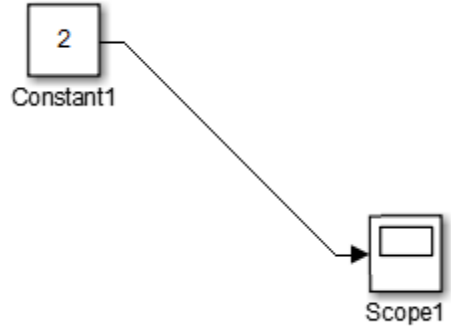


3. Draw a third line segment to connect to the Scope block.

4 Position the cursor at the bend of the second and third line segments. The cursor turns into a circle.



5 Hold the **Shift** key down and drag the cursor to make the second line segment a diagonal.

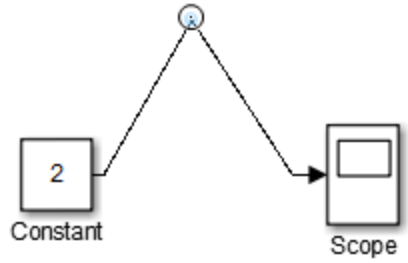


Move a Line Vertex

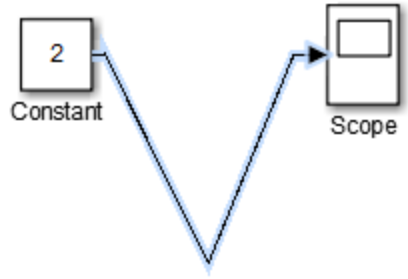
To move a vertex of a line:

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

The cursor changes to a circle.



2 Drag the vertex to the desired location.



3 Release the mouse button.

Insert a Block in a Line

You can insert a block in a line, if the block has only one input and one output.

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

2 Release the mouse button. Simulink inserts the block for you at the point where you drop the block.

Disconnect Blocks

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

Align, Distribute, and Resize Groups of Blocks

To align, distribute, or resize a group of blocks:

1. Select the blocks that you want to align, as described in "Select Multiple Objects" on page 4-6.

   Simulink highlights one of the selected blocks. Simulink uses the highlighted block as the reference for aligning the other selected blocks. For example, in the following model, the Constant block is the alignment reference block.

   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.

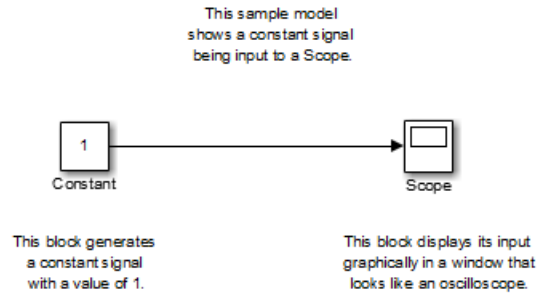
2. From the **Diagram > Arrange** menu, select an alignment, distribution, or sizing option. For example, select **Align Top** to align the top edges of the selected blocks with the top edge of the reference block.

Annotate Diagrams

In this section...

Add and Edit Annotations

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



Add an Annotation

To add an annotation:

1. Double-click an unoccupied area of the block diagram. A small rectangle appears and the cursor changes to an insertion point.

2 Type the annotation contents. Each line is centered in the rectangle that surrounds the annotation.

Alternatively, from the Simulink Editor palette (to the left of the model), select the **Annotation** button ( ) and either drag the cursor into the model window or click in the model window.

Move an Annotation

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

Annotations Properties Dialog Box

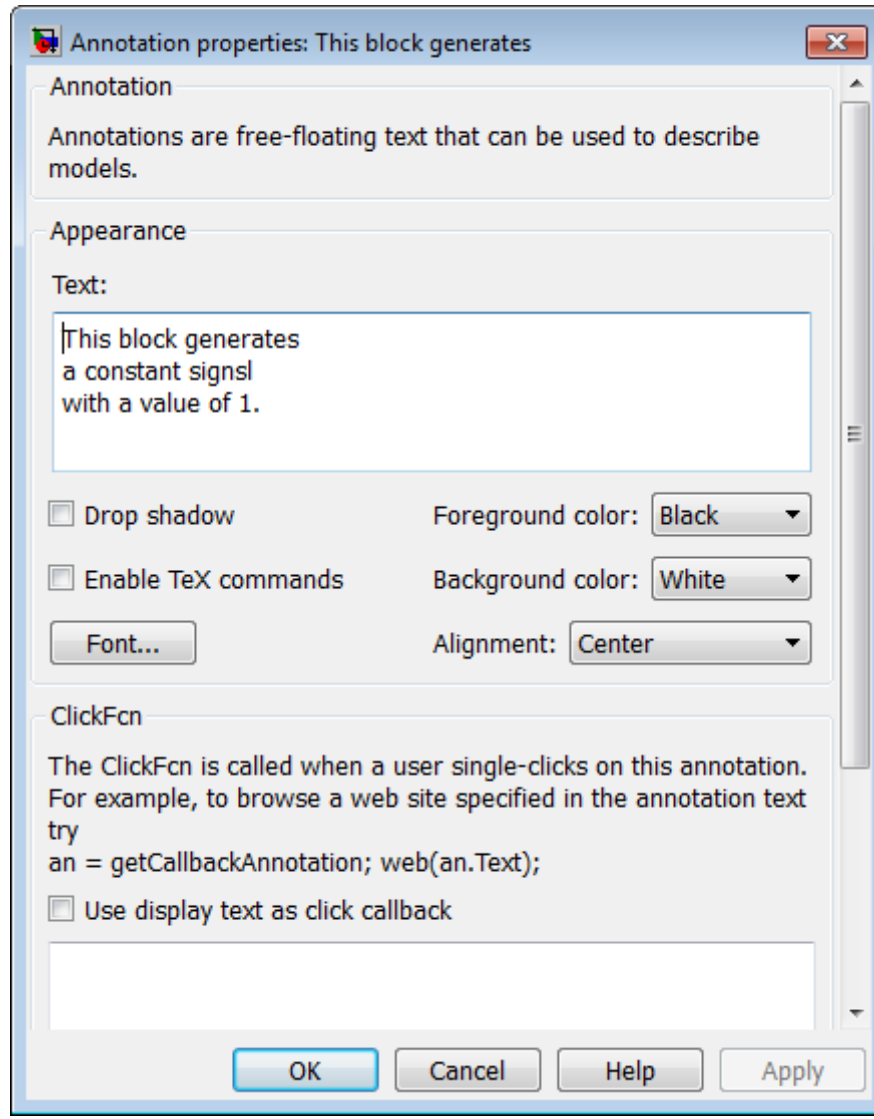
As an alternative to directly editing an annotation, you can use the Annotation properties dialog box to specify the contents and format of the currently selected annotation and to associate a click function with the annotation. The Annotations properties dialog box consolidates the options for specifying the content and appearance of an annotation.

To display the Annotation properties dialog box for an annotation:

1 Select an annotation.

2 Select **Diagram > Properties**.

The Annotation properties dialog box opens.



Edit an Annotation

To edit an annotation directly, select the 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 edit annotation text using the Annotations properties dialog box, edit the **Text** field.

Change Annotation Font

To change the annotation font:

1. Select the annotation.
2. Select **Diagram > Format > Font Style**.
3. Select a font and size from the dialog box.

To change the annotation font using the Annotations properties dialog box, press the **Font** button.

Use TeX commands

To use TeX (LaTeX) commands in an annotation:

1. Select the annotation.
2. Select **Diagram > Format > Enable TeX Commands**.
3. Enter TeX commands.

As an alternative, to enable the use of TeX commands using the Annotations properties dialog box, select **Enable TeX commands**.

For details, see "TeX Formatting Commands in Annotations" on page 4-32.

Text Alignment

To change the text alignment (left, center, or right) in an annotation:

1. Select the annotation.

2 Select **Diagram > Format > Text Alignment**.

3 Select an alignment option, such as **Center**.

As an alternative, to change the annotation text alignment using the Annotations properties dialog box, use the **Alignment** field.

Background Color or Text Color

To change the background color or text color of an annotation:

1 Select the annotation.

2 Set the annotation background color by selecting **Diagram > Format > Background**.

3 Set the annotation text color by selecting **Diagram > Format > Foreground**.

As an alternative, to change the background color or text color using the Annotations properties dialog box:

- To specify the color of the annotation box, use the **Background color** field.
- To specify the annotation text color of the annotation box, use the **Foreground color** field.

Border or Drop Shadow

To specify a border for the annotation:

1 Select the annotation.

2 Select the annotation background color by selecting **Diagram > Format > Annotation Border**.

To specify a drop shadow for the annotation (to give it a 3-D appearance), in the Annotations properties dialog box, select **Drop shadow**.

Delete an Annotation

To delete an annotation, do *one* of the following:

- Draw a selection box that includes part of the annotation and press **Delete**.
- Select all of the text in the annotation, press **Delete**, and move the cursor.

Summary of Annotations Properties Dialog Box

The dialog box includes the following controls.

Text

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

Enable TeX commands

Enables the use of TeX formatting commands in this annotation. For details, see "TeX Formatting Commands in Annotations" on page 4-32.

Font

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 bounding box of the annotation.

Alignment

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

ClickFcn

Specifies MATLAB code to be executed when a user single-clicks this annotation. Simulink stores the code entered in this field with the model. For details, see "Associate Click Functions with Annotations" on page 4-30.

Use display text as click callback

Treats the **Text** field as the annotation 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. For details, see "Associate Click Functions with Annotations" on page 4-30. Selecting this option disables the **ClickFcn** edit field.

Annotation Callback Functions

You can make an annotation interactive by adding a callback. For example, you can use an annotation click callback function to set up a link from annotation text.

You can associate the following callback functions with annotations.

Click Function

A click function is a MATLAB function that Simulink invokes when a user single-clicks an annotation. You can associate a click function with any model annotation (for details, see "Associate Click Functions with Annotations" on page 4-30).

You can use click functions to add hyperlinks and custom command "buttons" to a model. For example, you can use a click function 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.

Simulink uses the color blue to display the text of annotations associated with click functions.

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 4-32).

Delete function

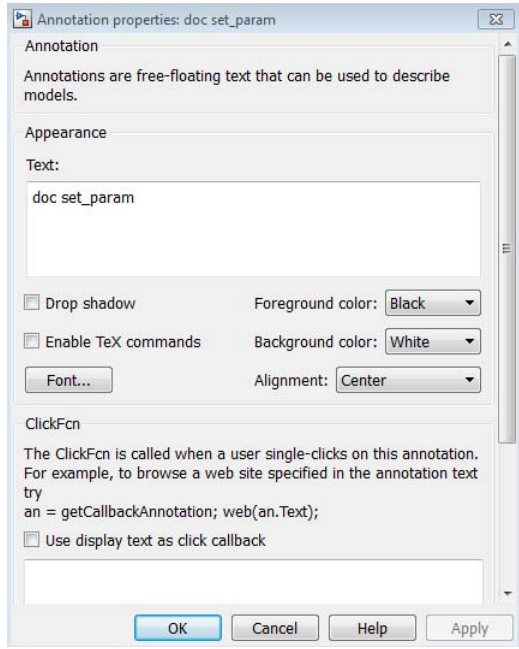
This function is invoked before deleting the associated annotation. To associate a delete function with an annotation, set the `DeleteFcn` property of the annotation to the desired function (see "Annotations API" on page 4-32).

Associate Click Functions with Annotations

Use one of two ways to associate a click function with an annotation with either the Annotation Properties dialog box (see "Summary of Annotations Properties Dialog Box" on page 4-28) or a separately defined function.

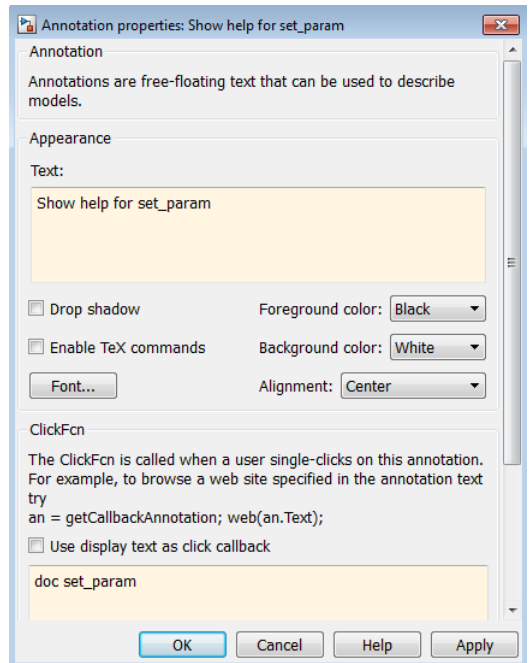
- Specify the annotation itself as the click function.

  Enter a valid MATLAB expression in the **Text** field and check the **Use display text as click callback**.



- Specify a separately defined click function.

  Enter the MATLAB code that defines the click function in the **ClickFcn** edit field.



Note You can also use MATLAB code to associate a click function with an annotation. See “Annotations API” on page 4-32 for more information.

Select and Edit Annotations Associated with Click Functions

If you associate an annotation with a click function, then you cannot select the annotation by clicking on it. Instead, use a boundary box to select the annotation.

To move the annotation, use the up, down, right, or left arrow keys.

Similarly, you cannot edit the annotation text by clicking on the text. To edit the annotation:

1. Drag select the annotation.
2. Right-click the selected annotation.
3. In the context menu, select **Properties**.
4. In the Properties dialog box, in the **Text** field, edit the text.

Annotations API

To use MATLAB code to get and set the properties of annotations, use:

- `Simulink.Annotation` class

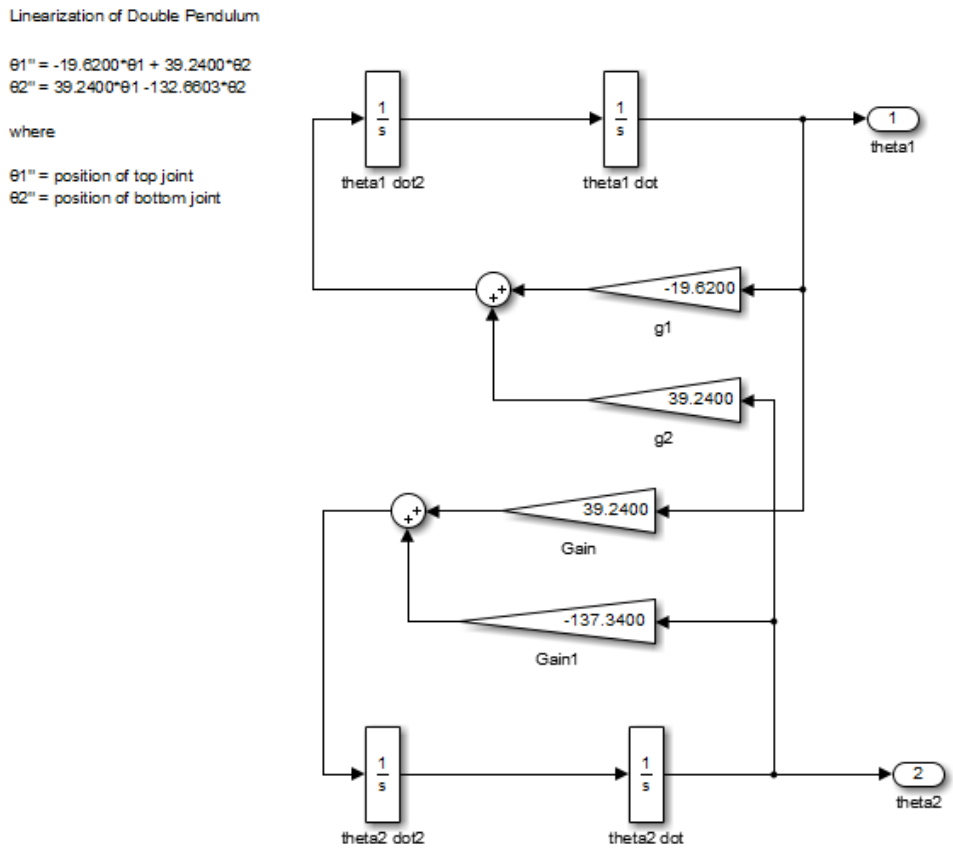
  Set the properties of annotations, by using MATLAB code. For example, annotation load functions (see "Load Function" on page 4-29).

- `getCallbackAnnotation` function

  Get the `Simulink.Annotation` object for the annotation associated with the currently executing annotation callback function. Use this function to determine which annotation was clicked to invoke the current callback. This function is also useful if you write a callback function in a separate MATLAB file contains multiple callback calls.

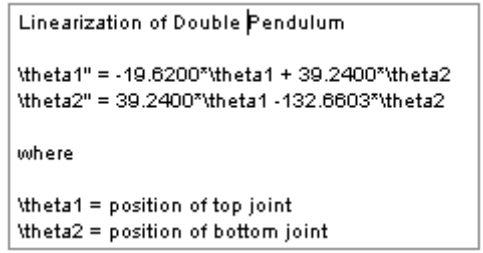
TeX Formatting Commands in Annotations

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:

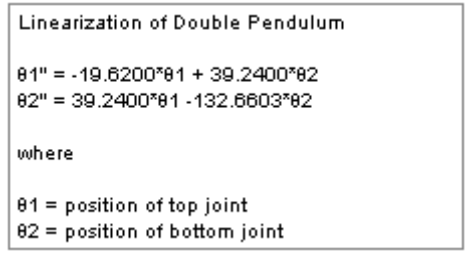
1. Select the annotation.
2. Select **Diagram > Format > Enable TeX Commands**.
3. Enter or edit the text of the annotation, using TeX commands where needed to achieve the desired appearance.



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

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

The text reflects the TeX formatting.



Create Annotations Programmatically

To create annotations at the command line or in a MATLAB program, use the `add_block` command.

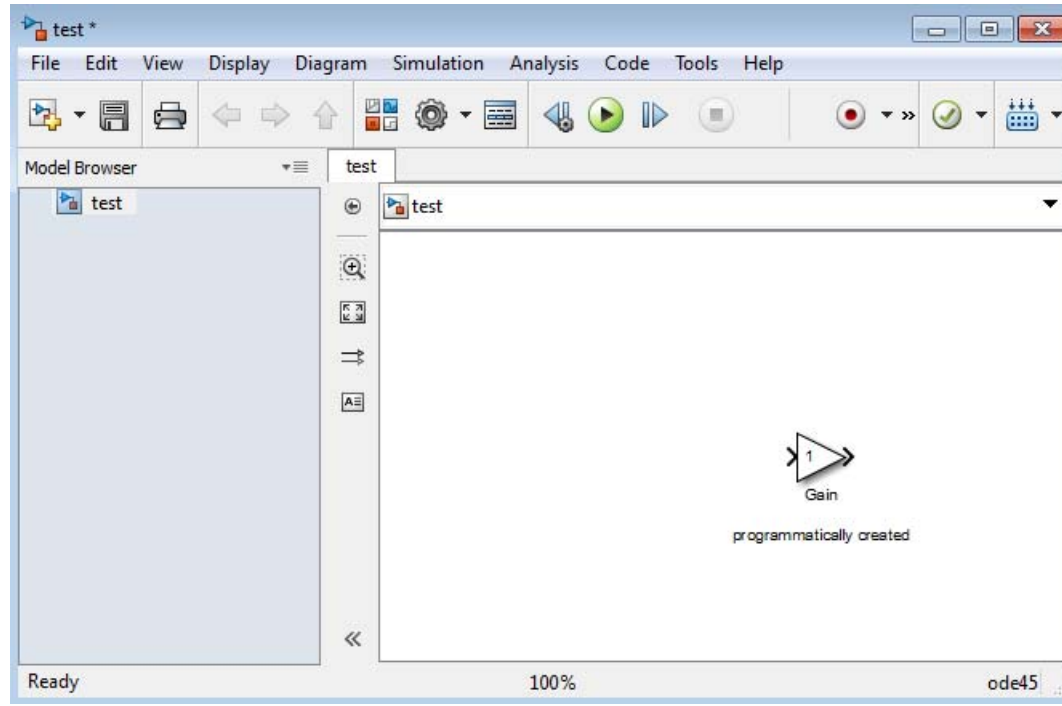
```
add_block('built-in/Note','path/text','Position', ...
[center_x, 0, 0, center_y]);
```

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:

```
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])
```

The code creates the following model, which includes an annotation.



To delete an annotation, use the `find_system` command to get the annotation handle. Then use the `delete` function to delete the annotation. For example:

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

Create a Subsystem

In this section...

Subsystem Advantages

A subsystem is a set of blocks that you replace with 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:

- Helps reduce the number of blocks displayed in your model window.
- Keeps functionally related blocks together.
- Establishes a hierarchical block diagram, where a Subsystem block is on one layer and the blocks that make up the subsystem are on another.

For additional information about how subsystems compare to other Simulink componentization techniques, see "Componentization Guidelines" on page 12-17.

Two Ways to Create a Subsystem

You can create a subsystem in two ways:

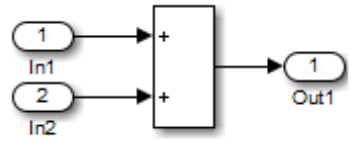
- Add a Subsystem block to your model, then open that block and add the blocks that it contains to the subsystem window.
- Add the blocks that make up the subsystem, then group those blocks into a subsystem.

Create a Subsystem by Adding the Subsystem Block

To create a subsystem before adding the blocks that 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.
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, this subsystem includes a Sum block and Inport and Outport blocks to represent input to and output from the subsystem.

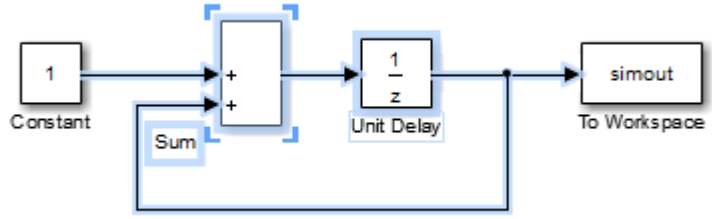


Create a Subsystem by Grouping Existing Blocks

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

1. Select individual blocks that you want to include in a subsystem. To select multiple blocks that are in one area of the model, click the left mouse button and drag the cursor to create a bounding box that encloses the blocks and the connecting lines that you want to include in the subsystem. For more information, see “Select Multiple Objects Using a Bounding Box” on page 4-6.

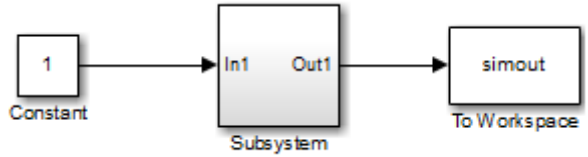
For example, this figure shows a model that represents a counter. The bounding box selects the Sum and Unit Delay blocks.



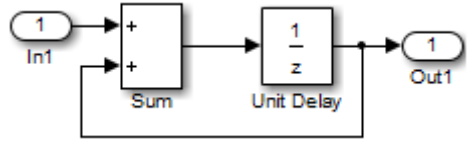
When you release the mouse button, the two blocks and all the connecting lines are selected.

2 Select **Diagram > Subsystems & Model Reference > Create Subsystem from Selection**. A Subsystem block replaces the selected blocks.

3 Resize the Subsystem block so the port labels are readable.



If you open the Subsystem block, the underlying system opens. For example:



Notice that Simulink 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. To customize the appearance and dialog box of the block, you can mask the subsystem (see "Masking").

Undoing Subsystem Creation

Right after you create subsystem by grouping blocks (see "Create a Subsystem by Grouping Existing Blocks" on page 4-37), you can undo that operation. To undo subsystem creation, select **Edit > Undo Subsystem Creation**.

Subsystem Execution

You can configure a subsystem to execute either conditionally or unconditionally.

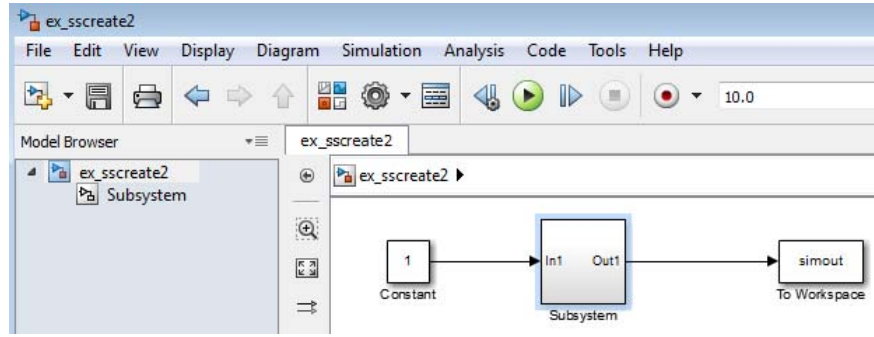
- An unconditionally executed subsystem always executes.
- A conditionally executed subsystem may or may not execute, depending on the value of an input signal. For details, see "Conditional Subsystems".

Navigate Model Hierarchy

Subsystems allow you to create a hierarchical model comprising many layers. You can navigate this hierarchy using the "Model Browser" on page 9-80 or with Simulink Editor model navigation commands.

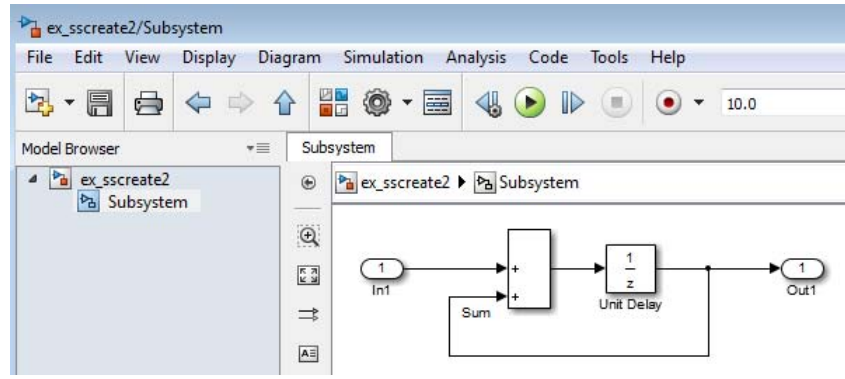
To open a subsystem using the Simulink Editor context menu for the Subsystem block:

1. In the Simulink Editor, right-click the Subsystem block.

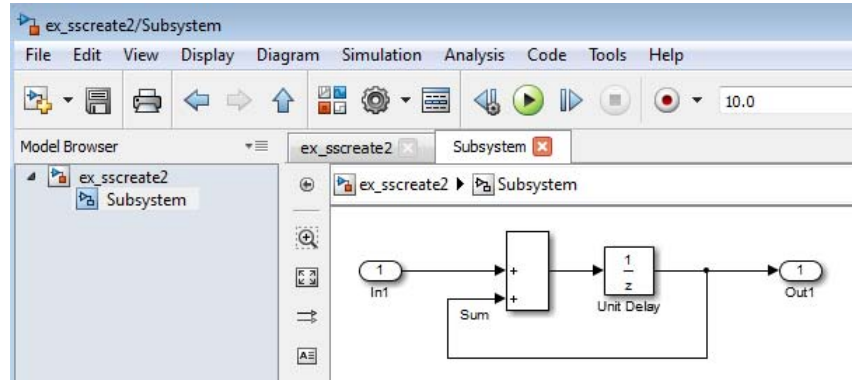


2 From the context menu, select one of these options:

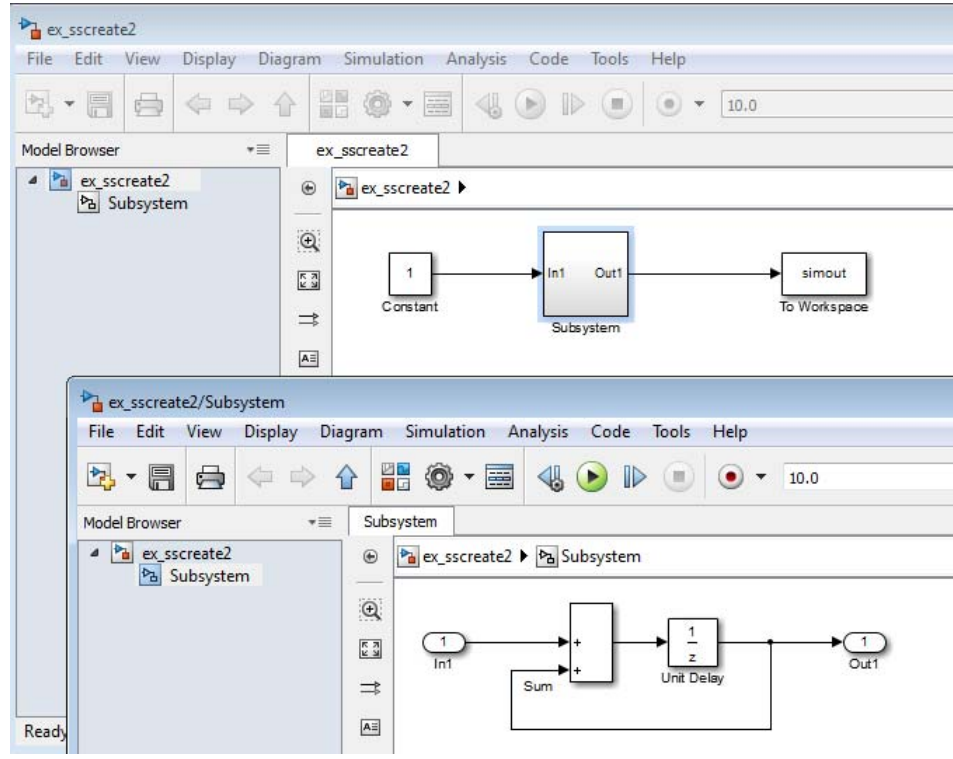
- **Open** — Open the subsystem, in the same window and tab as used for the top model.



- **Open In New Tab** — Open the subsystem, creating an additional tab for the subsystem.



- **Open In New Window**— Open the subsystem, opening a new Simulink Editor window.



For any operation to open a subsystem, you can use a keyboard shortcut to have the subsystem open in a new tab or window:

Where to Open the Subsystem	Keyboard Shortcut
In a new tab	Hold the **CTRL** key while opening the subsystem.
In a new window	Hold the **SHIFT** key while opening the subsystem.

To display the parent of a subsystem:

1 Open the tab that contains the subsystem.

2 Select **View > Navigate > Up to Parent**.

Label Subsystem Ports

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

You can specify how Simulink labels the ports of a subsystem.

1. Select the Subsystem block.
2. Select one of the labeling options from **Diagram > Format > Port Labels** menu (for example, `From Port Block Name`).

Control 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.

Note This method does not necessarily prevent a user from changing the access restrictions. To hide proprietary information that is in a subsystem, consider using protected model referencing models (see "Protected Model" on page 6-67).

To restrict access to a library subsystem, open the subsystem parameter dialog box and set **Read/Write permissions** to one of these values:

- `ReadOnly`: A user can view the contents of the library subsystem but cannot modify the reference subsystem without disabling its library link or changing its **Read/Write permissions** to `ReadWrite`.
- `NoReadOrWrite`: A user cannot view the contents of the library subsystem, modify the reference subsystem, or change reference subsystem permissions.

Both options allow a user to employ the library subsystem in models by creating links (see "Libraries"). For more information about subsystem access options, see the Subsystem block documentation.

Note You do 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, Simulink does not open the subsystem and does not display any messages.

Interconvert Subsystems and Block Diagrams

To interconvert subsystems and block diagrams, use one of these functions:

`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.

Empty Subsystems and Block Diagrams

To empty subsystems and block diagrams, use one of these functions:

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

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

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`

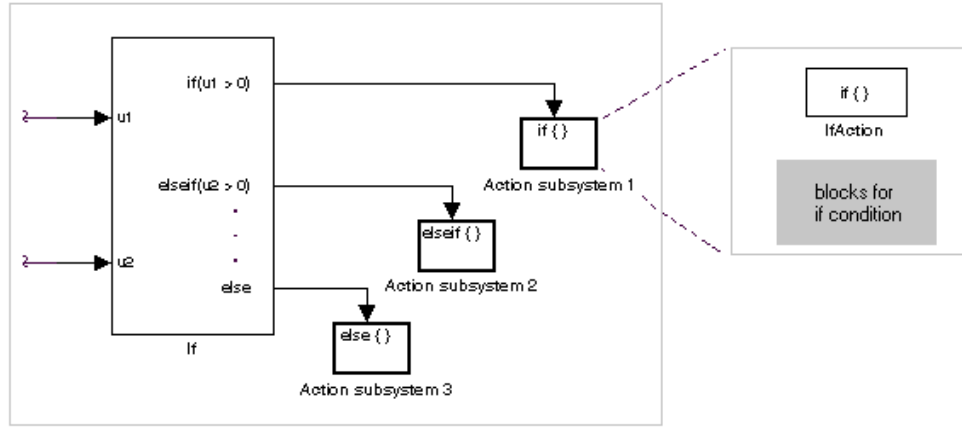
Conditional Control Flow Logic

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

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

If-Else Control Flow

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



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

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

In the If block parameters dialog box, set inputs to the If block. Internally, the inputs are designated as `u1, u2,..., un` and are used to construct output conditions.

2 In the If block parameters dialog box, set output port if-else conditions for the If block.

In the If block parameters dialog box, set Output ports. 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.

3 Connect each condition output port to an Action subsystem.

Connect each if, elseif, and else condition output port on the If block to a subsystem to be executed if the port's case is true.

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.

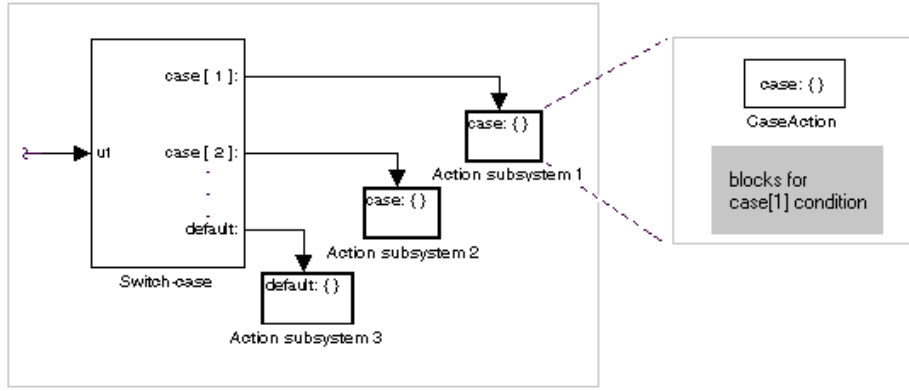
Once connected, the subsystem takes on the identity of the condition it is connected to and behaves like an enabled subsystem.

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.

Switch Control Flow

The following diagram represents `switch` control flow.



Construct a `switch` control flow statement as follows:

1. 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.

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

   Using the parameters dialog box of the Switch Case block, add cases to 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.

3 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 documentation for the Switch Case and Action Port blocks.

Note After the subsystem for a particular case executes, an implied break executes, which exits the `switch` control flow statement altogether. Simulink `switch` control flow statement implementations do not exhibit the "fall through" behavior of C `switch` statements.

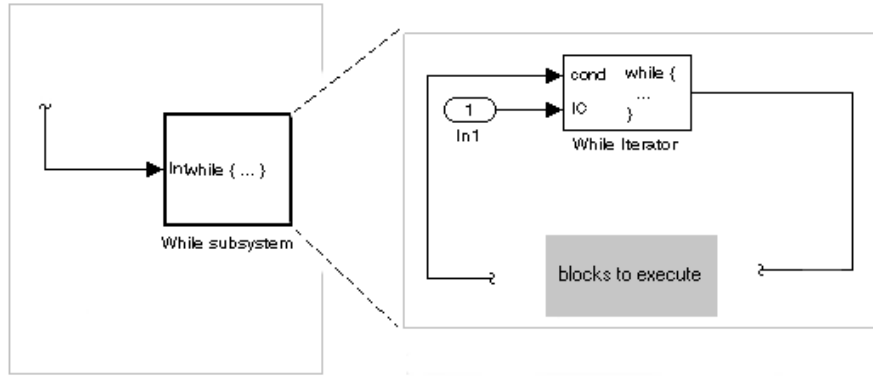
While and For Loops

Use the following blocks to perform `while` and `for` loops.

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

While Loops

The following diagram illustrates a `while` loop.



In this example, Simulink 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, Simulink 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 (that is, a block whose output depends on its previous input), reflects the value of its input at the previous iteration of the `while` loop. The output does *not* reflect that block's 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:

1. Place a While Iterator block in a subsystem.

   The host subsystem 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 that you want to iterate with the While Iterator block.

2. 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.

3. 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.

4. (Optional) 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.

5. (Optional) 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.

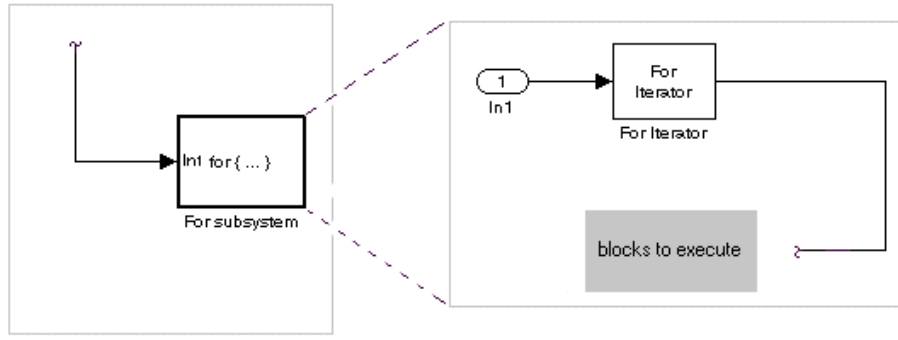
6. Create a block diagram in the subsystem that defines the subsystem's outputs.

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

For more information, see the While Iterator block.

Modeling For Loops

The following diagram represents a `for` loop:



In this example, Simulink executes the contents of the For subsystem multiples times at each time step. The input to the For Iterator block specifies the number of iterations . For each iteration of the `for` loop, Simulink invokes the update and output methods of all the blocks in the For subsystem in the same order that it invokes the methods if they are 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 (that is, a block whose output depends on its previous input) reflects the value of its input at the previous iteration of the `for` loop. The output does *not* reflect that block's 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:

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

2. (Optional) 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.

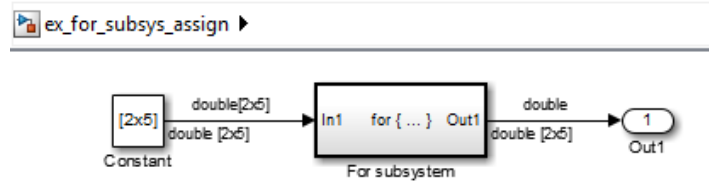
3. (Optional) Set the For Iterator block to output its iterator value for use in the block programming of the For Iterator Subsystem.

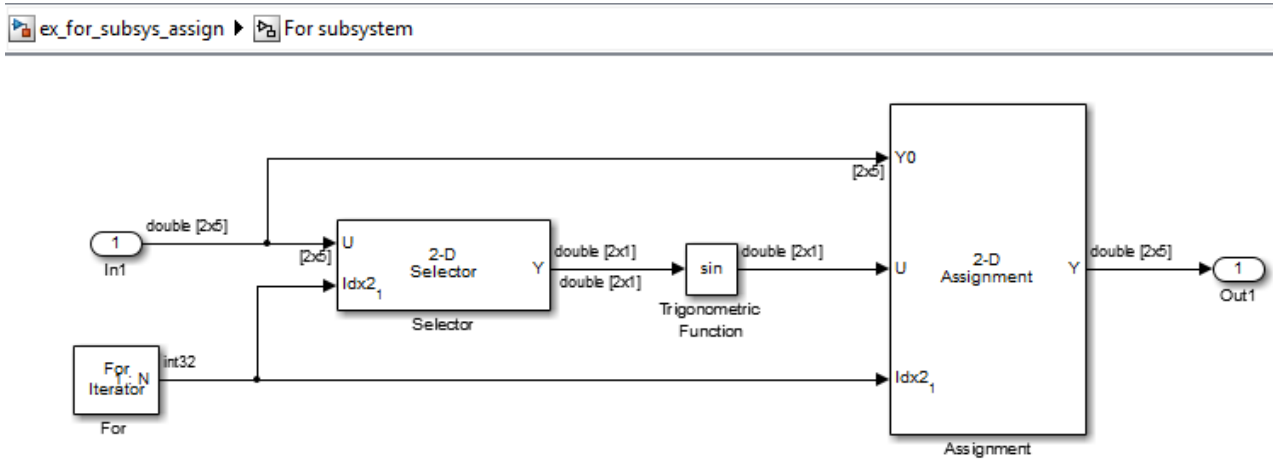
   The iterator value is 1 for the first iteration and is incremented by 1 for each succeeding iteration.

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

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

The For Iterator block works well with the Assignment block to reassign values in a vector or matrix. The following example shows the use of a For Iterator block. 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, (that is, all rows).

Note 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.

Callback Functions

In this section...

What You Can Do with Callback Functions

Callback functions are a powerful way to customize 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 that 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 "Callback Function Tasks" on page 4-64.

For related tasks, see

- "Model Workspaces" on page 4-67 for loading and modifying variables required by your model
- "Analyze Model Dependencies" on page 13-104 for analyzing model and block callbacks, and identifying and packaging files required by your model

Callback Tracing

Use callback tracing to determine the callbacks that Simulink invokes and in what order the it invokes them when you open or simulate a model.

To enable callback tracing, do one of the following:

- In the Preferences dialog box, select the **Callback tracing**.
- Execute `set_param(0, 'CallbackTracing', 'on')`.

  This option causes the callbacks to appear in the MATLAB Command Window as they are invoked. This option applies to all Simulink models, not just models that are open when you the preference is enabled.

Create Model Callback Functions

You can create model callback functions interactively or programmatically.

To create model callbacks interactively, use the **Callbacks** pane of the model's Model Properties dialog box (see "Specifying Callbacks" on page 4-111).

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 4-56).

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 model, `sldemo_clutch`, for routines associated with many model callbacks. This model defines the following callbacks:

- PreLoadFcn
- PostLoadFcn
- StartFcn
- StopFcn
- CloseFcn

Model Callback Functions

Model Callback Function	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	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. **Note** If you make structural changes with PostLoadFcn, the function does not set the model Dirty flag to indicate unsaved changes. You can close the model without being prompted to save.

Model Callback Function	When Executed
`PostSaveFcn`	After the model is saved. **Note** If you make structural changes with `PostSaveFcn`, the function does not set the model `Dirty` flag to indicate unsaved changes. You can close the model without being prompted to save.
`PreLoadFcn`	Before the model is loaded. Defining a callback routine for this parameter might be useful for loading variables used by the model. **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 "Model Reference".) For example, suppose:

- Model A references model B.
- Model A's `OpenFcn` creates variables in the MATLAB workspace.
- Model B's `CloseFcn` clears the MATLAB workspace.
- 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`.

Create Block Callback Functions

You can create block callback functions interactively or programmatically.

To create block callbacks interactively:

1. Right-click a block.
2. In the context menu, select **Properties**.
3. In the Block Properties dialog box, select the **Callback** tab.
4. Create the callback function. For details, see "Block Callbacks" on page 23-19.

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. For details, see "Block Callback Parameters" on page 4-59.

Note A callback for a masked subsystem cannot directly reference the parameters of the masked subsystem (see "Masking"). Simulink 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. For example:

```
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 execute. Routines that execute 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.
`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.

Parameter	When Executed
`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 (for example, 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.
`ErrorFcn`	When an error has occurred in a subsystem. Only Subsystem blocks have an `ErrorFcn` callback. For more information, see "Subsystem Error Function Callback" on page 4-62.
`InitFcn`	Before the block diagram is compiled and before block parameters are evaluated.
`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.

Parameter	When Executed
`MoveFcn`	When the block is moved or resized.
`NameChangeFcn`	After a block's name or path changes. When a Subsystem block's path changes, the Subsystem block recursively calls this function for all blocks that it contains after calling its own `NameChangeFcn` routine.
`OpenFcn`	When the block is opened. Generally, use this parameter 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 or in the Simulink Editor, select **Diagram > Subsystem & Model ReferenceCreate Subsystem from Selection** . 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 (for example, 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. For more information, see "S-Function Callback Methods".
`StopFcn`	At any termination of the simulation. In the case of an S-Function block, `StopFcn` executes after the block's `mdlTerminate` function executes. For more information, see "S-Function Callback Methods".
`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.

Subsystem Error Function Callback

The callback error function should have the following form:

```
newException = errorHandler(subsys, errorType, originalException)
```

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
- `originalException` is an MSLException (see "Error Handling in Simulink Using MSLException" on page 15-15)
- `newException` is an MSLException specifying the error message to be displayed to the user

If you provide the original exception, then you do not need to specify the subsystem and the error type.

The following command sets the `ErrorFcn` of the subsystem `subsys` to call the `errorHandler` callback function

```
set_param(subsys,'ErrorFcn','errorHandler')
```

In such calls to `set_param`, do not include the input arguments of the callback function. Simulink displays the error message `errorMsg` returned by the callback function.

Subsystem Error Function Callback: Compatibility Considerations

In terms of backward compatibility, the following command works but is not recommended:

```
errorMsg = errorHandler(subsys, errorType)
```

where `errorMsg` is a string containing the error message.

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)
```

Callback Function Tasks

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

Load 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.

Parameters in different parts of the Simulink model might require some variables. For example, if you have a model that contains a Gain block and the gain is specified as `K`, Simulink looks for the variable `K` to be defined. 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, in the Simulink Editor, select **File > Model Properties > Model Properties** and use the **Callbacks** tab to edit callbacks (see "Specifying Callbacks" on page 4-111).

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

```
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.slx` 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.

Execute a MATLAB Script by Double-Clicking a Block

You can use the `OpenFcn` callback to automatically execute MATLAB scripts when the you double-click a block. MATLAB scripts can perform many different tasks, such as defining variables for a block, making a call to MATLAB that 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** tab to edit callbacks (see "Block Callbacks" on page 23-19).

To create the `OpenFcn` callback programmatically, click the block to which you want to add this property, 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 set up the callback to execute a MATLAB script called `myfunction.m` when double clicking a subsystem called `mysubsystem`.

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

Execute Commands Before Starting Simulation

You can use the `StartFcn` callback to automatically execute commands before the 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. Create a simple MATLAB script named `openscopes.m` and save it on your MATLAB search path, as shown in the following code.

```
% 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 create 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 automatically open in the forefront.

Model Workspaces

In this section...

Model Workspace Differences from MATLAB Workspace

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 a Model file, a MAT-file, a MATLAB file, or MATLAB code stored in the model file. For more information, see "Data source" on page 4-72.

- 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 (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 6-53.

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.

Troubleshooting Memory Issues

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 the `Simulink.ModelWorkspace` 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

Change Model Workspace Data

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

Change 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 or MATLAB commands to change the model's workspace (see "Use MATLAB Commands to Change Workspace Data" on page 4-71).

For example, to create a variable in a model workspace:

1. Open the Model Explorer by selecting **View > Model Explorer**.
2. In the Model Explorer **Model Hierarchy** pane, select the model workspace.
3. Select **Add > MATLAB Variable**.

   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:

1. Open the Model Explorer by selecting **View > Model Explorer**.

2 In the Model Explorer **Model Hierarchy** pane, select the model workspace.

3 In the **Contents** pane, select the variable.

4 In the **Contents** pane or in **Dialog** pane, edit the value displayed.

To delete a model workspace variable:

1 Open the Model Explorer by selecting **View > Model Explorer**.

2 In the Model Explorer **Model Hierarchy** pane, select the model workspace.

3 In **Contents** pane, select the variable.

4 Select **Edit > Delete**.

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

You can use Model Explorer or MATLAB commands to modify workspace data whose source is a MAT-file or MATLAB file.

To make the changes permanent, in the Model Workspace dialog box, use the **Save To Source** button to save the changes to the MAT-file or MATLAB file.

1 Open the Model Explorer by selecting **View > Model Explorer**.

2 In the Model Explorer **Model Hierarchy** pane, right-click the workspace.

3 Select the **Properties** menu item.

4 In the Model Workspace dialog box, use the **Save To Source** button to save the changes to the MAT-file or MATLAB file.

To discard changes to the workspace, in the Model Workspace dialog box, use the **Reinitialize From Source** button.

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. Edit the MATLAB code and then in the Model Workspace

dialog box, use **Reinitialize From Source** button to clear the workspace and re-execute the code.

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 9-60 and "Importing Workspace Variables" on page 9-62.

Use 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

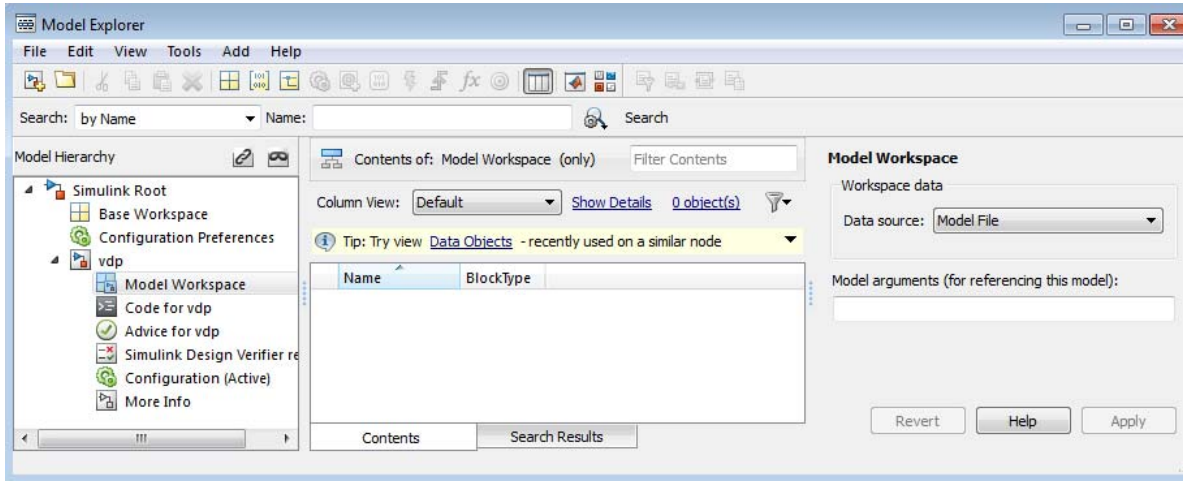
For example, the following MATLAB code creates variables specifying model parameters in the model workspace, saves the parameters, modifies one of them, and then reloads the workspace to restore it to its previous state.

```
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;
```

Specify Data Sources

To specify a data source for a model workspace, in the Model Explorer, use the Model Workspace dialog box. To display the dialog box for a model workspace:

1. Open the Model Explorer by selecting **View > Model Explorer**.
2. In the **Model Hierarchy** pane, right-click the model workspace.



3. Select the **Properties** menu item, which opens the Model Workspace dialog box.

To use MATLAB commands to change data in a model workspace, see "Use MATLAB Commands to Change Workspace Data" on page 4-71.

Data source

The **Data source** field in the Model Workspace dialog box includes the following data source options for a workspace:

- `Model 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 4-73).

- `MATLAB File`

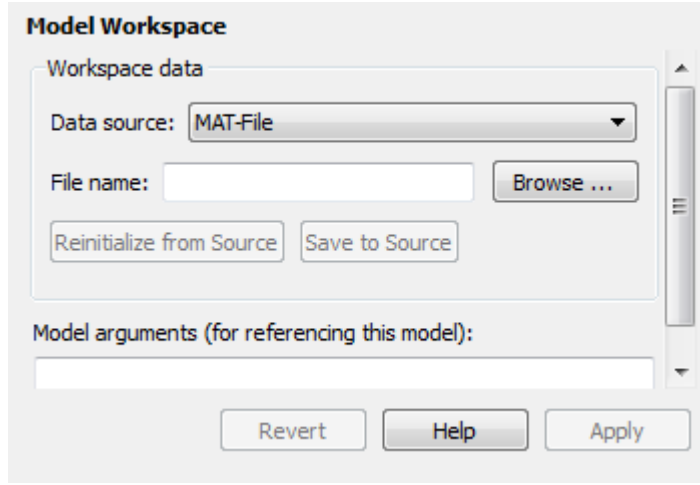
  Specifies that the data source is a MATLAB file. Selecting this option causes additional controls to appear (see "MAT-File and MATLAB File Source Controls" on page 4-73).

- `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 4-74).

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.



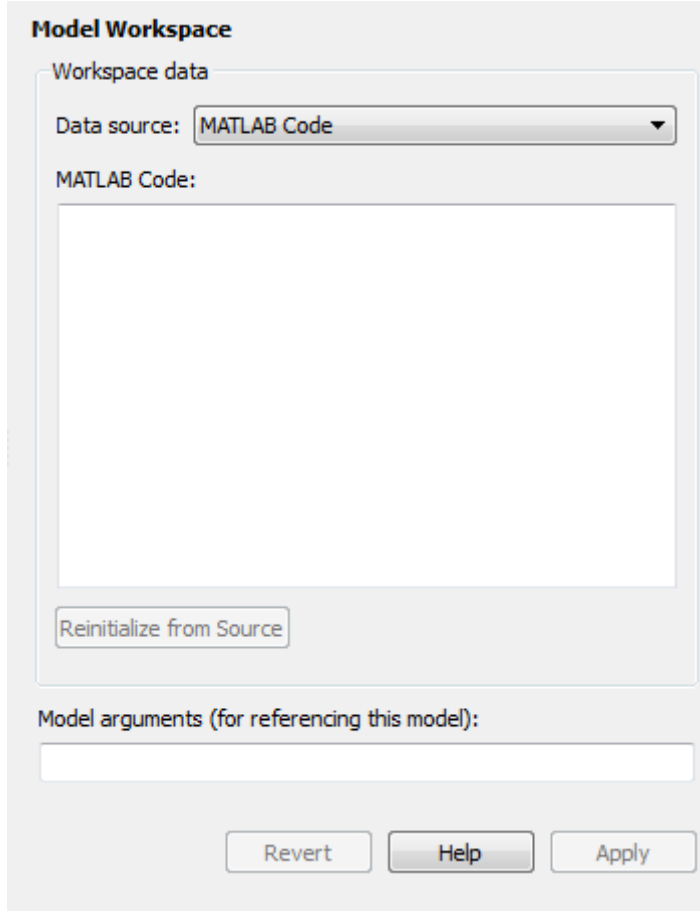
File name. Specifies the file name or path name of the MAT-file or MATLAB file that is the data source for the selected workspace. If you specify a file name, the name must reside on the MATLAB path.

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. Saves 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)

Specifies arguments that can be passed to instances of a model that another model references. For more information, see “Using Model Arguments” on page 6-53.

Symbol Resolution

In this section...

Symbols

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 you can define 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

Symbol Resolution Process

The process of finding an item that corresponds to a symbol is called *symbol resolution* or *resolving the symbol*. The matching item can provide the needed information directly, or it can itself be a symbol. A symbol must 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.

Simulink 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:

1. Any mask workspaces, in order from the block upwards (see "How Mask Parameters Work" on page 26-4)
2. The model workspace of the model that contains the block (see "Model Workspaces" on page 4-67)
3. The MATLAB base workspace (see "What Is the MATLAB Workspace?")

If Simulink 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, Simulink 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 resolves to the same item, irrespective of whether the model that contains the symbol is

a referenced model. For information about model referencing, see "Model Reference".

Numeric Values with Symbols

You can specify any block parameter that requires a numeric value 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.

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. You can use symbols for many purposes, including:

- Define data types
- Specify input data sources

- Specify logged data destinations

For 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.

Limit 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 4-80 for more information.

If the search does not find a match in the workspace, and terminates because the value is `ExplicitOnly` or `None`, Simulink 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 Controls" 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. For more information, see "Diagnostics Pane: Data Validity" > "Signal resolution".

Resolution that occurs because an option such as **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*.

Tip Implicit symbol resolution can be useful for fast prototyping. However, when you are done prototypying, consider using explicit symbol resolution, because implicit resolution slows performance, complicates model validation, and can have nondeterministic effects.

Consult 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 Simulink Coder 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 "Advice About Optimizing Models for Code Generation" in the Simulink Coder 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 “Simulink Checks”.

Software is inherently complex and may not be completely free of errors. Model Advisor checks might contain bugs. MathWorks reports known bugs brought to its attention on its Bug Report system at http://www.mathworks.com/support/bugreports/. The bug reports are an integral part of the documentation for each release. Examine periodically all bug reports for a release as such reports may identify inconsistencies between the actual behavior of a release you are using and the behavior described in this documentation.

While applying Model Advisor checks to your model will increase the likelihood that your model does not violate certain modeling standards or guidelines, their application cannot guarantee that the system being developed will be safe or error-free. It is ultimately your responsibility to verify, using multiple methods, that the system being developed provides its intended functionality and does not include any unintended functionality.

Start the Model Advisor

There are two Model Advisor GUIs to run checks that verify the syntax of your model: the Model Advisor window and the Model Advisor dashboard.

If you want to ...	Use the ...	Set Options ...
Consistently run the same set of checks on your model.	Model Advisor dashboard. The Model Advisor dashboard does not reload checks for an analysis, saving analysis time.	**1** From the Model Editor, select **Analysis > Model Advisor > Options**. **2** In the Model Advisor Options window, for the **Default GUI**, select `Model Advisor Dashboard`.
Select checks to run on your model.	Model Advisor window.	**1** From the Model Editor, select **Analysis > Model Advisor > Options**.

If you want to ...	Use the ...	Set Options ...
		2 In the Model Advisor Options window, for the **Default GUI**, select `Model Advisor`.

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

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

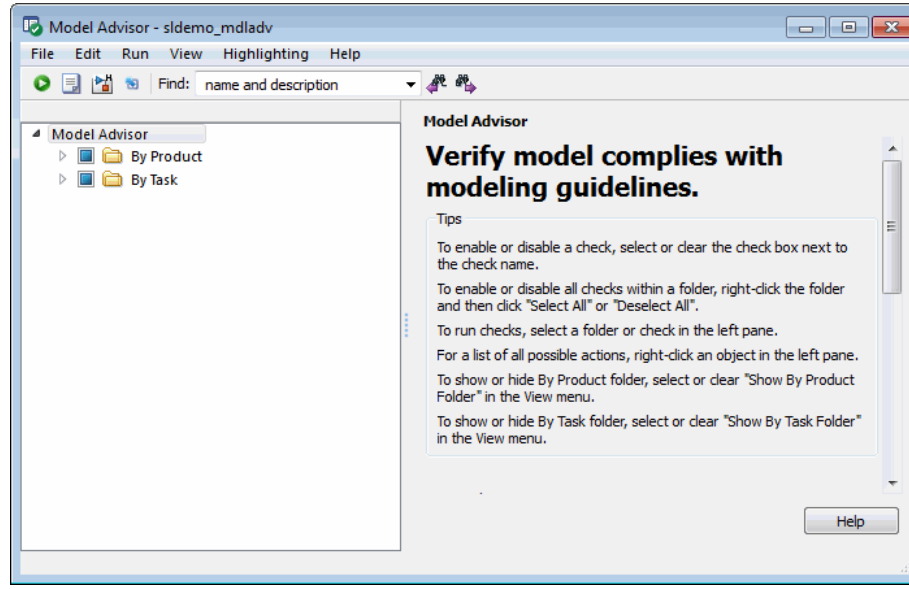
To start the Model Advisor, use any of the following methods:

To open the Model Advisor window or Model Advisor dashboard ...	For a...	Do this action:
From the Model Editor	Model or subsystem	**1** Select **Analysis > Model Advisor > Model Advisor** or **Model Advisor Dashboard**. Alternately, on the Model Editor toolbar  drop-down list, select `Model Advisor` or `Model Advisor Dashboard`.

To open the Model Advisor window or Model Advisor dashboard ...	For a...	Do this action:
		Note Clicking  opens the Model Advisor GUI set in the **Analysis > Model Advisor > Options** interface. **2** In the System Selector window, select the model or subsystem that you want. **3** Click **OK**.
From the Model Explorer	Model	In the **Contents** pane, select **Advice for *`model`***. ***`model`*** is the name of the model that you want to check. (For more information, see "Model Explorer Overview" on page 9-2.)
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`*`)`. *`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. It also provides a legend describing the displayed symbols.



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 for the checks, and then run one 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).

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

To customize the Model Advisor checks shown in the left pane, on the toolbar, you can select:

- **View > Show By Product Folder**
- **View > Show By Task Folder**

To run the selected checks, on the toolbar of the Model Advisor window, click **Run selected checks** ().

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. You can view this report in a separate browser window by clicking either **Open Report** () or the **Report** link at the folder level.

To view the analysis results for individual checks, you can specify that the Model Advisor use color highlighting on the model diagram. To enable Model Advisor highlighting, do one of the following in the Model Advisor window, on the toolbar:

- Select **Highlighting > Model Advisor Highlighting**.
- Click the **Enable Model Advisor highlighting** toggle button ().

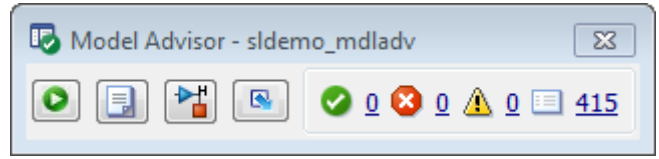
When you use highlighting on the model diagram, you can specify that the Model Advisor highlight model blocks that are excluded from individual Model Advisor checks. On the toolbar of the Model Advisor window, select **Highlighting > Highlight exclusions**. If you have a Simulink Verification and Validation license, you can create or modify exclusions to the Model Advisor checks.

To switch to the Model Advisor dashboard, click the **Switch to Model Advisor Dashboard** toggle button ().

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

Overview of the Model Advisor Dashboard

Using the Model Advisor dashboard, you can efficiently check that your model complies with modeling guidelines. When you use the Model Advisor dashboard, the Model Advisor does not reload checks for an analysis, saving analysis time.



To run checks, on the Model Advisor dashboard toolbar, click **Run model advisor** ( ).

After running checks, the Model Advisor generates an HTML report of the check results. You can view this report in a separate browser window by clicking the **Open Report** ( ).

To view highlighted results, click the **Highlighting results** toggle button ( ).

To switch to the Model Advisor window, click the **Switch to Model Advisor** toggle button ( ).

Tip Use the Model Advisor window to select and view checks. To open the Model Advisor window, click the **Switch to Model Advisor** toggle button ( ).

Run Model Advisor Checks

To perform checks on your model and view the results:

1. Open your model. For example, open the Model Advisor example model: `sldemo_mdladv`.

2. Start the Model Advisor.

   a. From the Model Editor, select **Analysis > Model Advisor > Model Advisor**.

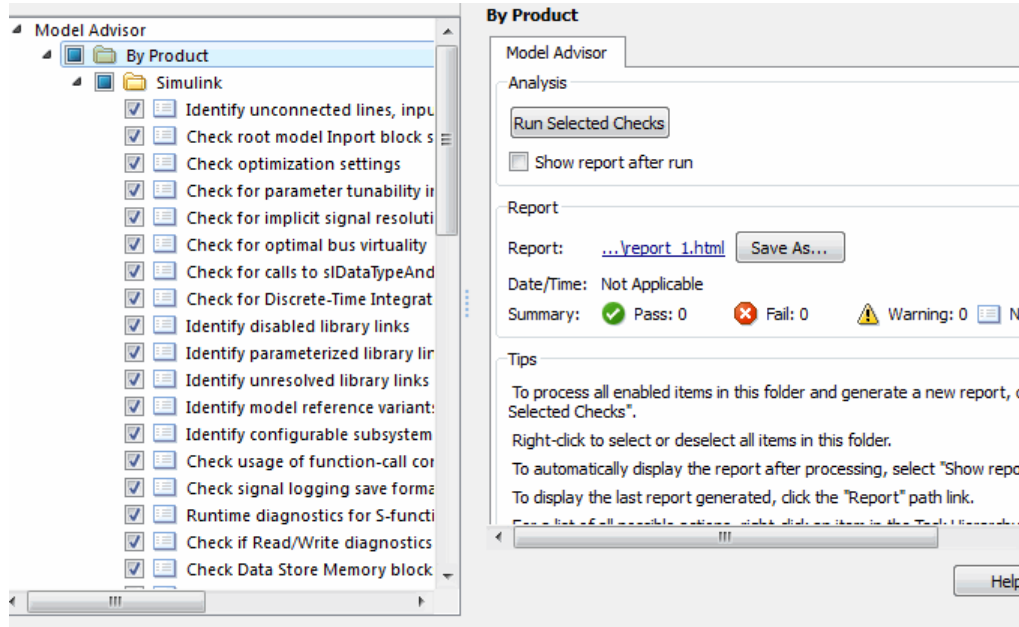
   Alternately, from the Model Editor toolbar  drop-down list, select `Model Advisor`.

   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` model.

3. In the left pane, expand the **By Product** folder to display the subfolders. Then expand the **Simulink** folder to display the available checks.

4. In the left pane, select the **By Product** folder. The right pane changes to a **By Product** view.



5 After you run the checks, select the **Show report after run** check box to see an HTML report of check results.

Tip Use the Model Advisor window for interactive fixing of warnings and failures. Model Advisor reports are best for viewing a summary of checks.

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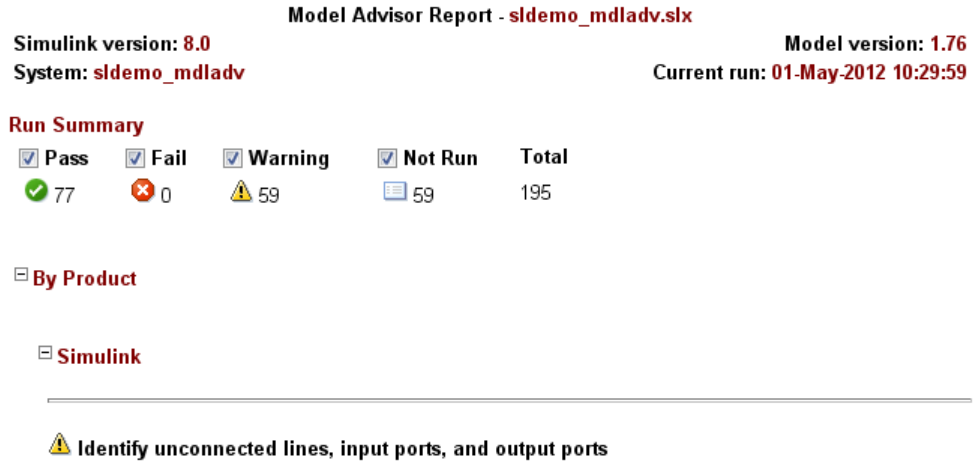
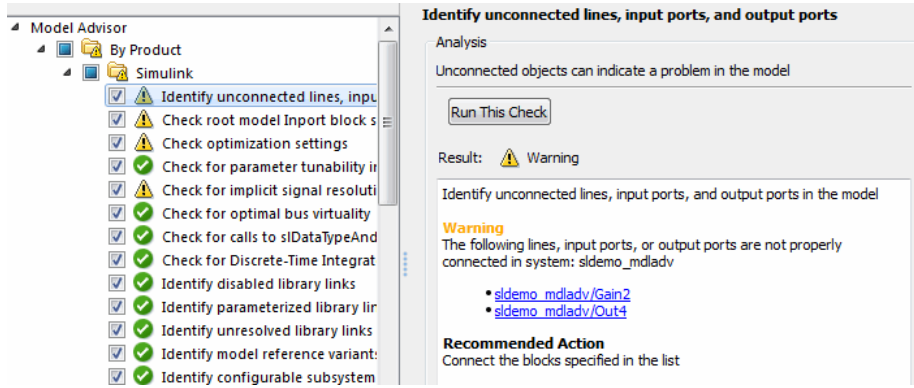
6 Run the selected checks by clicking the **Run Selected Checks** button. Alternately, select **Run selected checks** (). After the Model Advisor runs the checks, an HTML report displays the check results in a browser window.



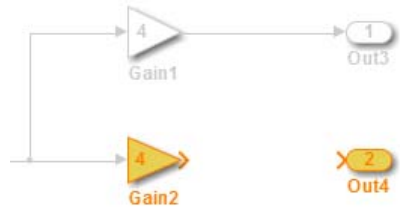
7 Return to the Model Advisor window, which shows the check results.

8 Select an individual check to open a detailed view of the results in the right pane. For example, selecting **Identify unconnected lines, input ports, and output ports** changes the right pane to the following view. Use this view to examine and exercise a check individually.

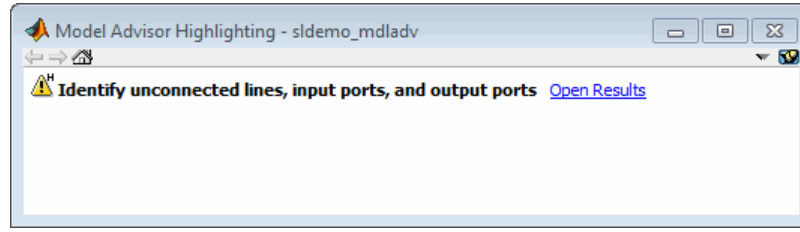


9 In the Model Advisor window, click the **Enable Model Advisor highlighting** toggle button ( ). Checks with highlighted results have an icon.

- The model window opens. The blocks causing the **Identify unconnected lines, input ports, and output ports** check warning are highlighted in yellow.



- The Model Advisor Highlighting information window opens with a link to the Model Advisor window. In the Model Advisor window, you can find more information about the check results and how to correct the warning condition.



10 After reviewing these check results in the Model Advisor window, you can choose to fix warnings or failures as described in "Fix a Warning or Failure" on page 4-95.

Run Checks Using Model Advisor Dashboard

To run checks on your model using the Model Advisor dashboard:

1 Open your model. For example, open the Model Advisor model, `sldemo_mdladv`.

2 Start the Model Advisor dashboard.

a From the Model Editor, select **Analysis > Model Advisor > Model Advisor Dashboard** .

Alternately, from the Model Editor toolbar drop-down list, select `Model Advisor Dashboard`.

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 dashboard opens.

3 Optionally, select or view checks to run on your model by clicking the **Switch to Model Advisor** toggle button ( ). The Model Advisor window opens.

a For example, in the Model Advisor window, open the **By Product** folder and select checks:

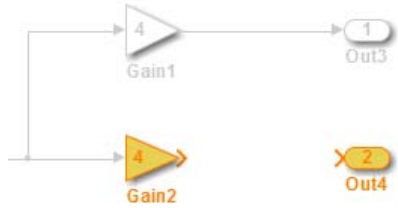
Identify unconnected lines, input ports, and output ports
Check root model Inport block specifications

b Switch back to the Model Advisor dashboard by clicking the **Switch to Model Advisor Dashboard** toggle button ( ).

4 On the Model Advisor dashboard, click **Run model advisor** ( ) to run the checks.

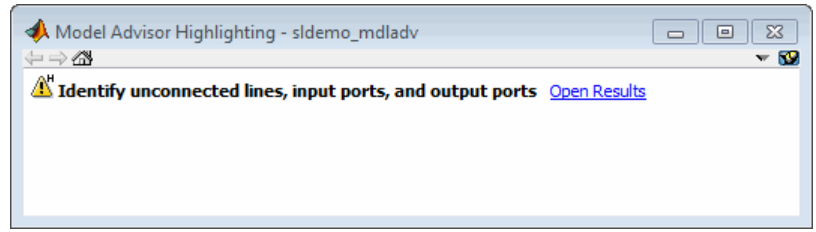
5 Click the **Highlighting results** toggle button ( ) to view highlighted results.

- The model window opens. The blocks causing the **Identify unconnected lines, input ports, and output ports** check warning are highlighted in yellow.



- The Model Advisor Highlighting information window opens with a link to the Model Advisor window. In the Model Advisor window, you can

find more information about the check results and how to correct the warning condition.



6 After reviewing the check results, you can choose to fix warnings or failures as described in "Fix a Warning or Failure" on page 4-95. For example, fix the **Identify unconnected lines, input ports, and output ports** check warning:

   a Connect model blocks `Gain2` and `Out4`.

   b On the Model Advisor dashboard, click **Run model advisor** ( ) to rerun the checks. The Model Advisor does not reload all the available checks, saving analysis time.

   The **Identify unconnected lines, input ports, and output ports** check passes.

Highlight Model Advisor Analysis Results

You can use color highlighting on the model diagram to indicate the analysis results for individual Model Advisor checks. Blocks that pass a check, fail a check, or cause a check warning are highlighted in color in the model window. Model Advisor highlighting is available for the following:

- Simulink blocks
- Stateflow charts

After you run a Model Advisor analysis, checks with highlighted results are indicated with an icon in the Model Advisor window.

To use Model Advisor highlighting:

1 Run Model Advisor checks on your model.

2 Enable Model Advisor highlighting by doing one of the following:

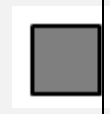
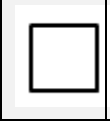
- On the toolbar of the Model Advisor window, select **Highlighting > Model Advisor Highlighting**.
- On the toolbar of the Model Advisor window, click the **Enable highlighting** button ().
- On the toolbar of the Model Advisor Dashboard, click the **Highlighting results** button ().

3 Optionally, to view model blocks that are excluded from the Model Advisor checks, select **Highlighting > Highlight exclusions** on the Model Advisor window toolbar. If you have a Simulink Verification and Validation license, you can create or modify exclusions to the Model Advisor checks .

4 In the left pane of the Model Advisor window, select a check with highlighted results. Checks with highlighted results are indicated with the  icon. Highlighting is not available for all checks.

Both the model window and a Model Advisor Highlighting information window open. The Model Advisor Highlighting information window provides a link to the Model Advisor window, where you can review the check results.

Highlight Colors in the model window		
Yellow with orange border		Blocks that cause the check failure or warning.
White with orange border		Subsystem with blocks that cause the check warning or failure.
White with gray border		Blocks or subsystems without highlighting.

Highlight Colors in the model window		
Gray with black border		Blocks that are excluded from the check.
White with black border		Subsystems that are excluded from the check.

5 After reviewing the check results in both the model window and the Model Advisor window, you can choose to fix warnings or failures as described in "Fix a Warning or Failure" on page 4-95.

6 To view highlighted results for another check, in the left pane of the Model Advisor window, select a check with an  icon.

Tip If a check warns or fails and the model window highlights all blocks in gray, closely examine the results in the Model Advisor window. A Model Advisor check might fail or warn due to your parameter or diagnostic settings.

Fix 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 check documentation. You can use Model Advisor highlighting to identify model objects that cause a check warning or failure.

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.

To fix warnings and failures:

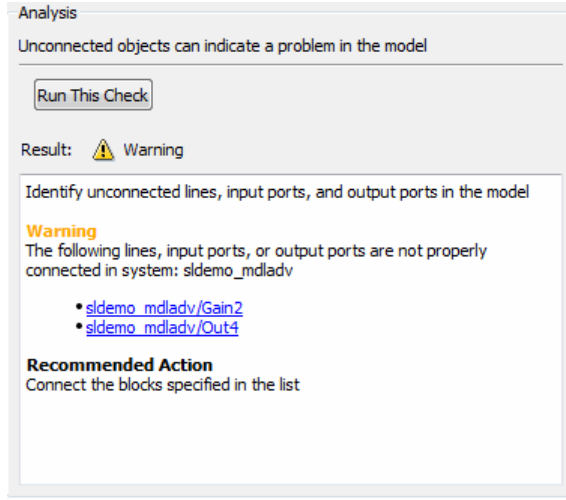
- Follow the instructions in the Analysis Result box to manually fix any warning or failure. See “Manually Fix Warnings or Failures” on page 4-96.
- Use the Action box, when available, to automatically fix all failures. See “Automatically Fix Warnings or Failures” on page 4-97.
- Use the Model Advisor Results Explorer, when available, to batch-fix failures. See “Batch-Fix Warnings or Failures” on page 4-98.

Manually Fix 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 “Revert Changes Using Restore Points” on page 4-99.
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 Fix 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 Before automatically fixing failures, review the Analysis Result box 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 "Revert Changes Using Restore Points" on page 4-99.
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-Fix 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 helps you to modify only the items that the Model Advisor is checking.

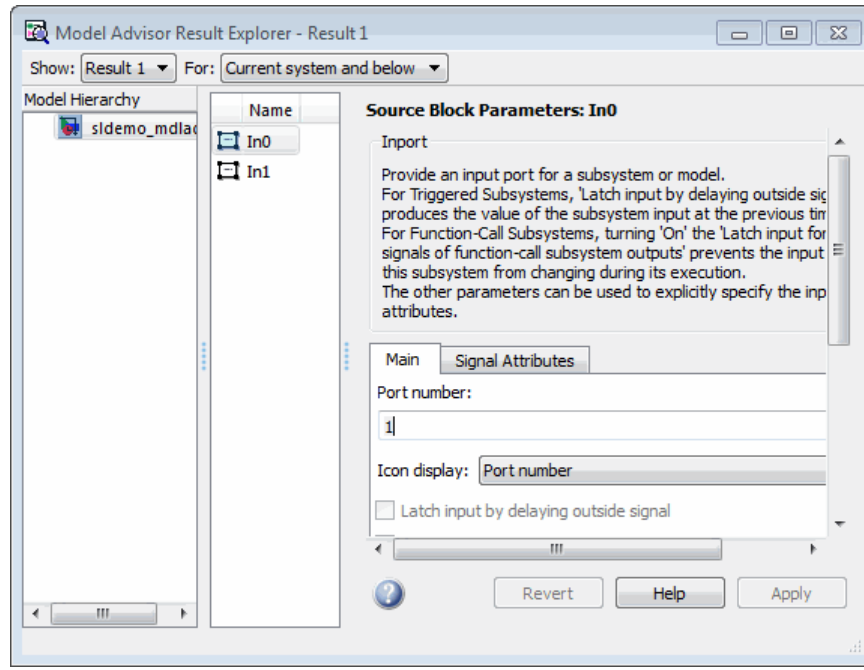
If a check does not pass and you want to explore the results and make batch changes:

1. Optionally, save a model and data restore point so you can undo any changes that you make. For more information, see "Revert Changes Using Restore Points" on page 4-99.
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.



Revert 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.

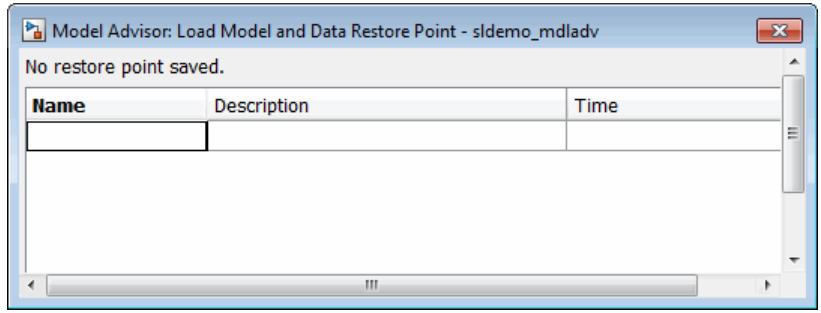
Save a Restore Point

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:

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*. *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.

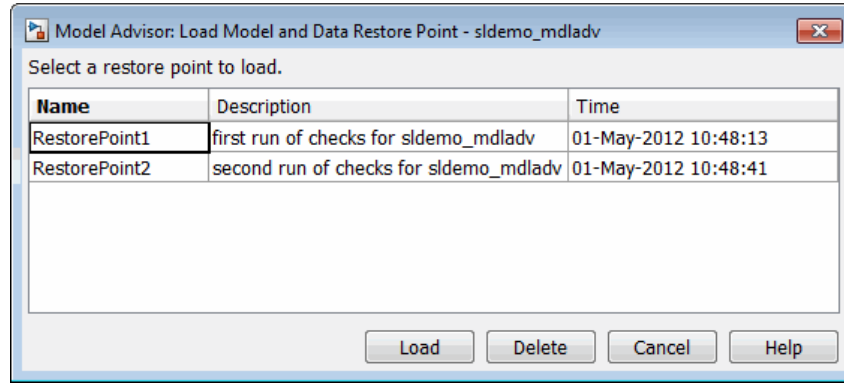
Load a Restore Point

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 that you selected.

The Model Advisor reverts the model, base workspace, and Model Advisor status.

View and Save Model Advisor Reports

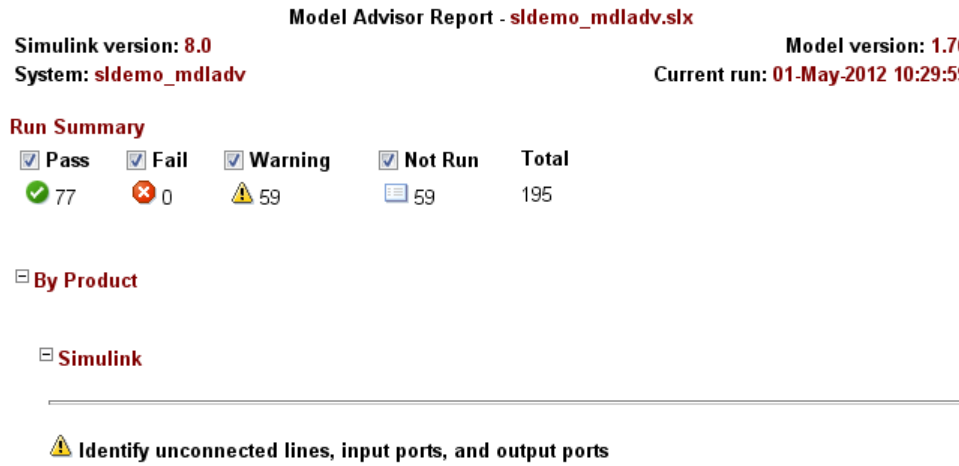
When the Model Advisor runs checks, it generates an HTML report of check results. Each folder in the Model Advisor contains a report for all of the checks in that folder and the subfolders within that folder.

View Model Advisor Reports

You can access any report by selecting a folder and clicking the link in the **Report** box.

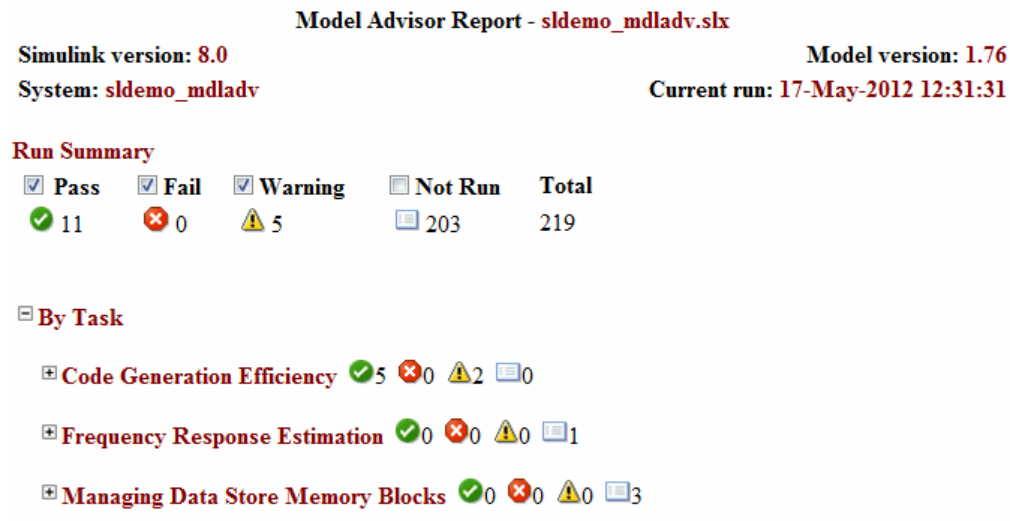
Tip While you can fix warnings and failures through Model Advisor reports, use the Model Advisor window for interactive fixing of warnings and failures. Model Advisor reports are best for viewing a summary of checks.

As you run checks, the Model Advisor updates the reports with the latest information for each check in the folder. When you run the checks at different times, a message appears in the report. 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.

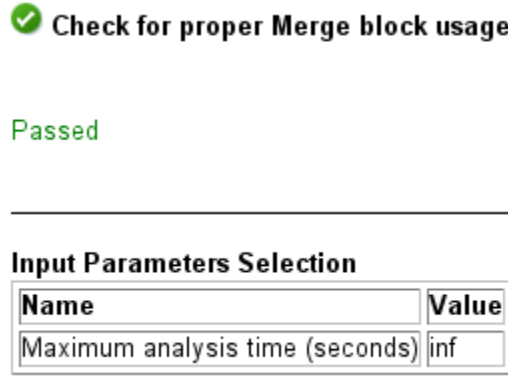


To show only what you are interested in viewing, you can manipulate the report.

- To view only the checks with the status that you are interested in, next to the Run Summary status, select the appropriate check boxes. 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 is updated to display a run summary for that folder:



Some checks have input parameters specified in the right pane of the Model Advisor. For example, **Check for proper Merge block usage** has an input parameter for **Maximum analysis time (seconds)**. When you run checks with input parameters, the Model Advisor displays the values of the input parameters in the HTML report.



For more information, see the `EmitInputParametersToReport` property of the `Simulink.ModelAdvisor` class.

Save Model Advisor Reports

You can archive a Model Advisor report by saving it to a new location.

1. In the Model Advisor window, navigate to the folder that contains the report that 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`.

Run the Model Advisor Programmatically

If you have a license for Simulink Verification and Validation, 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 that you open the model, start a simulation, or, if you have Simulink Coder, generate code from the model. For more information, see the `ModelAdvisor.run` function in the Simulink Verification and Validation documentation.

Check Support for Libraries

There are Model Advisor checks available to verify the syntax of library models. When you use the Model Advisor to check a library model, the Model Advisor window indicates (~) checks that do not check libraries. To determine if you can run the check on library models, you can also refer to the check

documentation, “Capabilities and Limitations”. You cannot use checks that require model compilation. If you have a license for Simulink Verification and Validation, you can use an API to create custom checks which support library models.

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.
- Checks do not search in model blocks or subsystem blocks with the block parameter **Read/Write** set to `NoReadorWrite`. However, on a check-by-check basis, Model Advisor checks do search in library blocks and masked subsystems.

For limitations that apply to specific checks, see the Limitations section within the documentation of each check.

Consult the Upgrade Advisor

Use the Upgrade Advisor to help you upgrade and improve models with the current release. The Upgrade Advisor can identify cases where you can benefit by changing your model to use new features and settings in Simulink. The Advisor provides advice for transitioning to new technologies, and upgrading a model hierarchy.

The Upgrade Advisor can also help identify cases when a model will not work because changes and improvements in Simulink require changes to a model.

The Upgrade Advisor offers options to perform recommended actions automatically or instructions for manual fixes.

You can open the Upgrade Advisor in the following ways:

1. From the Model Editor, select **Analysis > Model Advisor > Upgrade Advisor**
2. From the MATLAB command line, use the `upgradeadvisor` function:

   ```
   upgradeadvisor modelname
   ```

3. Alternatively, you can open the Upgrade Advisor from the Model Advisor.
   a. Under `By Task` checks, expand the folder `Upgrading to the Current Simulink Version` and select the check `Open the Upgrade Advisor`.
   b. In the right pane under `Recommended Action`, click the link Open the Upgrade Advisor . This action closes the Model Advisor and opens the Upgrade Advisor.

In the Upgrade Advisor, you create reports and run checks in the same way as when using the Model Advisor.

- Select the top Upgrade Advisor node in the left pane to run all selected checks and create a report.
- Select each individual check to open a detailed view of the results in the right pane. View the analysis results for recommended actions to manually fix warnings or failures. In some cases, the Upgrade Advisor provides mechanisms for automatically fixing warnings and failures.

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 Upgrade Advisor might report an invalid check result.

For more information on individual checks, see

- “Model Upgrades” for upgrade checks only
- “Simulink Checks” for all upgrade and advisor checks

.

Manage 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:

- Use Simulink Projects to manage your project files, connect to source control, review modified files and compare revisions. See "Simulink Projects".
- Model File Change Notification helps you manage work with source control operations and multiple users. See "Model File Change Notification" on page 4-108.
- As you edit a model, the Simulink software generates version information about the model, including a version number, who created and last updated the model, and an optional comments history log. The Simulink software automatically saves these version properties with the model.
  - Use the Model Properties dialog box to view and edit some of the version information stored in the model and specify history logging.
  - The Model Info block lets you display version information as an annotation block in a model diagram.
  - You can access Simulink version parameters from the MATLAB command line or a MATLAB script.
- See Simulink.MDLInfo to extract information from a model file without loading the block diagram into memory. You can use `MDLInfo` to query

model version and Simulink version, find the names of referenced models without loading the model into memory, and attach arbitrary metadata to your model file.

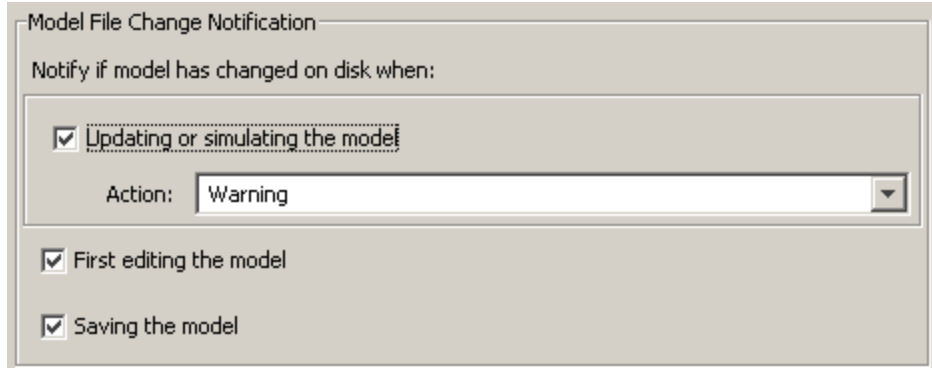
Model File Change Notification

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, use one of these approaches:

- In the Simulink Model Browser, select **File > Simulink Preferences**.
- From the MATLAB Toolstrip, in the **Home** tab, in the **Environment** section, select **Preferences**. Click the **Launch Simulink Preferences** button .



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.

For more options to help you work with source control and multiple users, see "Simulink Projects".

Specify 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, set the `USER` environment variable (if it is not already defined).

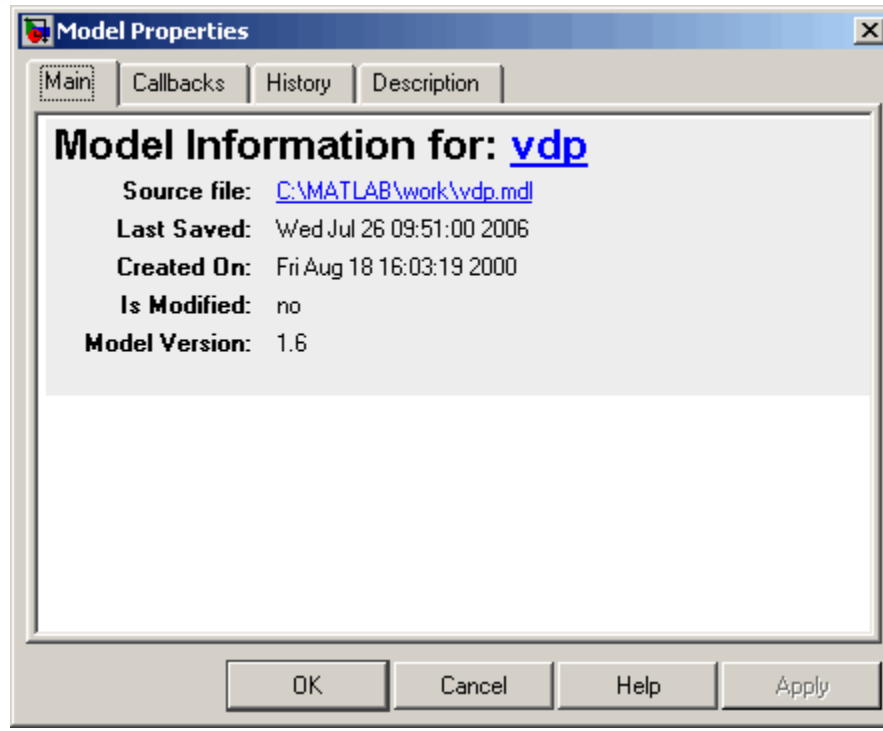
Manage Model Properties

You can use the Model Properties dialog box to view and edit model information (including some version parameters), callback functions, history, and the model description. To open the dialog box,

- In a model, select **File > Model Properties**.
- In a library, select **File > Library Properties**.

  Library Properties includes an additional tab, Forwarding Table, for specifying the mapping from old library blocks to new library blocks. For information on using the Fowarding Table, see "Make Backward-Compatible Changes to Libraries" on page 28-22.

Model Properties and Library Properties both include the tabs Main Model Information, Callbacks, History and Description. The controls in the shared tabs are described next on this page.



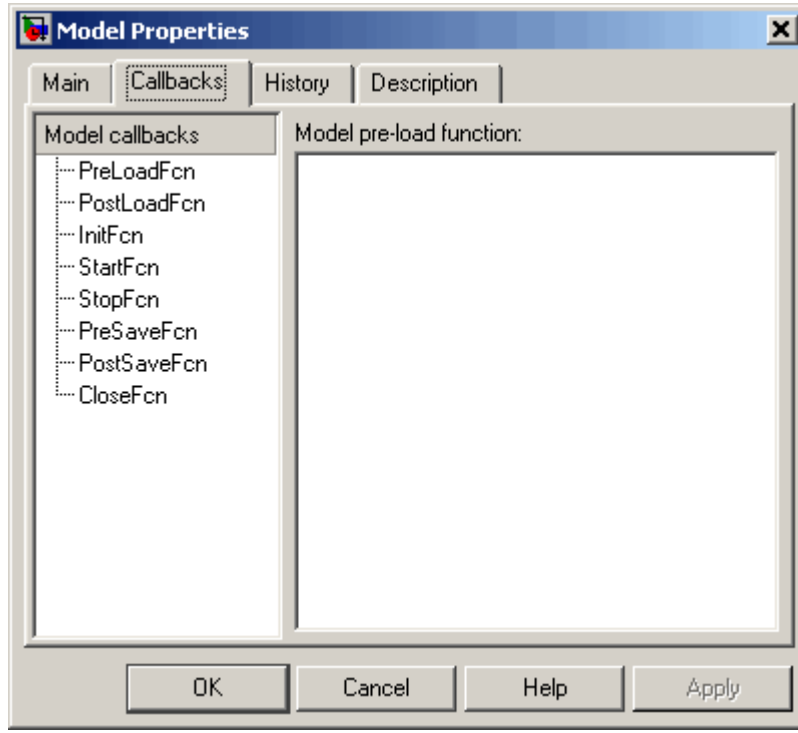
The dialog box includes the following panes.

Viewing Model Information

The **Main** pane summarizes information about the current version of this model, such as whether the model is modified, the Model Version, and Last Saved date. You can edit some of this information in the History tab, see "Viewing and Editing Model Information and History" on page 4-112.

Specifying Callbacks

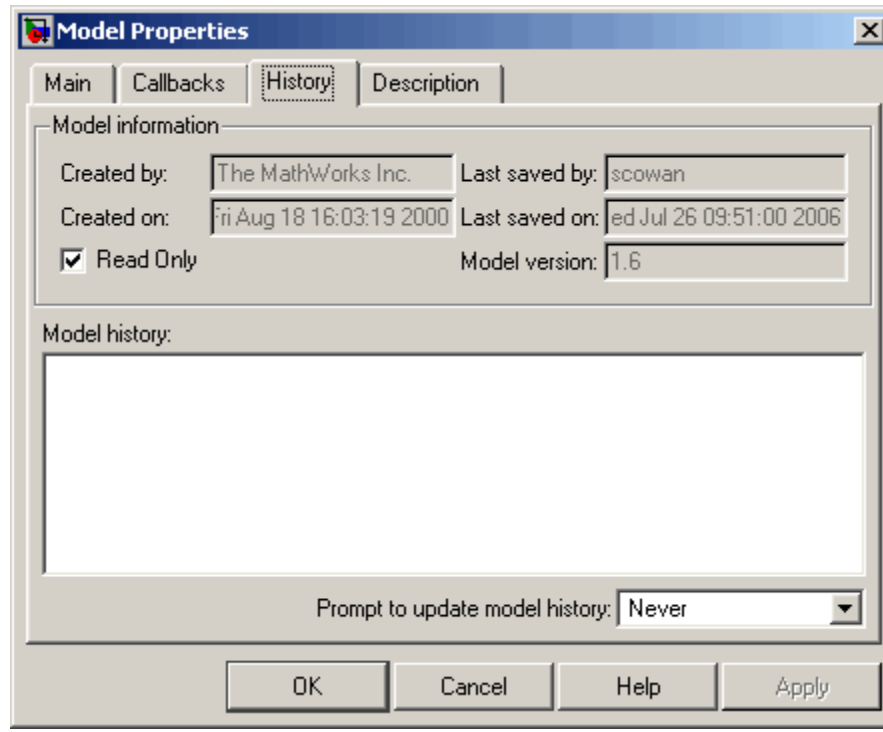
Use the **Callbacks** pane to specify functions to be invoked at specific points in the simulation of the model.



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 “Create Model Callback Functions” on page 4-55 for information on the callback functions listed on this pane.

Viewing and Editing Model Information and History

Use the **History** pane to view and edit model information, and to enable, view, and edit this model’s change history in the lower **Model history** field. To use the history controls see “Log Comments History” on page 4-117.



Viewing Model Information. When the **Read Only** check box is selected, you can view but not edit the following grayed out fields.

- **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.

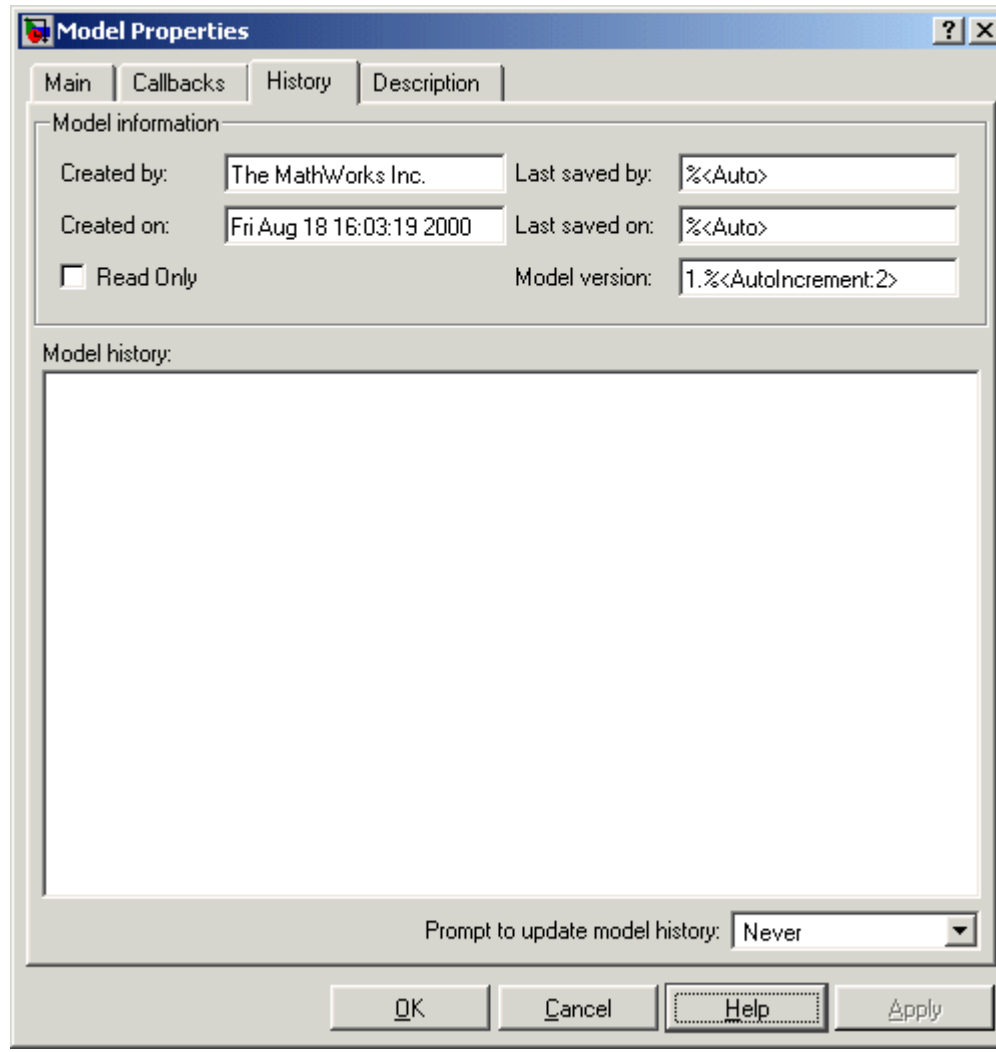
- **Last saved on**

  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.

Editing Model Information. Clear the **Read Only** check box to edit model information. When the check box 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>`. Simulink 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. Simulink 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
  ```

  Simulink increments # by 1 when saving the model. For example, when you save the model,

  ```
  1.%<AutoIncrement:2>
  ```

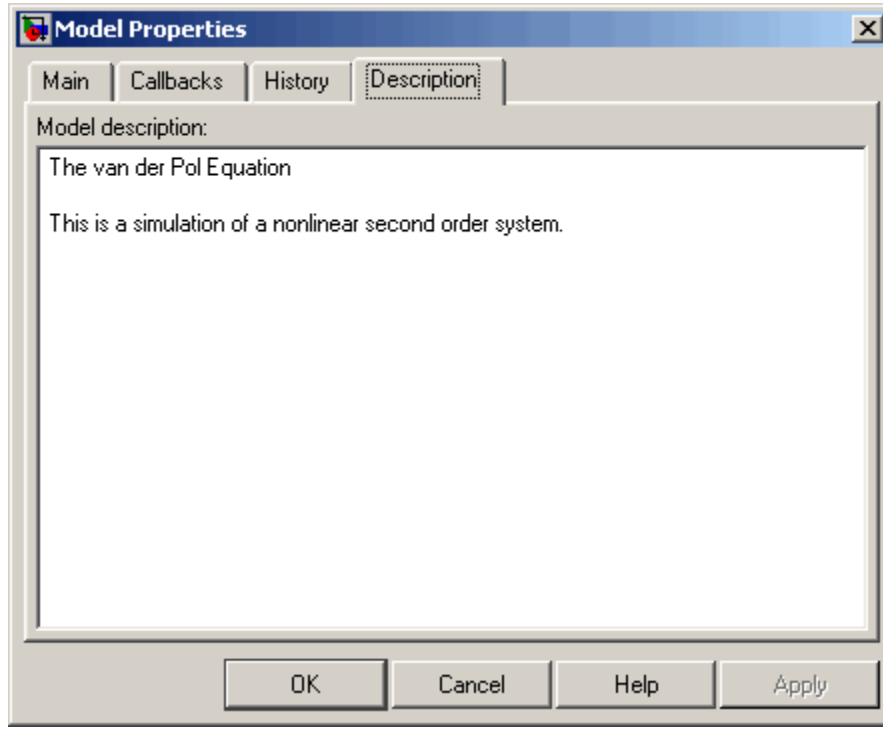
  becomes

  ```
  1.%<AutoIncrement:3>
  ```

  and the model version number is reported as `1.3`.

Viewing and Editing the Model Description

Use the Description pane to enter a description of the model. You can view the model description by typing `help` followed by the model name at the MATLAB prompt. The contents of the **Model description** field appear in the Command Window.



Log Comments 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. For more flexibility adding labels and comments to models and submissions, see instead “Simulink Projects”.

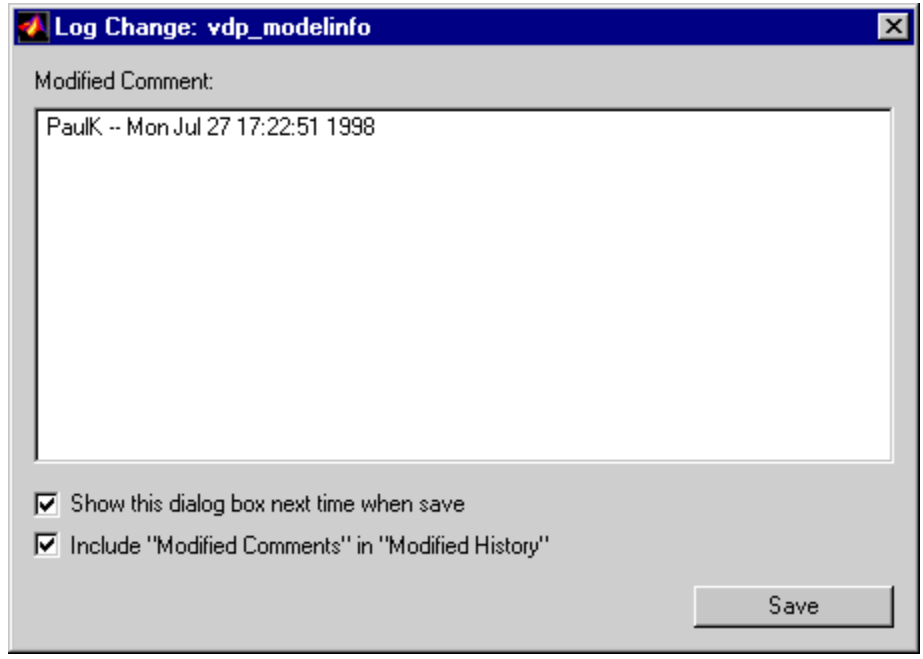
Logging Changes

To start a change history,

1. Select **File > Model Properties**.
2. In the Model Properties dialog box, select the **History** tab.
3. Select `When saving model` from the **Prompt to update model history** list.

   This causes Simulink to prompt you to enter a comment when saving the model.

The next time you save the model, the Log Change dialog box prompts you to enter a comment.



For example you could describe changes that you have made to the model since the last time you saved it. To add an item to the model's change history,

enter the item in the **Modified Comments** edit field and click **Save**. The information is stored in the model's change history log.

If you do not want to enter an item for this session, clear the **Include "Modified Comments" in "Modified History"** option.

To discontinue change logging, either:

- In the Log Change dialog box, clear the check box **Show this dialog box next time when save**.
- In the Model Properties dialog box History pane, select `Never` from the **Prompt to update model history** list.

Viewing and Editing the Model History Log

In the Model Properties dialog box you can view and edit the model history on the History tab.

The model history text field displays the history for the model in a scrollable text field. To change the model history, edit the contents of this field.

Version Information Properties

Some version 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 information.

Property	Description
Created	Date created.
Creator	Name of the person who created this model.

Property	Description
Description	User-entered description of this model. Enter or edit a description on the Description tab of the Model Properties dialog box. You can view the model description by typing `help 'mymodelname'` at the MATLAB command line.
LastModifiedBy	Name of the user who last saved the model.
LastModifiedDate	Date when the model was last saved.
ModifiedBy	Current value of the user name of the person who last modified this model. When you save, this information is saved with the file as `LastModifiedBy`.
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.
ModifiedDateFormat	Format of the `ModifiedDate` parameter. Value can be any string. The string can include the tag `%<Auto>`. Simulink 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.

Property	Description
ModelVersion	Version number.
ModelVersionFormat	Format of model version number. Can be any string. The string can contain the tag `%<AutoIncrement:#>` where # is an integer. Simulink replaces the tag with # when displaying the version number. It increments # when saving the model.

`LibraryVersion` is a block parameter for a linked block. `LibraryVersion` is the `ModelVersion` of the library at the time the link was created.

For source control version information, see instead “Simulink Projects”.

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

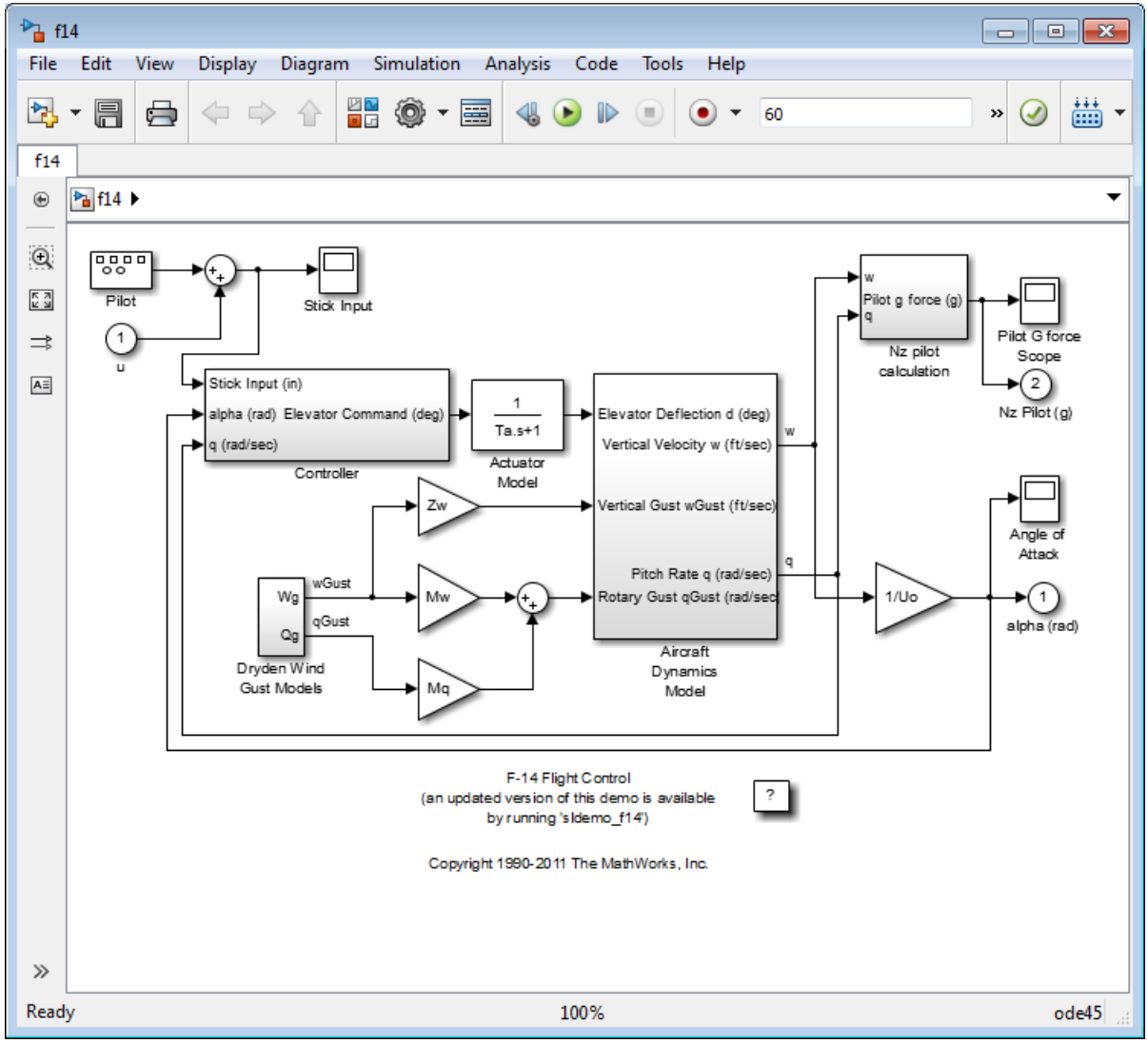
To use Model Discretizer, you must have a Control System Toolbox™ license, Version 5.2 or later.

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

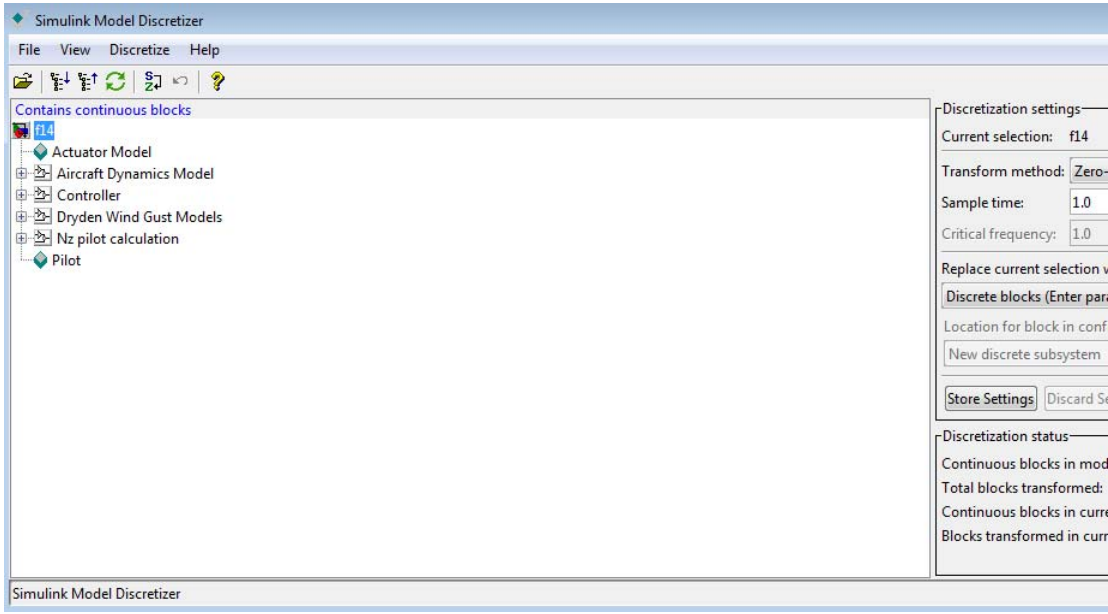
The `f14` model shows the steps in discretizing a model.



Start Model Discretizer

To open the tool, in the Simulink Editor, select **Analysis > Control Design > Model Discretizer**.

The **Simulink Model Discretizer** opens.



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 **File > Load model**.

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 4-127.

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 4-127

  Creates a discrete block whose parameters are retained from the corresponding continuous block.

- "Discrete blocks (Enter parameters in z-domain)" on page 4-128

  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 4-129

  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 4-130

  Create multiple discretization candidates in z-domain for the current selection. A configurable subsystem can consist of one or more blocks.

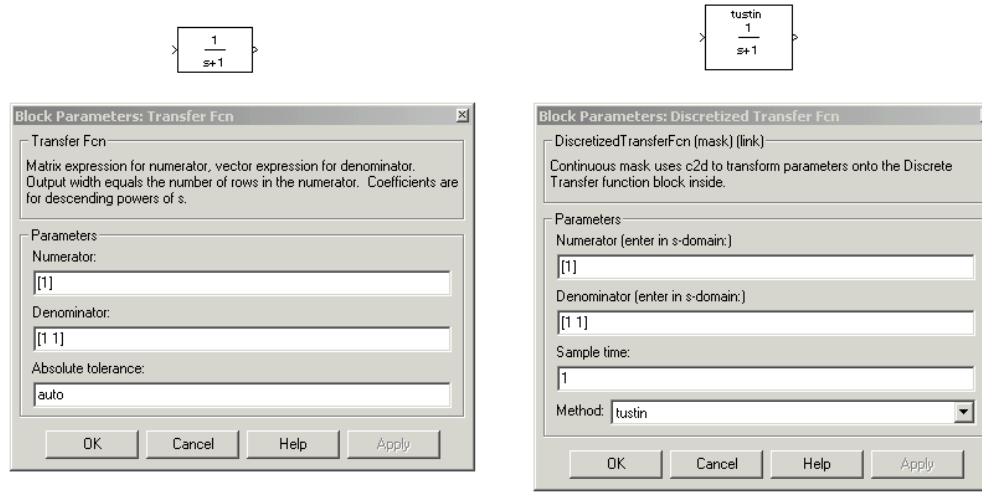
Discrete blocks (Enter parameters in s-domain). Creates a discrete block whose parameters are retained from the corresponding continuous block. The sample time and the discretization parameters are also on the block's parameter dialog box.

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 4-126.

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.

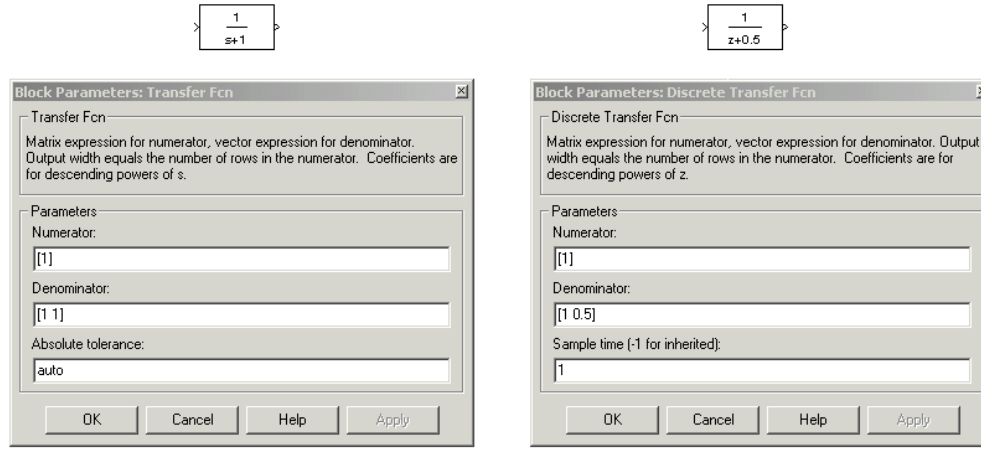


Discrete blocks (Enter parameters in z-domain). Creates a discrete block whose parameters are "hard-coded" values placed directly into the block's dialog box. Model Discretizer uses the `c2d` function to obtain the discretized parameters, if needed.

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.

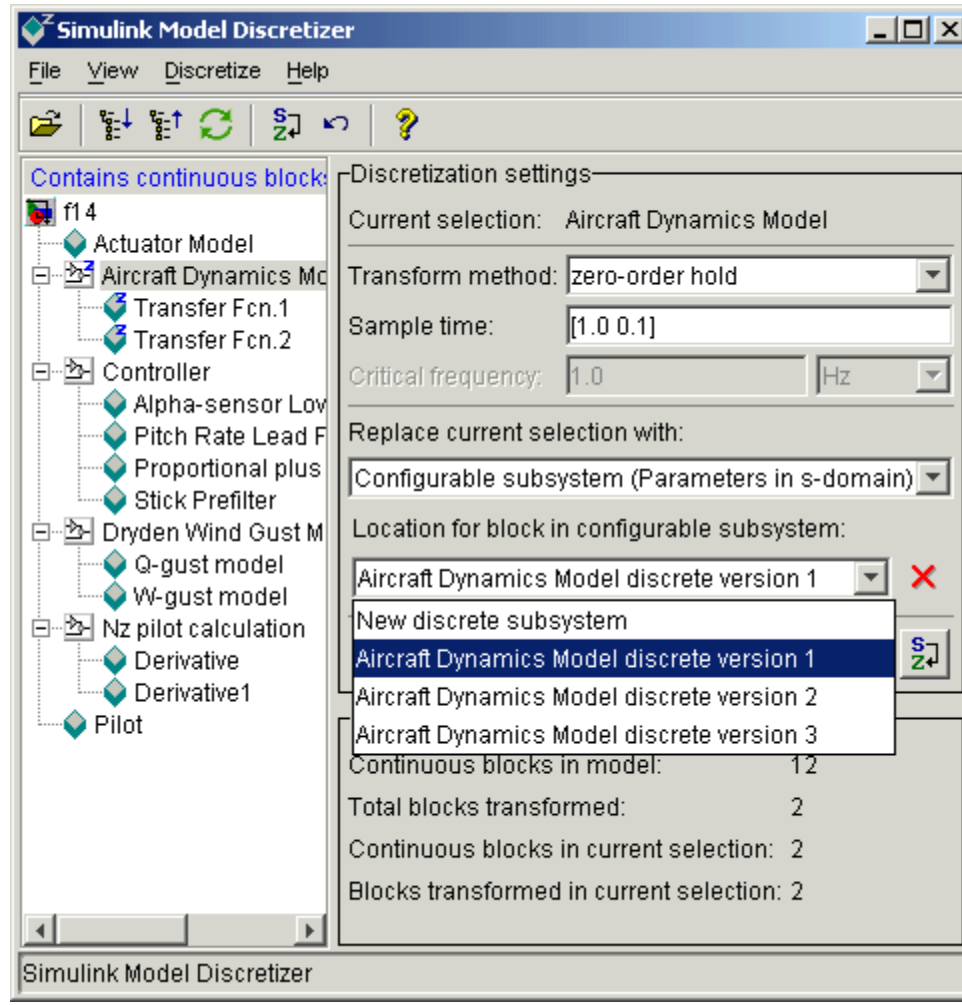
View the Discretized Model

Model Discretizer displays the model in a hierarchical tree view.

Viewing Discretized Blocks

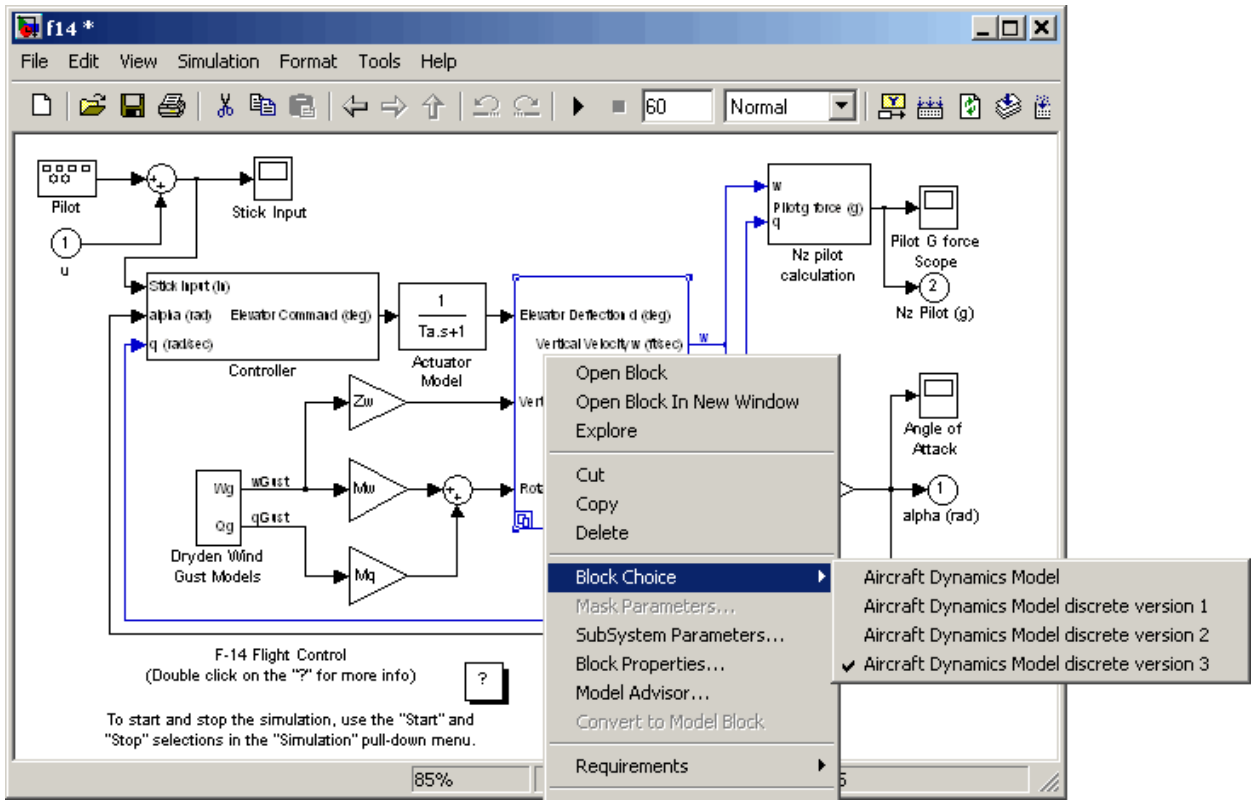
The block's icon in the tree view becomes highlighted with a "**z**" when the block has been discretized.

The following figure shows that the Aircraft Dynamics Model subsystem has been discretized into a configurable subsystem with three discretization candidates.

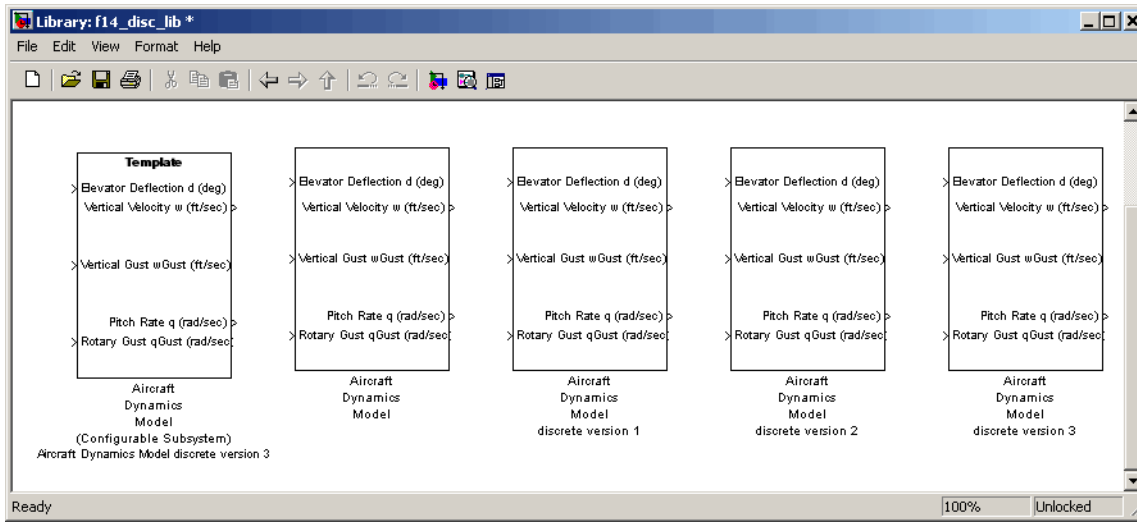


The other blocks in this `f14` model have not been discretized.

The following figure shows the Aircraft Dynamics Model subsystem of the `f14` example 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.

Discretize Blocks from the Simulink Model

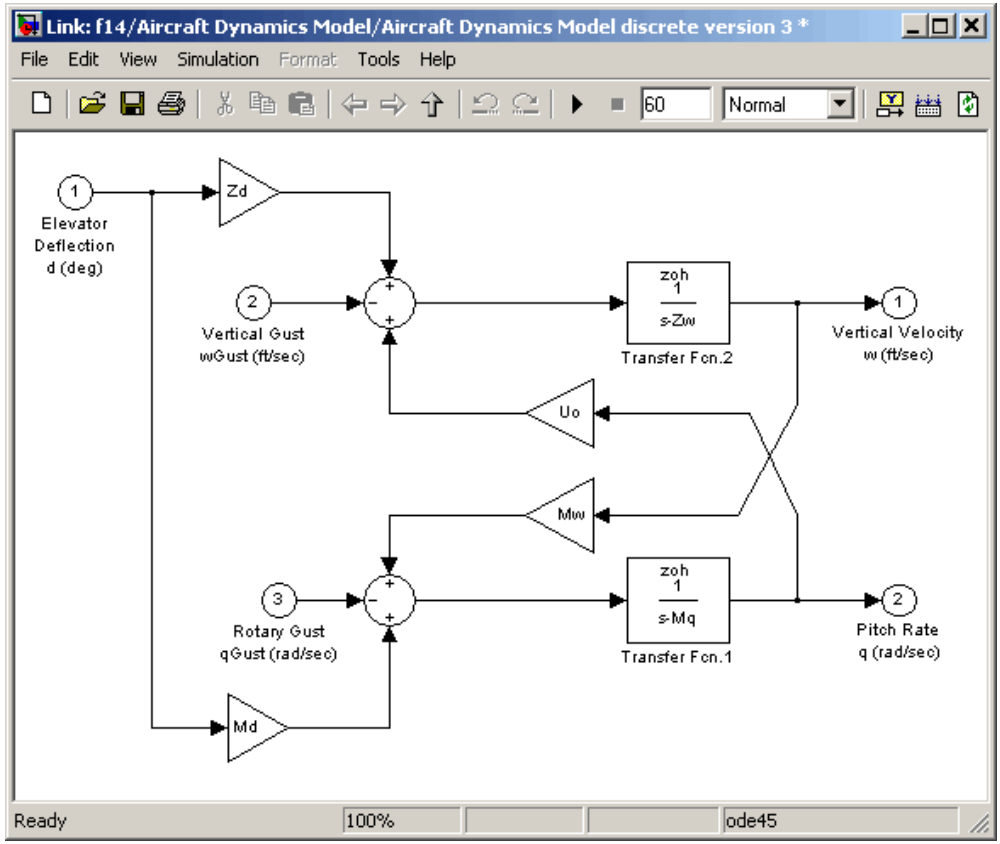
You can replace continuous blocks in a Simulink software model with the equivalent blocks discretized in the s-domain using the Discretizing library.

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.

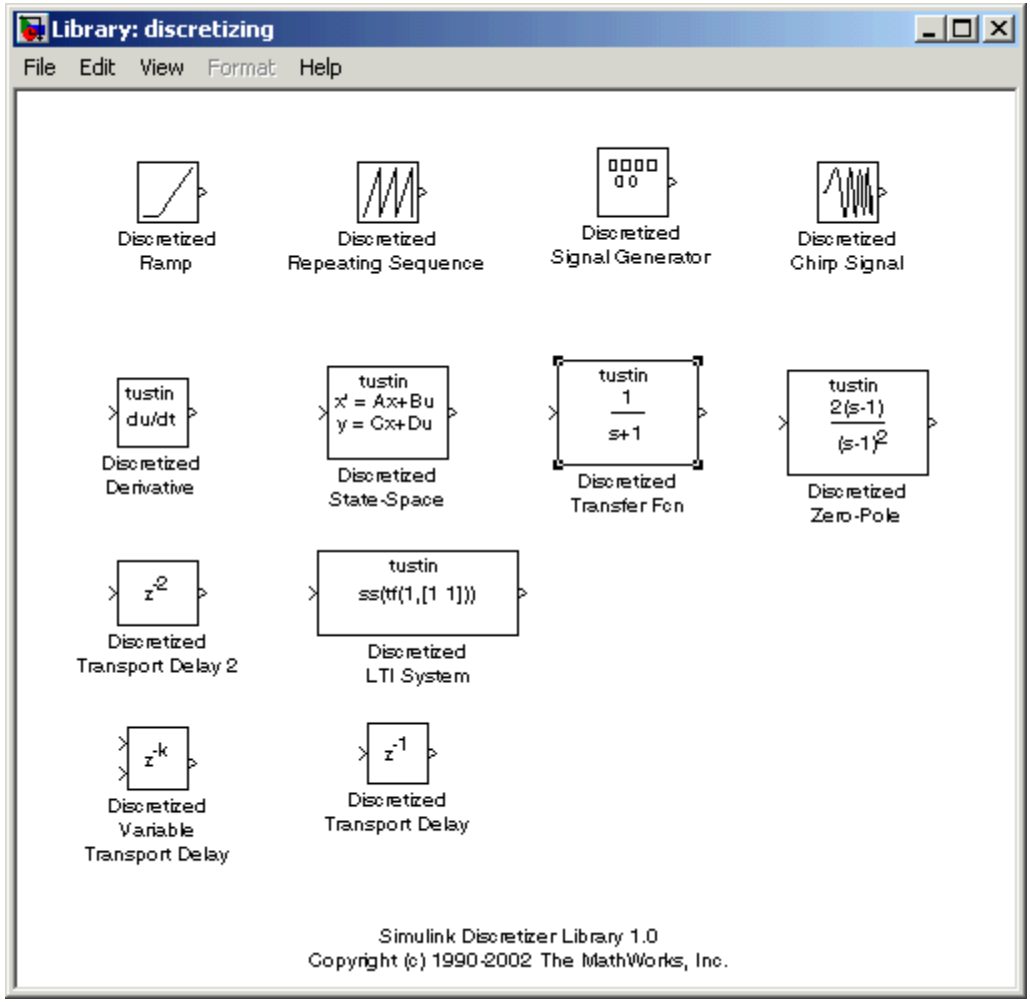
2 Open the Aircraft Dynamics Model subsystem in the `f14` model.



3 Open the Discretizing library window.

Enter `discretizing` at the MATLAB command prompt.

The **Library: discretizing** window opens.

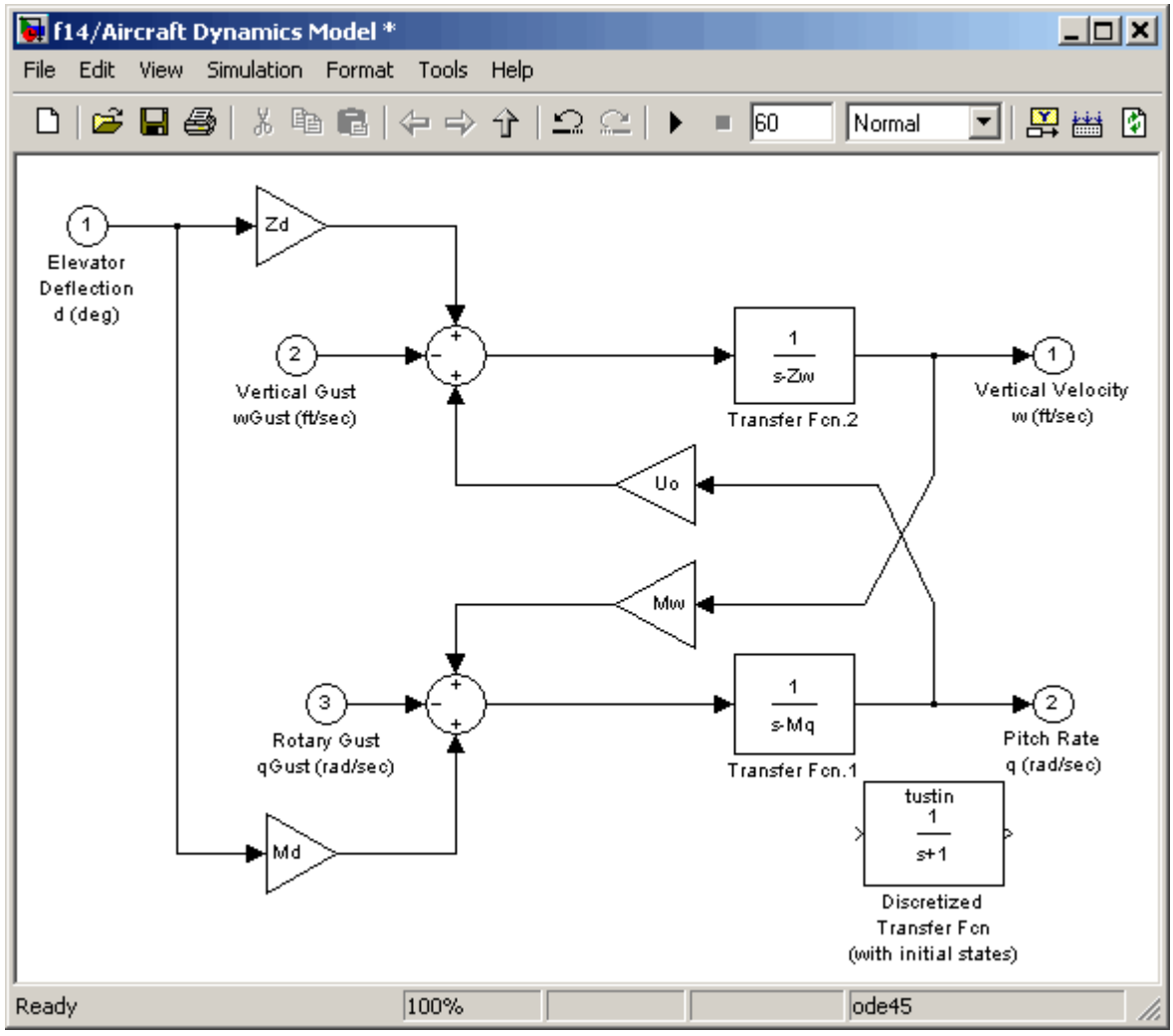


This library contains s-domain discretized blocks.

4 Add the Discretized Transfer Fcn (with initial states) block to the **f14/Aircraft Dynamics Model** window.

a Click the Discretized Transfer Fcn block in the **Library: discretizing** window.

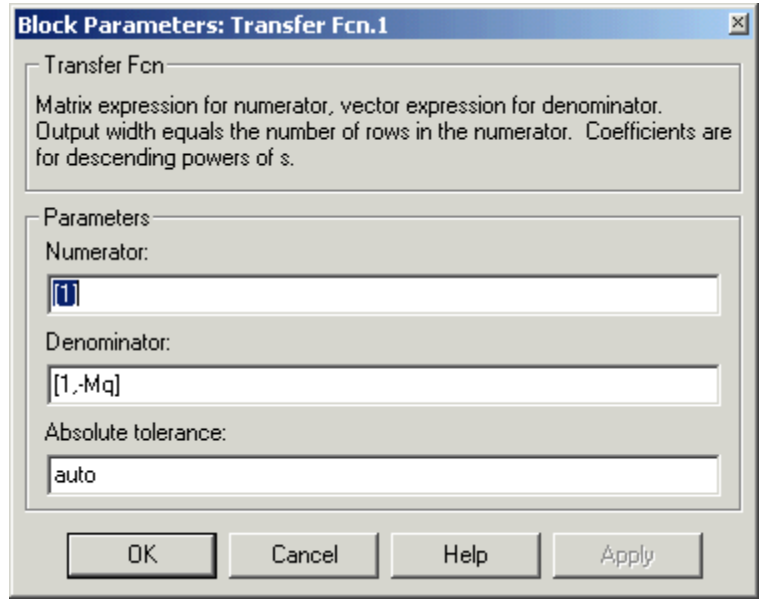
b Drag it into the **f14/Aircraft Dynamics Model** window.



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.

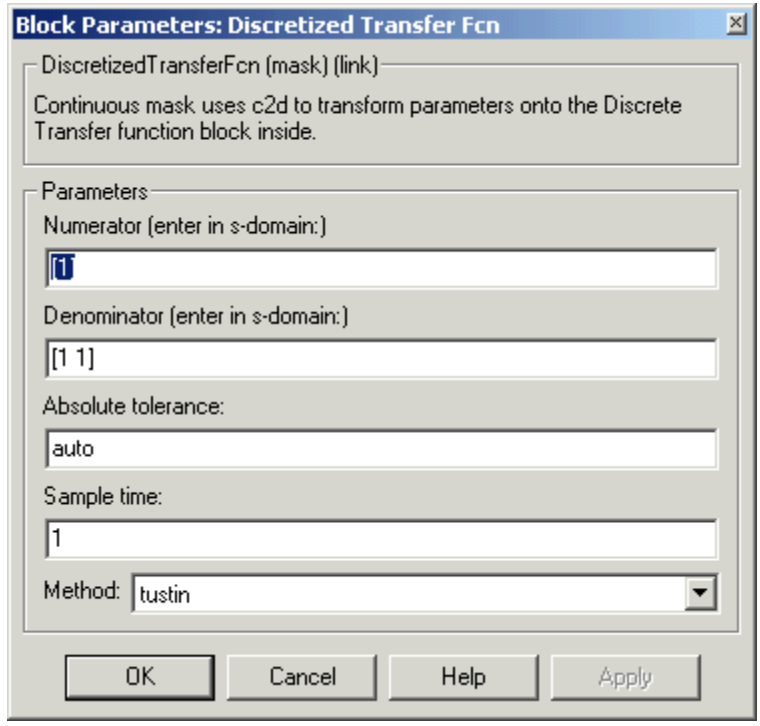
The Block Parameters: Transfer Fcn.1 dialog box opens.



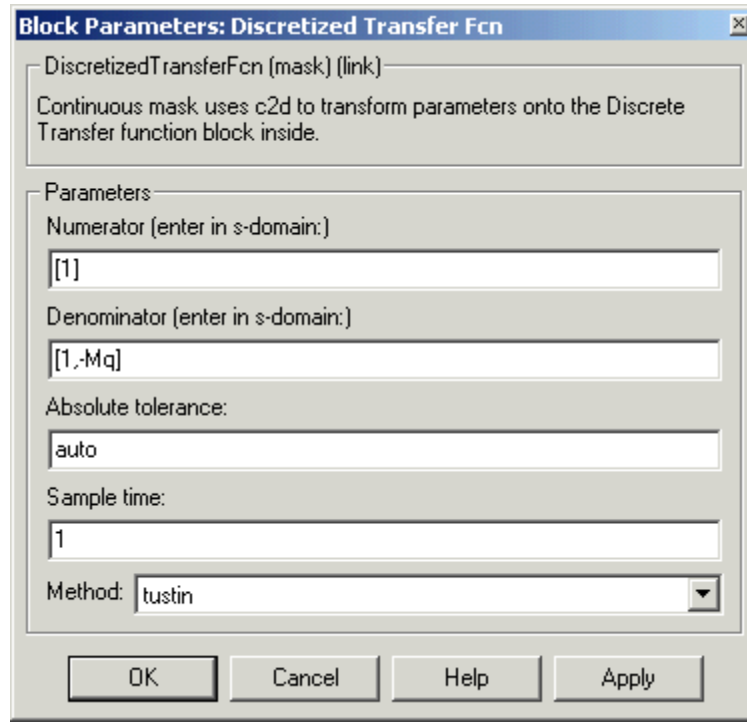
6 Open the parameter dialog box for the Discretized Transfer Fcn block.

Double-click the Discretized Transfer Fcn block in the **f14/Aircraft Dynamics Model** window.

The Block Parameters: Discretized Transfer Fcn dialog box opens.



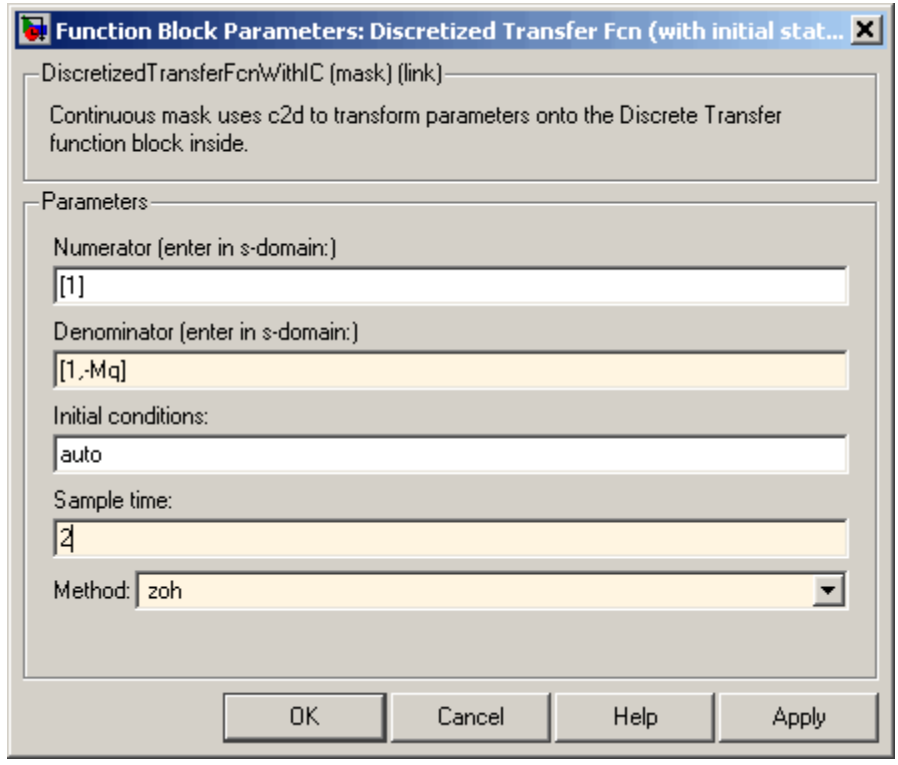
Copy the parameter information from the Transfer Fcn.1 block's dialog box to the Discretized Transfer Fcn block's dialog box.



7 Enter `2` in the **Sample time** field.

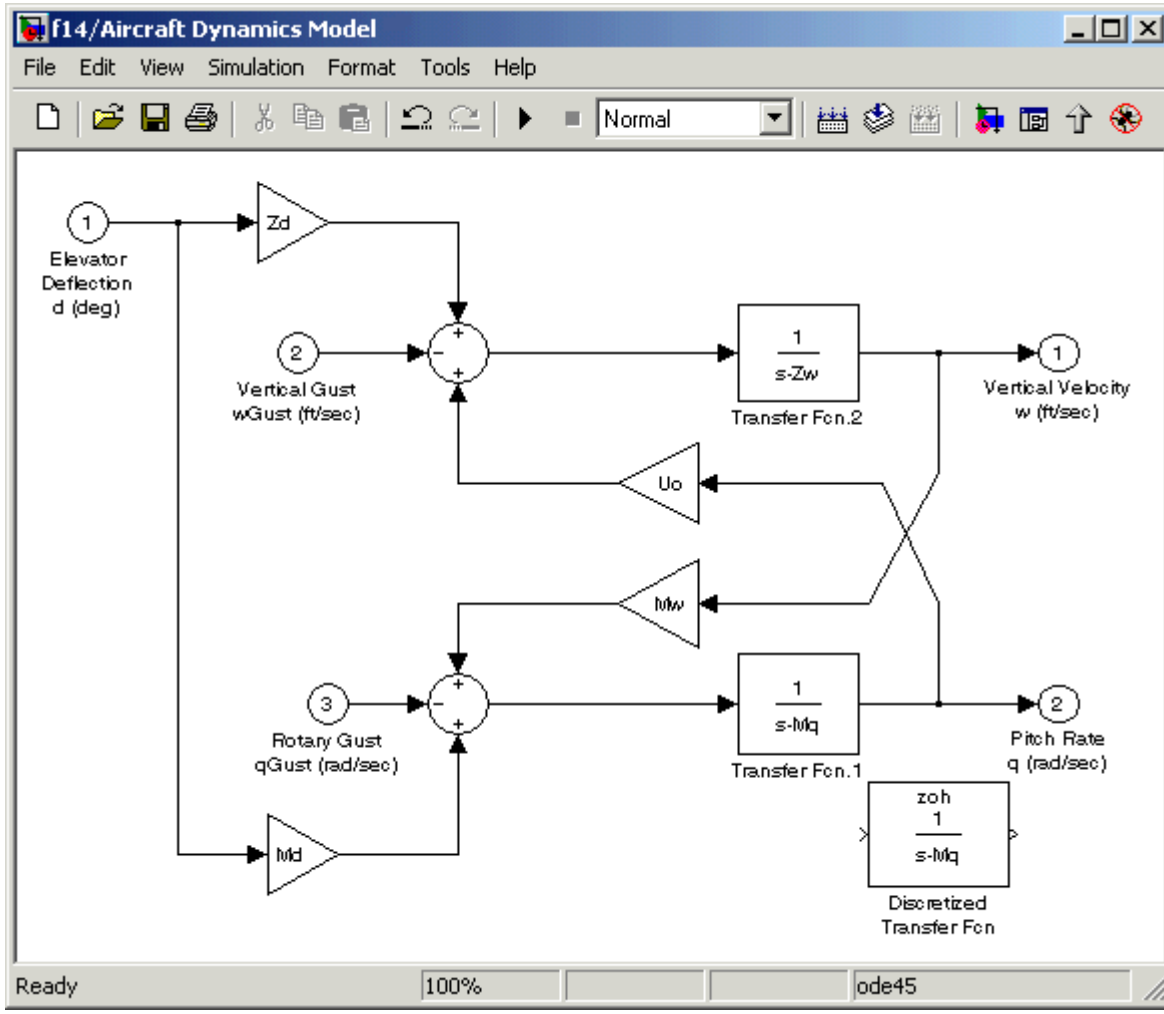
8 Select `zoh` from the **Method** drop-down list.

The parameter dialog box for the Discretized Transfer Fcn now looks like this.



9 Click **OK**.

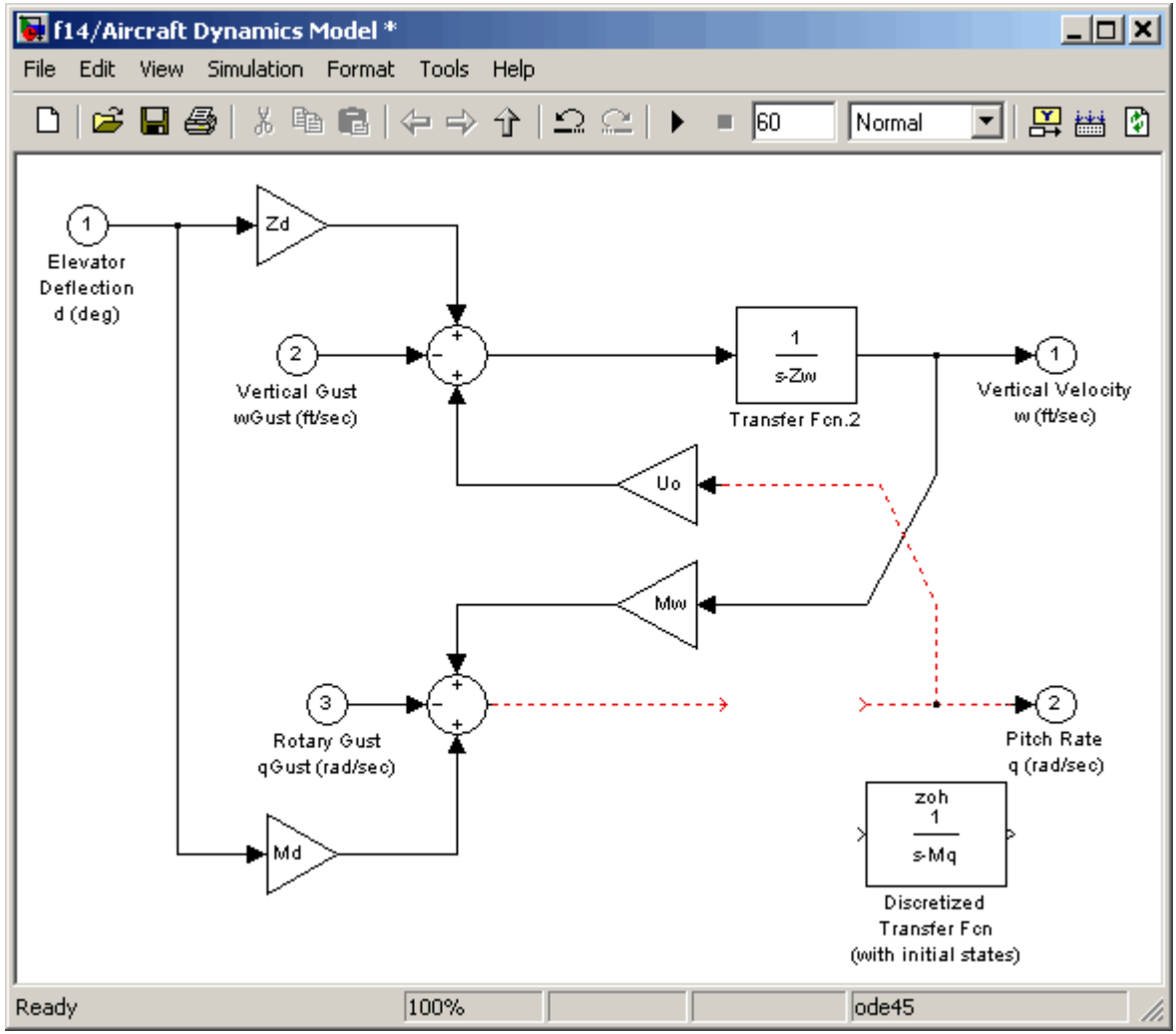
The **f14/Aircraft Dynamics Model** window now looks like this.



10 Delete the original Transfer Fcn.1 block.

- **a** Click the Transfer Fcn.1 block.
- **b** Press the **Delete** key.

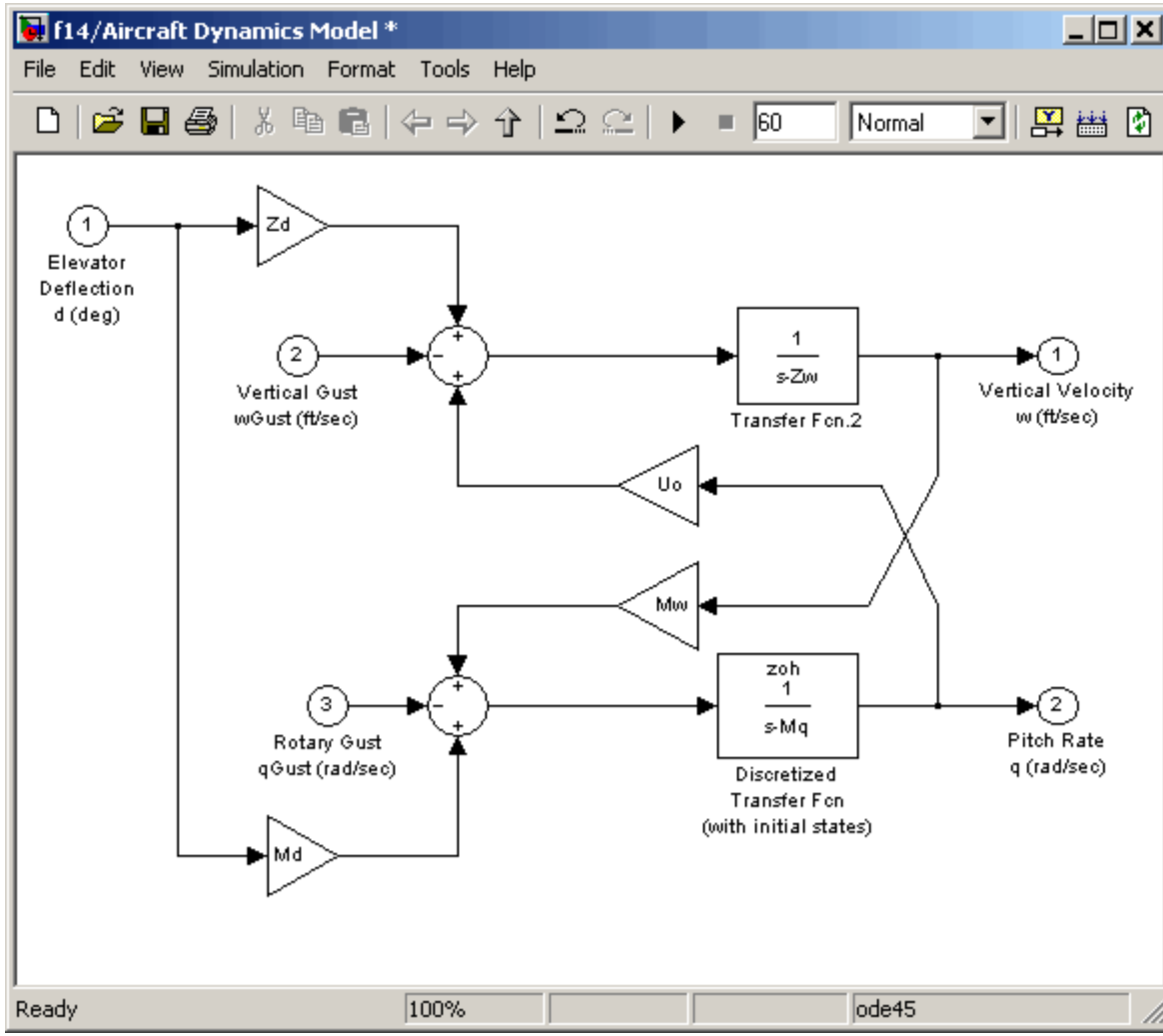
The **f14/Aircraft Dynamics Model** window now looks like this.



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.



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')
```

5

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.

Specify Sample Time

In this section...

Designate 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 5-14. 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 "View Sample Time Information" on page 5-9.)

Designations of Sample Time Information

Sample Time Type	Sample Time	Color	Annotation	Explicit
Discrete	$[T_s, T_o]$	In descending order of speed: 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

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 “Model Reference”.)

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.

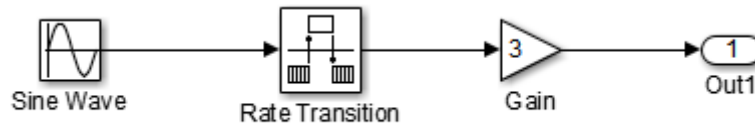
It is important to note that Mux and Demux blocks are simply grouping operators; signals passing through them retain their timing information. For this reason, the lines emanating from a Demux block can have different colors if they are driven by sources having different sample times. In this case, the

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.

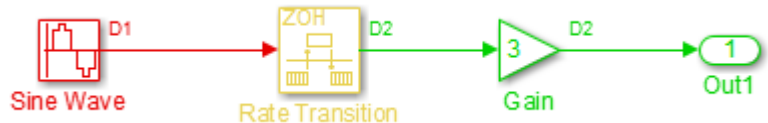
You can use the explicit sample time values in this table to specify sample times interactively or programmatically for either block-based or port-based sample times.

The following model, `ex_specify_sample_time`, serves as a reference for this section.



ex_specify_sample_time

In this example, set the sample time of the input sine wave signal to `0.1`. The goal is 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.)



Sample Time 0.1 Sample Time 0.2

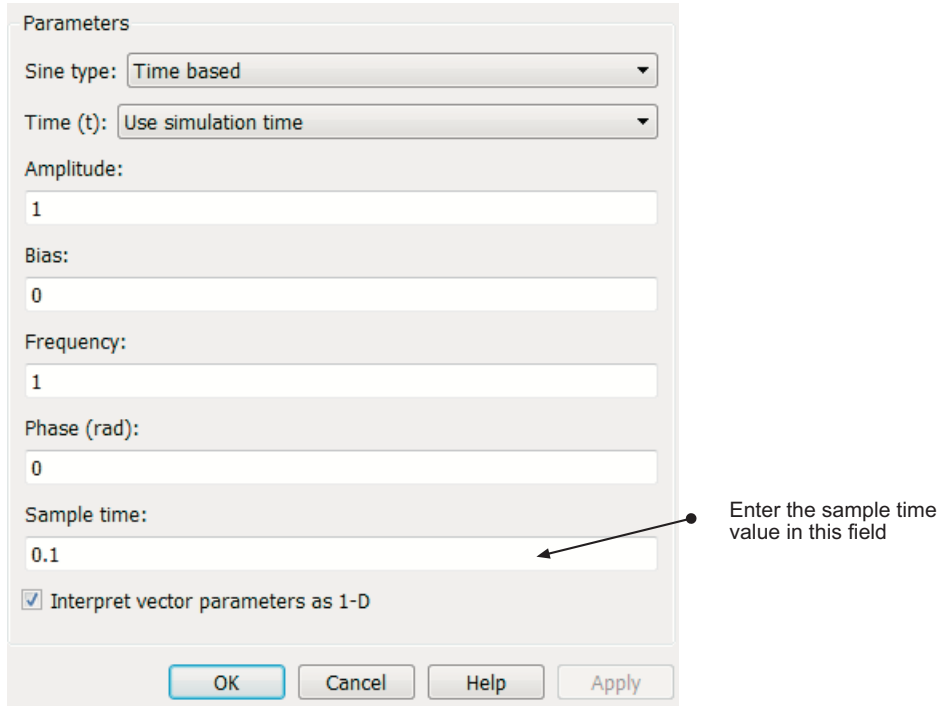
ex_specify_sample_time after Setting Sample Times

Specify 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.



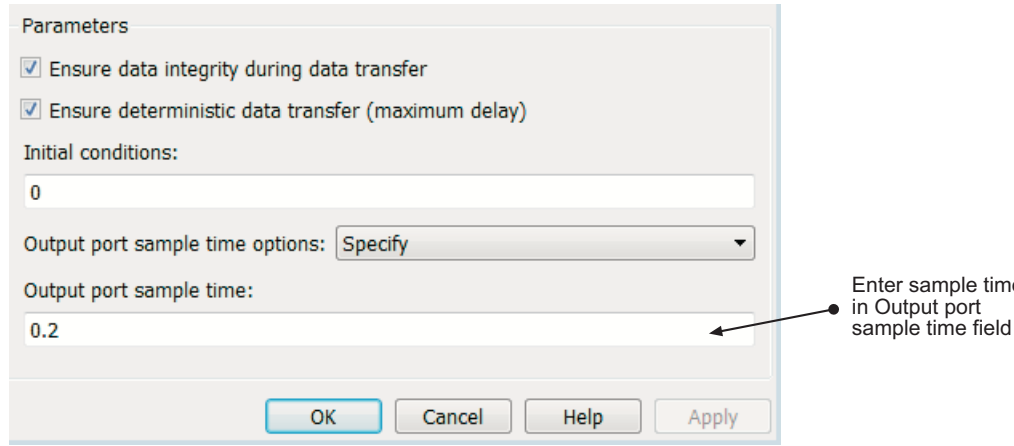
Specify Port-Based Sample Times Interactively

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.

Specify 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')
```

Specify 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')
```

Access 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`.

Specify 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`.

Change 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.

View Sample Time Information

In this section...

View Sample Time Display

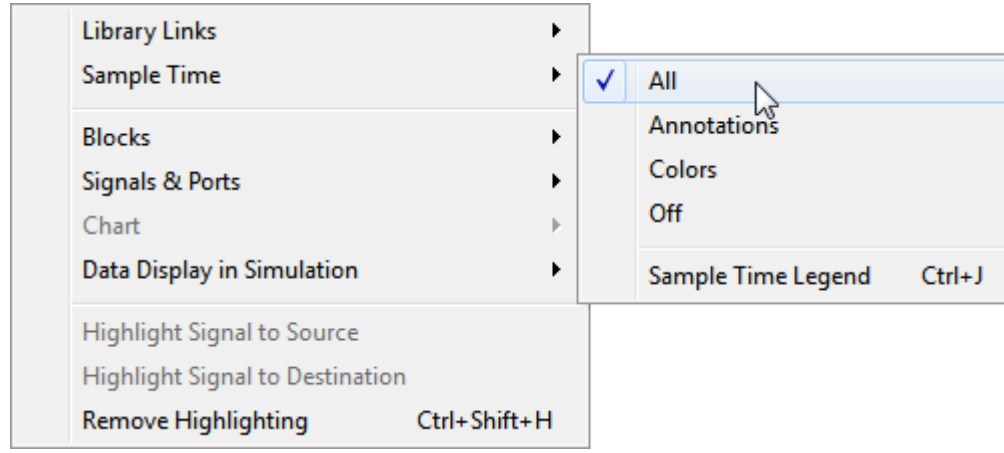
Simulink models can display color coding and annotations that represent specific sample times. As shown in the table Designations of Sample Time Information on page 5-4, each sample time type has one or more colors associated with it. You can display the blocks and signal lines in color, the annotations in black, or both the colors and the annotations. To choose one of these options:

1. In the Simulink model window, select **Display > Sample Time**.
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 **Display > Sample Time**.
2. Select **Off**.

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 5-4 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.

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** 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 **Simulation > Update Diagram**.
2. Select **Display > Sample Time > Sample Time Legend** or press **Ctrl +J**.

In addition, whenever you select **Colors**, **Annotations**, or **All** from the **Sample Time** 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 **Off**, 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, repeat the **Update Diagram** to access the latest known information.

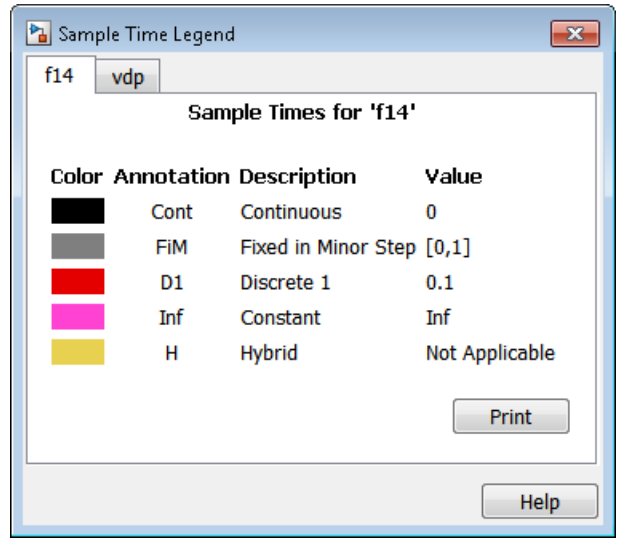
Turning the Legend Off

If you do not want to view the legend upon selecting **Sample Time Display**:

1. In the Simulink model window, select **File > Simulink 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 the `f14` and `vdp` models.



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**.

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 3-23). 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 "View Sample Time Information" on page 5-9.)

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 5-29

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** check box is selected on the Configuration Parameters dialog box **Optimization > Signal and Parameters** pane (see the "Optimization Pane: Signals and Parameters").
- 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 7-4).
- 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.

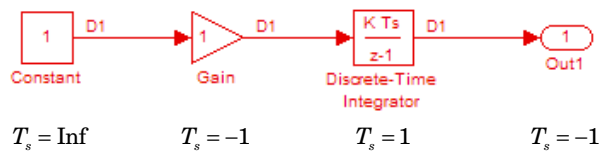
Note The Simulink block library includes several blocks, such as the MATLAB S-Function block, the Level-2 MATLAB S-Function block, and the Model block, whose ports can produce outputs at different sample rates. It is possible for some of the ports of such blocks to have a constant sample time. These 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 5-29) to determine the block sample time.

An example of a Constant block with tunable parameters is shown below (`ex_inline_parameters_off`. 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.

Inline Parameters Off



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 7-30.)
- 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 "Handle 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”.

Block Compiled Sample Time

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.

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.

Sample Times in Systems

In this section...

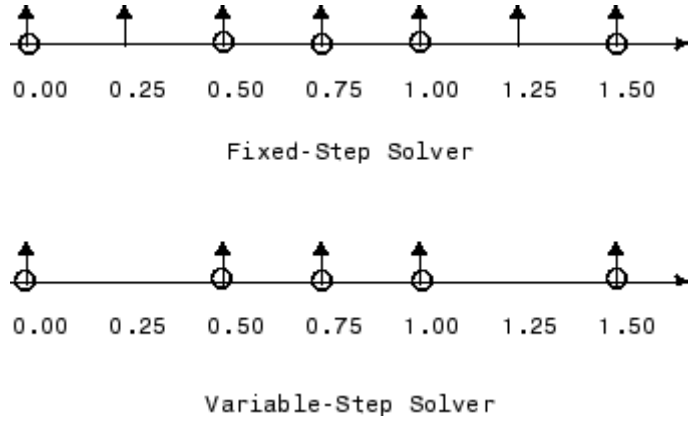
Purely Discrete Systems

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 largest double that is an 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.

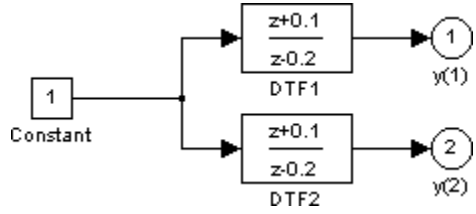
The importance of the fundamental sample time directly relates to whether you direct the Simulink software to use a fixed-step or a variable-step discrete solver to solve your multirate discrete system. A fixed-step solver sets the simulation step size equal to the fundamental sample time of the discrete 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 Simulink Coder). 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.

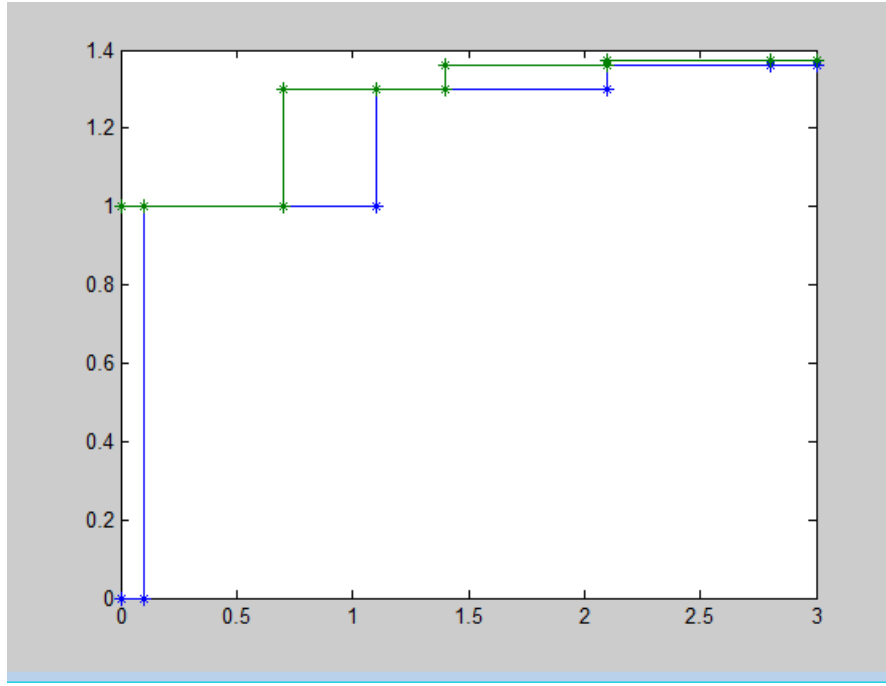
Consider the following example of a simple multirate system. For this example, the DTF1 Discrete Transfer Fcn block's **Sample time** is set to `[1 0.1]`, which gives it an offset of `0.1`. The **Sample time** of the DTF2 Discrete Transfer Fcn block is set to `0.7`, with no offset. The solver is set to a variable-step discrete solver.



Running the simulation and plotting the outputs using the `stairs` function

```
simOut = sim('ex_dtf','StopTime', '3');
t = simOut.find('tout')

y = simOut.find('yout')
stairs(t,y, '-*')
```

produces the following plot.



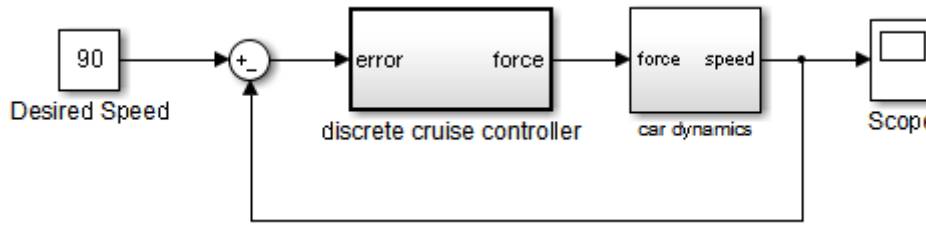
(For information on the `sim` command. see “Run Simulation Using the sim Command” on page 15-3.)

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

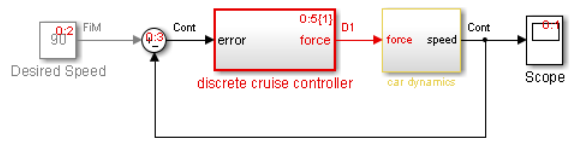
Hybrid systems contain both discrete and continuous blocks and thus have both discrete and continuous states. However, Simulink solvers treat any system that has both continuous and discrete sample times as a hybrid system. For information on modeling hybrid systems, see "Modeling Hybrid Systems" on page 3-8.

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". (See `ex_execution_order`.)

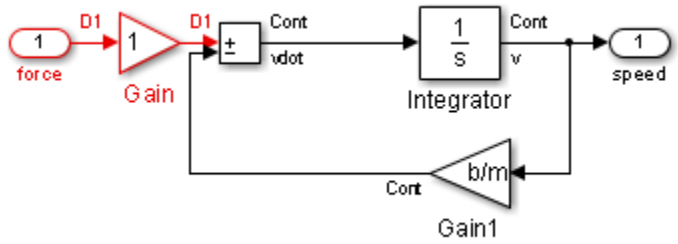


Car Model

With the **Sample Time** 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.

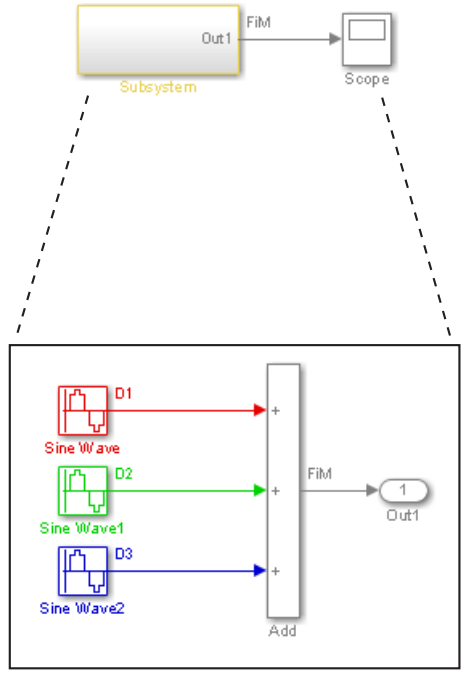


Car Model after an Update Diagram



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 after an Update Diagram

An **Update Diagram** turns the subsystem yellow because the subsystem contains more than one sample time. As shown in the block diagram, the Sine Wave blocks have discrete sample times D1, D2, and D3 and the output signal is fixed in minor step.

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.

Resolve 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:

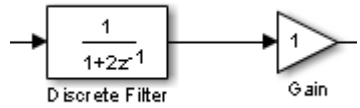
- A constant sample time (`[Inf, 0]`) never has a rate transition with any other rate.
- A continuous sample time (black) and the fastest discrete rate (red) never has a rate transition if you use a fixed-step solver.
- A variable sample time and fixed in minor step do not have a rate transition.

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 “Handle 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.

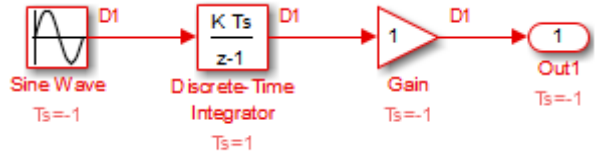
Simulink Rules for Assigning Sample Times

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.

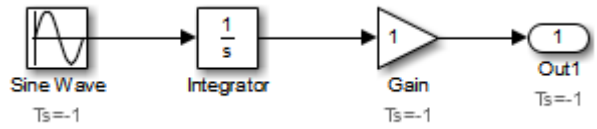
Monitor Backpropagation in Sample Times

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 > Colors** from the Simulink **Display** 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 in the model below, causes the Sine Wave and Gain blocks to change to continuous blocks. You can test this change by selecting **Simulation > Update Diagram** 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.

6

Referencing a Model

Overview of Model Referencing

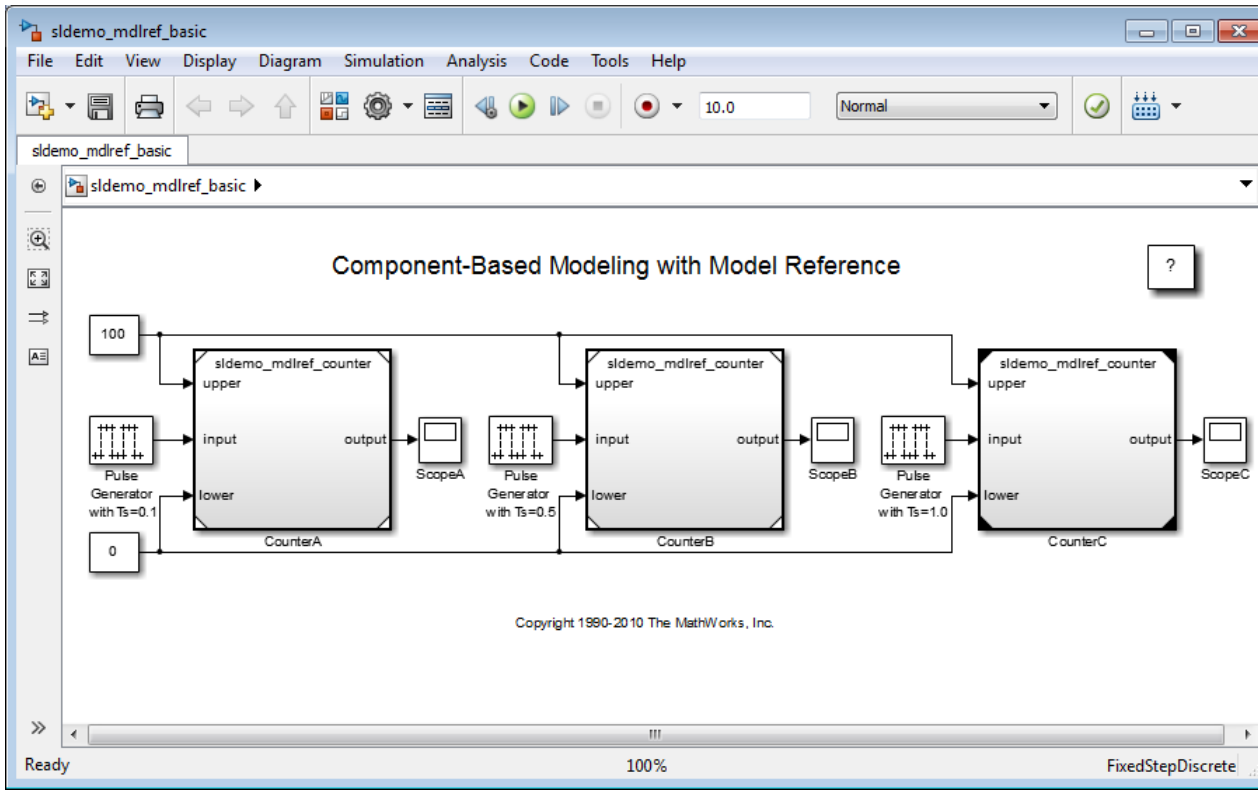
In this section...

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.

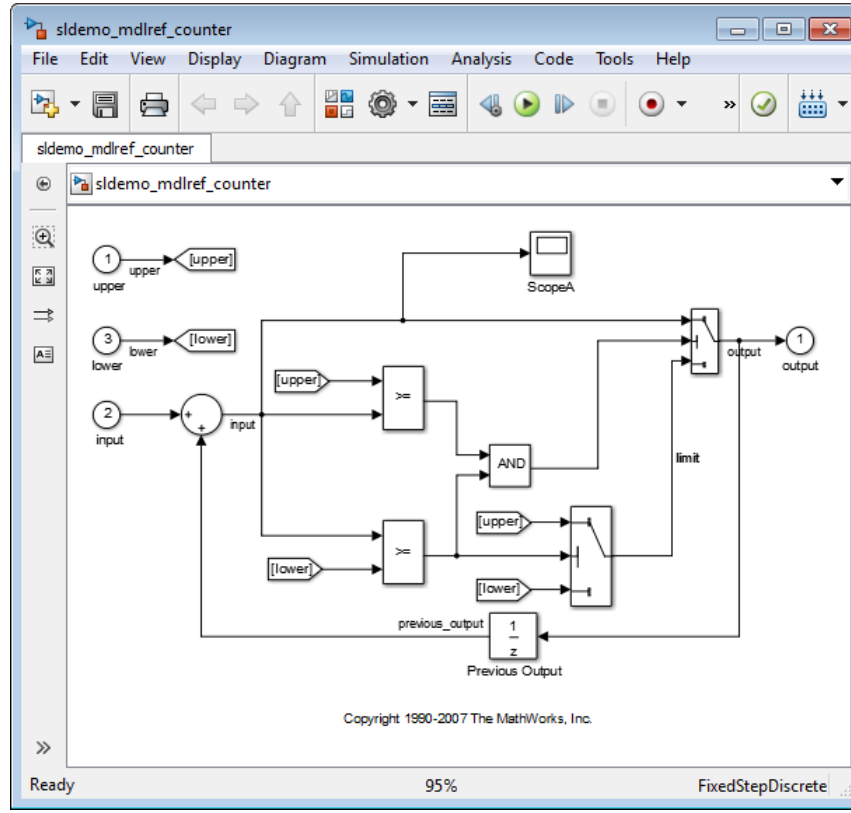
The interface of a referenced model consists of its input and output ports (and control ports, in the case of a conditional referenced model) and its parameter arguments. A Model block displays inputs and outputs corresponding to the root-level inputs and outputs of the model it references. These ports enable you to incorporate the referenced model into the block diagram of the parent model.

For example, the `sldemo_mdref_basic` model includes Model blocks that reference three instances of the same referenced model, `sldemo_mdlref_counter`.

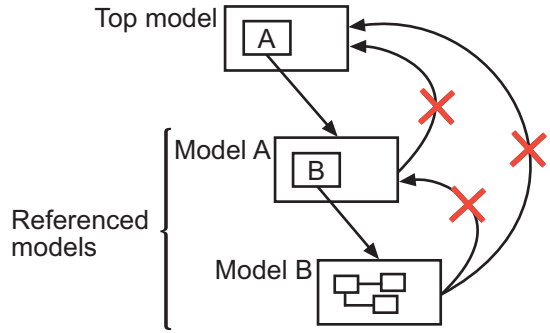


Use the ports on a Model block to connect the submodel to other elements of the parent model. Connecting a signal to a Model block port has the same effect as connecting the signal to the corresponding port in the submodel. For example, the Model block CounterA has three inputs: two Constant blocks and a Pulse Generator block with a sample time of .1. The Model block CounterB also has three inputs: the same two Constant blocks, and a Pulse Generator block with a sample time of .5. Each Model block has an output to a separate Scope block.

The referenced model includes Inport and Outport blocks (and possibly Trigger or Enable blocks) to connect to the parent model. The `sldemo_mdlref_counter` model has three Inport blocks (upper, input, and lower) and one Outport block (output).



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 "Parameterize Model References" on page 6-52 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 6-21 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.

For additional information about how model referencing compares to other Simulink componentization techniques, see “Componentization Guidelines” on page 12-17. For a video summarizing advantages of model referencing, see Modular Design Using Model Referencing

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 information about block masks, see “Masking”.

Models That Use Model Referencing

Simulink includes several models that illustrate model referencing.

The `Introduction to Managing Data with Model Reference` example 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` example.

In addition, the `sldemo_absbrake` model 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.

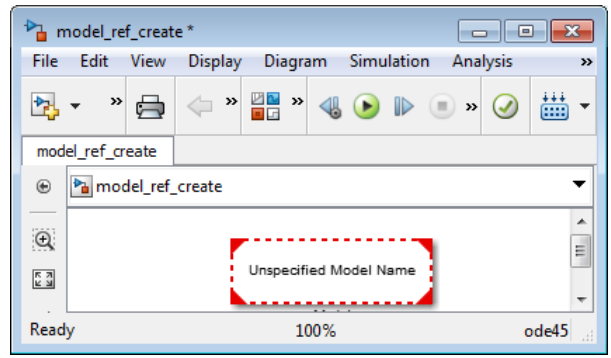
Create a Model Reference

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.

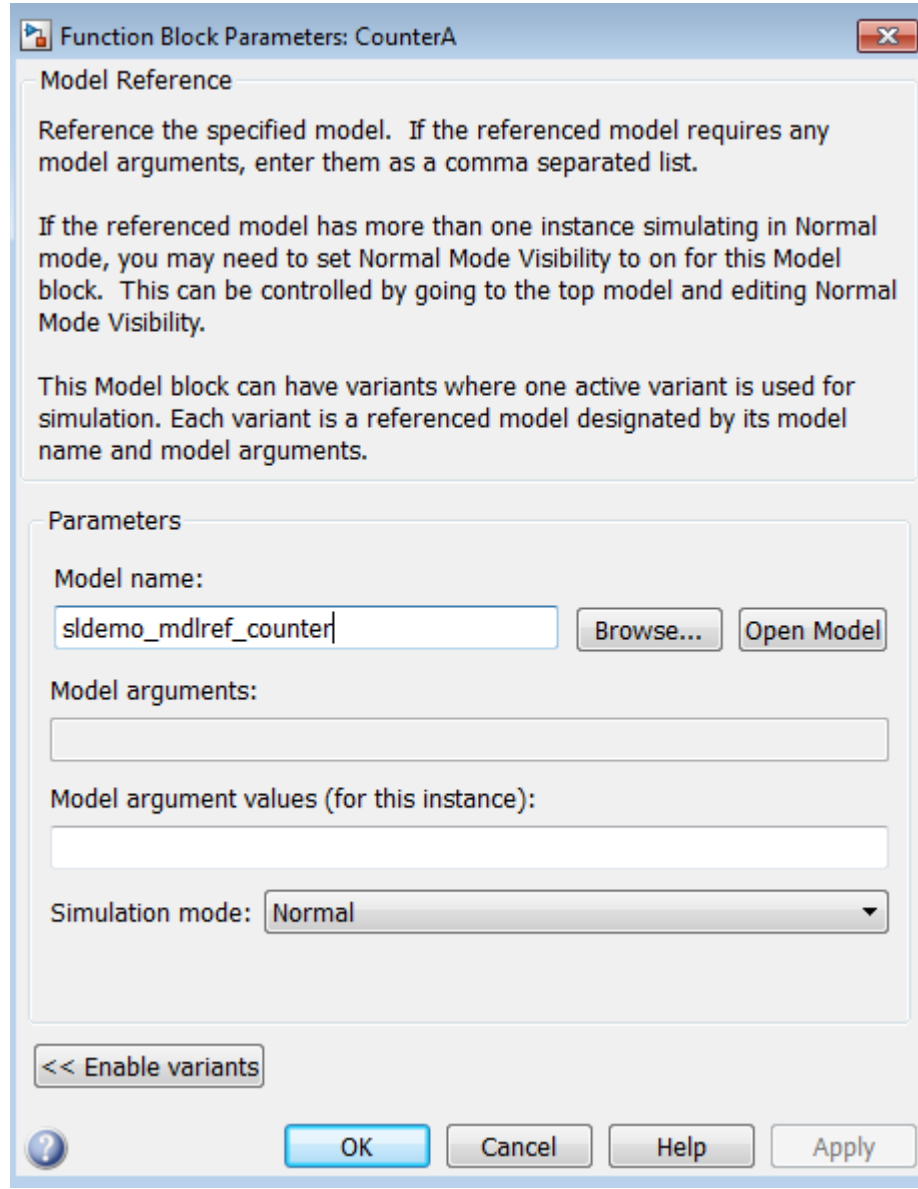
For a video introducing how to create model references, see Getting Started with Model Referencing.

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 6-49 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.


Function Block Parameters: CounterA
Model Reference
Reference the specified model. If the referenced model requires any model arguments, enter them as a comma separated list.
If the referenced model has more than one instance simulating in Normal mode, you may need to set Normal Mode Visibility to on for this Model block. This can be controlled by going to the top model and editing Normal Mode Visibility.
This Model block can have variants where one active variant is used for simulation. Each variant is a referenced model designated by its model name and model arguments.
Parameters
Model name:
sldemo_mdlref_counter
Browse...
Open Model
Model arguments:
Model argument values (for this instance):
Simulation mode:
Normal
<< Enable variants
OK
Cancel
Help
Apply

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 6-45.)
   - For information about **Model Arguments** and **Model argument values**, see "Using Model Arguments" on page 6-53.
   - For information about the **Simulation mode**, see "Referenced Model Simulation Modes" on page 6-21.
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 6-50.

Convert a Subsystem to a Referenced Model

Conversion Process

The process for converting a subsystem to a referenced model involves these tasks:

1. "Select Subsystems to Convert" on page 6-12.
2. "Prepare the Model for Conversion" on page 6-13.
3. "Run a Conversion Tool" on page 6-16.
4. "Connect the Model Block and Perform Other Post-Conversion Tasks" on page 6-18.

Select Subsystems to Convert

Model referencing offers several benefits for modeling large, complex systems and for team-based development, as summarized in "Referenced Model Advantages" on page 6-5.

Subsystems or libraries are better suited for some modeling goals than model referencing. Many large models involve using a combination of subsystems and referenced models. For information to help you to decide which subsystems to convert to referenced models, see "Componentization Guidelines" on page 12-17.

The types of subsystems that you can convert to a referenced model are:

- Atomic Subsystem
- "Triggered Subsystems" on page 7-20
- "Enabled Subsystems" on page 7-4
- "Triggered and Enabled Subsystems" on page 7-24
- "Function-Call Subsystems" on page 7-30

Note If you want to create a referenced model that accepts an asynchronous function call, see "Asynchronous Support Limitations".

If you convert a masked subsystem, you might need to perform some additional tasks to maintain the same general behavior that the masked subsystem provided. For details, see "Convert a Masked Subsystem" on page 6-19.

Prepare the Model for Conversion

Simulink provides a tool that you can use to convert a subsystem to a referenced model.

When the conversion tool identifies a change that you need to make to a model or subsystem to support the conversion, the conversion processing stops. The conversion tool reports conversion issues one at a time. To perform the conversion efficiently, before using the conversion tool, consider modifying your model as described in the following steps.

When you run the conversion tool, it will flag any additional model modifications that you may need to make.

1. Save a backup copy of the model.

   You can use the backup copy of the model to help you to configure the model after performing the conversion. For example, if you convert a masked subsystem and want to have a masked Model block, you might want to copy information from the masked subsystem into the masked Model block.

   Also, you can revert to the original version of the model if you decide not to convert the subsystem after you have started to modify the model, or if the conversion processing is unsuccessful.

2. Use the Configuration Parameters dialog box to set the following model configuration parameters.

   a. Select **Optimization > Inline parameters**.

b Set **Diagnostics > Data Validity > Signal resolution** to `Explicit only`.

c Set **Diagnostics > Connectivity > Mux blocks used to create bus signals** to `Error`. For information about proper mux usage, see "Avoid Mux/Bus Mixtures" on page 48-95.

As an alternative for steps b and c, consider using the associated Model Advisor checks.

3 Configure subsystem interfaces to the model.

Subsystem Interface	What to Look For	Model Modification
Goto or From blocks	Crossing of subsystem boundaries.	Add input or output ports to the subsystem. Reconfigure the model as necessary to reflect the added ports.
Data stores	Data Store Memory blocks accessed by Data Store Read or Data Store Write blocks from outside of the subsystem.	Replace the Data Store Memory block with a global data store. Define a global data store with a `Simulink.Signal` object. For details, see "Data Stores with Signal Objects" on page 46-12.
Tunable parameters	Global tunable parameters listed in the dialog box that opens when you select the **Configuration Parameters > Optimization > Signals and Parameters > Configure** button.	Use `tunablevars2parameterobjects` to create a `Simulink.Parameter` object for each tunable parameter. The `Simulink.Parameter` objects must have a non-Auto storage class. For more information, see "Parameterize Model References" on page 6-52 and "Tunable Parameters" on page 3-9.

4 Configure the subsystem and its contents.

Subsystem Configuration	What to Look For	Model Modification
Inactive subsystem variants	Variant Subsystem blocks.	Make active the subsystem variant that you want to convert. The conversion tool does not convert inactive subsystem variants. To have the new Model block behave similar to the subsystem variant, convert each variant subsystem separately. For details, see "Set Up Variant Subsystems" on page 8-15.
Function calls	Function-call signals that cross virtual subsystem boundaries.	Move the Function-Call Generator block inside of the subsystem that you want to convert.
	Function-call outputs.	Change the function-call outputs to data triggers.
	Wide function-call ports.	Eliminate wide signals for function-call subsystems.
Sample times	Sample time of an Inport block that does not match the sample time of the block driving the Inport.	Insert Rate Transition blocks where appropriate.
Inport blocks	Merged Inport blocks.	Configure the model to avoid merged Inport blocks. See the Merge block documentation.
Constant blocks	Constant blocks that input to subsystems.	Consider moving the Constant blocks into the subsystem.

Subsystem Configuration	What to Look For	Model Modification
Buses	Bus signals that enter and exit a subsystem.	Match signal names and bus element names for blocks inside of the subsystem.
	Duplicate signal names in buses.	Make signal names of the bus elements unique.
	Signal names that are not valid MATLAB identifiers. A valid identifier is a character string of letters, digits, and underscores, such that the first character is a letter, and the length of the string is less than or equal to the value returned by the `namelengthmax` function.	Change any invalid signal names to be valid MATLAB identifiers.

Run a Conversion Tool

Run a conversion tool, using one of these approaches:

- From the context menu of the subsystem, select **Subsystem & Model Reference > Convert to > Referenced Model**.
- Use the `Simulink.SubSystem.convertToModelReference` command.

  This function provides more capabilities than the **Referenced Model** menu option. For example, with the function, you can replace a subsystem with an equivalent Model block in a single operation.

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.

Model Name

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.

Error Handling

During the conversion, if an error occurs, the outcome depends on the kind of error.

- For some errors, a message box appears that gives you the choice of cancelling or continuing.

  Before you continue, note any changes that you want to make after the conversion. If you cancel, then the conversion tool exits.

- If continuing is impossible, Simulink cancels the conversion without offering a choice to continue. If the new Model block has *not* been created, then the model is not affected by the conversion tool processing.

What Gets Copied by the Conversion?

The conversion tool copies the following elements from the original model to the newly created referenced model:

- **Configuration sets** – If the referencing model uses a configuration set that is not a referenced configuration set, then the conversion tool copies that entire configuration set to the referenced model.

  If the referencing model uses a referenced configuration set, then both the referencing and referenced models use the same referenced configuration set.

- **Variables** – All of the model workspace variables of the original model are copied into the model workspace of the *referenced* model.

- **Requirements links** – Requirements links created with the Simulink Verification and Validation software (for example, requirements links to blocks and signals) are copied. Any requirements links on the subsystem that you convert are transferred to the new Model block.

Connect the Model Block and Perform Other Post-Conversion Tasks

After you successfully complete the conversion:

1. Connect the referenced model.
   a. Delete the subsystem block from the source model.
   b. Copy the new Model block to the location of the deleted subsystem block.

   Simulink automatically reconnects all signals. The source model is a parent model that contains the referenced model.

2. For root Inport blocks in the new referenced model, check the **Interpolate data** parameter to make sure it is appropriate. For details, see the Inport block documentation.

3. (Optional) Delete unused duplicate variables.

   The conversion tool copies into the model workspace of the *referenced* model (for example, `ModelB`) all of the model workspace variables of the *referencing* model (`ModelA`). This step results in duplicate variables in the two model workspaces. To improve the reliability of your model in case the model changes in the future, consider removing unused variables or moving variables that are used by both `ModelA` and `ModelB`:

   - For a model workspace variable used only by the referencing model (`ModelA`), delete the variable from the model workspace of the referenced model (`ModelB`).
   - For a model workspace variable used only by the referenced model (`ModelB`), delete the variable from the model workspace of the referencing model (`ModelA`).
   - For model workspace variables used by both the referencing and referenced model, consider moving that variable to the base workspace.

4. (Optional) To achieve similar results in the new referenced model as you did by using the Variant Subsystem block, convert each of the variant subsystems to referenced models, and then use a Model Variants block. For more information, see “Set Up Model Variants” on page 8-5.

If you convert a masked subsystem, you may need to perform some additional tasks to maintain the same general behavior that the masked subsystem provided. For details, see “Convert a Masked Subsystem” on page 6-19.

Convert a Masked Subsystem

Perform the tasks described in:

- “Select Subsystems to Convert” on page 6-12.
- “Prepare the Model for Conversion” on page 6-13.
- “Run a Conversion Tool” on page 6-16.
- “Connect the Model Block and Perform Other Post-Conversion Tasks” on page 6-18.

If the subsystem that you converted contains a mask, then you might want to mask the Model block in your new referenced model (see “Masking”). Configure the referenced model to support the functionality that was in the masked subsystem.

Note The referenced model does not support the functionality that you can achieve with mask initialization code to create masked parameters.

Masked Subsystem Functionality	Referenced Model Configuration
Masked parameters	**1** In the model workspace of the referenced model, create a variable for each masked parameter. **2** In the Model Explorer, select the `Model Workspace` node. In the Dialog pane, in the **Model arguments** parameter, enter the variables that you want to be model arguments.

Masked Subsystem Functionality	Referenced Model Configuration
	3 In the new Model block, for the **Model arguments** parameter, specify the values for the model arguments.
Masked callbacks, icons, ports, and documentation	In the backup copy of the masked subsystem, open the Mask Editor and select the content to copy into to masked Model block. In the Mask Editor for the new Model block, copy the appropriate content from the masked subsystem that you converted.

Referenced Model Simulation Modes

In this section...

Simulation Modes for Referenced Models

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 6-25.

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 6-37 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 Embedded Coder software.

For more information, see "Numerical Equivalence Testing" in the 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 Embedded Coder software.

For more information, see "Numerical Equivalence Testing" in the Embedded Coder documentation.

Specify 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 Embedded Coder documentation:

- "Code Interfaces for SIL and PIL"
- "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 a Normal mode 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.

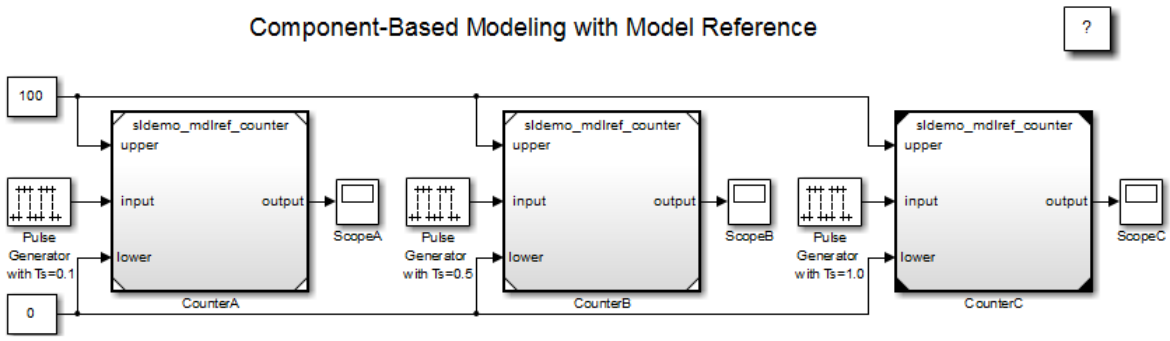
For a description of how to set up your model to control which instance of a referenced model in Normal mode has visibility and to ensure proper simulation of the model, see "Specify the Instance That Has Normal Mode Visibility" on page 6-28.

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` model has three Model blocks (`CounterA`, `CounterB`, and `CounterC`) that each reference the `sldemo_mdlref_counter` model.

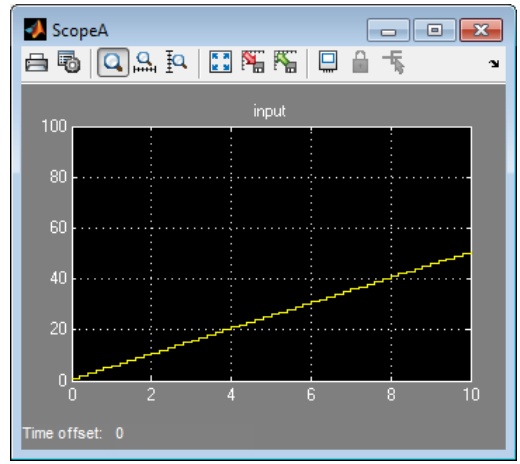
If you update the diagram, the `sldemo_mdlref_basic` displays different icons for each of the three Model blocks that reference `sldemo_mdlref_counter`.



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` model shows the use of the Model Dependency Viewer for a model that has multiple Normal mode instances of a referenced model. The model shows what you need to do to set up a model with multiple referenced instances in Normal mode.

Set 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 "Specify the Instance That Has Normal Mode Visibility" on page 6-28.

Specify 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 Visibility" on page 6-29.

2 "Set Normal Mode Visibility" on page 6-30.

3 Simulate the top model to apply the new Normal Mode Visibility settings.

Determine Which Instance Has Normal Mode Visibility. 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 `ModelReferenceNormalModeVisibilityBlockPath` 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 is the block path for the Model block that references the model that has Normal Mode Visibility enabled. For example:

```
get_param('sldemo_mdlref_basic',...
 'ModelReferenceNormalModeVisibilityBlockPath')

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 **Diagram > Subsystem & Model Reference > Model Block 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 "Model Block Normal Mode Visibility Dialog Box" on page 6-31.

- 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);
    ```

  - 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.

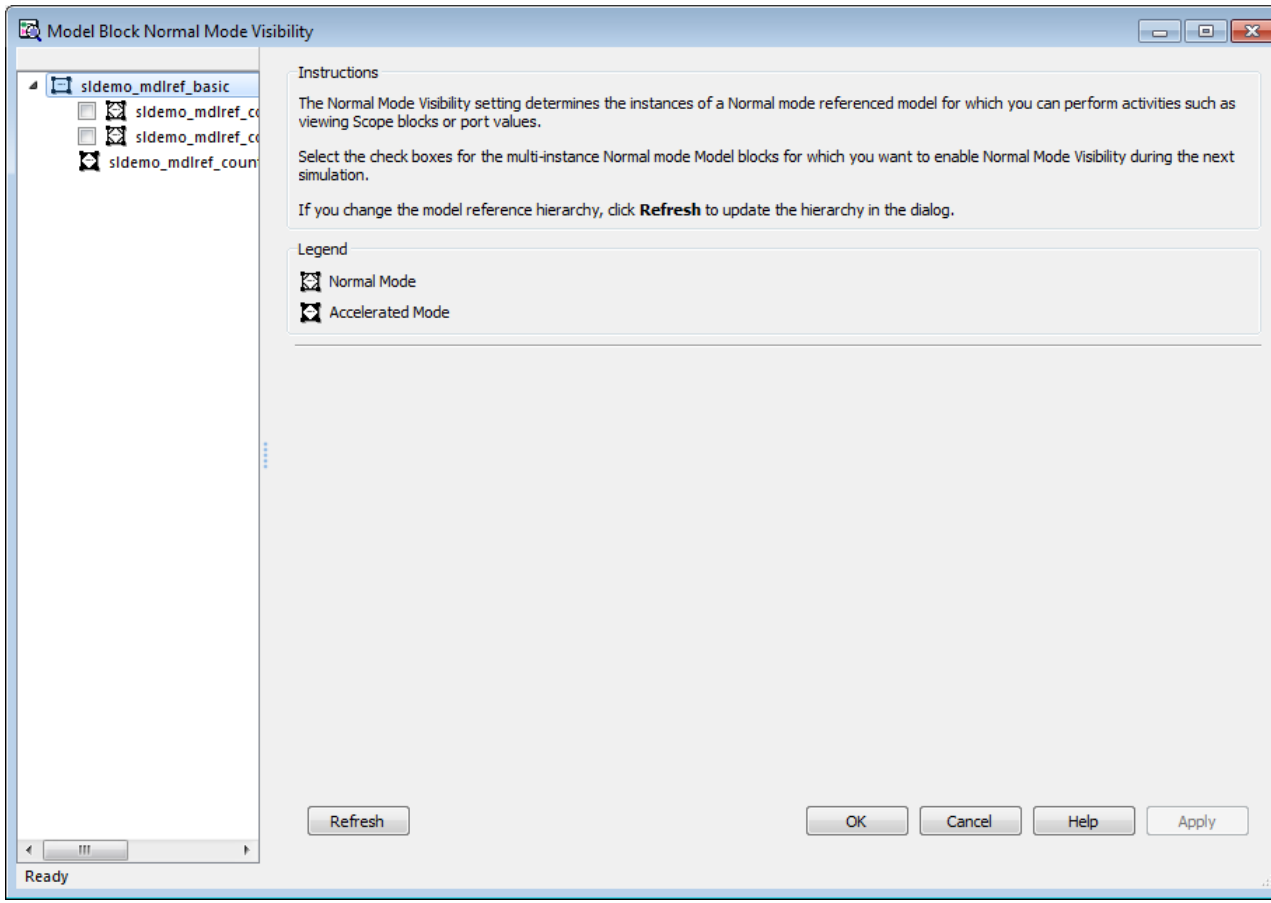
Model Block Normal Mode Visibility Dialog Box

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 6-25.

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 "Specify the Instance That Has Normal Mode Visibility" on page 6-28.

Open 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 **Diagram > Subsystem & Model Reference > Model Block Normal Mode Visibility**.

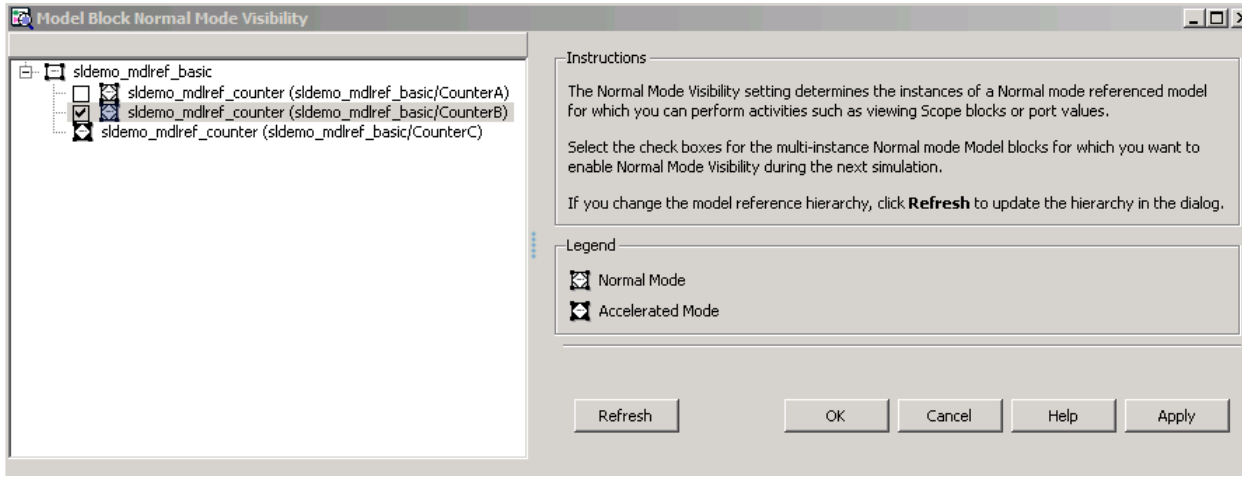
The dialog box for the `sldemo_mdlref_basic` model, with the hierarchy pane expanded, looks like this:



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.

Select 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 Hierarchy. 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 "Acceleration" documentation. For information about Rapid Accelerator mode, see "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 “Acceleration”
- Rapid Accelerator mode execution of a freestanding or top model, as described in “Rapid Simulations”

While the different types of acceleration share many capabilities and techniques, they have different implementations, requirements, and limitations.

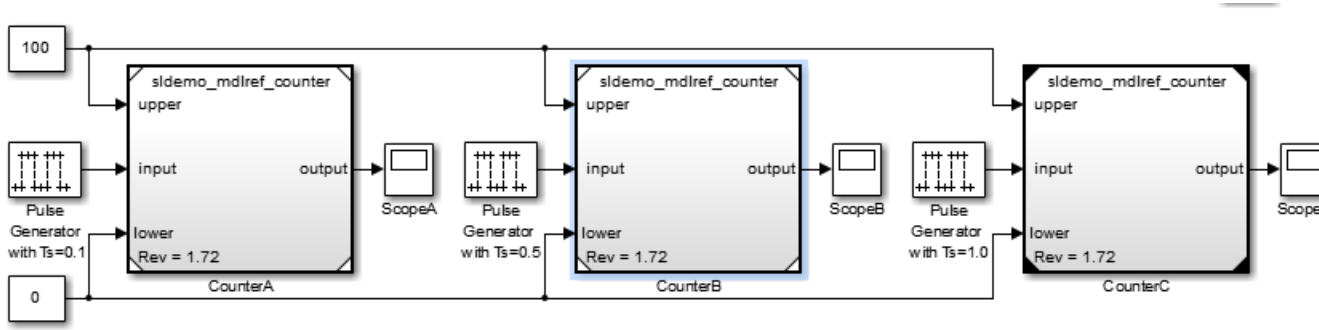
View a Model Reference Hierarchy

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 "Model Dependency Viewer" on page 9-83 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.

Display Version Numbers

To display the version numbers of the models referenced by a model, for the parent model, choose **Display > Blocks > Block Version for Referenced Models**. 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 changed

See “Manage Model Versions” on page 4-107 and “Refresh Model Blocks” on page 6-74 for more information.

Model Reference Simulation Targets

In this section...

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.

If you have a Simulink Coder license, 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 Simulink Coder generates code
- System target — A file that tells Simulink Coder how to generate code for particular purpose
- Rapid Simulation target (RSim) — A system target file supplied with Simulink Coder
- Model reference target — A library module that contains Simulink Coder 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 or more instance of a submodel executes in Normal mode, and one or more instance executes in Accelerator mode:

- Simulink creates a simulation target for the Accelerator mode instances.

- The Normal mode instances do 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 6-84 for details.

Build 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 perform an update diagram for a parent model

If the simulation target already exists, then by default Simulink checks whether the submodel has structural changes since the target was last generated. If so, Simulink regenerates the target to reflect changes in the model. For details about how Simulink detects whether to rebuild a model reference target, see the "Rebuild" parameter documentation.

You can change this default behavior to modify the rebuild criteria or specify that Simulink always or never rebuilds targets. See "Rebuild" for details.

To generate simulation targets interactively for Accelerator mode referenced models, do one of these steps:

- Update the diagram on a model that directly or indirectly references the model that is in Accelerator mode
- 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.

Reduce 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".)
- To minimize change detection time, consider setting **Configuration Parameters > Model Referencing > Rebuild options** to `If any changes in known dependencies detected` on the top model. See "Rebuild".

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.

Simulation Target Output File Control

Simulink creates simulation targets in the `slprj` subfolder of the working folder. If `slprj` does not exist, Simulink creates it.

Note Simulink Coder code generation also uses the `slprj` folder. Subdirectories in `slprj` provide separate places for simulation code, Simulink Coder code, and other files. For details, see "Control the Location for Generated Files".

By default, the files generated by Simulink diagram updates and model builds are placed in a build folder, the root of which is the current working folder (`pwd`). However, in some situations, you might want the generated files to go to a root folder outside the current working folder. For example:

- You need to keep generated files separate from the models and other source materials used to generate them.
- You want to reuse or share previously-built simulation targets without having to set the current working folder back to a previous working folder.

You might also want to separate generated simulation artifacts from generated production code.

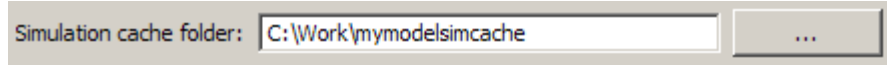
To allow you to control the output locations for the files generated by diagram updates and model builds, the software allows you to separately specify the *simulation cache folder* build folder. The simulation cache folder is the root folder in which to place artifacts used for simulation.

To specify the simulation cache folder, use *one* of these approaches:

- Use the `CacheFolder` MATLAB session parameter.
- Open the Simulink Preferences dialog box (**File > Simulink Preferences**) and specify a location on your file system for the **Simulation cache folder**, which, if specified, provides the initial defaults for the MATLAB session parameters.

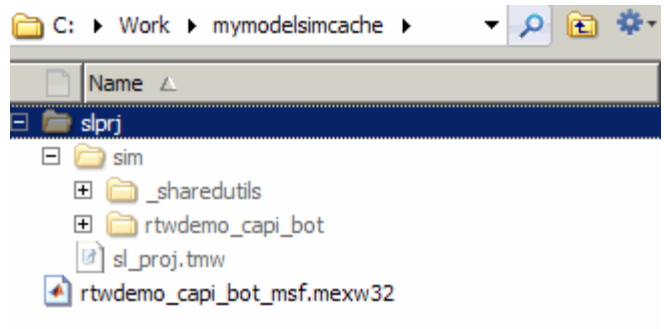
Control Output Location for Model Build Artifacts Used for Simulation

The Simulink preference **Simulation cache folder** provides control over the output location for files generated by Simulink diagram updates. The preference appears in the Simulink Preferences Window, Main Pane, in the **File generation control** group. To specify the root folder location for files generated by Simulink diagram updates, set the preference value by entering or browsing to a folder path, for example:



The folder path that you specify provides the initial default for the MATLAB session parameter `CacheFolder`. When you initiate a Simulink diagram update, any files generated are placed in a build folder at the root location specified by `CacheFolder` (if any), rather than in the current working folder (`pwd`).

For example, using a 32-bit Windows host platform, if you set the **Simulation cache folder** to `'C:\Work\mymodelsimcache'` and then simulate the model `rtwdemo_capi`, files are generated into the specified folder as follows:



As an alternative to using the Simulink preferences GUI to set **Simulation cache folder**, you also can get and set the preference value from the command line using `get_param` and `set_param`. For example,

```
>> get_param(0, 'CacheFolder')

ans =

     ''

>> set_param(0, 'CacheFolder', fullfile('C:','Work','mymodelsimcache'))
>> get_param(0, 'CacheFolder')

ans =

C:\Work\mymodelsimcache
```

Also, you can choose to override the **Simulation cache folder** preference value for the current MATLAB session.

Override Build Folder Settings for the Current MATLAB Session

The Simulink preferences **Simulation cache folder** and **Code generation folder** provide the initial defaults for the MATLAB session parameters `CacheFolder` and `CodeGenFolder`, which determine where files generated by Simulink diagram updates and model builds are placed. However, you can override these build folder settings during the current MATLAB session, using the `Simulink.fileGenControl` function. This function allows you to directly manipulate the MATLAB session parameters, for

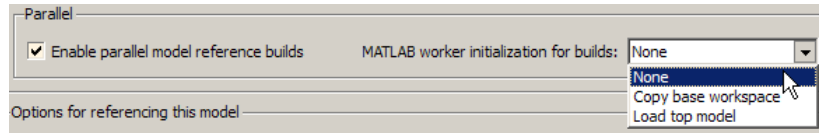
example, overriding or restoring the initial default values. The values you set using `Simulink.fileGenControl` expire at the end of the current MATLAB session. For more information and detailed examples, see the `Simulink.fileGenControl` function reference page.

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 "Model Referencing Limitations" on page 6-80.

Name Length Requirement

The name of a referenced model must contain fewer than 60 characters, exclusive of the `.slx` or `.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 "Manage a Configuration Set" on page 10-12. 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. The Simulink 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 "Manage a Configuration Reference" on page 10-18 for details.

Note Configuration parameters on the **Code Generation** pane of the Configuration Parameters dialog box do not affect simulation in either Normal or Accelerated mode. **Code Generation** parameters affect only code generation by Simulink Coder itself. Accelerated mode simulation requires code generation to create a simulation target. Simulink uses default values for all **Code Generation** 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 6-48.
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 6-49.
	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 6-49.
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 3-21 and "Choose a Solver" on page 14-9.

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 "Parameterize Model References" on page 6-52 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. The **Configuration Parameters > Model Referencing > Total number of instances allowed per top model** parameter 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 Simulink Coder 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 6-81 and "Accelerator Mode Reusability Limitations" on page 6-85.

Model Structure Requirements

The following requirements relate to the structure of a model reference hierarchy.

Signal Propagation Requirements

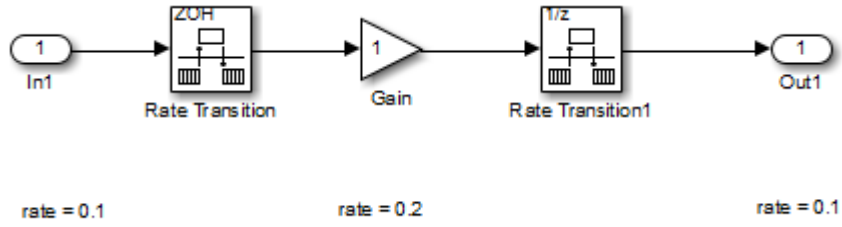
The signal name must explicitly appear on any signal line connected to an Outport block of a referenced model. A signal connected to an unlabeled line of an Outport block of a referenced model cannot propagate out of the Model block to the parent model.

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 48-2 for more information.

Sample Time Requirements

The first nonvirtual block connected to a root-level Inport or Outport block of a referenced model must have the same sample time as the port to which it connects. 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

Parameterize 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 6-49, 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.

You can use a structure parameter to group variables for parameterizing model references. For details, see "Structure Parameters" on page 24-16.

Global Nontunable Parameters

A *global nontunable parameter* is a MATLAB variable or a `Simulink.Parameter` object whose storage class is `auto`. The parameter must exist in the MATLAB workspace.

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 "Specify Parameter Values" on page 24-6 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 "Tunable Parameters" on page 24-13 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 `sldemo_mdlref_datamngt` model demonstrates techniques for using model arguments. The model 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 "Masking" 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:

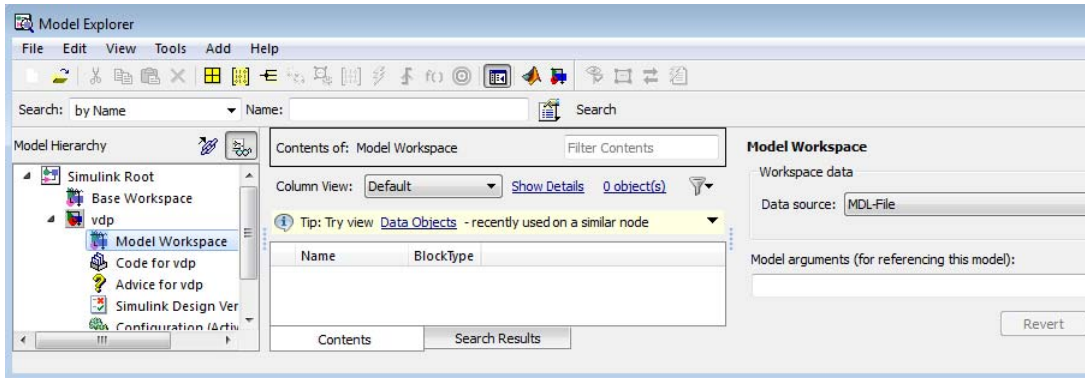
- Create MATLAB variables in the model workspace.
- Register the variables to be model arguments.
- Assign values to those arguments in Model blocks.

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.

Register the Model Arguments

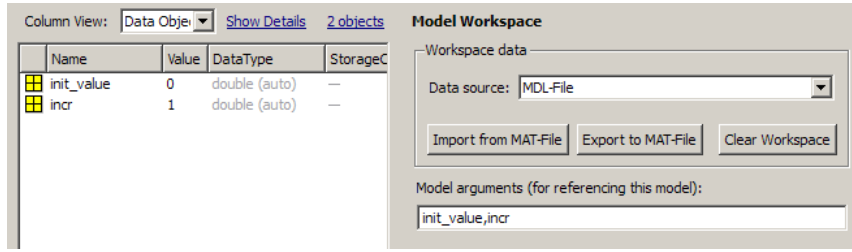
To register MATLAB variables as model arguments:

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:

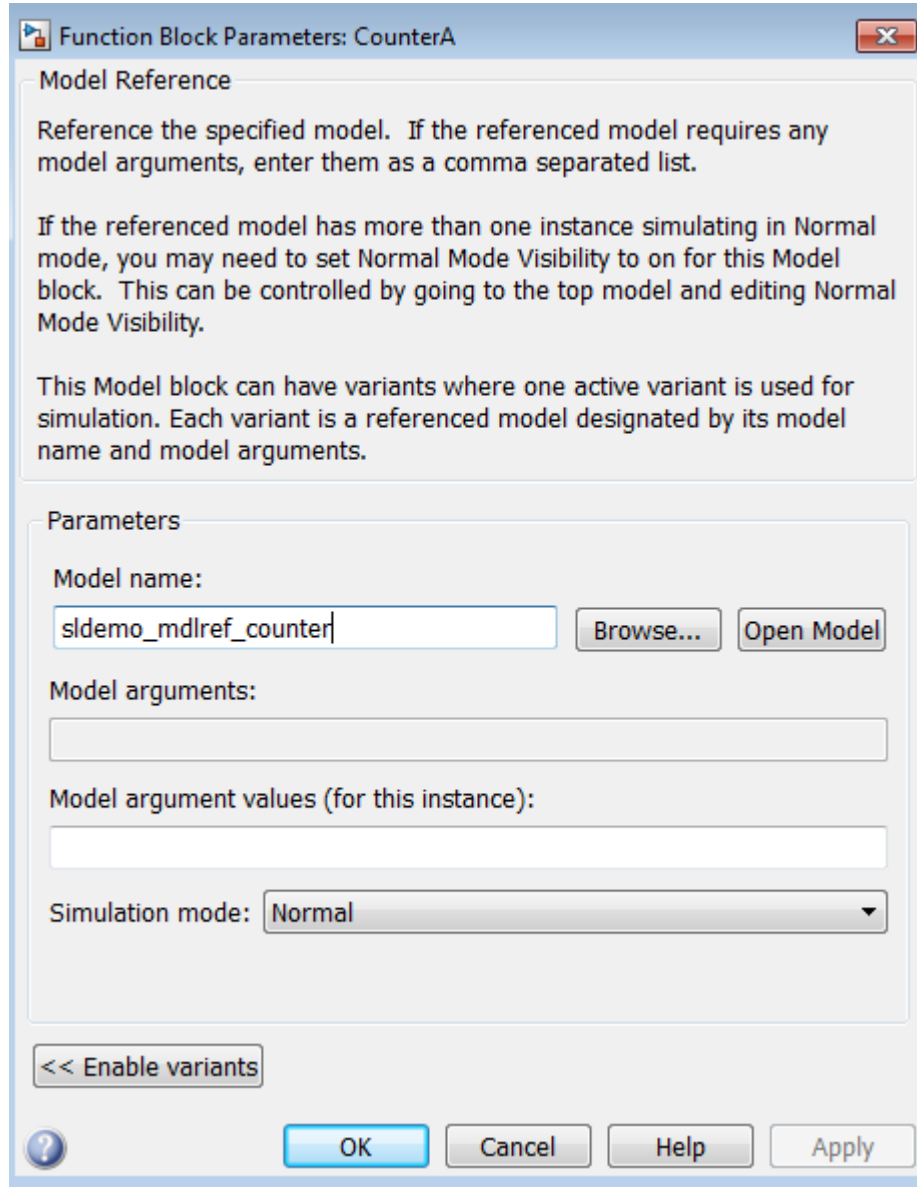


3 Click **Apply** to confirm the entered names.

Assign 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 block parameters dialog box of the Model block by right-clicking the block and choosing **Block Parameters (ModelReference)** 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 "Symbol Resolution Process" on page 4-76. All values must be numeric (including objects with numeric values).

Note Simulink generates an error if you use a model argument in an expression that is nontunable because of "Tunable Expression Limitations".

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.

Conditional Referenced Models

In this section...

Kinds of Conditional Referenced Models

You can set up referenced models so that they execute conditionally, similar to conditional subsystems. For information about conditional subsystems, see "About Conditional Subsystems" on page 7-2.

You can use the following kinds of conditionally executed referenced models:

- Enabled
- Triggered
- Enabled and triggered
- Function-call

Enabled Models

Use an Enable block to insert an enable port in a model. Add an enable port to a model if you want a referenced model to execute at each simulation step for which the control signal has a positive value.

To see an example of an enabled *subsystem*, see `enablesub`. A corresponding enabled referenced model would use the same blocks as are in the enabled subsystem.

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 trigger type (`rising`, `falling`, or `either`).

To view a model that illustrates how you can use trigger ports in referenced models, see the Introduction to Managing Data with Model Reference example. In that example, see the "Top Model: Scheduling Calls to the Referenced Model" section.

Triggered and Enabled Models

A triggered and enabled model executes once at the time step for which a trigger event occurs, if the enable control signal has a positive value at that step.

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 7-30 for more information. A referenced model that you can invoke in this way is a *function-call model*.

For an example of a function-call model, see the `sldemo_mdlref_fcncall` model.

Working with Conditional Referenced Models

Use a similar approach for each kind of conditionally executed referenced model for these tasks:

- "Create Conditional Models" on page 6-61
- "Reference Conditional Models" on page 6-63
- "Simulate Conditional Models" on page 6-64
- "Generate Code for Conditional Models" on page 6-64

Each kind of conditionally executed model has some model creating requirements. For details, see “Requirements for Conditional Models” on page 6-65.

Create Conditional Models

To create a conditional model:

1. At the root level of the referenced model, insert one of the following blocks:

Kind of Model	Blocks to Insert
Enabled	Enable
Triggered	Trigger
Triggered and Enabled	Trigger and Enable
Function-Call	Trigger

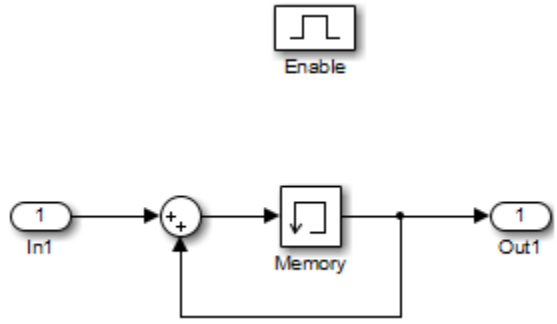
   For an enabled model, go to Step 3.

2. For the Trigger block, set the **Trigger type** parameter, based on the kind of model:

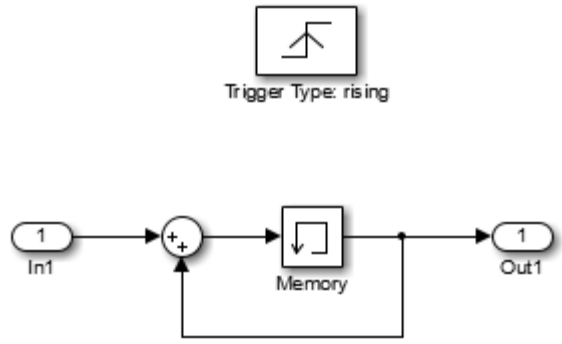
Kind of Model	Trigger Type Parameter Setting
Triggered Triggered and enabled	One of the following: • `rising` • `falling` • `either`
Function-Call	`function-call`

3. Create and connect other blocks to implement the model.

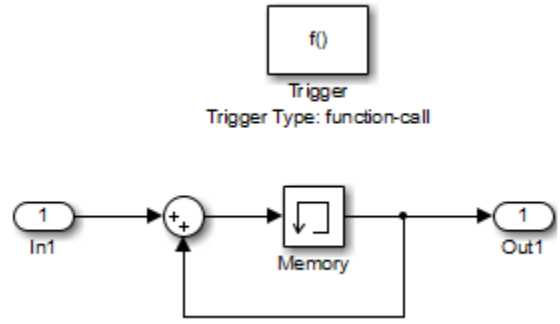
   Enabled model example:



Triggered model example:



Function-call model example:



4 Ensure that the model satisfies the requirements for a conditional model. See the appropriate section:

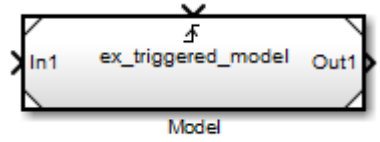
- “Enabled Model Requirements” on page 6-65
- “Triggered Model Requirements” on page 6-65
- “Function-Call Model Requirements” on page 6-65

Reference Conditional Models

To create a reference to a conditional model:

1 Add a Model block to the model that you want to reference the triggered model. See “Create a Model Reference” on page 6-8 for details.

The top of the Model block displays an icon that corresponds to the kind of port used in the referenced model. For example, for a triggered model, the top of the Model block displays the following icon.



For enabled, triggered, and triggered and enabled models, go to Step 3.

2 For a function-call model, 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 Create and connect other blocks to implement the parent model.

4 Ensure that the referencing model satisfies the conditions for model referencing. See "Simulink Model Referencing Requirements" on page 6-45 and "Model Referencing Limitations" on page 6-80 for details.

Simulate Conditional Models

Use Normal, Accelerator, or Rapid Accelerator mode to simulate a conditional model.

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 or Enable 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 conditional model, specify the inputs using the **Configuration Parameters > Data Import/Export > Input** parameter. The following conditions apply when you use the "Input" parameter for trigger and enable port inputs:

- Use the last data input for the trigger or enable input. For a triggered and enabled model, use the last data input for 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 "Techniques for Importing Signal Data" on page 45-61.

You can log data to determine which signal caused the model to run. For the Trigger or Enable block, in the **Main** pane of the Block Parameters dialog box, select **Show output port**.

Generate Code for Conditional Models

You can build model reference Simulink Coder and SIM targets for referenced models that contain a trigger or enable port. You cannot generate standalone Simulink Coder or PIL code. For information about code generation for

referenced models, see “Reusable Code and Referenced Models” and “Generate Code for Referenced Models”.

Requirements for Conditional Models

Conditional models must meet the requirements for:

- Conditional subsystems (see “Conditional Subsystems”)
- Referenced models (see “Simulink Model Referencing Requirements” on page 6-45)

In addition, conditional models must meet the requirements described below.

Enabled Model Requirements

- Multi-rate enabled models cannot use multi-tasking solvers. You must use single-tasking.
- For models with enable ports at the root, if the model uses a fixed-step solver, the fixed-step size of the model must not exceed the rate for any block in the model.
- The signal attributes of the enable port in the referenced model must be consistent with the input that the Model block provides to that enable port.

Triggered Model Requirements

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.

Function-Call Model Requirements

- 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.

Protected Model

A protected model provides the ability to deliver a model without revealing the intellectual property of the model. A protected model is a referenced model that hides all block and line information. It does not use encryption technology. Creating a protected model requires a Simulink Coder license. However, you can simulate a protected model with only a Simulink license. A third party that receives a protected model must match the platform and the version of Simulink for which the protected model was generated.

You cannot view the contents of a protected model, therefore you cannot log signals in a protected model. Protected models do not appear in the model hierarchy in the Model Explorer.

Simulating a protected model requires that the protected model:

- Be available somewhere on the MATLAB path.
- Be referenced by a Model block in a model that executes in Normal or Accelerator mode. To run in Accelerator mode, the protected model must include code generation capabilities.
- Receives from the Model block the values needed by any defined model arguments.
- Connects via the Model block to input and output signals that match the input and output signals of the protected model.

To locate protected models in your model:

- The MATLAB Folder Browser shows a small image of a lock on the node for the protected model file.
- A Model block that references a protected model shows a small image of a shield in the lower left corner of the Model block.

For more information, see “Use Protected Model in Simulation” on page 6-68. For more information about creating protected referenced models, see “Protect a Referenced Model”.

Use Protected Model in Simulation

When you receive a protected model it might be included in a protected model package. The package could include additional files, such as a harness model and a MAT-file. A protected model file has an `.slxp` extension. A typical workflow for using a protected model in a simulation 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 referencing the protected model into your model.
4. If a protected model report was generated when the protected model was created, double-click the Model block to open it. In the **Summary** of the report, check that your Simulink version and platform match the software and platform used to create the protected model.
5. Connect signals to the Model block that match its input and output port requirements.
6. Provide any needed model argument values. See "Assign Model Argument Values" on page 6-56.

There are also other ways to include the protected model into your model:

- Use your own Model block rather than the Model block in the harness model.

  Note When you change a Model block to reference a protected model, the **Simulation mode** of the block becomes `Accelerator`. You cannot change the mode.

- Start with the harness model, add more constructs to it, and use it in your model.
- Use the protected model as a variant in a Model Variant block, as described in "Set Up Model Variants" on page 8-5.

- Apply a mask to the Model block that references the protected model. See "Masking".
- Configure a callback function, such as **LoadFcn**, to load the MAT-file automatically. See "Callback Functions" on page 4-54.

Now you can simulate the model that includes the protected model. Because the protected model is set to Accelerator mode, the simulation produces the same outputs that it did when used in Accelerator mode in the source model.

Inherit 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 6-71
- 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 6-73.

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 `Timeseries` or `Structure With Time` 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 "Sample Times" 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.

Refresh Model Blocks

Refreshing a Model block updates its internal representation to reflect changes in the interface of the model that it references.

Examples of when to refresh a Model block include:

- Refresh a Model block that references model that has gained or lost a port.
- Refresh all the Model blocks that reference a model whose interface has changed.

You do not need to refresh a Model block if the changes to the interface of the referenced model do not affect how the referenced model interfaces to its parent.

To update a specific Model block, from the context menu of the Model block, select **Diagram > Subsystem & Model Reference > Refresh Selected Model Block**.

To refresh all Model blocks in a model (as well as linked blocks in a library or model), in the Simulink Editor select **Diagram > Refresh Blocks**. You can also refresh a model by starting a simulation or generating code.

You can use Simulink diagnostics 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**

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 Parameters > 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.
- Simulink Coder 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 "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.

Simulink Coder Considerations

A referenced model in Accelerator mode cannot use S-functions generated by the Simulink Coder software.

Noninlined S-functions in referenced models are supported when generating Simulink Coder code.

The Simulink Coder S-function target does not support model referencing.

For general information about using Simulink Coder and model referencing, see "Model Reference".

Buses in Referenced Models

To have bus data cross model reference boundaries, use a nonvirtual bus. Use a bus object (`Simulink.Bus`) to define the bus.

For an example of a model referencing model that uses buses, see `sldemo_mdref_bus`. For more information, see "Bus Data Crossing Model Reference Boundaries" on page 48-93.

Signal Logging in Referenced Models

In a referenced model, you can log any signal configured for signal logging. Use the Signal Logging Selector to select a subset or all of the signals configured for signal logging for a model reference hierarchy. For details, see "Models with Model Referencing: Overriding Signal Logging Settings" on page 45-45.

Model Referencing Limitations

In this section...

Introduction

The following limitations apply to model referencing. In addition, a model reference hierarchy must satisfy all the requirements listed in "Simulink Model Referencing Requirements" on page 6-45.

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)

An example of a block that accepts indexes is the Assignment block. An example of a block that produces indexes is the For Iterator block.

The two cases result in a lack of propagation that can cause Simulink to fail to detect incompatible index connections. These two cases are:

- If a root-level input port of the referenced model connects 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 block.

- If a root-level output port of the referenced model connects 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 block.

General Reusability Limitations

If a referenced model has any of the following characteristics, 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. An error occurs if you do not set the parameter correctly, or if more than one instance of the model exists in the hierarchy. The model characteristics that require that the **Total number of instances allowed per top model** setting be `One` are:

- The model contains any To File blocks
- 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. Also, mask callbacks cannot change the Model block name or simulation mode. These invalid callbacks generate an error.
- If a mask specifies the name of the model that a Model block references, the mask must provide the name of the referenced model directly. You cannot use a workspace variable to provide the name.
- The mask workspace of a Model block is not available to the model that the Mask block references. Any variable that the referenced model uses must resolve to either of these workspaces:
  - A workspace that the referenced model defines
  - The MATLAB base workspace

For information about creating and using block masks, see “Masking”.

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 model that the Model block references. See “Debugging” for more information.

Stateflow Limitations

You cannot reference a model multiple times in the same model reference hierarchy if that model that contains a Stateflow chart that:

- Contains exported graphical functions
- Is part of a Stateflow model that contains machine-parented data

Subsystem Limitations

- You cannot place a Model block in an iterator subsystem, if the Model block references a model that contains Assignment blocks that are not in an iterator subsystem.
- In a configurable subsystem with a Model block, during model update, do not change the subsystem that the configurable subsystem selects.

Other Limitations

- Referenced models can only use asynchronous rates if the model meets *both* of these conditions:
  - An external source drives the asynchronous rate through a root-level Inport block.
  - The root-level Inport block outputs a function-call signal. See Asynchronous Task Specification.
- A referenced model can input or output only those user-defined data types that are fixed-point or that `Simulink.DataType` or `Simulink.Bus` objects define.

- To initialize the states of a model that references other models with states, specify the initial states in structure or structure with time format. For more information, see “Import and Export State Information for Referenced Models” on page 45-120.
- A referenced model cannot directly access the signals in a multi-rate bus. To overcoming this limitation, see Connecting Multi-Rate Buses to Referenced Models.
- 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.
- To use a masked subsystem in a referenced model that uses model arguments, do not create in the mask workspace a variable that derives its value from a mask parameter. Instead, use blocks under the masked subsystem to perform the calculations for the mask workspace variable.

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. The Normal Mode Visibility setting determines which instance Simulink displays. Normal Mode Visibility includes the display of Scope blocks and data port values.

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 “Set Up a Model with Multiple Instances of a Referenced Model in Normal Mode” on page 6-28.

Simulink Profiler

In Normal mode, enabling the Simulink Profiler on a parent model does not enable profiling for referenced models. You must enable profiling separately for each referenced model. See “Capture Performance Data” on page 22-31.

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

Subsystem Limitations

If you generate code for an atomic subsystem as a reusable function, when you use Accelerator mode, the inputs or outputs that connect the subsystem to a referenced model can affect code reuse. See "Reusable Code and Referenced Models" for details.

Simulink Tool Limitations

Simulink tools that require access to the internal data or the configuration of a model 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. Examples of tools that require access to model internal data or configuration include:

- Model Coverage
- Simulink Report Generator
- Simulink Debugger
- Simulink Profiler

Runtime Checks

Some blocks include runtime checks that are disabled when you include the block in a referenced model in Accelerator mode. Examples of these blocks include Assignment, Selector, and MATLAB Function blocks)

Data Logging Limitations

The following logging methods have no effect when specified in referenced models executing in Accelerator mode:

- To Workspace blocks (for formats other than `Timeseries`)

- Scope blocks
- All types of runtime display, such as Port Values Display

During simulation, the result is the same as if the constructs did not exist.

Accelerator Mode Reusability Limitations

You must set **Configuration Parameters > Model Referencing > Total number of instances allowed per top model** to `One` for a referenced model that executes in Accelerator mode and has any of the following characteristics:

- A subsystem that is marked as function
- An S-function that is:
  - Inlined but has not set the option `SS_OPTION_WORKS_WITH_CODE_REUSE`
  - Not inlined
- A function-call subsystem that:
  - Has been forced by Simulink to be a function
  - Is called by a wide signal

An error occurs in either of these cases:

- You do not set the parameter correctly.
- Another instances of the model exists in the hierarchy, in either Normal mode or Accelerator mode

Customization Limitations

- For restrictions that apply to grouped custom storage classes in referenced models in Accelerator mode, see “Custom Storage Class Limitations”.
- Simulation target code generation for referenced models in Accelerator mode does not support data type replacement.

S-Function Limitations

- If a referenced model in Accelerator mode 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.
- You cannot use the Simulink Coder S-function target in a referenced model in Accelerator mode.
- A referenced model in Accelerator mode cannot use noninlined S-functions in the following cases:
  - The model uses a variable-step solver.
  - Simulink Coder generated the S-function.
  - The S-function supports use of fixed-point numbers as inputs, outputs, or parameters.
  - The S-function uses string 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.

MATLAB Function Block Limitation

A MATLAB Function block in a referenced model that executes in Accelerator mode cannot call MATLAB functions.

Stateflow Limitation

A Stateflow chart in a referenced model that executes in Accelerator mode cannot call MATLAB functions.

Target Limitations

- The Simulink Coder `grt_malloc` targets do not support model referencing.

- The Simulink Coder 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. See "Specify the Simulation Mode" on page 6-23.
- 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 **External mode** 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. To work around this limitation, set the model to Normal mode. See "Specify the Simulation Mode" on page 6-23.

For more information about using PIL mode with model referencing, see "Model Reference" in the Embedded Coder documentation.

7

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 for which execution can be externally controlled. For information that applies to all subsystems, see "Create a Subsystem" on page 4-36.

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 a 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. Simulink supports the following types of conditional subsystems:

- 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 as long as the control signal remains positive. For a more detailed discussion, see "Enabled Subsystems" on page 7-4.
- 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. For more information about triggered subsystems, see "Triggered Subsystems" on page 7-20.
- A *triggered and enabled subsystem* executes once at the time step for which a trigger event occurs if the enable control signal has a positive value at that step. See "Triggered and Enabled Subsystems" on page 7-24 for more information.
- A *control flow subsystem* executes one or more times at the current time step when enabled by a control flow block. A control flow block implements control logic similar to that expressed by control flow statements of programming languages (e.g., `if-then`, `while`, `do`, and `for`). See "Control Flow Logic" on page 4-44 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 7-15 for more information.

For examples of conditional subsystems, see:

- Simulink Subsystem Semantics
- Triggered Subsystems
- Enabled Subsystems
- Advanced Enabled Subsystems

Enabled Subsystems

In this section...

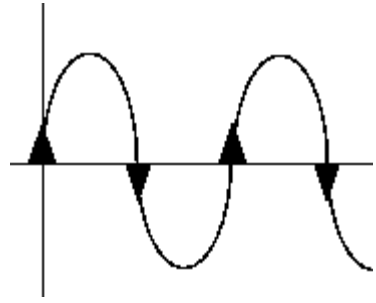
What Are Enabled Subsystems?

Enabled subsystems are subsystems that execute at each simulation step for which the control signal has a positive value.

An enabled subsystem has a single control input, which can be a scalar or a vector.

- 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 one* of the vector elements is greater than zero.

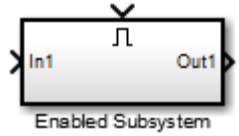
For example, if the control input signal is a sine wave, the subsystem is alternately enabled and disabled. This behavior is shown in the following figure, where an up arrow signifies enable and a down arrow disable.



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 block. 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 block parameters dialog box.
2. In the **Source of initial output value** drop-down list, select `Dialog`.
3. Specify a valid value for the **Initial output** parameter. Valid values include the empty matrix. But `Inf` and `Nan` are not valid values.

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 7-7.

Inheriting Initial Conditions. The Outport block can inherit an initial output value for the subsystem 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 block parameters dialog box.
2. In the **Source of initial output value** drop-down list, select `Dialog` .
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 block parameters dialog box.
2. In the **Source of initial output value** drop-down list, select `Input signal`.

3 Click **OK**.

   The **Initial output** and **Output when disabled** parameters are disabled, and both values are inherited from the input signal.

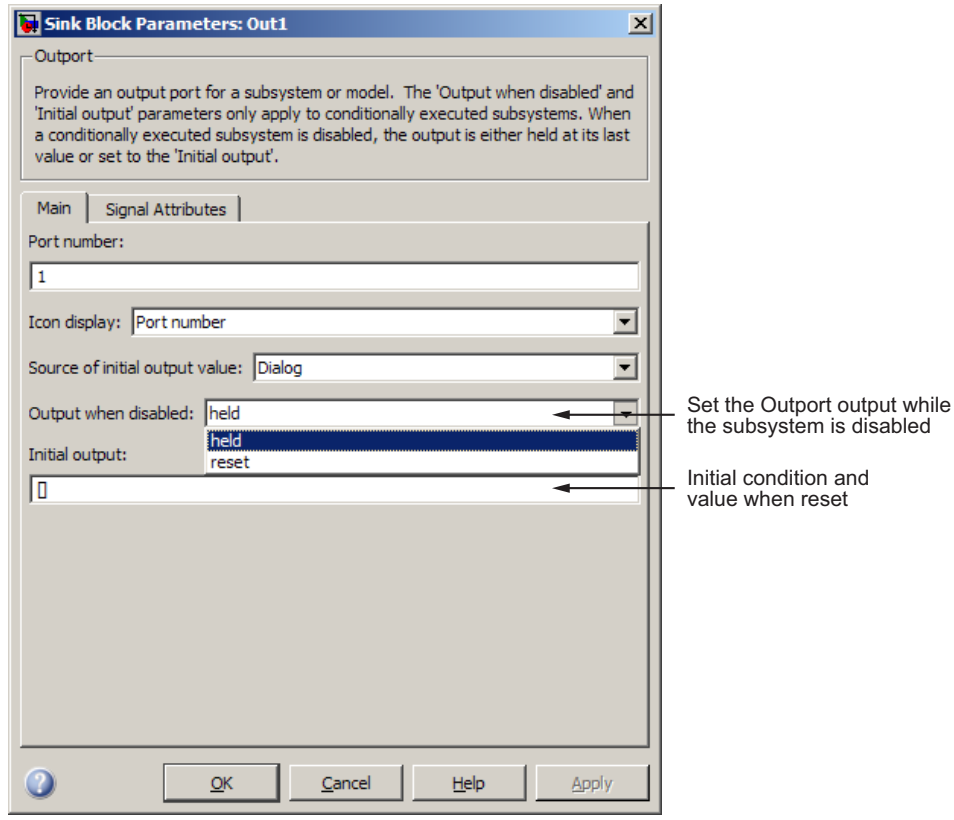
For more information on classic and simplified initialization mode, see "Underspecified initialization detection".

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 the block parameters dialog box for each Outport block and for the **Output when disabled** parameter, select one of the choices.

- 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.

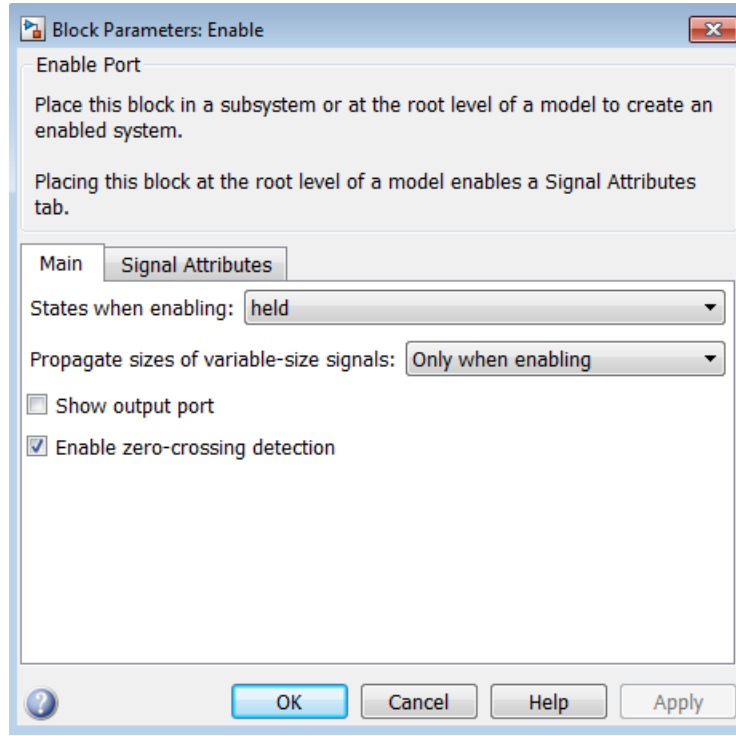
If you are using simplified initialization mode, you must select `held` when connecting a conditionally executed subsystem to a Merge block. For more information, see “Underspecified initialization detection”.

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 parameters 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.

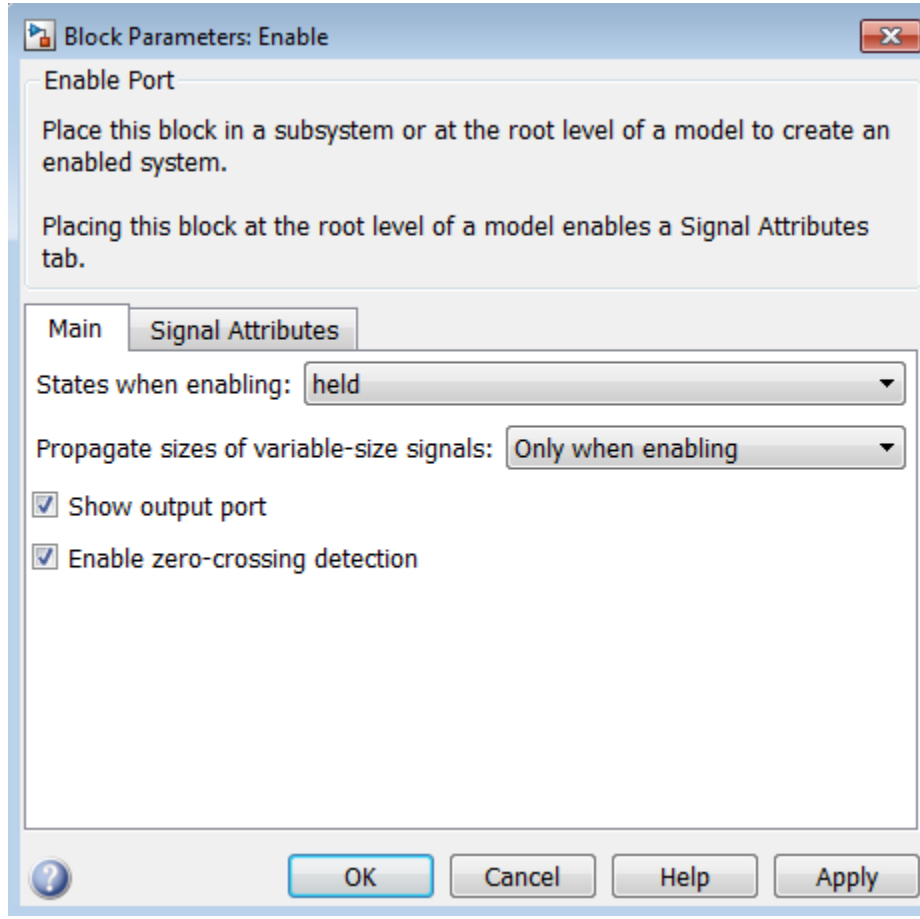


Note If you are using simplified initialization mode, the subsystem elapsed time is always reset during the first execution after becoming enabled, whether or not the subsystem is configured to reset on enable.

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 that 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

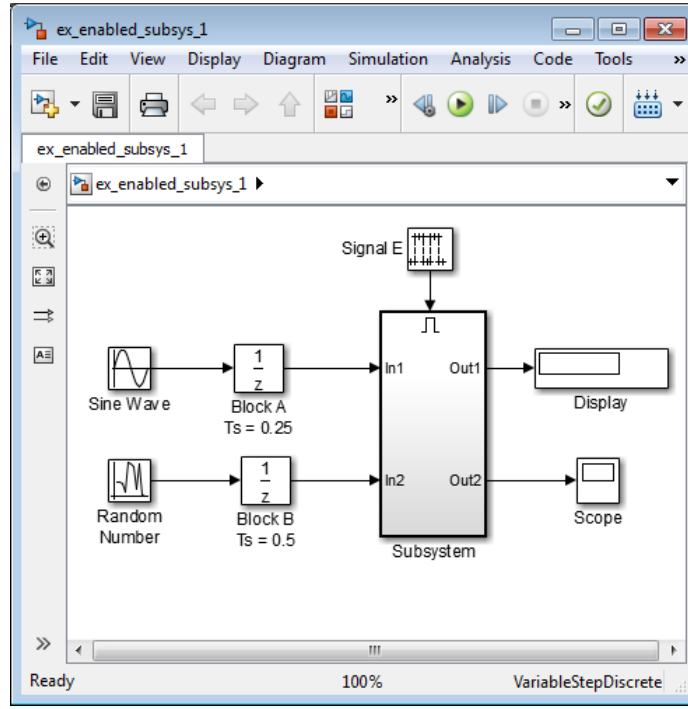
simulation sample time. Enabled subsystems and the model use a common clock.

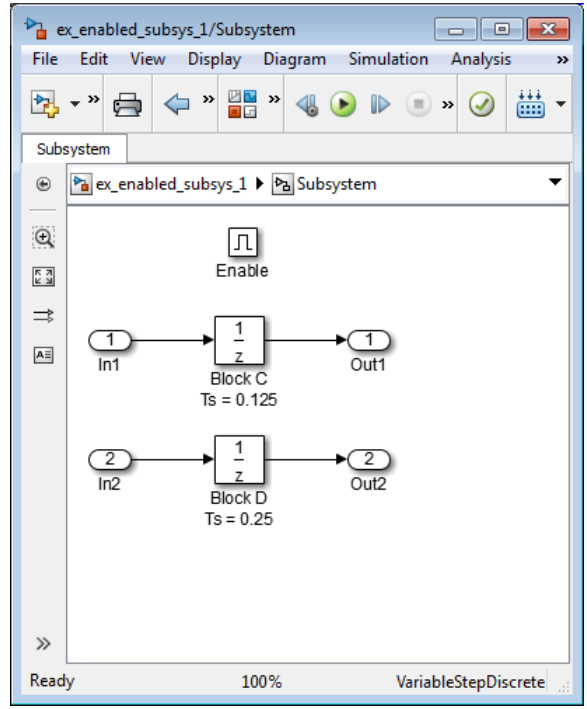
Note Enabled subsystems can contain Goto blocks. However, only state ports can connect to Goto blocks in an enabled subsystem. In the `sldemo_clutch` model, see the `Locked` subsystem for an example of how to use Goto blocks in an enabled subsystem.

For example, this system contains four discrete blocks and a control signal. The discrete blocks are:

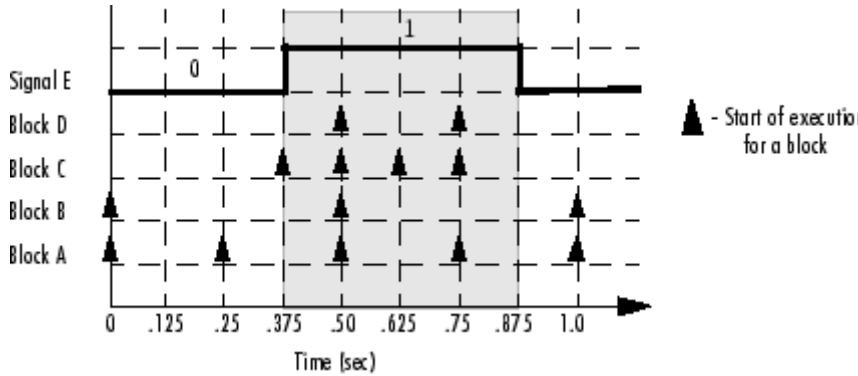
- Block A, which has a sample time of 0.25 second
- Block B, which has a sample time of 0.5 second
- Block C, within the enabled subsystem, which has a sample time of 0.125 second
- Block D, also within the enabled subsystem, which has a sample time of 0.25 second

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.


ex_enabled_subsys_1
File Edit View Display Diagram Simulation Analysis Code Tools
ex_enabled_subsys_1
ex_enabled_subsys_1
Signal E
Sine Wave
1
z
Block A
Ts = 0.25
In1
Out1
Display
Random
Number
1
z
Block B
Ts = 0.5
In2
Out2
Scope
Subsystem
Ready
100%
VariableStepDiscrete



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.

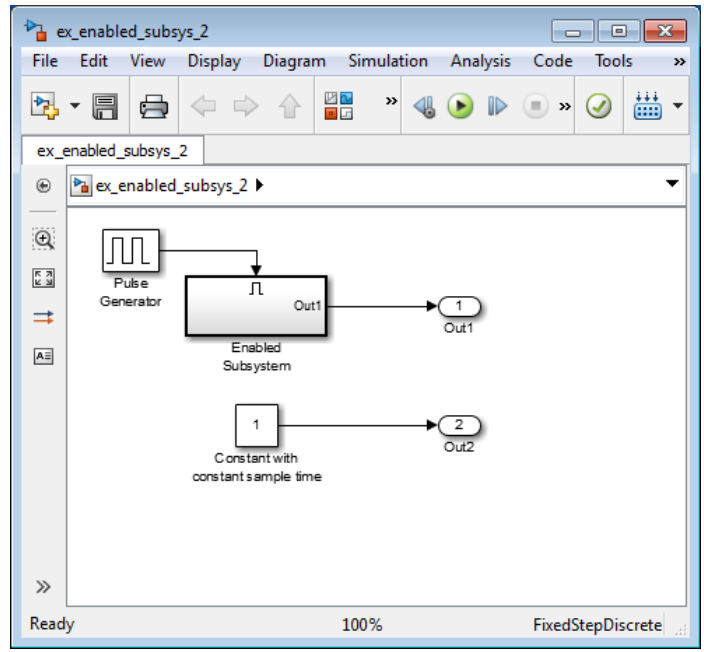
Using Blocks with Constant Sample Times in Enabled Subsystems

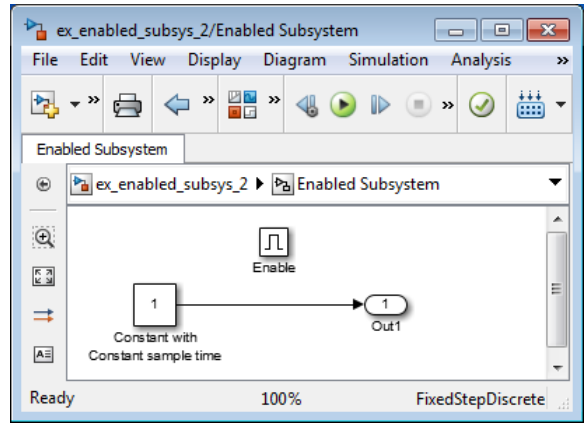
Certain restrictions apply when you connect blocks with constant sample times (see "Constant Sample Time" on page 5-16) to the output port of a conditional subsystem.

- 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 `ex_enabled_subsys_2.mdl`.

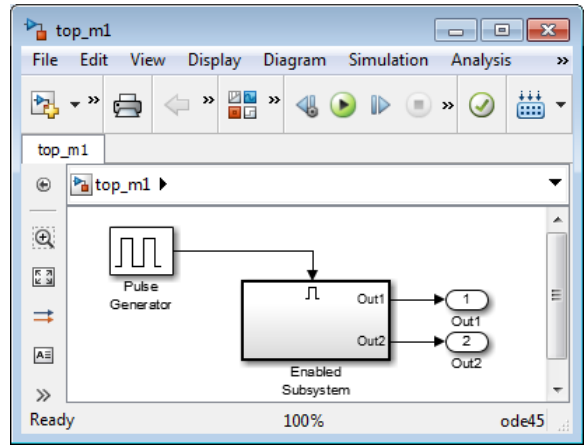


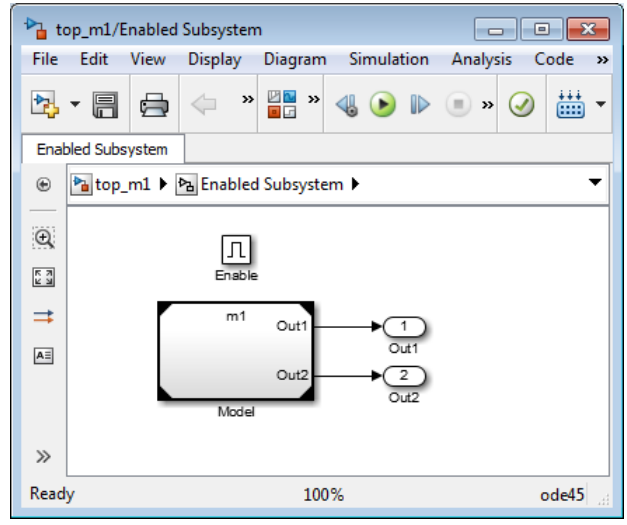


The two Constant blocks in this model have constant sample times. When you simulate the model, the Simulink software converts the sample time of the Constant block inside the enabled subsystem to the rate of the Pulse Generator. If you simulate the model with sample time colors displayed

(see “View Sample Time Information” on page 5-9), 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.

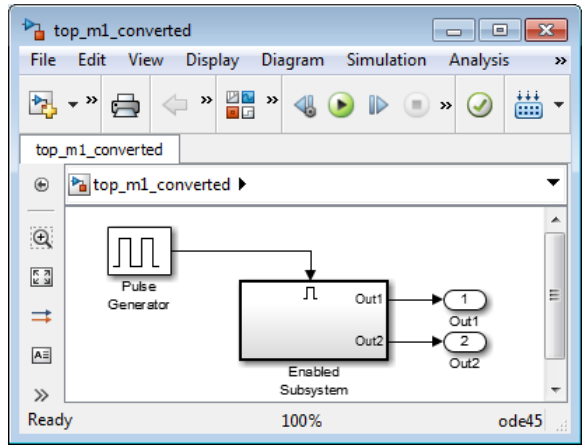
Suppose the model above is referenced from a Model block inside an enabled subsystem, as shown below. (See “Model Reference”.)

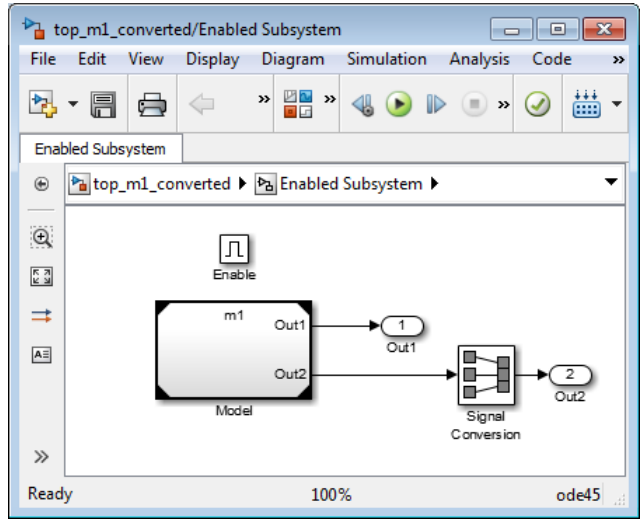




An error appears when you try to simulate the top model, indicating that the second output of the Model block may not be wired directly to the enabled subsystem output port because it has a constant sample time. (See “Model Reference”.)

To avoid this error, insert a Signal Conversion block between the second output of the Model block and the Outport block of the enabled subsystem.





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. In this case, the systems are hybrid because they contain multiple sample times.

Triggered Subsystems

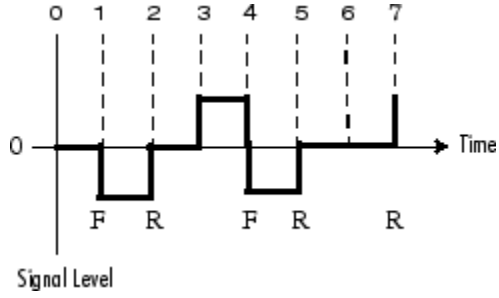
In this section...

What Are Triggered Subsystems?

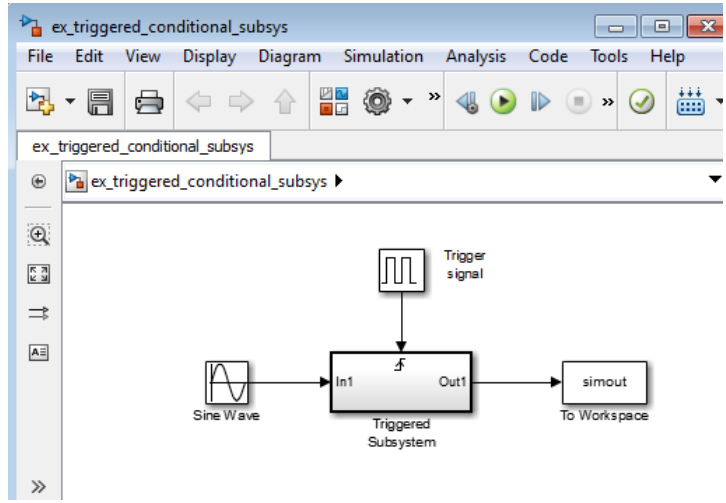
Triggered subsystems are subsystems that execute each time a trigger event occurs.

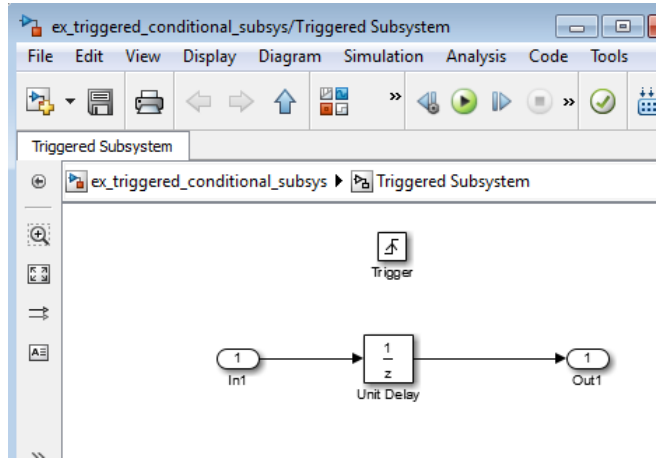
A triggered subsystem has a single control input, called the *trigger input*, that determines whether the subsystem executes. You can choose from three types of trigger events to force a triggered subsystem to begin execution:

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 remains at zero for only one time step prior to the rise.



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:

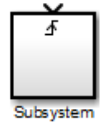
- A triggered subsystem in a referenced model
- A Model block in a triggered subsystem

For information about using trigger ports in referenced models, see "Conditional Referenced Models" on page 6-59.

To convert a subsystem to use model referencing, see "Convert a Subsystem to a Referenced Model" on page 6-12.

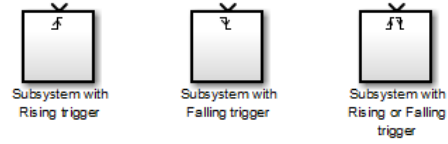
Creating a Triggered Subsystem

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; the states of any discrete block is 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, 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

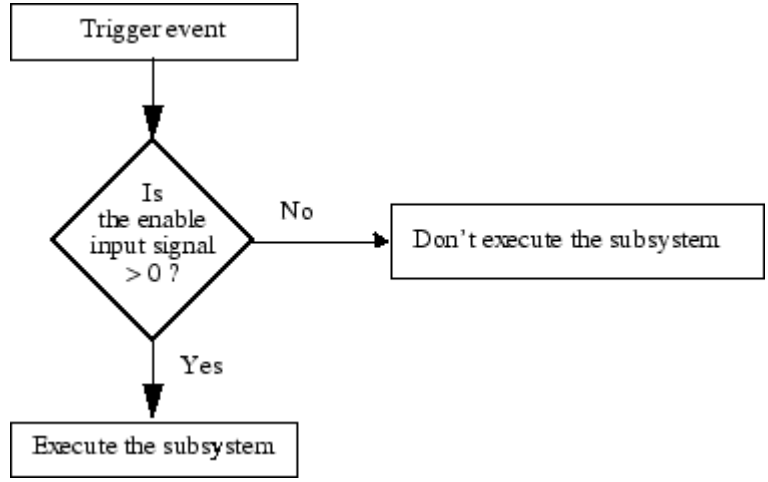
All blocks in a triggered subsystem must have either inherited (`-1`) or constant (`inf`) sample time. This is to indicate that the blocks in the triggered subsystem run only when the triggered subsystem itself runs, for example, when it is triggered. This requirement means that a triggered subsystem 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 two 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.

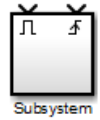


A triggered and enabled subsystem contains both an enable input port and a trigger input port. When the trigger event occurs, the enable input port is checked to evaluate the enable control signal. If its value is greater than zero, the subsystem is executed. If both inputs are vectors, the subsystem 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 control inputs to the Subsystem block.

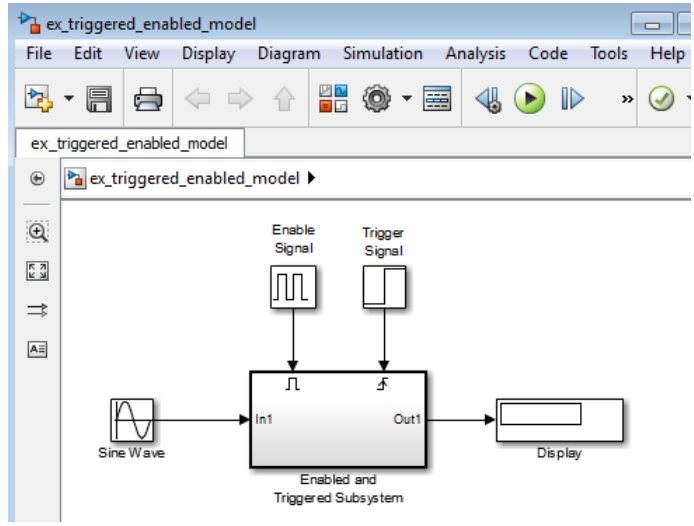


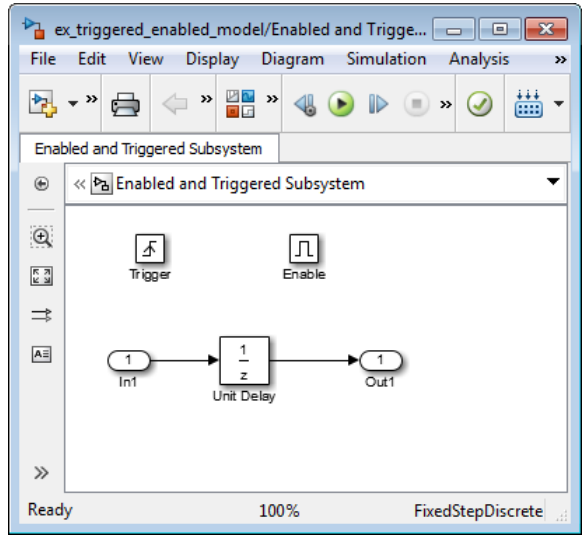
You can set output values when a triggered and enabled subsystem is disabled as you would for an enabled subsystem. For more information, see “Setting Output Values While the Subsystem Is Disabled” on page 7-7. Also, you can specify what the values of the states are when the subsystem is reenabled. See “Setting States When the Subsystem Becomes Enabled” on page 7-9.

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.

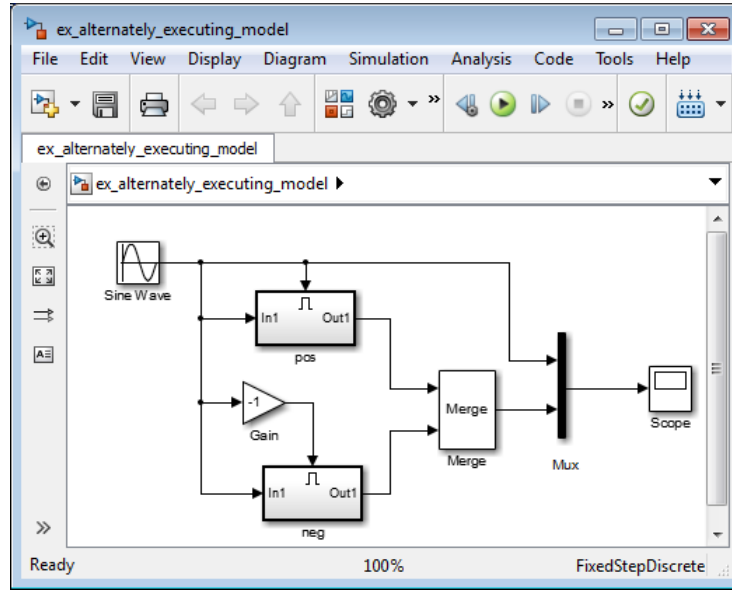


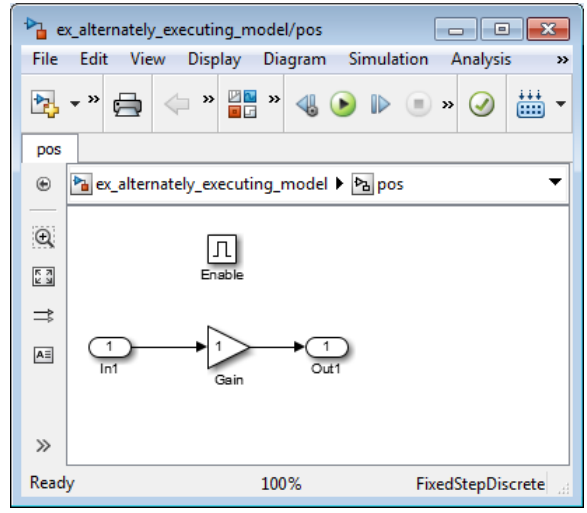


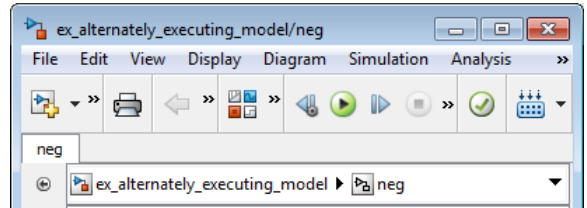
Creating Alternately Executing Subsystems

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.

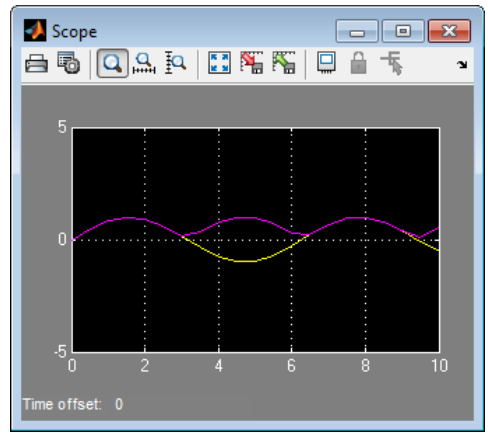






The block labeled pos is enabled when the AC waveform is positive; it passes the waveform unchanged to its output. The block labeled neg is enabled when the waveform is negative; it inverts the waveform. The Merge block passes the output of the currently enabled block to the Mux block, which passes the 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 3-16) of the blocks that the subsystem contains in sorted order (See "How Simulink Determines the Sorted Order" on page 23-45). 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. First create a Subsystem block in your model and then create a Trigger block in the subsystem. Next, on the Trigger block parameters pane, set the **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 is 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 same 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.

Note During range checking, the design minimum and maximum are back-propagated to the actual source port of the function-call subsystem, even when the function-call subsystem is not enabled.

To prevent this back propagation, add a Signal Conversion block and a Signal Specification block after the source port, set the **Output** of the Signal Conversion block to `Signal copy`, and specify the design minimum and maximum on the Signal Specification block instead of specifying them on the source port.

For more information about function-call subsystems, see "Function-Call Subsystems" in "Writing S-Functions" in the online documentation.

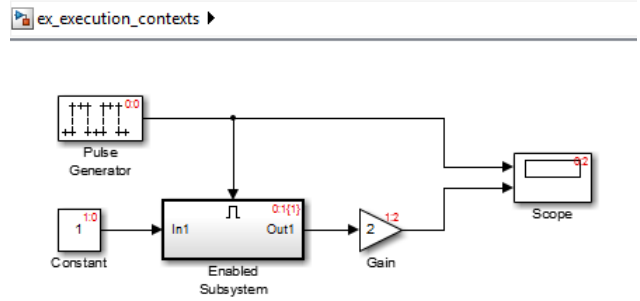
Conditional Execution Behavior

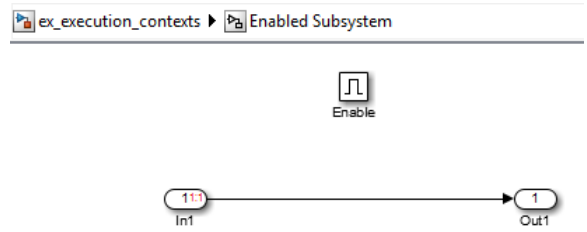
In this section...

What Is Conditional Execution Behavior?

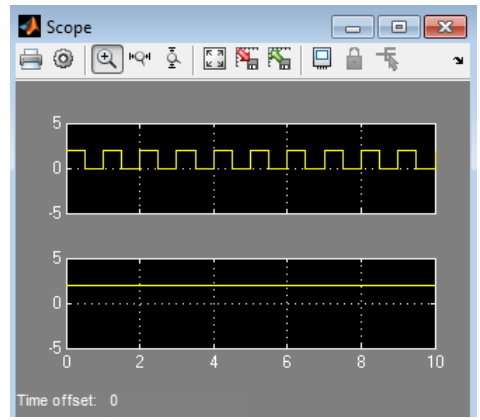
To speed the simulation of a model, by default the Simulink software avoids unnecessary execution of blocks connected to Switch, Multiport Switch, and of conditionally executed blocks. This behavior is *conditional execution (CE)* behavior. You can disable this behavior for all Switch and Multiport Switch blocks in a model, or for specific conditional subsystems. See "Disabling Conditional Execution Behavior" on page 7-37.

The following model illustrates conditional execution behavior.





The Scope block shows the simulation result:



This model:

- Has the **Display > Signals & Ports > Execution Context Indicator** menu option enabled.
- The `Pulse Generator` block has the following parameter settings:
  - **Pulse type** — `Sample based`
  - **Period** — `100`
  - **Pulse width** — `50`
  - **Phase delay** — `50`
  - **Sample Time** — `0.01`

- The `Gain` block's sorted order (1:2) is second (2) in the enabled subsystem's execution context (1).
- The `Enabled Subsystem` block has the **Propagate execution context across subsystem boundary** parameter enabled.
- In the enabled subsystem, the `Out1` block has the following parameter settings:
  - **Initial output** — `[]`
  - **Output when disabled** — `held`

The outputs of the Constant block and Gain blocks are computed only while the enabled subsystem is enabled (for example, at time steps 0.5 to 1.0 and 1.5 to 2.0). This behavior is necessary 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 root system of the model, the Simulink software invokes the block 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 root level (id = 0) of the model. The Gain block's sorted order (1:2) is second (2) in the enabled subsystem's execution context (1).

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:

- The block output is required only by a conditional subsystem or the block input changes only as a result of the execution of a conditionally executed subsystem.
- The execution context of the subsystem can propagate across the subsystem boundaries.
- The output of the block is not a test point (see "Test Points" on page 47-58).
- The block is allowed to inherit its conditional execution context.

  The Simulink software does not allow some built-in blocks, such as 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.
- The block sample time is set to 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 7-37), the Simulink software moves the block into the execution context of the subsystem. This ensures that the block methods execute during the simulation loop only when the corresponding conditional subsystem executes.

Note Execution contexts are not propagated to blocks having a constant sample time.

Behavior of Switch Blocks

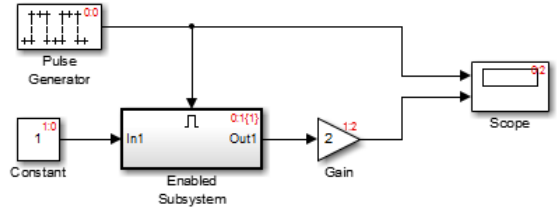
This behavior treats the input branches of a Switch or Multiport Switch block as invisible, conditional subsystems, each of which has its own execution context. This CE is enabled only when the control input of the switch selects the corresponding data input. As a result, switch branches execute only when selected by switch control inputs.

Displaying Execution Contexts

To determine the execution context to which a block belongs, in the Simulink Editor, select **Display > Blocks > Sorted Execution Order**. 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 sorted order in the execution context of the subsystem. For example, 0:0 indicates that the block is the first block in the execution context of the root subsystem.

If a bus is connected to a block input, the block sorted order is displayed as **s**:B. For example, 0:B indicates that the block belongs to the execution context of the root system 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 root system of the model. The first `1` indicates that the enabled subsystem is the second block on the sorted list of the root system (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 fact that the Constant block has an index of `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: General"). 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.

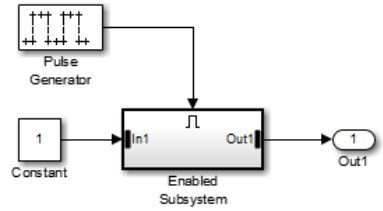
Even if this option is enabled, the execution context of the subsystem cannot propagate across its boundaries under either of the following circumstances:

- The subsystem is a triggered subsystem with a latched input port.
- The subsystem has one or more output ports that specify an initial condition other than `[]`. In this case, a block connected to the subsystem output cannot inherit the execution context of the subsystem.

Displaying Execution Context Bars

Simulink can optionally display bars next to the ports of subsystems across which execution contexts cannot propagate. To display the bars, select **Display > Signals & Ports > Execution Context Indicator**.

For example, it displays bars on subsystems from which no block can inherit its execution context. In the following figure, the context bars appear next to the `In1` and `Out1` ports of the Enabled Subsystem block.



8

Modeling Variant Systems

Working with Variant Systems

In this section...

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 an automobile. Various models of an automobile can have many similarities, yet differ in specific ways, such as fuel usage, engine size, or emission standards.

With blocks for variant systems, Simulink provides techniques to customize a model for different applications through design and simulation:

- The Model Variants block references two or more models, where the referenced model used during simulation is the active variant.
- The Variant Subsystem block consists of a set of subsystems, where the subsystem used during simulation is the active variant.

Each variant, active or inactive, has an object. Simulink evaluates the variant objects to determine the active variant.

You can parameterize the variant object by making it dependent on the values of variables and objects in the MATLAB base workspace. For a quick overview, see "Model Variants Block Overview" on page 8-5 and "Variant Subsystem Block Overview" on page 8-15.

You can programmatically switch the active variant by modifying the values of variant control variables in the base workspace. Alternatively, you can manually override the variant selection on the block parameter dialog box.

Both variant models and variant subsystems use variants in a similar workflow. For more information, see "Workflow for Implementing Variant Systems" on page 8-3.

For *alternative* techniques to customize a model for different specifications, see:

Technique	Reference
Change data values in the base workspace.	"Tunable Parameters" on page 3-9
Select alternate subsystems from a library.	Configurable Subsystem block
Use a mask to change a subsystem.	"Create Dynamic Masked Subsystems" on page 26-61
Change the arguments to a parameterized referenced model.	"Parameterize Model References" on page 6-52

Workflow for Implementing Variant Systems

You can implement a variant system in your model by using the Model Variants block or the Variant Subsystem block. Both blocks use a similar workflow.

1. Create the subsystems or referenced models that you want to use as variants.
2. Set up your model to use the variants. Add the Model Variants block or the Variant Subsystem block, depending on your application. Use the blocks to:
   a. Specify variant models or subsystems.
   b. Create a variant object to associate with each variant.
   c. Define a condition for each variant. When the condition is `true`, Simulink uses this *active variant* for simulation.

   For more information, see "Set Up Model Variants" on page 8-5 and "Set Up Variant Subsystems" on page 8-15.
3. Create the control variables for evaluating variant conditions and selecting the active variant. See "Set Up Variant Control" on page 8-25 and "Select the Active Variant" on page 8-29.

4 Simulate using the active variant.

5 Modify the variant specification to select another variant and simulate again.

6 Generate code for the active variant or all variants, depending on your application. See “Code Generation of Variants” on page 8-36.

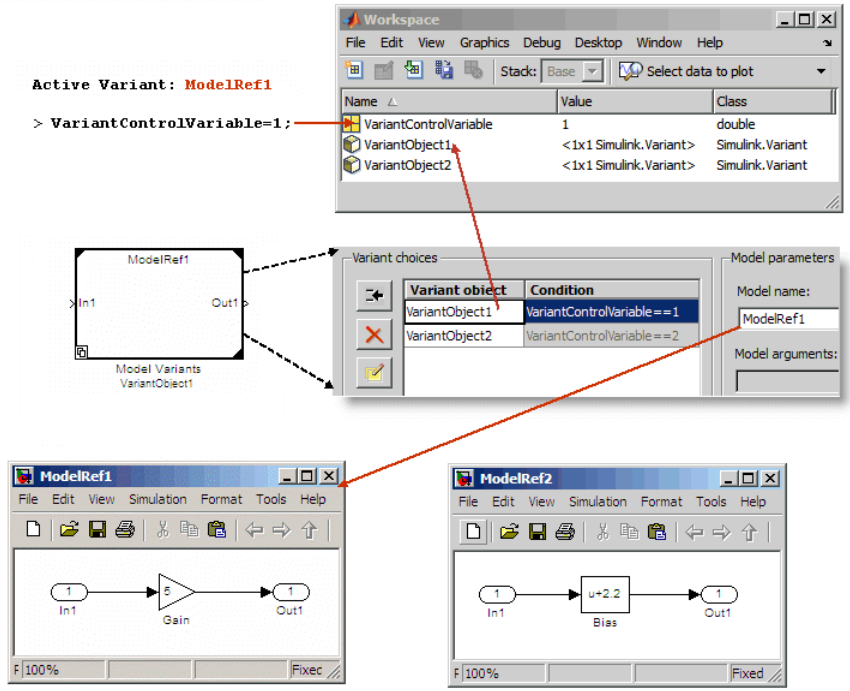
7 Save the control variables and objects for your variants from the base workspace as described in “Exporting Workspace Variables” on page 9-60.

Set Up Model Variants

In this section...

Model Variants Block Overview

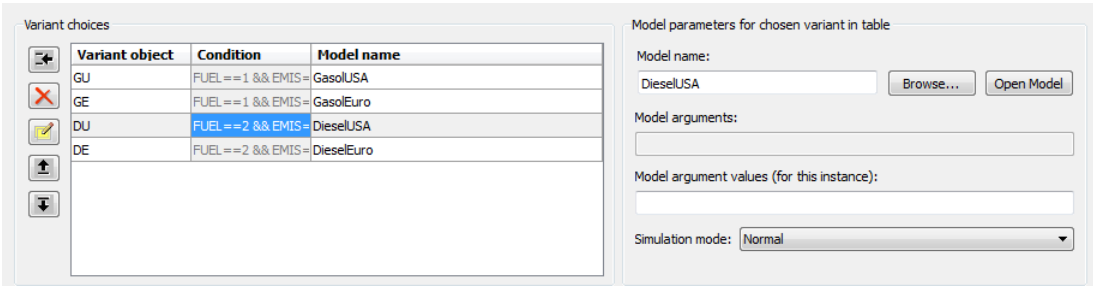
Model variants provide multiple implementations of a referenced model, with only one implementation active during simulation. You can programmatically swap the active implementation with another, without modifying the model. For example, you could use variants to switch between data types, such as `double` and `int8`, by specifying different data types in your referenced models.



A Model Variants block can reference multiple models, using variants as follows:

- Each variant has a variant object that you associate with it.
- Each variant has a condition that you specify. When compiling the model, Simulink tests each variant to determine which condition is `true`. The variant with the `true` condition 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.

You specify the model variant associations in the Model Reference Parameter dialog box, in the **Variant choices** table.



The Model Variants block parameters specification must include at least:

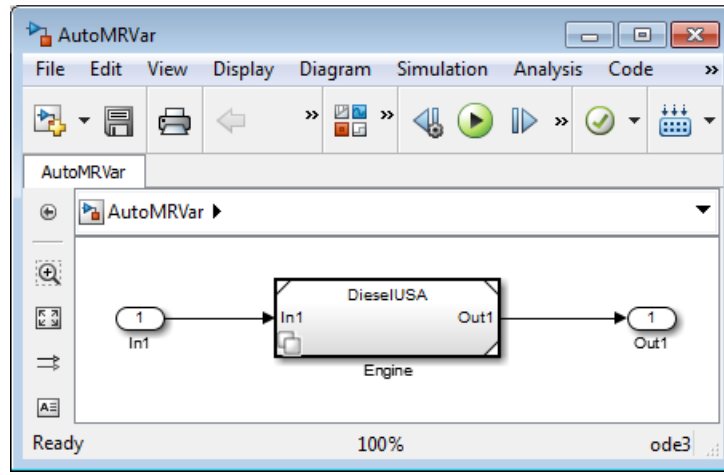
- The name of a variant object, in the **Variant object** column of the **Variant choices** table
- The name of a referenced model, in the **Model name** column of the **Variant choices** table
- A simulation mode, in the **Simulation mode** field of the **Model parameters** section
- Values in the **Model argument values** field of the **Model parameters** section, if a referenced model has arguments

Instructions for specifying model variants are in “Configuring the Model Variants Block” on page 8-9.

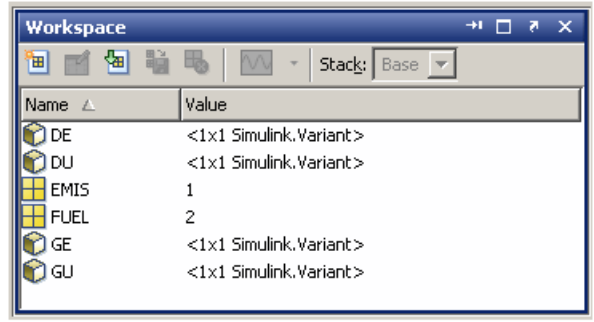
Example of a Model Variants Block

To view the example model, either click `AutoMRVar`, or execute:

```
addpath([docroot '/toolbox/simulink/ug/examples/variants/mdlref/']);
open('AutoMRVar');
```



- 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 you saved the model appears at the top of the block.
- When you change the active variant and press **Ctrl+K**, the variant block refreshes and its 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.



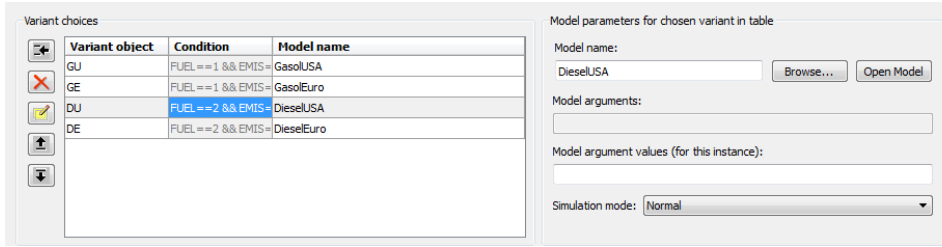
The example implements the following application:

- An automobile that can use either a diesel or a gasoline engine
- Each 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 specifies four variant referenced models. Each referenced model represents one permutation of engine fuel and emission standards.

Variant Object	Variant Condition	Model Name
GU	`FUEL==1 && EMIS==1`	GasolUSA
GE	`FUEL==1 && EMIS==2`	GasolEuro
DU	`FUEL==2 && EMIS==1`	DieselUSA
DE	`FUEL==2 && EMIS==2`	DieselEuro

To see how to specify these variants, in the Simulink Editor, right-click the `Engine` block, and select **Block Parameters (ModelReference)** or select **Diagram > Block Parameters (ModelReference)**. View the **Variant choices** table in the dialog box.



For instructions, see “Configuring the Model Variants Block” on page 8-9.

Configuring the Model Variants Block

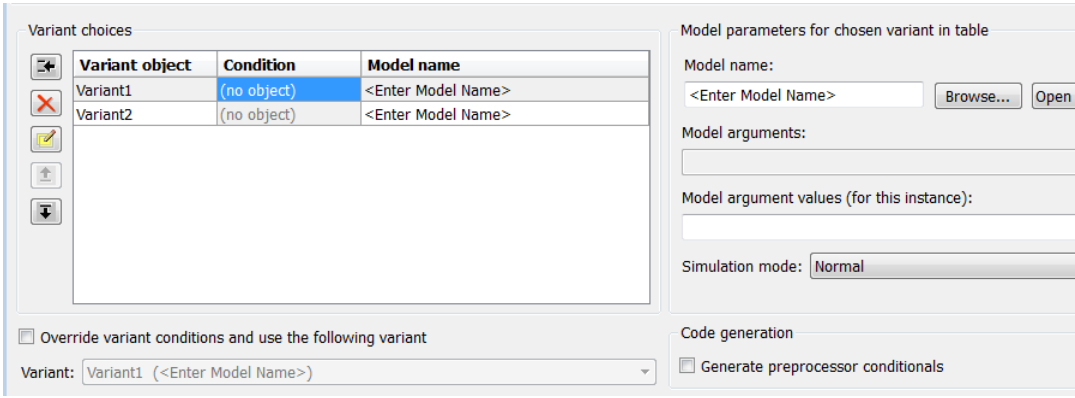
To add and configure a Model Variants block to specify your variants, do the following:

1 From the Simulink Library Browser, add a Model Variants block to your model:

Simulink > Ports and Subsystems→Model Variants block.

2 To configure your variants, open the Model Variants block dialog box. In the Simulink Editor, right-click the Model Variants block, and select **Block Parameters (ModelReference)** or select **Diagram > Block Parameters (ModelReference)**.

The Model Variants block parameters dialog box opens.



3 Specify the variant name in the **Variant object** column of the **Variant choices** table. Double-click the default `Variant1` name, then type the name of the variant object. For an existing variant object, Simulink retrieves the variant condition for the object when you press **Enter** or click away from the **Variant object**.

4 To specify the **Condition** that determines which variant is active, click the **Create/Edit selected variant** button  . For the selected variant choice, you create a variant object in the base workspace if necessary, or edit an existing variant. The Simulink.Variant parameter dialog box opens.

a Specify the **Condition** for the variant object. For example, `FUEL==1 && EMIS==1`. Do *not* surround the condition with parentheses or single quotes.

When the variant object condition evaluates to `true` at compile time, the referenced model associated with the variant becomes the active variant.

b Click **Apply** to check the expression, then click **OK**.

5 Choose a referenced model to associate with the variant object.

a In the **Variant choices** table, click to select a variant.

b Enter the model name into either the **Model name** table cell, or the **Model name** field for the chosen variant, in the **Model parameters for chosen variant in table** pane to the right of the table. To specify a protected model, use the extension `.slxp`. See "Protected Model" on page 6-67.

Alternatively, to find a model, click the **Browse** button next to the **Model name** field. Select the model, and click **Open**. The model name appears in the **Model name** column and edit box.

c (Optional) For the selected model, you can also click **Open Model** to check which model you are specifying, specify model arguments (see "Parameterizing Model Variants" on page 8-12), or specify the **Simulation mode**. All simulation modes work with model variants. See "Referenced Model Simulation Modes" on page 6-21.

d Click **Apply** to associate the referenced model with its variant object.

6 To add another variant, click the **Add a new variant** button  .

A new **Variant choices** table row appears below the other variant choices.

7 Repeat the previous steps until you have specified all your referenced models and their associated variant objects. For information on the other buttons, see the Model Variants block page.

8 Click **OK** to close the Model Variants dialog box.

Note Your variant conditions might require you to define control variables in the base workspace before they can be evaluated. See "Creating Control Variables" on page 8-25 and "Saving Variant Components" on page 8-26.

For next steps, see “Select the Active Variant” on page 8-29. The model diagram displays the new active variant on the block when you refresh the block by pressing **Ctrl+K**.

Disabling and Enabling Model Variants

You can disable model variants without losing your variant settings. After 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 block or Model Variants block:

1. Right-click the block and select **Block Parameters (ModelReference)** 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
   - Ignores subsequent changes to variant control variables, variant conditions, and other models, other than the current model.

If you decide to reenable variants, select the **Enable Variants** button.

- The Model block or Model Variants block remembers your previous variant specifications as they were before.
- The Model block or Model Variants block selects an active variant according to the current base workspace variables and conditions.

You can also override variants and specify the active variant. See “Overriding Variant Conditions” on page 8-30.

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 for chosen variant in table** section using the **Model argument values** field. You can use the same values as for any referenced model. For more information, see "Parameterize Model References" on page 6-52.

Requirements, Limitations, and Tips for Model Variants

A Model Variants block and its referenced models must satisfy the requirements in "Simulink Model Referencing Requirements" on page 6-45 and "Model Referencing Limitations" on page 6-80. You can nest Model Variants blocks to any level.

Note Requirements and limitations that apply to *code generation* are in "Limitations on Generating Code for Variants".

Tips for working with model variants:

- A Model Variants block can log only those signals that the referenced model specifies as logged. If a model is a variant model, or contains a variant model, then you can either log all logged signals or log no logged signals.

  The Signal Logging Selector configuration for the model must be in one of these states:

  - The **Logging Mode** is set to `Log all signals as specified in model`.
  - The **Logging Mode** is set to `Override signals` and the check box for the model block is either checked () or empty (). The check box cannot be filled ().

  For more information about logging referenced models, see "Models with Model Referencing: Overriding Signal Logging Settings" on page 45-45.

  To enable logging programmatically, use the `DefaultDataLogging` parameter.

- 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”.
- During model compilation, Simulink evaluates variant objects before calling the model `InitFcn` callback. Therefore, do not modify the condition of the variant object in the `InitFcn` callback.

Model Variants Example

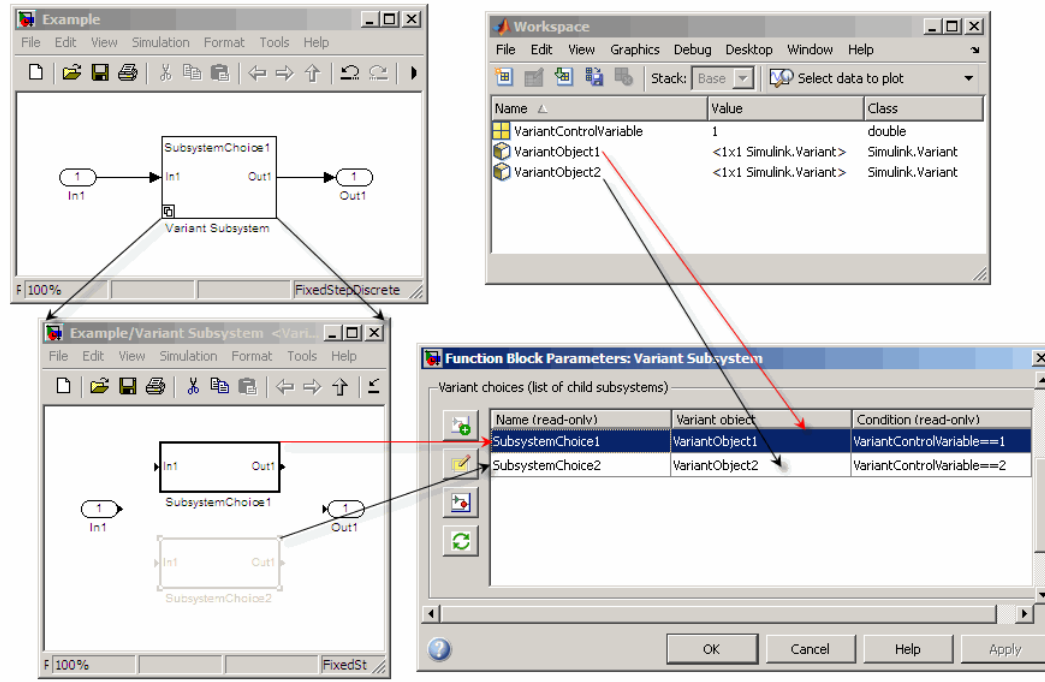
To see a example that shows how to define a variant model in Simulink , click `sldemo_mdlref_variants`. In the Help Browser select: **Simulink > Examples > Modeling Features > Model Reference > Model Reference Variants**.

Set Up Variant Subsystems

In this section...

Variant Subsystem Block Overview

A variant subsystem provides multiple implementations of a subsystem, with only one implementation active during simulation. You can programmatically swap the active implementation with another, without modifying the model.



A Variant Subsystem block consists of multiple subsystems as follows:

- Each subsystem has a variant object that you associate 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:

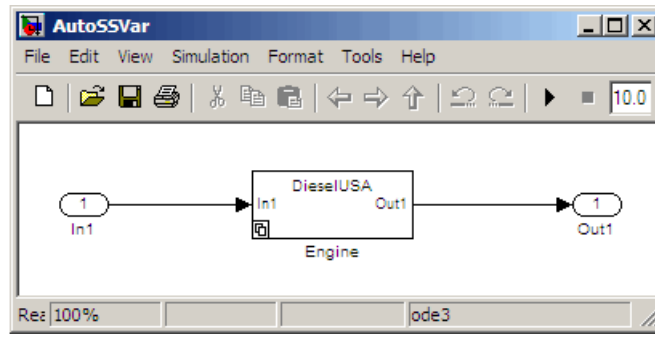
- The name of a variant object, in the **Variant object** column of the **Variant choices** table.
- The variant object must have a conditional expression that evaluates to `true` or `false`.

Instructions for specifying a variant subsystem are in “Configuring the Variant Subsystem Block” on page 8-20.

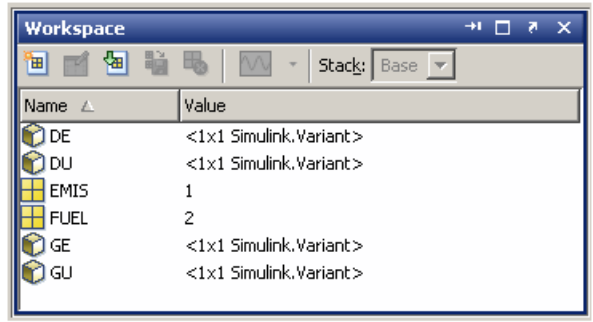
Example of a Variant Subsystem Block

To view the example model, either click `AutoSSVar`, or execute:

```
addpath([docroot '/toolbox/simulink/ug/examples/variants/mdlref/']);
open('AutoSSVar');
```



- 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 you saved the model appears at the top of the block.
- When you change the active variant and refresh the diagram by pressing **Ctrl+K**, 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.

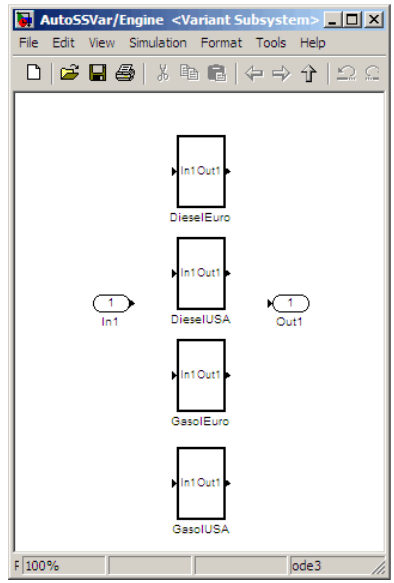


The example model illustrates the same application as the "Example of a Model Variants Block" on page 8-7, but using variant *subsystems* instead of variant *referenced models*. Both examples show the use of variants for the following cases:

- An automobile that can use either a diesel or a gasoline engine
- Each 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.

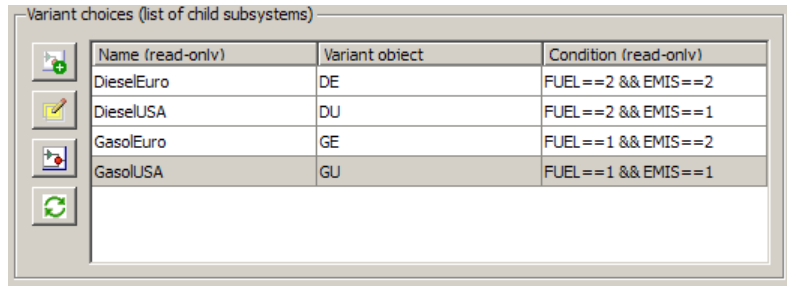
Double-click the Variant Model block, `Engine`, to view the child subsystems.



The subsystem diagram for a Variant Subsystem block has no connections. 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 Variant Subsystem Code Generation".

To view how to specify these variants, in the Simulink Editor, right-click the `Engine` block, and select **Block Parameters (Subsystem)** or select **Diagram > Block Parameters (Subsystem)**.

View the **Variant choices (list of child subsystems)** table in the dialog box, as shown in the following figure.



For instructions, see “Configuring the Variant Subsystem Block” on page 8-20.

Configuring the Variant Subsystem Block

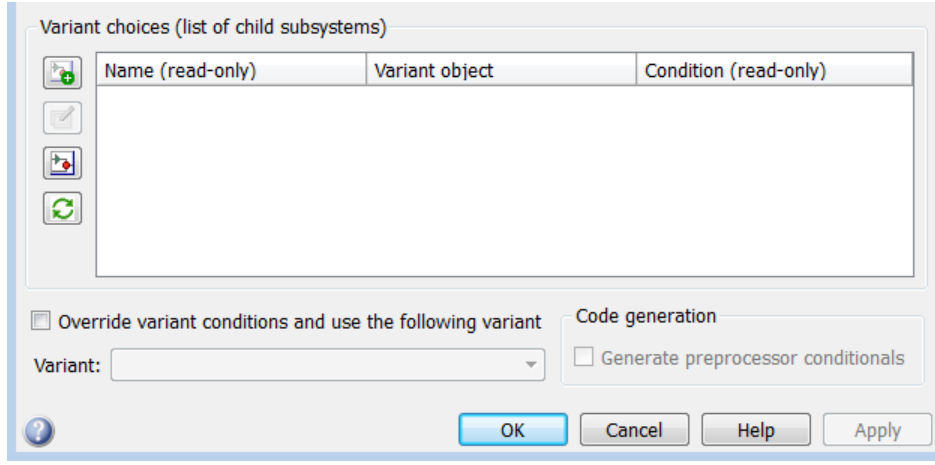
To add and configure a Variant Subsystem block to specify your variants, do the following:

1. From the Simulink Library Browser, add a Variant Subsystem block to your model:

   Simulink > Ports and Subsystems > Variant Subsystem block

2. To configure your variants, open the Variant Subsystem block dialog box. In the Simulink Editor, right-click the Variant Subsystem block, `Engine`, and select **Block Parameters (Subsystem)** or select **Diagram > Block Parameters (Subsystem)**.

   The Variant Subsystem block parameters dialog box opens.



3. Add a new 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.

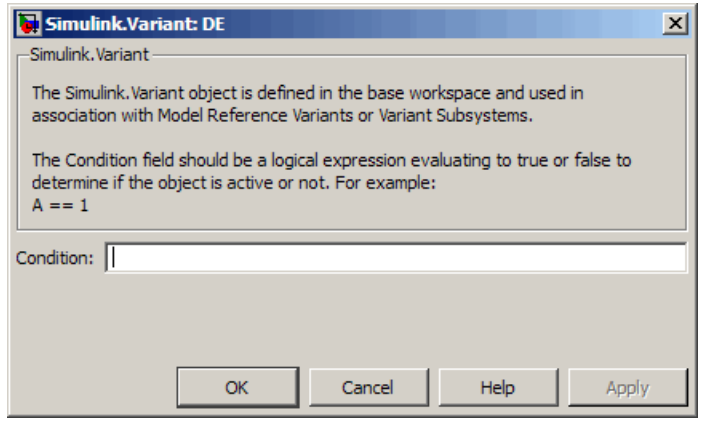
4 Rename the subsystem in the Variant Subsystem block diagram window, and open and configure the subsystem as desired. You can drag and drop existing subsystems into the new variant subsystem.

Note

- 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.

5 Return to the Variant Subsystem parameter dialog box. In the **Variant object** column of the **Variant choices** table, specify the variant name in the row of the subsystem you just configured. Double-click the default name, then type the name of the variant object. For an existing variant object, Simulink retrieves the variant condition for the object when you press **Enter** or click away from the **Variant object**. In the **Variant choices** table, double-click the **Variant object** field in the row of the subsystem you just configured. Specify the name for the **Variant object**.

6 To specify the **Condition** that determines which variant is active, click the **Create/Edit selected variant** button  . For the selected variant choice, you create a variant object in the base workspace if necessary, or edit an existing variant. The Simulink.Variant parameter dialog box opens.



a Specify the **Condition** for the variant object. For example, `FUEL==2 && EMIS==2`.

When the variant object condition evaluates to `true` at compile time, the subsystem associated with the variant becomes the active variant.

b Click **Apply** to check the expression, then click **OK**.

The **Variant choices** table is updated with the condition for the new variant object. 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.

7 To add another variant, click the **Create and add a new subsystem choice** button 

8 Repeat the previous steps until you have specified all your variant subsystems and their associated variant objects.

For more information on the block controls, see the Variant Subsystem block page.

9 Click **OK** to close the Variant Subsystem dialog box.

Note Your variant conditions might require you to define control variables in the base workspace before they can be evaluated. See "Creating Control Variables" on page 8-25 and "Saving Variant Components" on page 8-26.

For next steps, see "Select the Active Variant" on page 8-29. The model diagram does not display the new active variant on the block until you refresh the diagram by pressing **Ctrl+K**.

Disabling and Enabling Subsystem Variants

You can disable individual subsystem choices. To ignore a subsystem for simulation and code generation, you can comment out the variant object in the Variant Choices table as follows:

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**.

To enable the subsystem variant again, remove the %' from the variant object name.

You can also override variants and specify the active variant. See "Overriding Variant Conditions" on page 8-30.

Variant Subsystem Block 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.

Note Requirements and limitations that apply to *code generation* are in "Limitations on Generating Code for Variants".

Variant Subsystem Example

To see an example that shows how to define a variant subsystem, click `sldemo_variant_subsystems`. In the Help Browser, select: **Simulink > Examples > Modeling Features > Subsystems > Variant Subsystems**.

Set Up Variant Control

In this section...

Creating Control Variables

You must create variant control variables to control which variant is active. You create variant control variables in the same way for variant subsystems or variant models.

To specify the condition of a variant object, you can use MATLAB variables, or `Simulink.Parameter` objects that reside in the base workspace. The conditions of the variant objects determine which variant is the active variant. At the MATLAB command line or in the Model Explorer, create variant control variables to match your specified conditions. Before compiling or simulating, you set the variant control variables to values that specify the environment in which you want to simulate.

Note To control variants using meaningful readable names, you can use a `Simulink.Parameter` object of enumerated type to define the variant condition. See "Using Enumerated Types for Variant Control Variable Values" on page 8-27.

At the MATLAB Command Window or in the Model Explorer, create variant control variables:

- **In the MATLAB Command Window**

  For example,

```
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 creates the variant control variables in the base workspace.

Note A variant control variable for *code generation* must be a Simulink parameter that meets the requirements described in "Generate Preprocessor Conditionals for Variant Systems".

Saving 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.

Example Variant Control Variables

The example `AutoMRVar` uses the control variables `EMIS` and `FUEL`. Depending on the values of `EMIS` and `FUEL`, you can see which variant is active.

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`

To try an example changing control variables:

1. Open `AutoMRVar`.

2. Specify `FUEL=2` and `EMIS=2` in the base workspace. When you choose these values for the variant control variables, the variant condition associated with the variant object `DE` is `true`. Therefore, the active variant is `DieselEuro`, and the model `AutoMRVar` uses `DieselEuro` as its referenced model during simulation.

3. Press **Ctrl+K** to updated the active variant.

Note To control variants using meaningful readable names, you can use a `Simulink.Parameter` object of enumerated type to define the variant condition. See "Using Enumerated Types for Variant Control Variable Values" on page 8-27.

For an example explaining control variables for variant subsystems, including the use of enumerated types, see the example `sldemo_variant_subsystems`.

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 "About Simulink Enumerations" on page 44-2. 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 “About Variant Objects” on page 8-32, 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.

For an example explaining the use of enumerated types with variants, see the example `sldemo_variant_subsystems`.

Select the Active Variant

In this section...

What Is an Active Variant?

The active variant is the variant Simulink uses 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.

You control variants by setting conditions. Simulink determines the active variant by which variant object condition evaluates to `true` at compile time.

Selecting the Active Variant for Simulation

You select the active variant in the same way for variant models or variant subsystems.

You can switch the active variant by:

- Programmatically modifying the values of variant control variables or parameters in the base workspace
- Using the **Variant** menu to choose a variant. Right-click the block or select **Diagram > Variant > Override using > *`variant choice`***.
- Manually overriding the variant selection on the block parameter dialog box

The condition of the variant objects determine which variant is active. You define the condition using variant control variables or parameters defined in the base workspace, so you can modify the values of the variant control

variables to select the active variant. See “Creating Control Variables” on page 8-25.

You can also override the variant conditions and manually select one active variant. For instructions, see “Overriding Variant Conditions” on page 8-30.

Checking and Opening the Active Variant

When you open a model, variant blocks display the name of the variant that was active the last time the model was saved.

When the active variant changes (for example, when you change the control variables for variant conditions), you can update the variant block name by pressing **Ctrl+K** to refresh.

You can use the **Variant** menu to open the active variant. Right-click the block or select **Diagram > Variant > Open > (active variant)**

To find the name of the active variant for the currently selected block, enter at the command line:

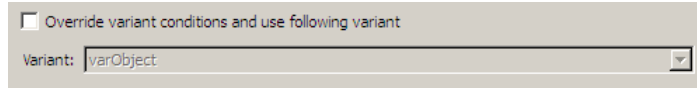
```
get_param(gcb, 'ActiveVariant')
```

Overriding Variant Conditions

You can specify one variant as the active variant. You can either:

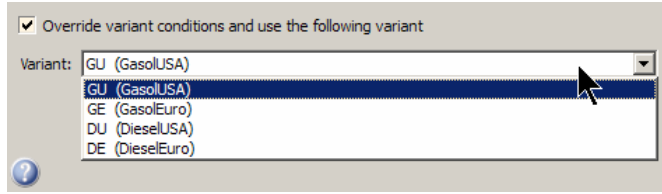
- Use the **Variant** menu to choose a variant. Right-click the block or select **Diagram > Variant > Override using > *`variant choice`***.
- Manually override the variant selection on the block parameter dialog box.

In both the Model Variants and Variant Subsystem block parameters dialog boxes, use the “Override variant conditions and use following variant” parameter, at the bottom left.



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. In the Model Variants block, the list shows each variant and the associated model name.



In the Variant Subsystem block, the list shows only variant object names. Check the variant choices table for the name of the subsystem associated with each variant.

3 After you make the change, click **Apply** or **OK**. 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**.

About Variant Objects

In this section...

What Is a Variant Object?

A variant object is an instance of the `Simulink.Variant` class in the base workspace. You can use the controls in the variant blocks to create variant objects. Alternatively, you can create variant objects in the Model Explorer or at the command line.

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 model variant or a variant subsystem so that, when the model compiles, only one variant condition is `true` based on the current base workspace values.

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 "Reusing Variant Objects" on page 8-33.

Creating Variant Objects

There are three techniques for defining variant objects for your applications. Choose the technique that complements your workflow.

- **Using the Create variant option**

  Click the **Create/Edit selected variant** button in either the Model Variants block or the Variant Subsystem block dialog boxes. Specify the condition in the dialog box and click **Apply**. The blocks create variant objects for you in the base workspace, as described in "Configuring the Model Variants Block" on page 8-9 and "Configuring the Variant Subsystem Block" on page 8-20.

- **In the Model Explorer**

  1. Select the `Base Workspace`.
  2. Select **Add > Simulink Variant**.

     The Model Explorer creates a new variant object named `Variant` in the base workspace.
  3. Specify the name and condition for the variant object in the same way as from the variant blocks.

- **In the MATLAB Command Window**

  Enter code like the following to define your variant object name and condition:

  ```
  variantObjectName=Simulink.Variant(conditionExpression)
  ```

  For example:

  ```
  DU=Simulink.Variant('FUEL==2 && EMIS==1')
  ```

Reusing Variant Objects

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. Your applications may use multiple variant blocks.

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. Specify a Boolean expression that references at least one base workspace variable or parameter. The expression can include:

- MATLAB variables defined in the base workspace
- `Simulink.Parameter` objects defined in the base workspace
- Scalar variables
- Enumerated values
- Operators `==`, `!=`, `&&`, `||`, `~`
- Parentheses for grouping

For instructions on specifying variant conditions, see “Configuring the Model Variants Block” on page 8-9 and “Configuring the Variant Subsystem Block” on page 8-20.

For instructions on variant control variables, see “Set Up Variant Control” on page 8-25.

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. See "Using Enumerated Types for Variant Control Variable Values" on page 8-27.

Code Generation of Variants

Generating code from variants depends on your MathWorks code generation software.

- Simulink Coder generates code only for the variant that is active in your system.
- Embedded Coder generates code for *all* variants, unless you override variant conditions and specify a variant for code generation.
  - By default, Embedded Coder generates code for all variants. The generated code for each variant is surrounded by C preprocessor conditionals, `#if`, `#elif`, and `#endif`. At C compile time, the preprocessor conditionals select the active variant and determine which code to execute.
  - You can specify a single variant for code generation by using the **Override variant conditions and use following variant** option in the Model Variants block or Variant Subsystem block.

  For instructions, see "Generate Preprocessor Conditionals for Variant Systems".

Variant System 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

9

Exploring, Searching, and Browsing Models

Model Explorer Overview

In this section...

What You Can Do Using 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.

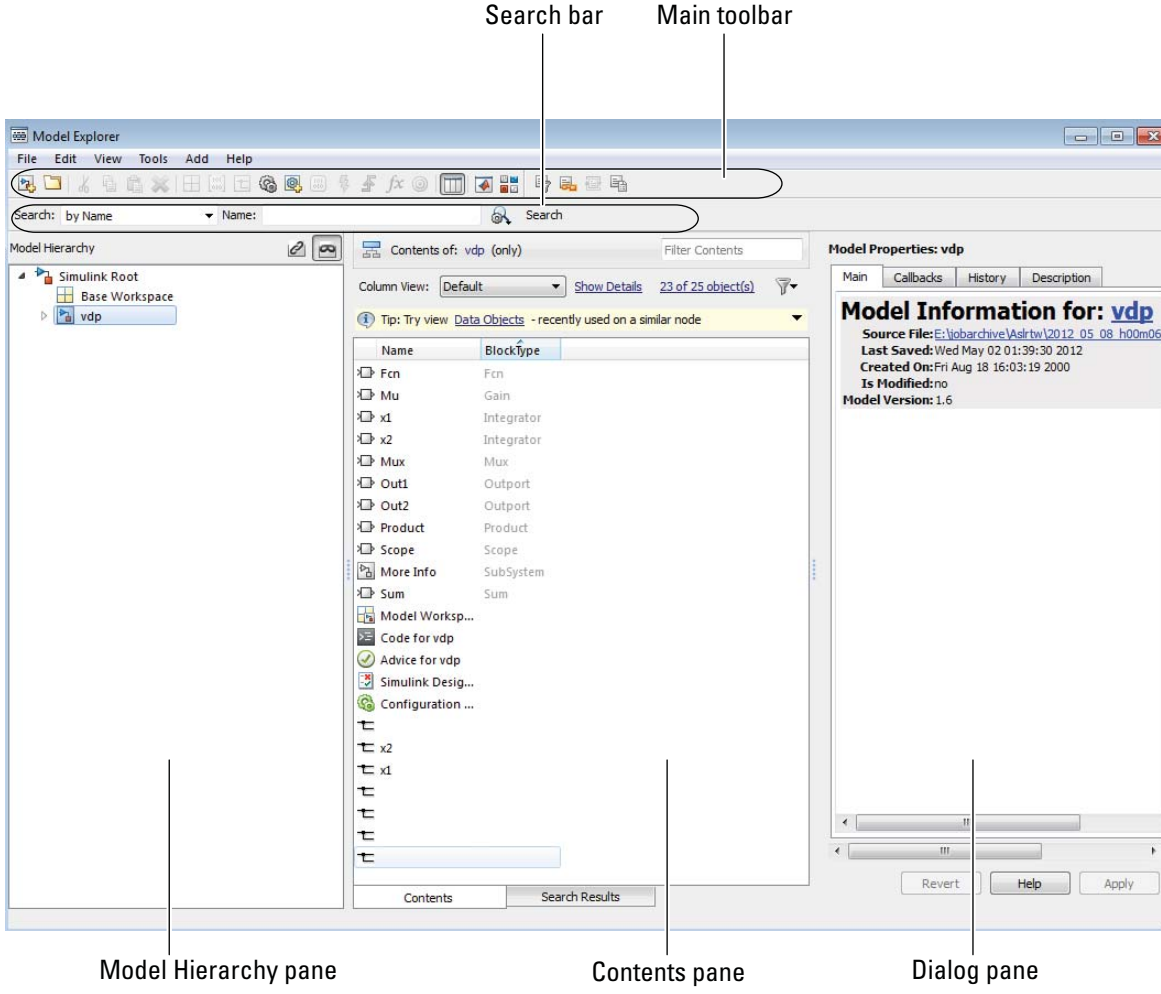
Opening the Model Explorer

To open the Model Explorer, use one of these approaches:

- From the Simulink Editor **View** menu, select **Model Explorer** or select the Model Explorer icon  from the toolbar.
- In an open model in the Simulink 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 9-4
Search bar	Perform a search within the context of the selected node in **Model Hierarchy** pane.	"Search Using Model Explorer" on page 9-63
Model Hierarchy pane	Navigate and explore model, chart, and workspace nodes	"Model Explorer: Model Hierarchy Pane" on page 9-9
Contents pane	Display and modify model or chart objects	"Model Explorer: Contents Pane" on page 9-19
Dialog pane	View and change the details of object properties	"Model Explorer: Property Dialog Pane" on page 9-70

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.

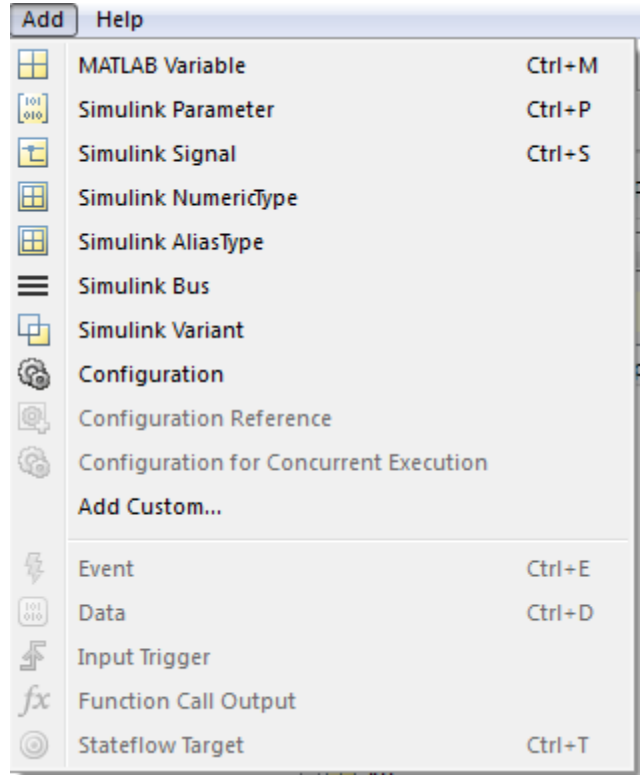
The toolbar buttons in the following table perform actions that you cannot perform using Model Explorer menus:

Button	Usage
	Bring the MATLAB window 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 9-45
- "Showing and Hiding the Search Bar" on page 9-64
- "Showing and Hiding the Dialog Pane" on page 9-70

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, specifying whether the Model Explorer displays only the current system or the whole system hierarchy of the current system

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. To edit workspace variables, you can use the Variable Editor.

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
Show partial or whole model hierarchy contents	To control how much of a hierarchical model to display	"Displaying Partial or Whole Model Hierarchy Contents" on page 9-12
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 9-46

Technique	When to Use	Documentation
Search	To find objects that might not be currently displayed	"Search Using Model Explorer" on page 9-63
Filter contents	To focus on specific objects in the **Contents** pane, based on a search string	"Filtering Contents" on page 9-48

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.

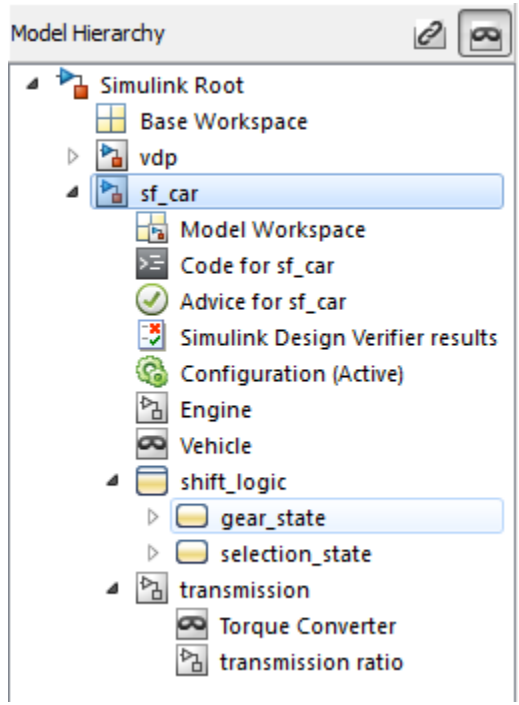
Technique	When to Use	Documentation
Sort	To quickly organize data for a property in ascending or descending order	"Sorting Column Contents" on page 9-36
Group by property column	To logically group data based on values for a property	"How to Group by a Property Column" on page 9-39
Use column views	To display a named subset of property columns to apply to different kinds of nodes in the **Model Hierarchy** pane	"Control Model Explorer Contents Using Views" on page 9-26
Add, delete, or rearrange property table columns	To customize property columns	"Organize Data Display in Model Explorer" on page 9-36

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 9-60 and “Importing Workspace Variables” on page 9-62.

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 "Manage a Configuration Set" on page 10-12). 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" on page 10-28).

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.

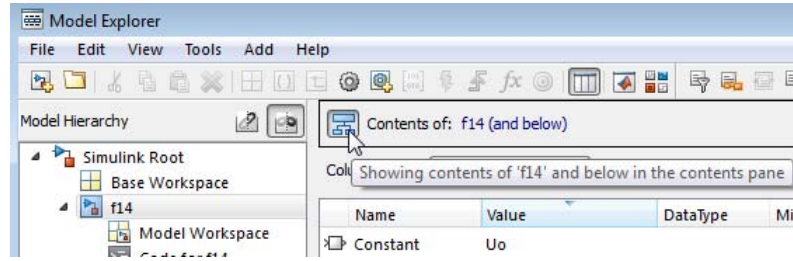
Node	Description
Model workspace	For information about how to use the Model Explorer to work with model workspace variables, see the following sections: • "Finding Variables That Are Used by a Model or Block" on page 9-52 • "Finding Blocks That Use a Specific Variable" on page 9-55 • "Editing Workspace Variables" on page 9-58 • "Exporting Workspace Variables" on page 9-60 • "Importing Workspace Variables" on page 9-62 • "Model Workspaces" on page 4-67
Configuration sets	For information about adding, deleting, saving, and moving configuration sets, see "Manage a Configuration Set" on page 10-12.
Top-level subsystems	Expand a node representing a subsystem to display underlying subsystems, if any.

Node	Description
Model blocks	Expand model blocks to show contents of referenced models (see “Expanding Model References” on page 9-15).
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 Partial or Whole Model Hierarchy Contents

By default, the Model Explorer displays objects for the system that you select in the **Model Hierarchy** pane. It does not display data for child systems. You can override that default, so that the Model Explorer displays objects for the whole hierarchy of the currently selected system. To toggle between displaying only the current system and displaying the whole system hierarchy of the current system, use one of these techniques:

- Select **View > Show Current System and Below**.
- Click the **Show Current System and Below** button ( ) at the top of the **Contents** pane.



When you select the **Show Current System and Below** option:

- The **Model Hierarchy** pane highlights in pale blue the current system and its child systems.

- After the path in the **Contents of** field, the text `(and below)` appears.
- The appearance of the **Show Current System and Below** button at the top of the **Contents** pane and in the **View** menu changes.
- The status bar indicates the scope of the displayed objects when you hover over the **Show Current System and Below** button.

Loading very large models for the current system and below can be slow. To stop the loading process at any time, either click the **Show Current System and Below** button or click another node in the tree hierarchy.

If you show the current system and below, you might want to change the view to better reflect the displayed system contents. For details about views, see "Control Model Explorer Contents Using Views" on page 9-26.

The setting for the **Show Current System and Below** option is persistent across Simulink sessions.

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

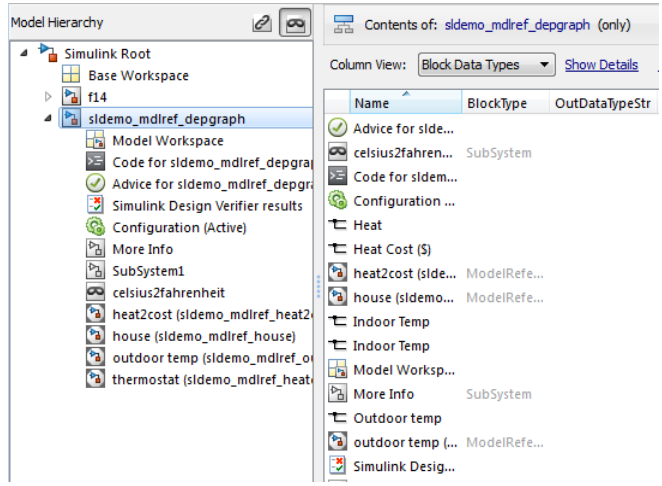
To open a graphical object (for example, a model, subsystem, or chart) in an editor window, right-click the object in the **Model Hierarchy** pane. From the context menu, select **Open**.

Working with Configuration Sets

See "Manage a Configuration Set" on page 10-12 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` 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`.



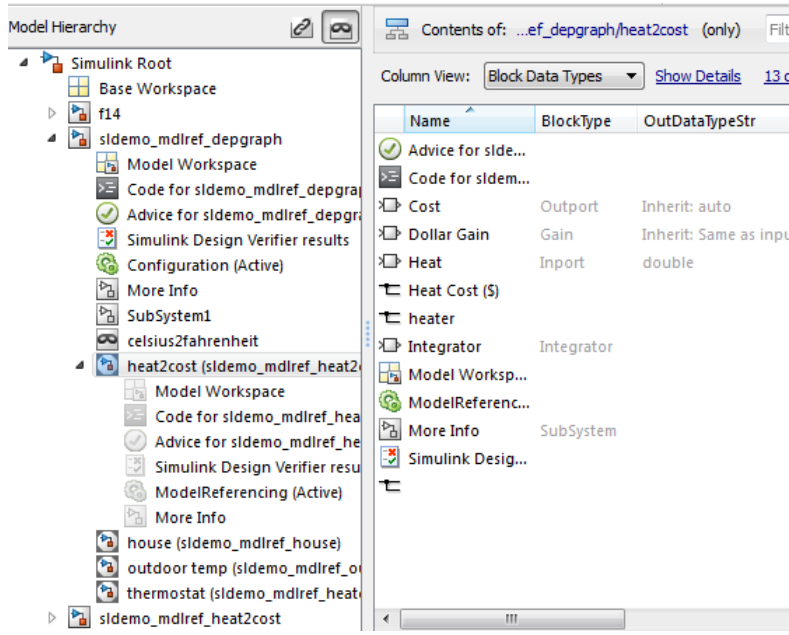
To browse a model referenced by a Model block:

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).

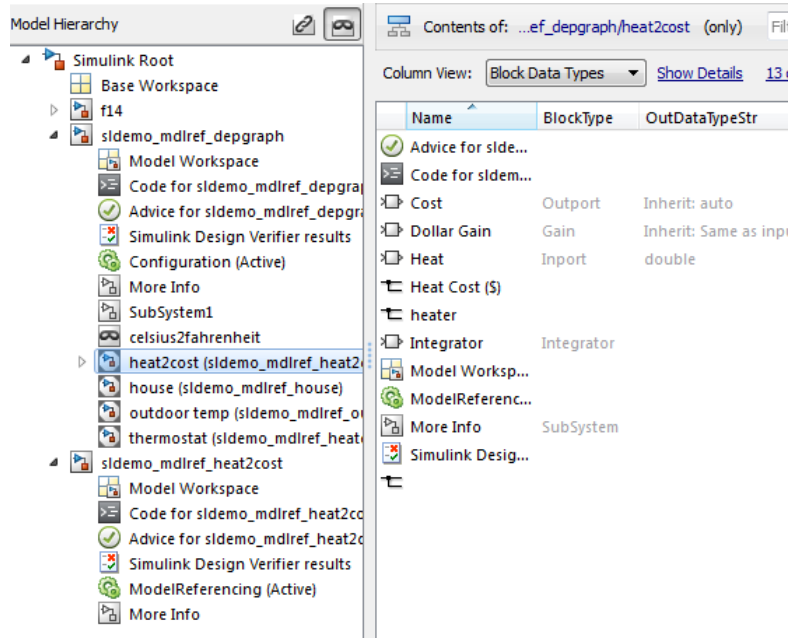
For example, if you right-click the `heat2cost` Model block node and select the **Open Model** option, the **Contents** pane displays the objects corresponding to the `heat2cost` Model block. You can expand the `heat2cost` node.



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 “Model Reference”.

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.

Model Explorer: Contents Pane

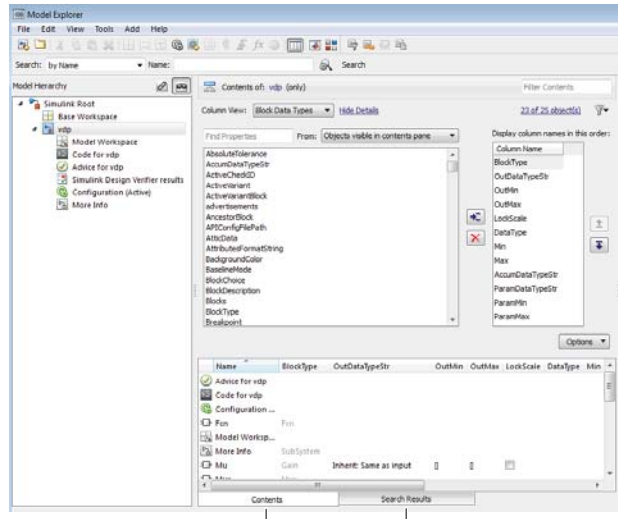
In this section...

Contents Pane Tabs

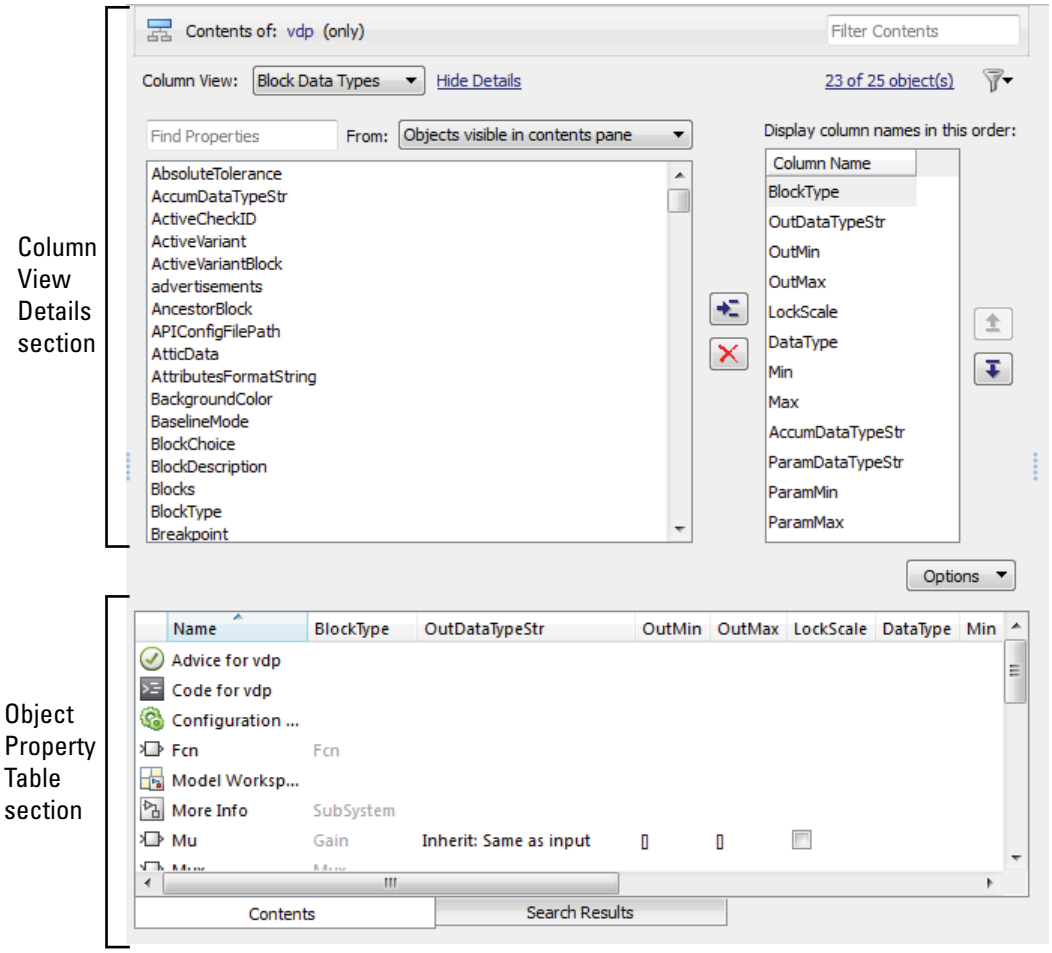
The **Contents** pane displays one of two tables containing information about models and charts, depending on the tab that you select:

- 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 "Search Using Model Explorer" on page 9-63).

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.



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:

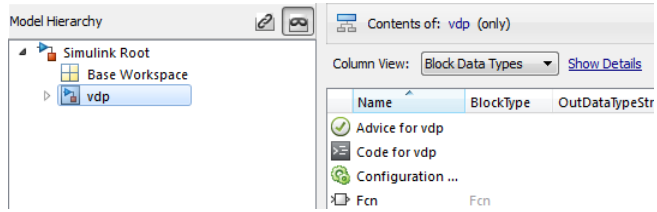
- The column view that you select in the **Contents** pane
- The node that you select in the **Model Hierarchy** pane
- The kind of object (for example, subsystem, chart, or configuration set) that you select in the **Model Hierarchy** pane
- The **View > Row Filter** options that you select

For more information about controlling which objects and properties to display in the **Contents** pane, see:

- "Control Model Explorer Contents Using Views" on page 9-26
- "Organize Data Display in Model Explorer" on page 9-36
- "Filter Objects in the Model Explorer" on page 9-46

Link to the Currently Selected Node

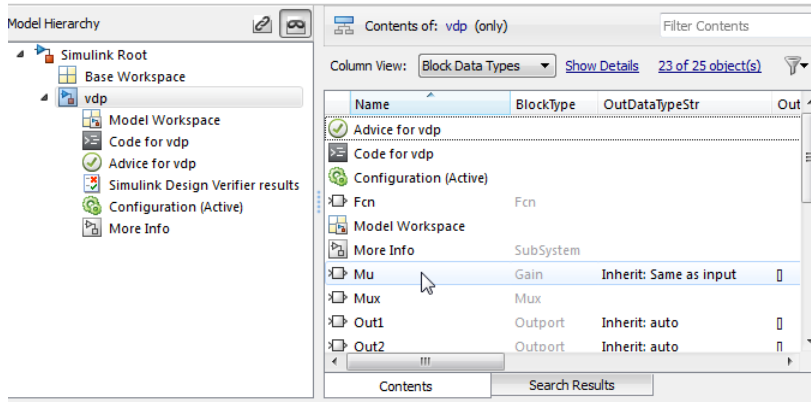
The **Contents of** link at the top left side of the **Contents** pane links to the currently selected node in the **Model Hierarchy** pane. The model data displayed in the Contents pane reflects the setting of the **Current System and Below** option. In the following example, **Contents of** links to the `vdp` model, which is the currently selected node.



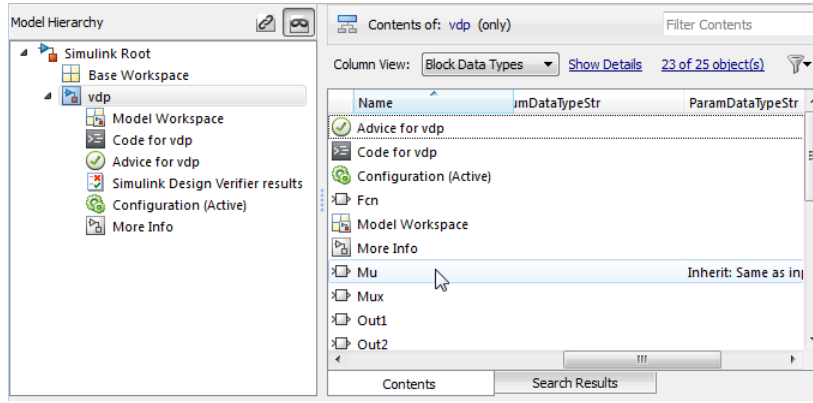
Horizontal Scrolling in the Object Property Table

The object property table displays the first two columns (the object icon and the `Name` property) persistently. These columns remain visible, regardless of how far you scroll to the right.

For example, the following image shows the initial display of the object property table for the `vdp` model. The `ParamDataTypeStr` column is too far to the right to be displayed.



The next image shows the results of scrolling to the right. The icon and `Name` columns remain visible, but now you can see the `ParamDataTypeStr` column.



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 9-46
Search within the selected set of objects.	"Search Using Model Explorer" on page 9-63
Specify a set of properties to display based on the kind of node.	"Control Model Explorer Contents Using Views" on page 9-26
Group data based on unique values in a property column.	"Grouping by a Property" on page 9-37
Manage views (for example, save and export a view).	"Managing Views" on page 9-30
Add, remove, or rearrange columns.	"Organize Data Display in Model Explorer" on page 9-36
Edit object property values.	"Editing Object Properties" on page 9-25

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). For workspace variables that are arrays or structures, you can use the Variable Editor. 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 "Model Explorer: Property Dialog Pane" on page 9-70.

Control Model Explorer 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 9-29)

- Layout of the **Contents** pane (for example, grouping by property, the order of property columns, and sorting), as described in "Organize Data Display in Model Explorer" on page 9-36.

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 9-28.

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.

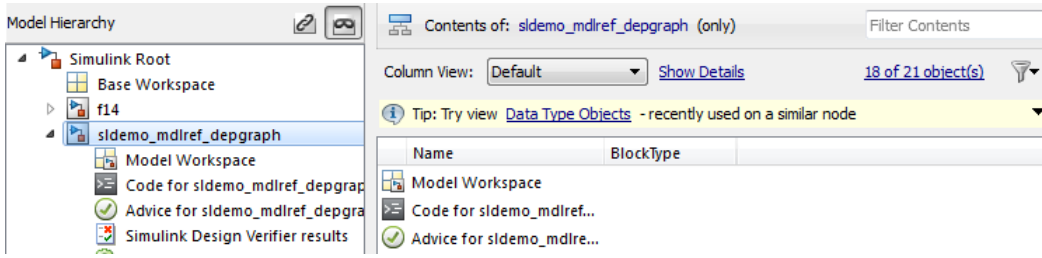
To enable the manual view selection mode:

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 9-42
- “Hiding or Removing Property Columns” on page 9-43
- “Changing the Order of Property Columns” on page 9-41

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 9-29.

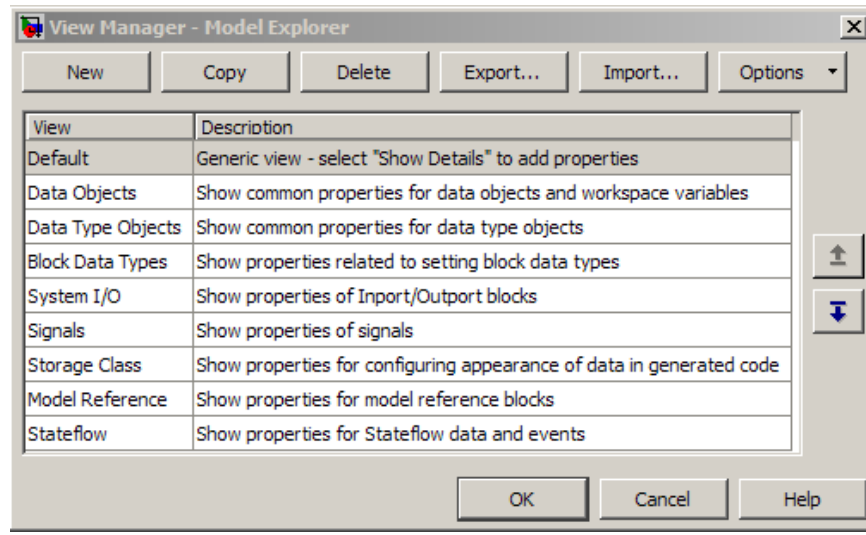
You can manage views (for example, create a new view or export a view) using the View Manager dialog box.

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 9-32
- "Deleting Views" on page 9-33
- "Reordering Views" on page 9-33
- "Exporting Views" on page 9-33
- "Importing Views" on page 9-34
- "Resetting Views to Factory Settings" on page 9-34

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 9-29.

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 9-33).

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.

Organize Data Display in Model Explorer

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 sort the column contents in ascending order, click the heading of the property column. A triangle pointing up appears in the column heading. To change the order from ascending to descending, or from descending to ascending, click the heading of the 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.

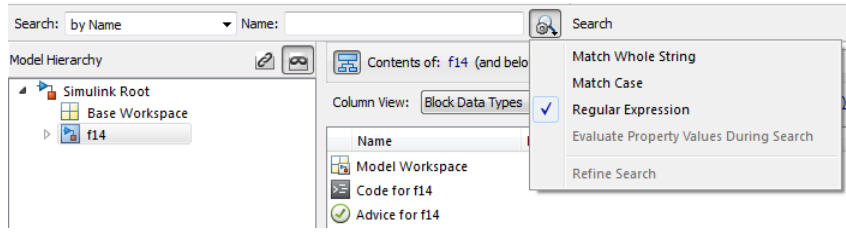
Note When you group by property, the Model Explorer applies sorting of column contents within each group.

Grouping by a Property

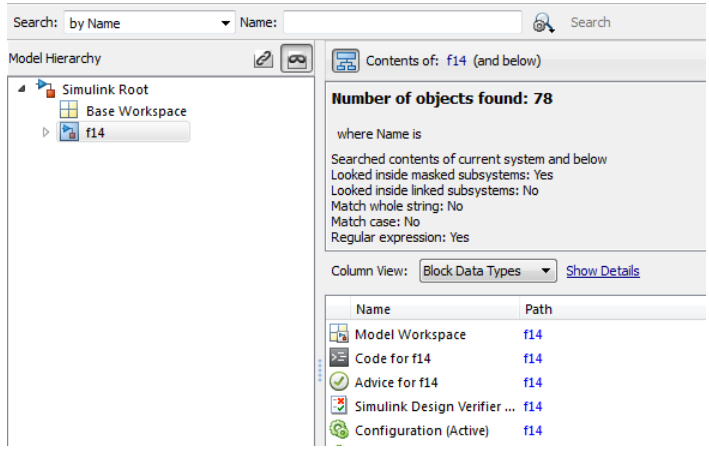
Organizing Contents by Property Values

When you explore a model, you might want to focus on all objects with the same property value. One approach is to group data by a property column.

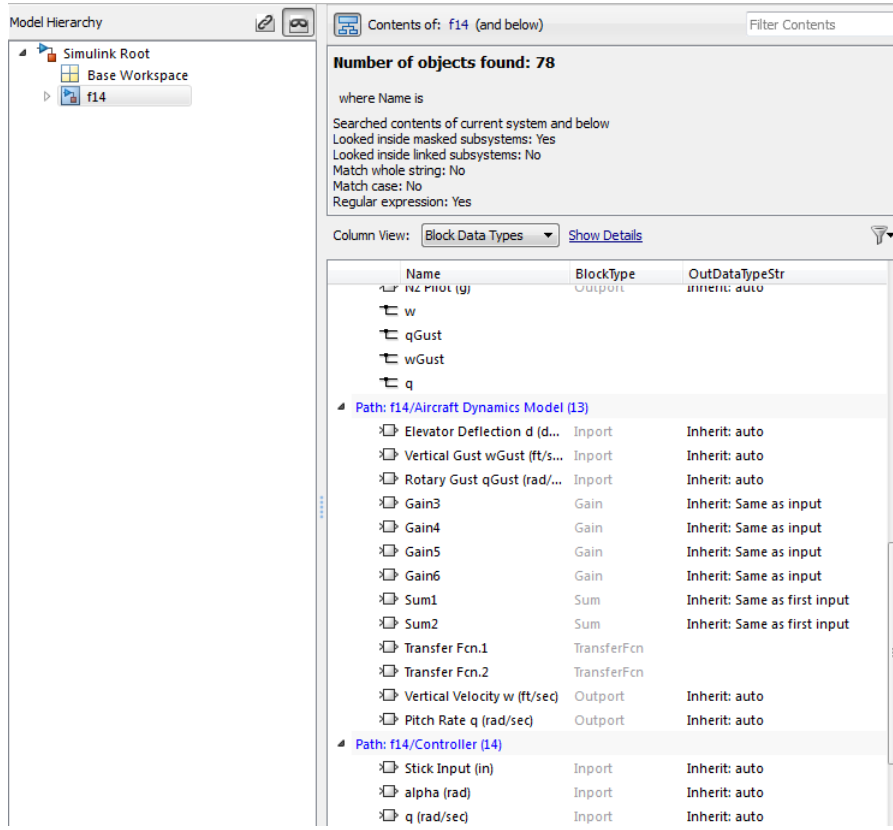
For example, suppose that you want to see all of the blocks in the `f14` model. You could perform the following search.



The search results obscure the whole path name for lower-level nodes:



By grouping on the `Path` property column, you 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.

   You can group by object icons, such as a block icon (), which represents a type of object. Right-click the empty column heading in the first column.

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**).

Hiding the Group Column

By default, the property column that you use for grouping appears in the property table. That property also appears in the top row for each group.

To hide the group column in the property table, use one of the following approaches:

- From the **View** menu, clear the **Show Group Column** check box.
- Right-click a column heading in the property table and clear the **Show Group Column** check box.

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

Object Icon and Name Columns Are Always First

The first two columns of every object property table are the object icon column (the column with a blank column heading) and the `Name` property column. You cannot hide, remove, or change the location of the first two columns.

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 table.

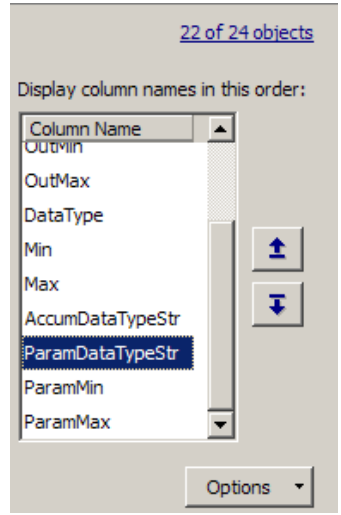
  This approach avoids opening the column view details section and makes it easier to move a column a short distance to the right or left.

- In the 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.

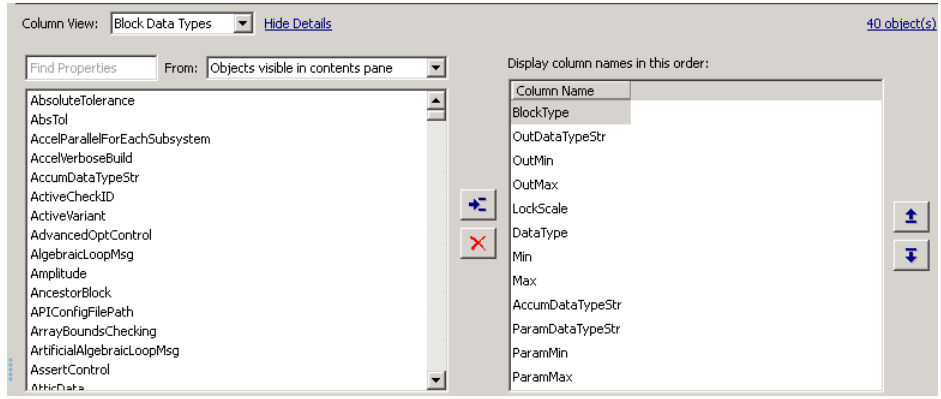


2 Click the **Move column left in view** button ( ) or the **Move column right in view** button ( ).

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.

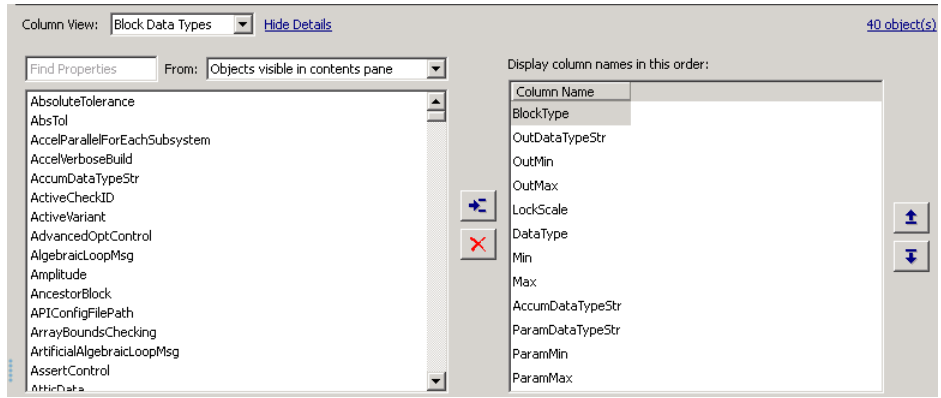
Hiding a Column Using the Column Heading Context Menu

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**.

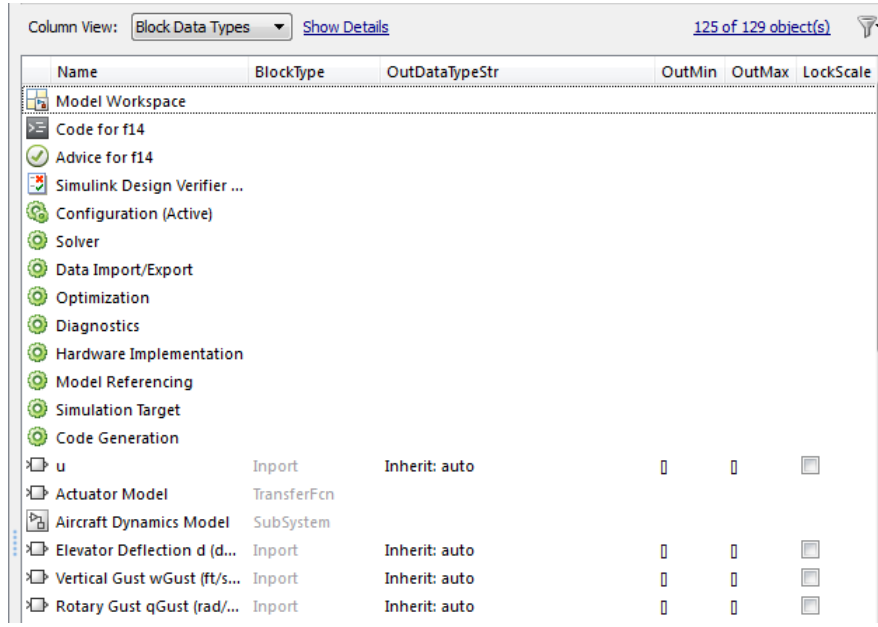
3 Select the column that you want to insert.

See “Hiding or Removing Property Columns” on page 9-43.

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:



Filter Objects in the Model Explorer

In this section...

Controlling the Set of Objects to Display

Two techniques that you can use to control the set of objects that the **Contents** pane displays are:

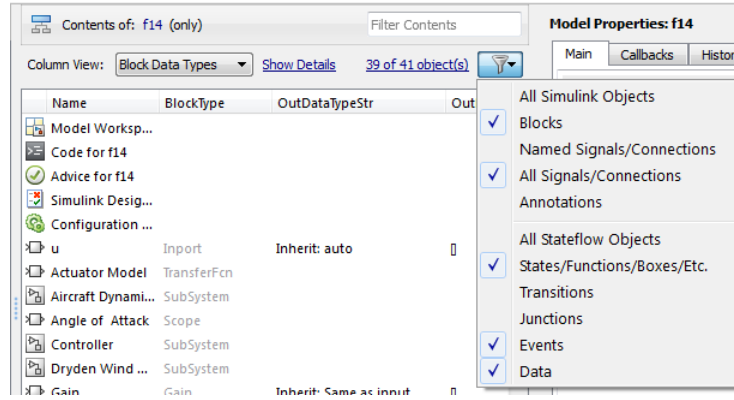
- Using the Row Filter option
- Filtering contents

For a summary of other techniques, see "Focusing on Specific Elements of a Model or Chart" on page 9-7.

Using the Row Filter Option

You can filter the kinds of objects that the **Contents** pane displays:

1. Open the **Row Filter** options menu. In the Model Explorer, at the top-right corner of the **Contents** pane, click the **Row Filter** button.

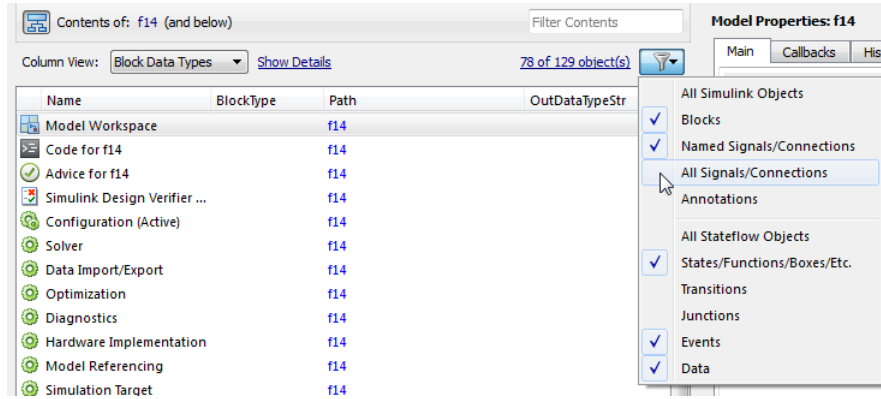


An alternative way to open the Row Filter menu is to select **View > Row Filter**.

By default, the **Contents** pane displays these kinds of objects for the selected node:

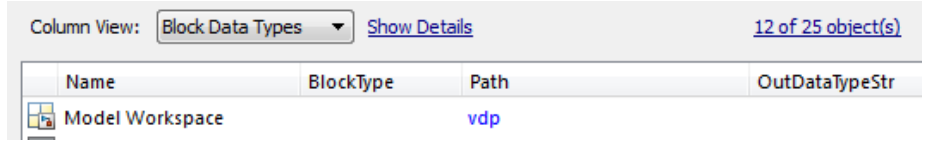
- Blocks
- Signals and connections
- Stateflow states, functions, and boxes
- Stateflow events
- Stateflow data

2. Clear the kinds of objects that you do not want to display in the **Contents** pane, or enable any cleared options to display more kinds of objects. For example, clear **All Signals/Connections** to prevent the display of signal and connection objects in the **Contents** pane.



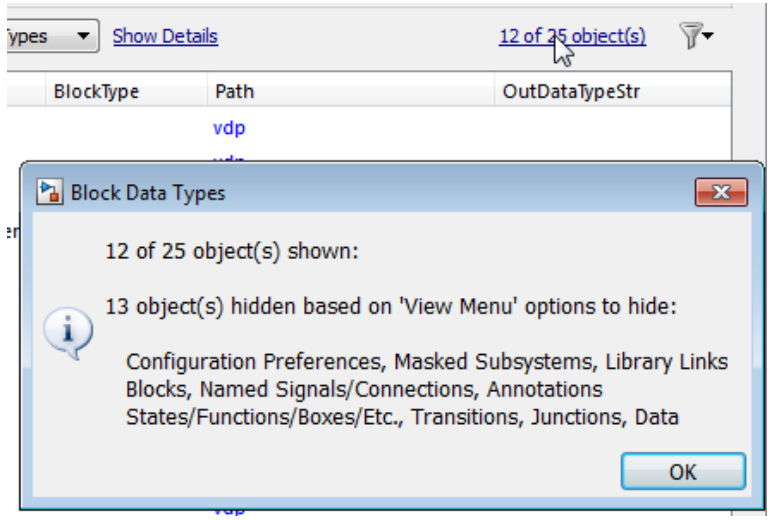
Object Count

The top-right portion of the **Contents** pane includes an object counter, indicating how many objects the **Contents** pane is displaying.



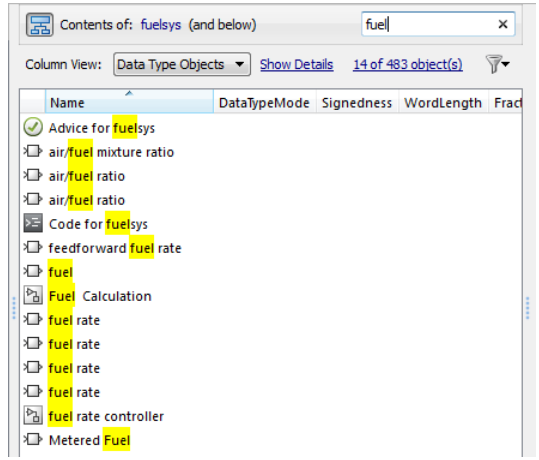
When you use the **Row Filter** option to filter objects, the object count indicator reflects that the **Contents** pane displays a subset of all the model and chart objects.

To view an explanation of the current object count, click the object count link (for example, `12 of 25 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.

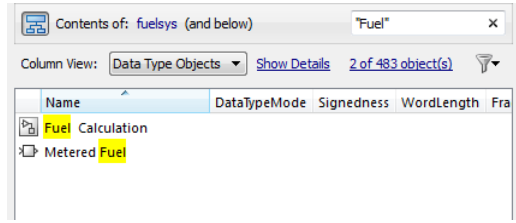
Specifying Filter Text Strings

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.

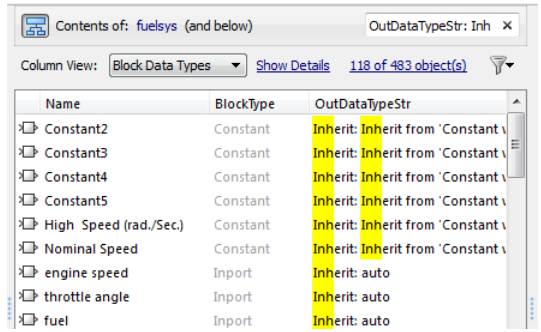
The text strings you enter must be in the format consistent with the guidelines described in the following sections.

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.

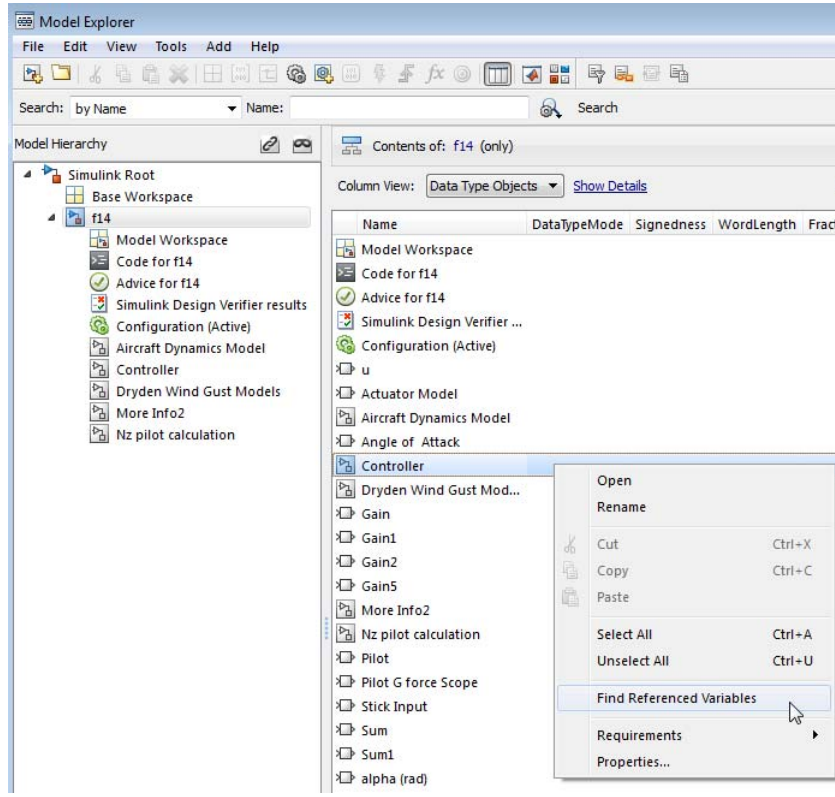
Workspace Variables in Model Explorer

In this section...

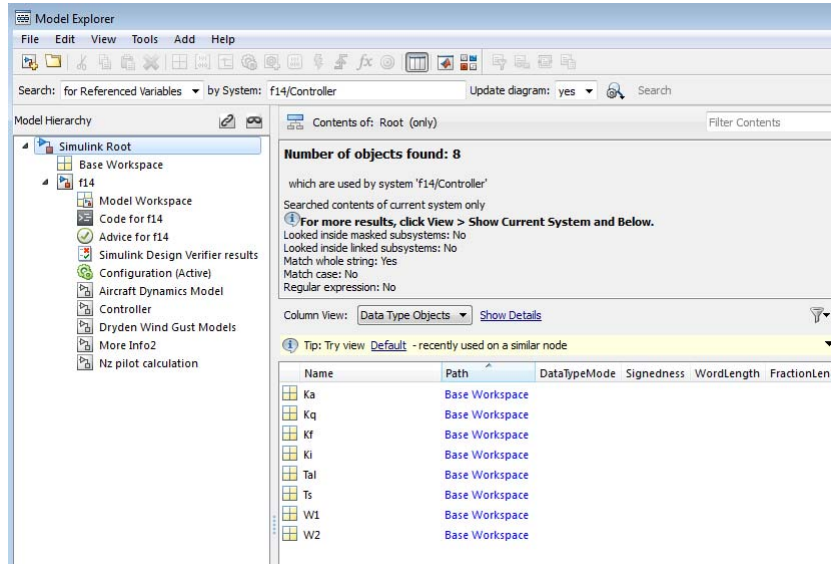
Finding Variables That Are Used by a Model or Block

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 these:



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 **Model Hierarchy** pane, right-click a block or model node and select the **Find Referenced Variables** menu item.
- 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.

For information about limitations when finding referenced variables, see the `Simulink.findVars` documentation.

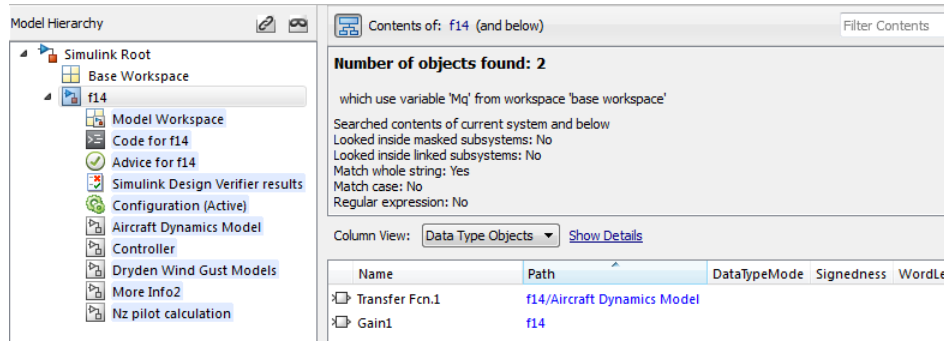
Using the Set of Returned Variables

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 9-55). Also, you can export variables from the returned set of variables. For details, see “Exporting Workspace Variables” on page 9-60.

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:

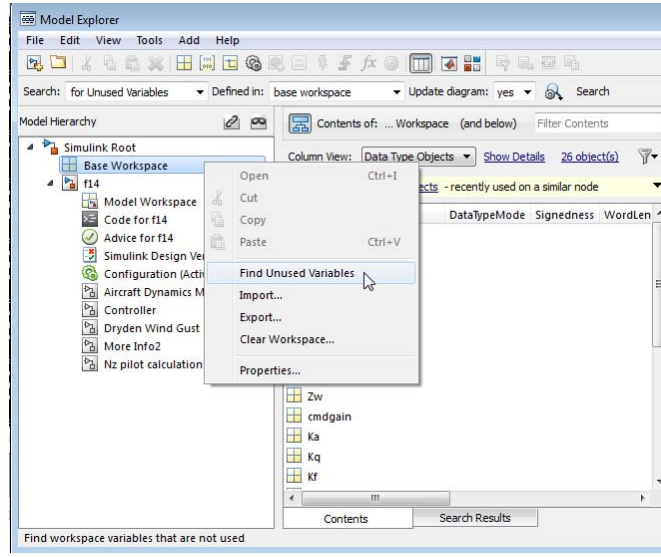
- In the search bar, select the `for Variable Usage` search type option.
- In the **Search Results** pane, right-click a variable and select the **Find Where Used** menu item.

If you do not find the variable that you are looking for because that variable is not in the currently selected system, try selecting **View > Show Current System and Below** and repeat the search.

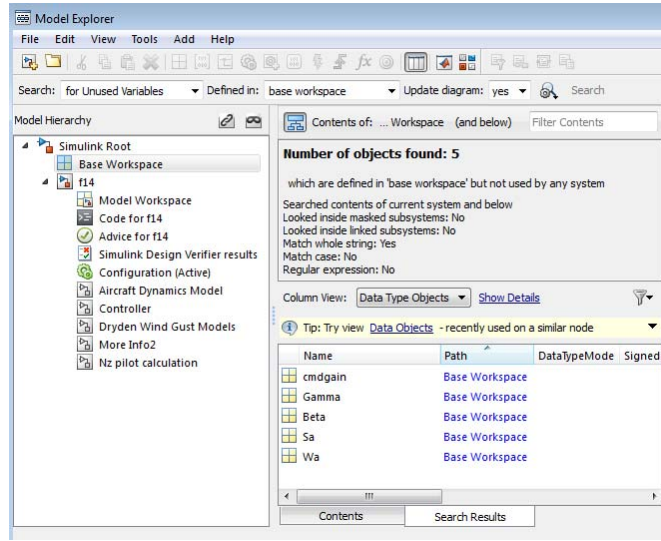
Finding Unused Workspace Variables

You can use the Model Explorer to get a list of variables that are defined in a workspace but not used by a model or block. One way to get that list of variables is to right-click a workspace name in the **Model Hierarchy** pane and select the **Find Unused Variables** menu item. For example:

1. Open the `f14` model.
2. Open the Model Explorer.
3. In the search toolbar, set the **Update diagram** field to `yes`.
4. In the **Model Hierarchy** pane, right-click the `Base Workspace` node and select the **Find Unused Variables** menu item.



5 The Model Explorer displays output similar to this:



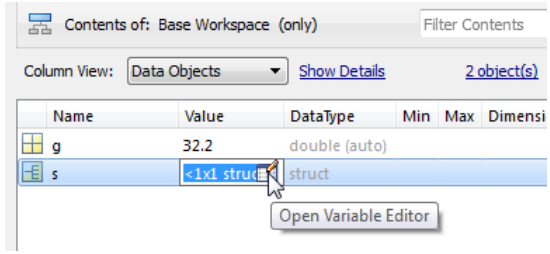
The `Simulink.findVars` function provides additional options for returning information about unused workspace variables that is not available from the Model Explorer or Model Editor.

Editing Workspace Variables

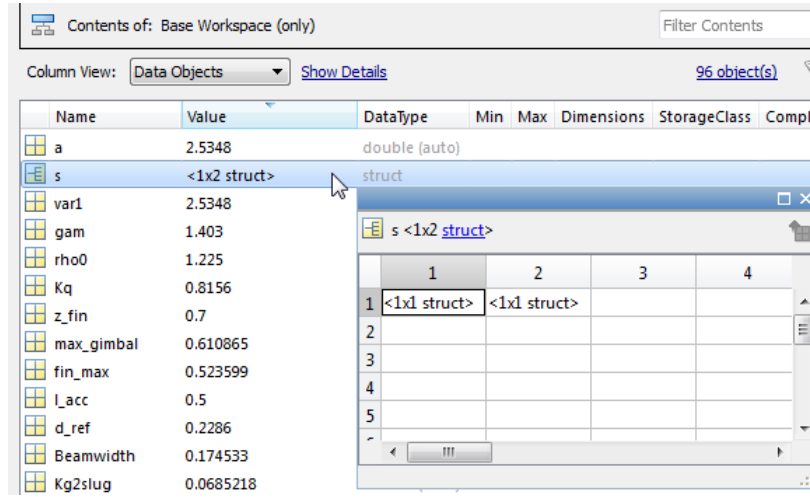
In the Model Explorer **Contents** pane, you can use the Variable Editor to edit variables from the MATLAB workspace or model workspace. The Variable Editor is available for editing large arrays and structures.

To open the Variable Editor for a variable that is an array or structure:

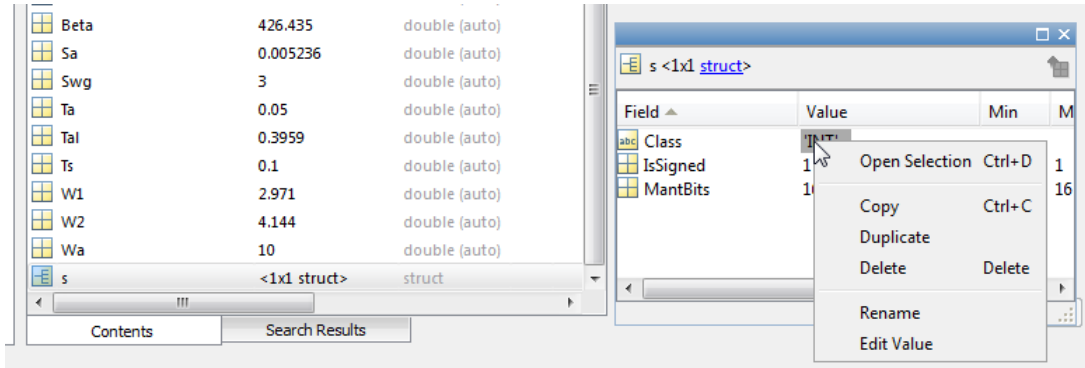
1. Click the Value cell for the variable.
2. Select the Variable Editor icon.



The Variable Editor opens:



Right-click in an edit box to open a context menu with several editing options:



You can resize and move the Variable Editor. The **Contents** pane reflects the edits that you make in the Variable Editor.

When you finish editing, the Variable Editor closes when you click the **Close** button in the upper right corner of the editor or when you click outside of the editor.

Exporting Workspace Variables

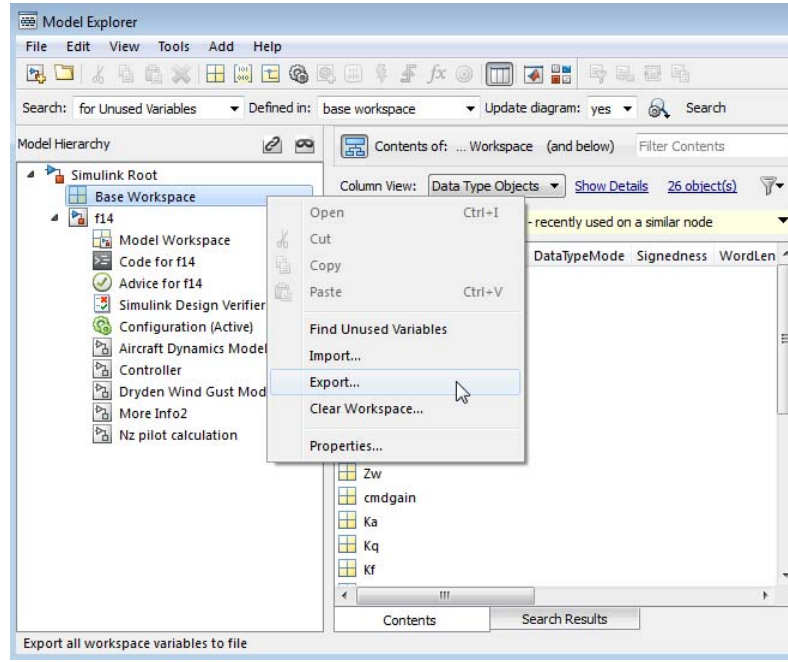
You can export (save) a set of variables listed in the Model Explorer, exporting either individual variables or all the variables in the base or model workspace.

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 9-52.

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 9-37.

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.

Search Using Model Explorer

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.

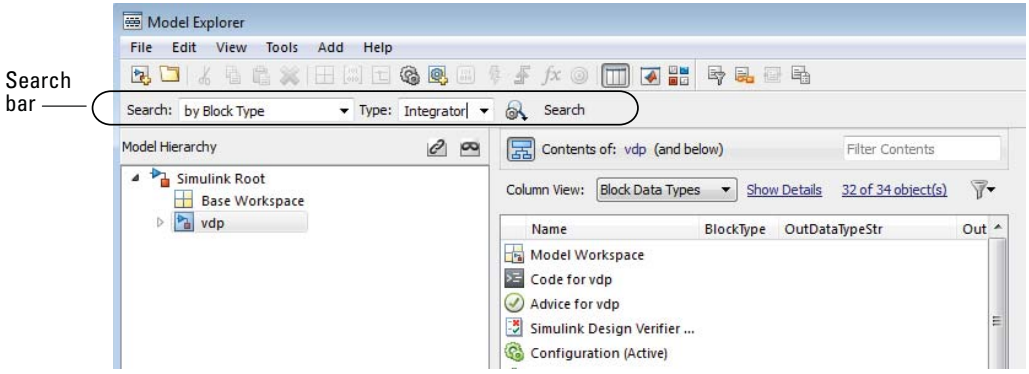
The search results appear in a table that is similar to the object property table in the **Contents** tab. The search results table uses the current column view (the object property table) definition as a starting point, and adds relevant properties that are not already included in the current view. 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.

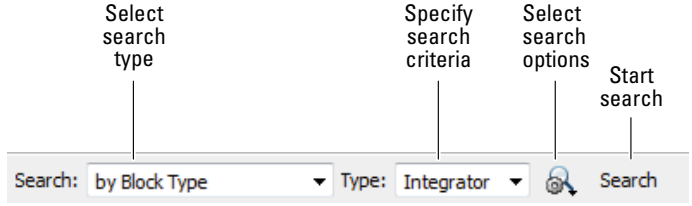


Showing and Hiding the Search Bar

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 9-68.
`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 9-68.
`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 blocks that use variables defined in a workspace. Select the base workspace or a model workspace (model name) and, optionally, the name of a variable. See "Search Strings" on page 9-68.
`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.

Search Type Option	Description
`for Unused Variables`	Searches for variables that are defined in a workspace but not used by any model or block. Select the name of the workspace from the drop-down list for the **in Workspace** field.
`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 9-68.
`by String`	Searches a model for all objects in which the string you specify occurs. See "Search Strings" on page 9-68.

Search Options

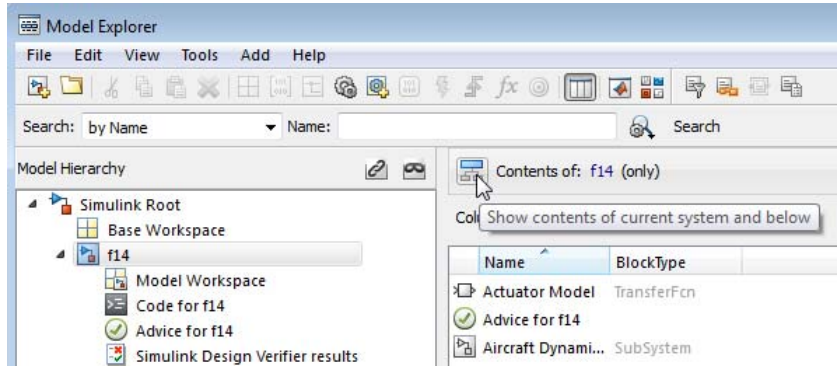
Use the **Search Options** control to specify the scope and how to apply search strings.

Search Option	Description
Match Whole String	Do not allow partial string matches (for example, do not allow `sub` to match `substring`).
Match Case	Considers case when matching strings (for example, `Gain` does not match `gain`).

Search Option	Description
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 9-69).

By default, the Model Explorer searches for objects in the system that you select in the Model Hierarchy pane. It does not search in child systems. You can override that default, so that the Model Explorer searches for objects in the whole hierarchy of the currently selected system. To toggle between searching only in the current system and searching in the whole system hierarchy of the current system, use one of these techniques:

- Select **View > Show Current System and Below**.
- Click the **Show Current System and Below** button at the top of the **Contents** pane.



Search Strings

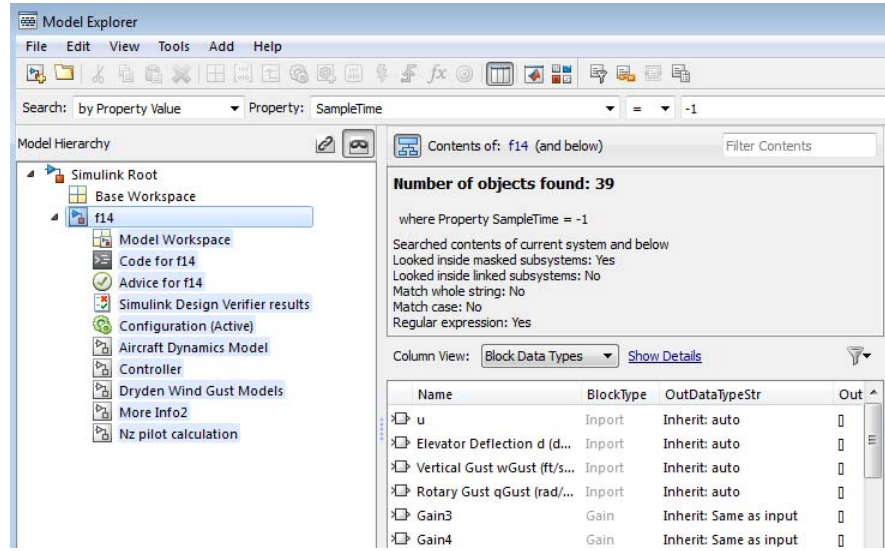
By default, search strings are case-insensitive and are treated as regular expressions.

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.

Model Explorer: Property 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

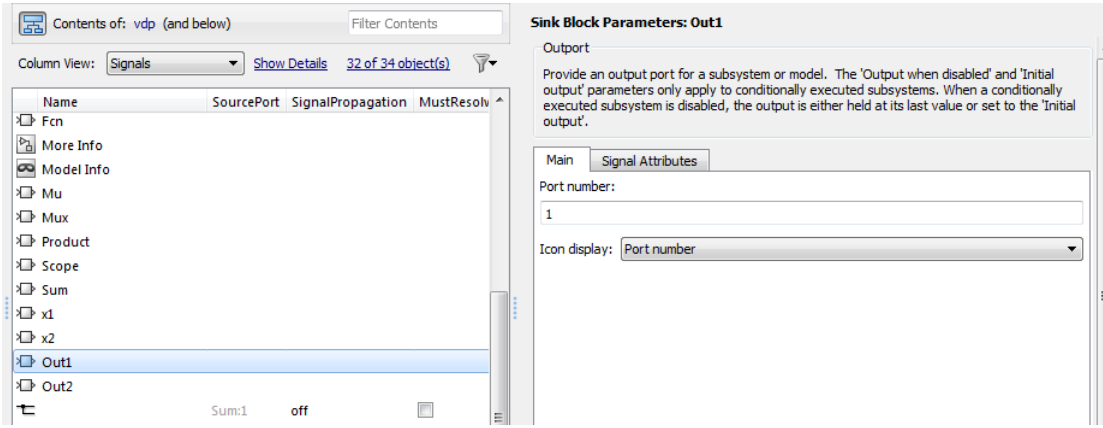
By default, the **Dialog** pane appears in the Model Explorer, to the right of the **Contents** pane. To show or hide the **Dialog** pane, use one of these approaches:

- 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:

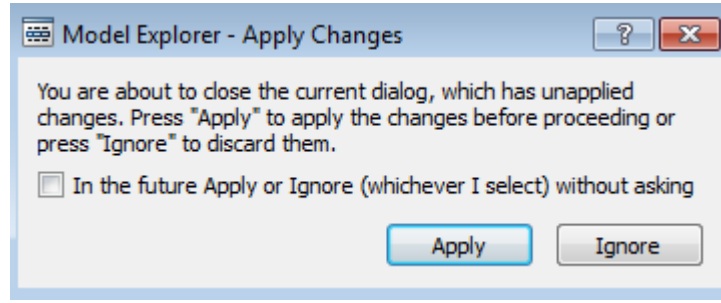
1. In the **Contents** pane, select an object (such as a block or signal). The **Dialog** pane displays the properties of the object you selected.



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**.

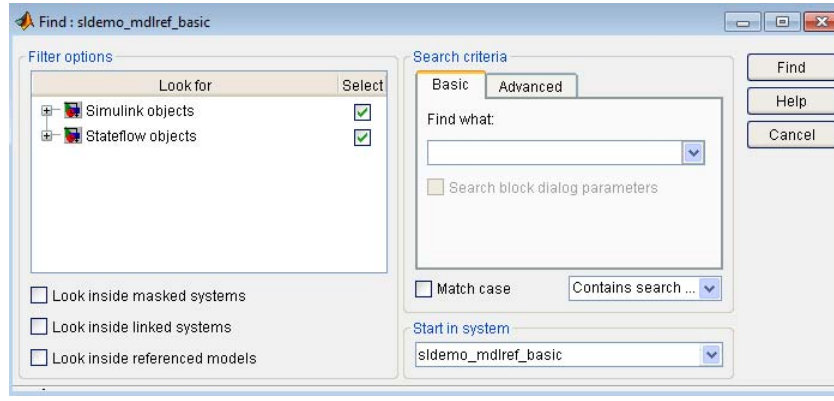
Finder

In this section...

Find Model Objects

Use the Finder to locate blocks, signals, states, or other objects in a model.

1 Open the Finder. In the Simulink Editor, either select **Edit > Find**, or press **Ctrl+F**.



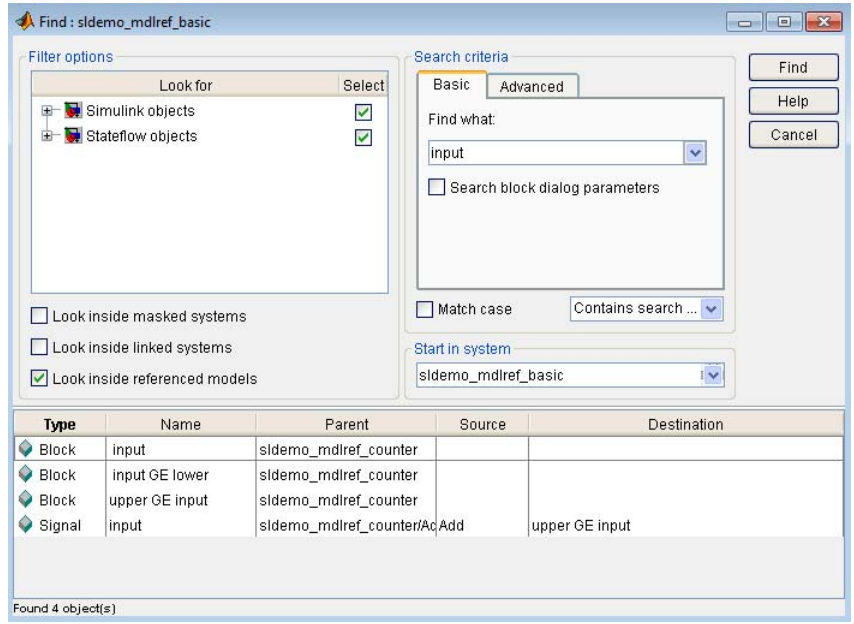
2 In the **Filter options** area, specify the kinds of objects to look for, and where to search for them. See “Filter Options” on page 9-75.

3 In the **Search criteria** area, specify the criteria that objects must meet to satisfy your search request. See “Search Criteria” on page 9-76.

4 If you have more than one system or subsystem open, click the **Start in system** list. From this list, select the system or subsystem where you want the search to begin.

5 Click **Find**.

The Finder searches the selected system for objects that meet the criteria that you have specified. Any objects that satisfy the criteria appear in the results panel at the bottom of the dialog box.



Display a Found Object

To display a found object, double-click 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 based on the values in a column, click the button at the top of that column. For example, to sort the results by object type, click the **Type** button. To sort the list in ascending order, click the button once. To sort the list in descending order, click the button twice.

To display the parameters or properties of an object, right-click the object in the list. From the context menu, select **Parameter** or **Properties**.

If you close a model that has objects in the Finder search results list, then double-clicking a found object from that model does not open the model. To

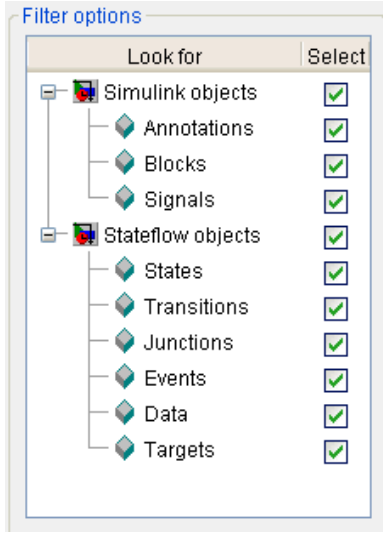
open an object that was in the Finder search results list, simply rerun the search by clicking the **Find** button.

Filter Options

To specify the kinds of objects to look for, and where to search for them, use the **Filter options** panel.

Object Type List

The object type list lists the types of objects that the Finder can find. To exclude a type of object from the Finder search, clear the check box for the object.



Specifying Kinds of Systems To Search

You can configure the Finder to search inside masked systems, linked library systems, and referenced models. The search starts with the system that you specify in the **Start in system** field.

Object Type Option	Where the Finder Searches
Look inside masked systems	Inside masked subsystems
Look inside linked systems	Inside subsystems linked to libraries
Look inside referenced models	Inside referenced models, down through a model reference hierarchy **Note** The Finder loads unopened referenced models. You can stop the search by using the pop-up cancel dialog box.

If you select more than one option, then the Finder searches in systems that fit any of the specified options. For example, if you select the **Look inside linked systems** and **Look inside referenced models** options, then the Finder:

- Searches in linked library systems and referenced models that are not in a masked system
- Does *not* search inside:
  - Masked systems, including those that are in linked library systems or referenced models
  - Linked library systems or model referenced models, if the system or model is in a masked system

Search Criteria

To specify the criteria that objects must meet to satisfy your search request, use the **Search criteria** panel.

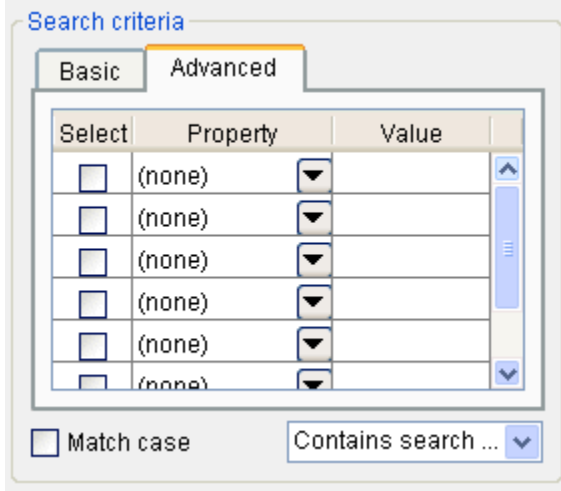
Basic

To search for an object whose name matches a specified text string, use the **Basic** panel. Enter search text in the **Find what** edit box. To reuse previous search text, select the appropriate search text from the dropdown list.

To include dialog parameters in the search, select **Search block dialog parameters**.

Advanced

To specify a set of as many as seven properties that an object must have to satisfy your search request, use the **Advanced** panel.



To specify a property, enter its name in one of the cells in the **Property** column or select the property from the property list of a cell. To display the property list, select the down arrow button next to the cell. Next enter the value of the property in the **Value** column. 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. To exclude the property, clear the check box.

Match case

Select this option if you want the Finder 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 dropdown list that specifies other match options.

- **Matches search string**

  Specifies a match if the property value and the search text are identical except possibly for case.

- **Contains search string**

  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.
`\`	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.

Character	Meaning
*	Matches zero or more instances of the preceding character. For example, ba* matches b, ba, baa, and so on.
+	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.

Model Browser

In this section...

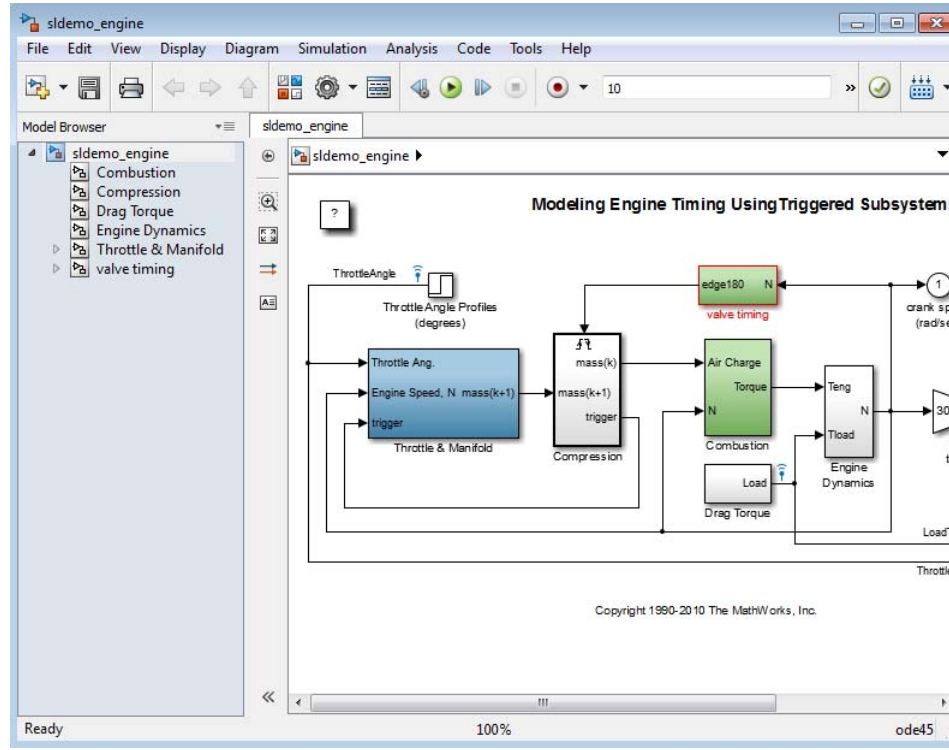
About the Model Browser

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, in the Simulink Editor, select **View > Model Browser > Show Model Browser**.



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, in the Simulink Editor, select **File > Simulink Preferences**.

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 Dependency Viewer

In this section...

About Model Dependency Views

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. To identify and package *all required files*, see instead "Analyze Model Dependencies" on page 13-104.

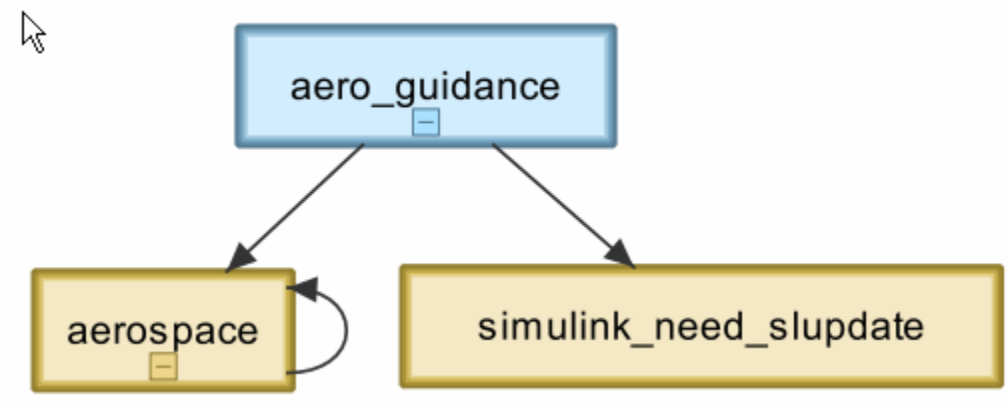
The Model Dependency Viewer allows you to choose between the following types of dependency views of a model reference hierarchy.

- "File Dependency View" on page 9-83
- "Referenced Model Instances View" on page 9-85
- "Processor-in-the-Loop Mode Indicator" on page 9-87
- "Warning Icon" on page 9-88

File Dependency View

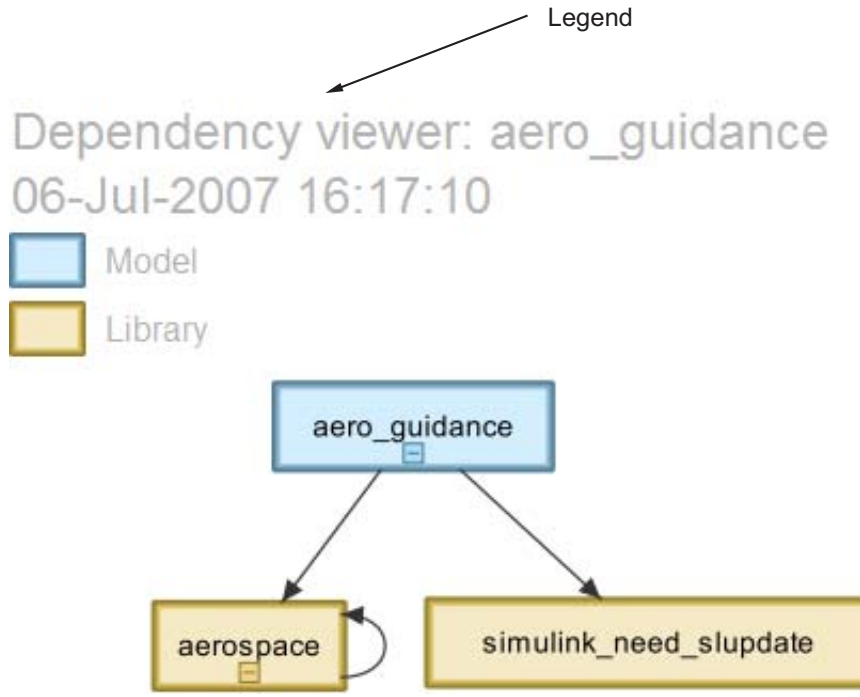
A *file dependency* view shows the model and library files referenced by a top model. A referenced model or library file appears only once in the view even if it is referenced more than once in the model hierarchy displayed in the view. A file dependency view consists of a set of blocks connected by 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`.



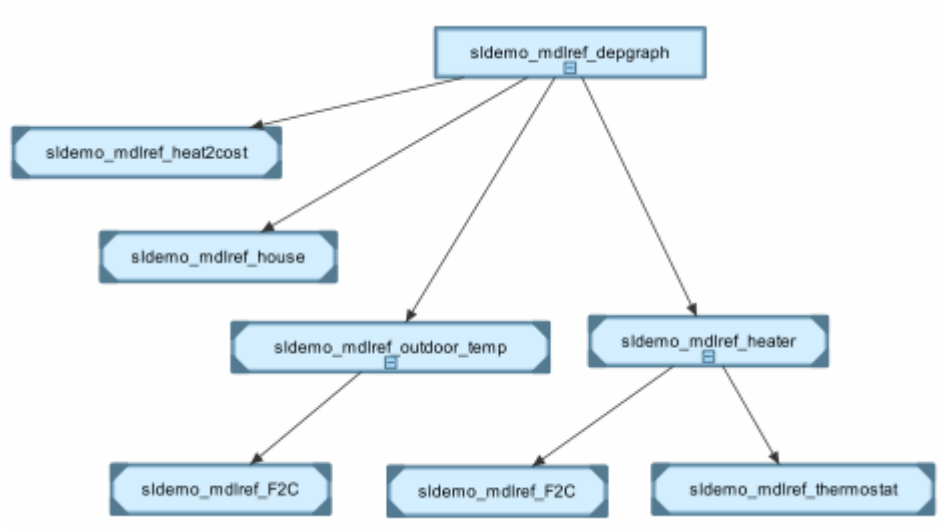
An arrow that points to the library from which it emerges indicates that the library references itself, i.e., blocks in the library reference other blocks in that same library. For example, the preceding view indicates that the `aerospace` library references itself.

A file dependency view optionally includes a legend that identifies the model in the view and the date and time the view was created.

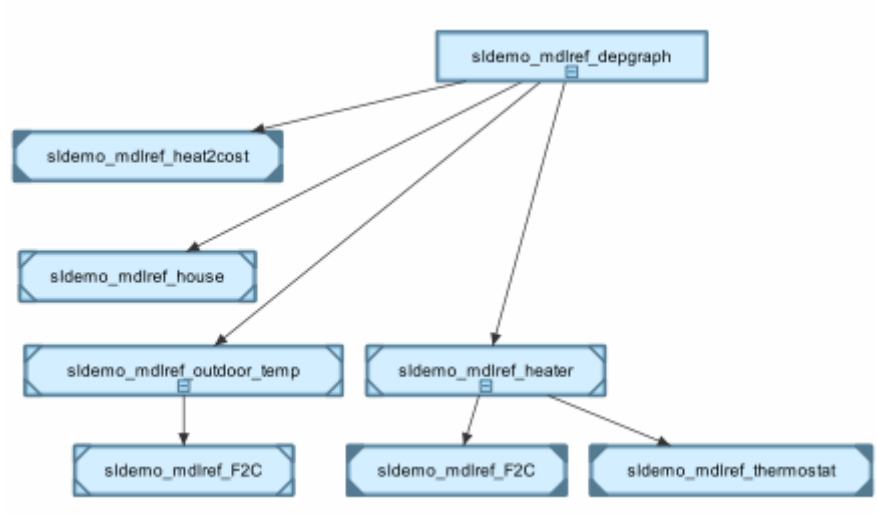


Referenced Model Instances View

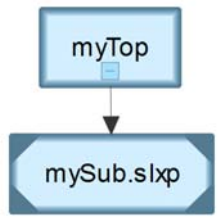
A *referenced model instances* view shows every reference to a model in a model reference hierarchy (see "Model Reference") rooted at the top model targeted by the view. If a model hierarchy references the same model more than once, the referenced model appears multiple times in the instance view, once 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 6-21) 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.

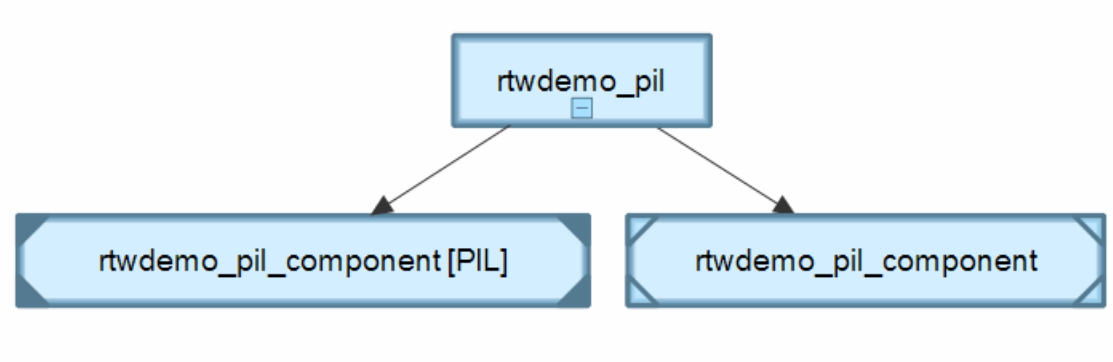


Boxes representing protected referenced models models have a lock icon, and the model name has the `.slxp` extension. Protected referenced model boxes have no expand(+)/collapse(–) button.



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 “Specify the Simulation Mode” on page 6-23). 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  .

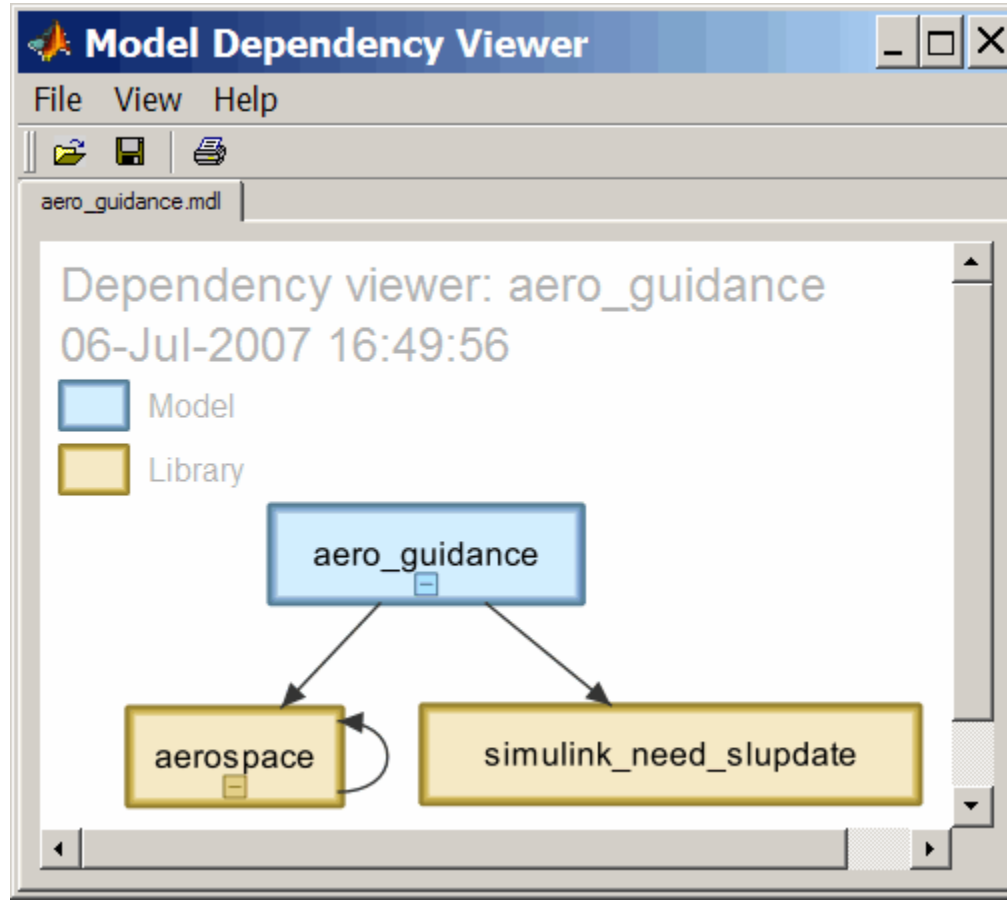
Opening the Model Dependency Viewer

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 **Analysis > Model Dependencies > Model Dependency Viewer**, then select the type of view you want to see:
   - **Models & Libraries**
   - **Models Only**
   - **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 9-90
- “Excluding Block Libraries from a File Dependency View” on page 9-90

Changing Dependency View Type

You can change the type of dependency view displayed in the viewer.

To change the type of dependency view, in the Model Dependency Viewer:

- Select **View > Dependency Type > Model File Dependencies** (see "File Dependency View" on page 9-83)

  or

- Select **View > Dependency Type > Referenced Model Instances** (see "Referenced Model Instances View" on page 9-85).

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:

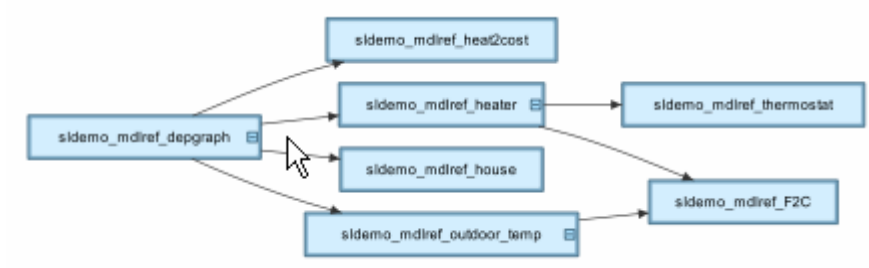
- Select **View > Show MathWorks Dependencies**.

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**.

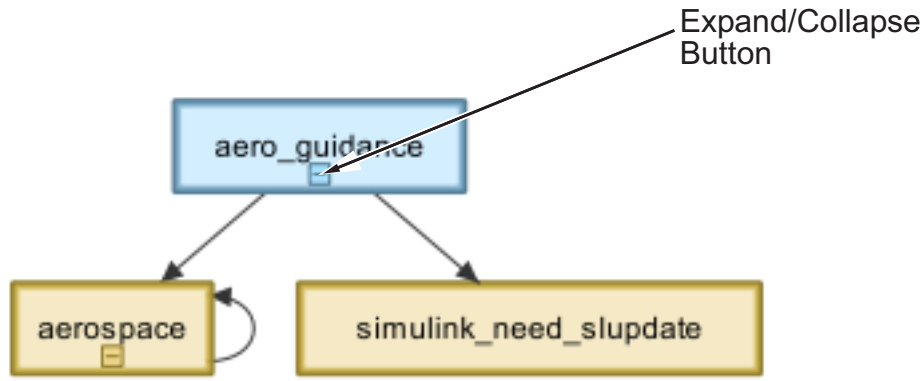


Expanding or Collapsing Views

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.

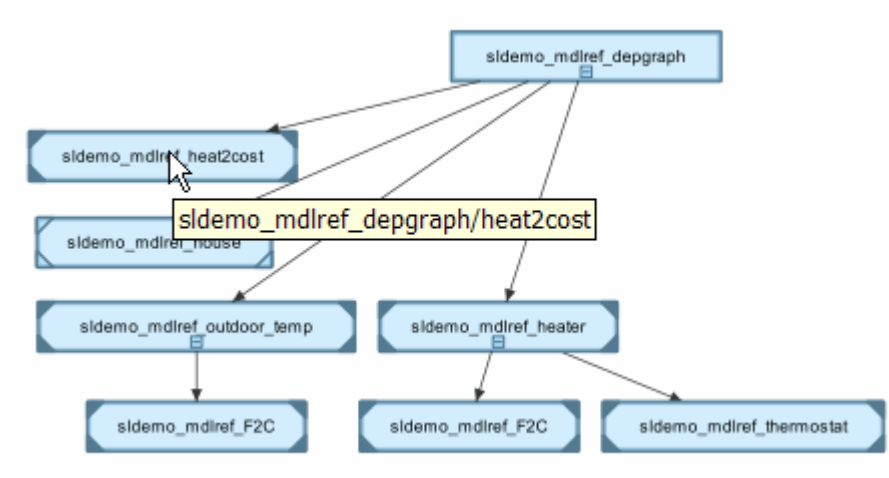
Displaying Full Paths of Referenced Model Instances

In an instance view (see "Referenced Model Instances View" on page 9-85) , 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.

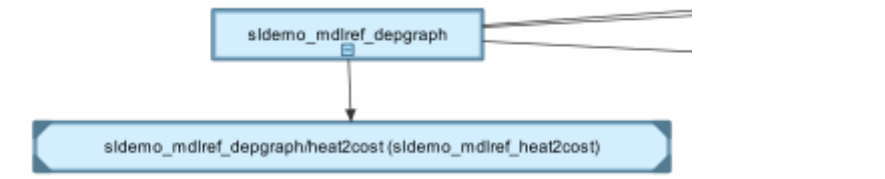
  A tooltip appears, displaying the path displays the full path of the Model block corresponding to the instance.



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.

View 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 following 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 the 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 Simulink Editor and the Model Explorer provide this capability.

Note If your model contains a Model block whose referenced model contains requirements, those requirements are not highlighted. If you have Simulink Verification and Validation, 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 "Report for Requirements in Model Blocks".

Highlighting a Model Using the Simulink Editor

If you are working in the Simulink Editor and want to see which model objects in the `slvnvdemo_fuelsys_officereq` model have requirements, follow these steps:

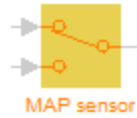
1. Open the example model:

   ```
   slvnvdemo_fuelsys_officereq
   ```

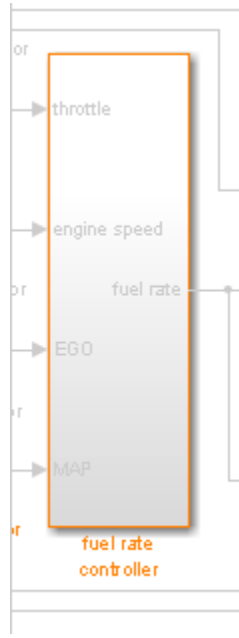
2. Select **Analysis > Requirements > Highlight Model**.

   Two types of highlighting indicate model objects with requirements:

   - Yellow highlighting 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 are colored gray.

3 To remove the highlighting from the model, select **Analysis > 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.

Highlighting a Model Using the Model Explorer

If you are working in Model Explorer and want to see which model objects have requirements, follow these steps:

1 Open the example model:

```
slvnvdemo_fuelsys_officereq
```

2. Select **View > Model Explorer**.
3. To highlight all 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.

Note If you are running a 64-bit version of MATLAB, when you navigate to a requirement in a PDF file, the file opens at the top of the page, not at the bookmark location.

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` example model, follow these steps:

1. Open the example 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 application, with the requirements text highlighted.

1. Open the example 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.

Note If you are running a 64-bit version of MATLAB, when you navigate to a requirement in a PDF file, the file opens at the top of the page, not at the bookmark location.

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 example model:

   ```
   slvnvdemo_fuelsys_officereq
   ```

2. Select **Analysis > 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" on page 9-102

• "Filtering Options for Highlighting Requirements" on page 9-103

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 example model:

   ```
   slvnvdemo_fuelsys_officereq
   ```

2. In the Simulink Editor, select **Analysis > 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 **Analysis > 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 **Analysis > 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.

10

Managing Model Configurations

About Model Configurations

A model configuration is a named set of values for the parameters of a model. It is referred to as a *configuration set*. Every new model is created with a default configuration set, called `Configuration`, that initially specifies default values for the model parameters. You can change the default values for new models by setting the Model Configuration Preferences. For more information, see "Model Configuration Preferences" on page 10-28.

You can subsequently create and modify additional configuration sets and associate them with the model. The configuration sets associated with a model can specify different values for any or all configuration parameters. For more information, see "About Configuration Sets" on page 10-26. For examples on how to use configuration sets, see:

- "Multiple Configuration Sets in a Model" on page 10-3
- "Manage a Configuration Set" on page 10-12

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 other models can use it. 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 freestanding configuration set. A freestanding configuration set allows you to single-source a configuration set for several models. For more information, see "About Configuration References" on page 10-29. For examples on how to use configuration references, see:

- "Share a Configuration for Multiple Models" on page 10-4
- "Share a Configuration Across Referenced Models" on page 10-6
- "Manage a Configuration Reference" on page 10-18

Multiple Configuration Sets in a Model

A model can include many different configuration sets. This capability is useful if you want to compare the difference in simulation output after changing the values of several parameters. Attaching additional configuration sets allows you to quickly switch the active configuration.

1. To create additional configuration sets in your model, in the Model Explorer, select your model node in the Model Hierarchy pane and do one of the following:
   - Right-click the model node and select **Configuration > Add Configuration**.
   - Right-click an existing configuration set. In the context menu, select **Copy**.
2. To import a previously saved configuration set, right-click the model node and select **Configuration > Import**. In the Import Configuration From File dialog box, select a configuration file.
3. To modify the newly added configuration set, in the Model Hierarchy pane, select the configuration node. In the **Contents** pane, select a component, and then modify any parameters which are displayed in the right pane.
4. To make the new configuration set the active configuration, in the configuration set context menu, select **Activate**. In the Model Hierarchy pane, the new configuration set name is now displayed as `(Active)`.
5. To simulate your model using a different configuration set, switch the active configuration by repeating step 4.

Share a Configuration for Multiple Models

To share a configuration set between models, the configuration set must be a configuration set object in the base workspace and you must create a configuration reference in your model to reference the configuration set object. You can create configuration references in other models that also point to the same configuration set object.

For example, first convert an existing configuration set in your model to a configuration reference:

1. Open the Model Explorer.
2. In the Model Hierarchy pane, right-click the active configuration set to share.
3. In the configuration set context menu, select **Convert to Configuration Reference**, which opens a dialog box. Alternatively, you can right-click the model node and select **Configuration > Convert Active Configuration to Reference**.
4. In the Convert Active Configuration to Reference dialog box, use the default configuration set object name, `configSetObj`, or type a name.
5. Click **OK**, which creates a configuration reference in the model and a configuration set object in the base workspace. The configuration reference points to the configuration set object, which has the same values as the original active configuration set. The configuration reference name in the Model Hierarchy is now marked as `(Active)`.
6. To change the name of the configuration reference, select it in the Model Hierarchy, and in the right pane, change the **Name** field.

To share the preceding configuration set, which is stored as `configSetObj` in the base workspace, create a configuration reference in another model:

1. In the Model Hierarchy pane, right-click the model node.
2. In the context menu, select **Configuration > Add Configuration Reference**.

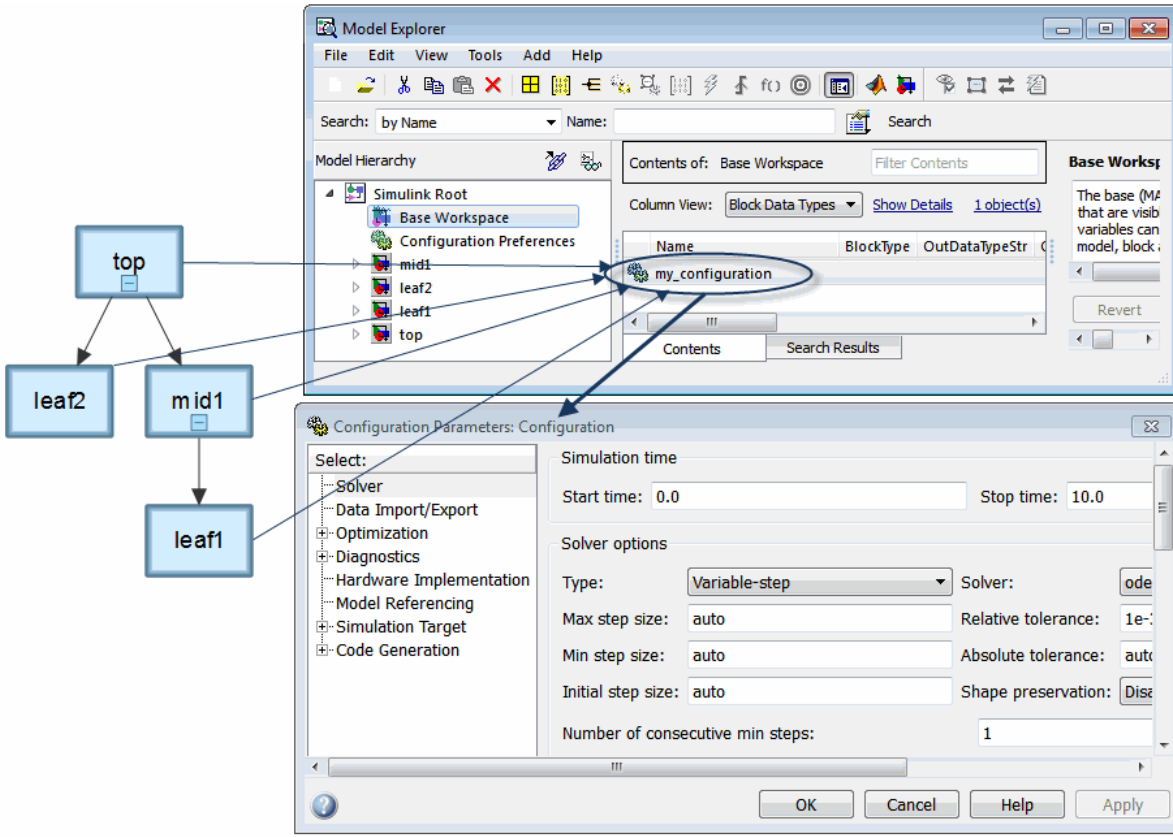
3. The Create Configuration Reference dialog box opens. Specify the name of the configuration set object, `configSetObj`, in the base workspace.

4. To make the new configuration reference the active configuration, in the Model Hierarchy, right-click the configuration reference. In the context menu, select **Activate**.

Both models now contain a configuration reference that points to the same configuration set object in the base workspace. Before saving and closing your models, follow the instructions to "Save a Referenced Configuration Set" on page 10-23. If you do not save the referenced configuration set from the base workspace, when you reopen your model, the configuration reference is unresolved. To set up your model to automatically load the configuration set object, see "Callback Functions" on page 4-54.

Share a Configuration Across Referenced Models

If you have a model reference hierarchy, you might want the top model and the referenced models to share the same configuration set. You can use a configuration reference in each of the models to reference the same configuration set object in the base workspace.

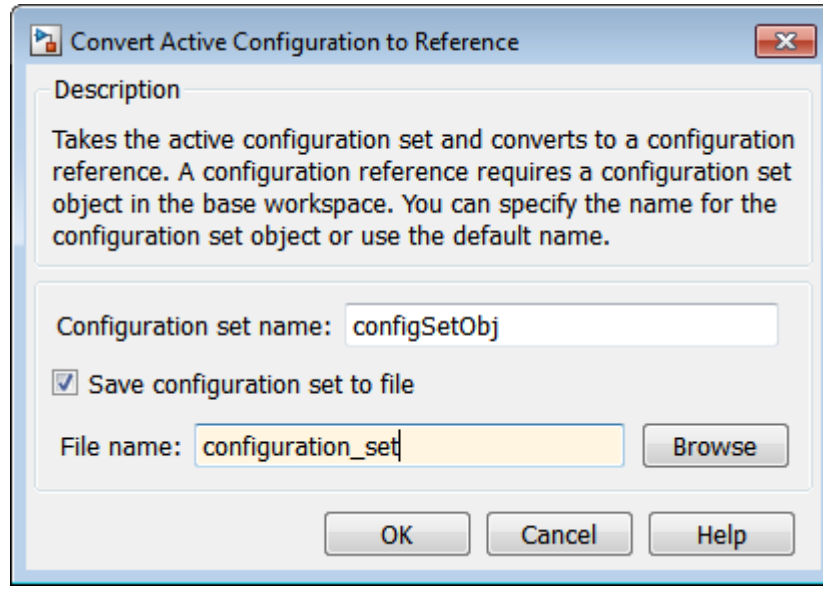


In the diagram, each model shown in the Model Dependency Viewer specifies the configuration reference, `my_configuration`, as its active configuration set. `my_configuration` points to the freestanding configuration set, `Configuration`. Therefore, the parameter values in `Configuration` apply to all four models. Any parameter change in `Configuration` applies to all four models.

Convert Configuration Set to Configuration Reference

In the top model, you must convert the active configuration set to a configuration reference:

1. Open the `sldemo_mdlref_depgraph` model and the Model Explorer.
2. In the Model Hierarchy pane, expand the top model, `sldemo_mdlref_depgraph`. In the list, right-click `Configuration (Active)`. In the context menu, select **Convert to Configuration Reference**.
3. In the **Configuration set name** field, specify a name for the configuration set object, or use the default name, `configSetObj`. This configuration set object is stored in the base workspace.
4. Optionally, you can save the configuration set to a MAT-file. Select **Save configuration set to file**. This enables the **File name** parameter.
5. In the **File name** field, specify a name for the MAT-file.



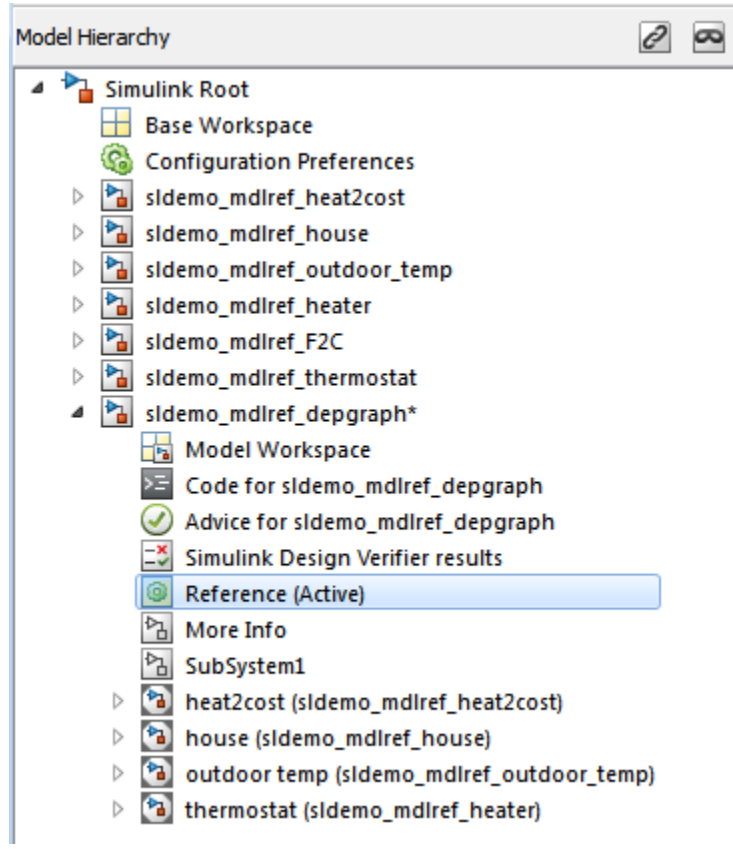
6 Click **OK**.

The original configuration set is now stored as a configuration set object, `configSetObj`, in the base workspace. The configuration set is also stored in a MAT-file, `configuration_set.mat`. The active configuration for the top model is now a configuration reference. This configuration reference points to the configuration set object in the base workspace.

Propagate a Configuration Reference

Now that the top model contains an active configuration reference, you can propagate this configuration reference to all of the child models. Propagation creates a copy of the top model configuration reference in each referenced model. For each referenced model, the configuration reference is now the active configuration. The configuration references point to the configuration set object, `configSetObj`, in the base workspace.

1 In the Model Explorer, in the Model Hierarchy pane, expand the `sldemo_mdlref_depgraph` node.



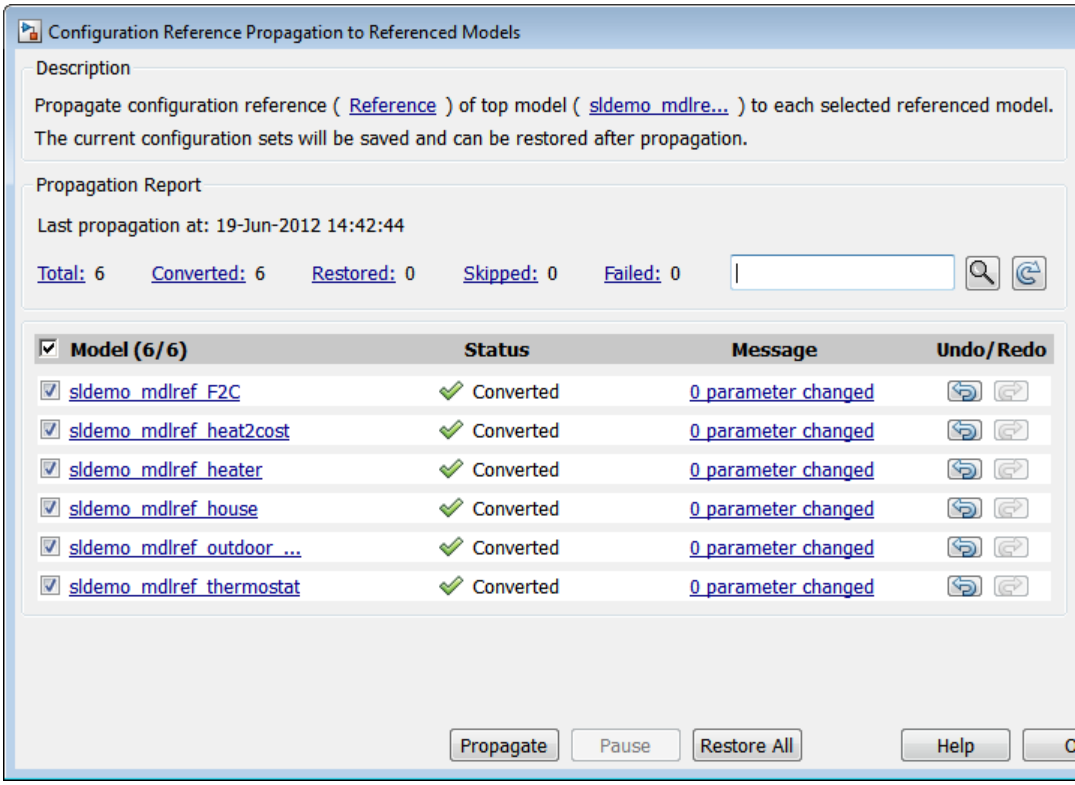
2 Right-click the active configuration reference, **Reference (Active)**. In the context menu, select **Propagate to Referenced Models**.

3 In the Configuration Reference Propagation dialog box, select the check box for each referenced model. In this example, they are already selected.

4 Verify that your current folder is a writable folder. The propagation mechanism saves the original configuration parameters for each referenced model so that you can undo the propagation. Click **Propagate**.

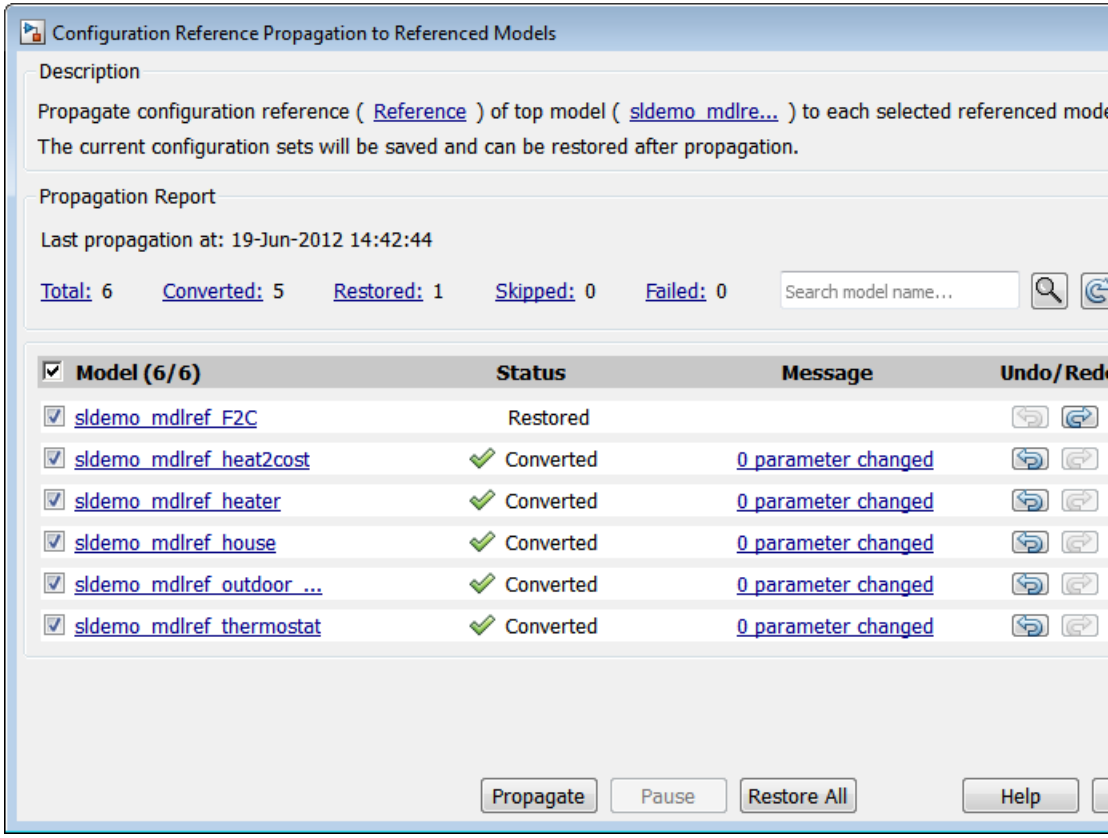
5 In the Propagation Confirmation dialog box, click **OK**.

6 In the Configuration Reference Propagation dialog box, the Propagation Report is updated and the **Status** for each referenced model is marked as `Converted`.



Undo a Configuration Reference Propagation

After propagating a configuration reference from a top model to the referenced models, you can undo the propagation for all referenced models by clicking **Restore All**. If you want to undo the propagation for individual referenced models, in the **Undo/Redo** column, click the **Undo** button. The Propagation Report is updated and the **Status** for the referenced model is set to `Restored`.


Configuration Reference Propagation to Referenced Models
Description
Propagate configuration reference (Reference) of top model (sldemo_mdlre...) to each selected referenced mode
The current configuration sets will be saved and can be restored after propagation.
Propagation Report
Last propagation at: 19-Jun-2012 14:42:44
Total: 6
Converted: 5
Restored: 1
Skipped: 0
Failed: 0
Search model name...
Model (6/6)
Status
Message
Undo/Red
sldemo_mdlref_F2C
Restored
sldemo_mdlref_heat2cost
Converted
0 parameter changed
sldemo_mdlref_heater
Converted
0 parameter changed
sldemo_mdlref_house
Converted
0 parameter changed
sldemo_mdlref_outdoor_...
Converted
0 parameter changed
sldemo_mdlref_thermostat
Converted
0 parameter changed
Propagate
Pause
Restore All
Help

Manage a Configuration Set

In this section...

Create a Configuration Set in a Model

1. Open the Model Explorer.
2. In the Model Hierarchy pane, select the model name.
3. You can create a new configuration set in any of the following ways:
   - From the **Add** menu, select **Configuration**.
   - On the toolbar, click the **Add Configuration** button  .
   - In the Model Hierarchy pane, right-click an existing configuration set and copy and paste the configuration set.

Create a Configuration Set in the Base Workspace

1. Open the Model Explorer.
2. In the Model Hierarchy pane, select **Base Workspace**.
3. You can create a new configuration set object in the following ways:
   - From the **Add** menu, select **Configuration**

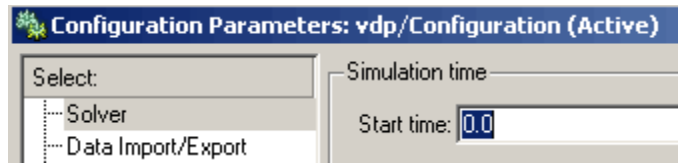
- In the toolbar, click the **Add Configuration** button 

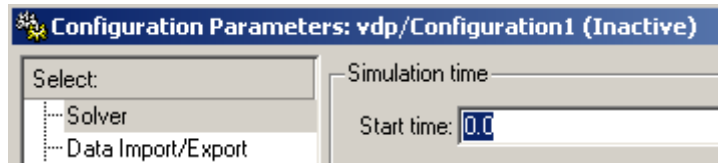
4 The configuration set object appears in the Contents pane, with the default name, `ConfigSet`.

Open a Configuration Set in the Configuration Parameters Dialog Box

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.

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.

Activate a Configuration Set

Only one configuration set associated with a model is active at any given time. The active set determines the current values of the model parameters. 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.

To activate a configuration set, right-click the configuration set node to display the context menu, then select **Activate**.

Set Values in a Configuration Set

To set the value of a parameter in a configuration set, in the Model Explorer:

1. In the Model Hierarchy, select the configuration set node.
2. In the Contents pane, select the component from where the parameter resides.
3. In the Dialog pane, edit the parameter value.

Copy, Delete, and Move a Configuration Set

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 from one model to another:

1. In the **Model Hierarchy** pane, right-click the configuration set node that you want to copy.
2. Select **Copy** in the configuration set context menu.
3. Right-click the model node in which you want to create the copy.
4. Select **Paste** from the model context menu.

To copy the configuration set using object drag-and-drop, hold down the right mouse button and drag the configuration set 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 node to the node of the destination model.

Note You cannot move or delete an active configuration set from a model.

Save a Configuration Set

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.

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 **Configuration > 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.

Load a Saved Configuration Set

You can load configuration sets that you previously saved as MATLAB functions or scripts.

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 **Configuration > Import**.
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 "Activate a Configuration Set" on page 10-13.

Copy 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. From either the Model Explorer **Edit** menu or the component context menu, select **Copy**.
3. Select the configuration set into which you want to copy the component.
4. From either the Model Explorer **Edit** menu or the component context menu, select **Paste**.

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.

Manage a Configuration Reference

In this section...

Create and Attach a Configuration Reference

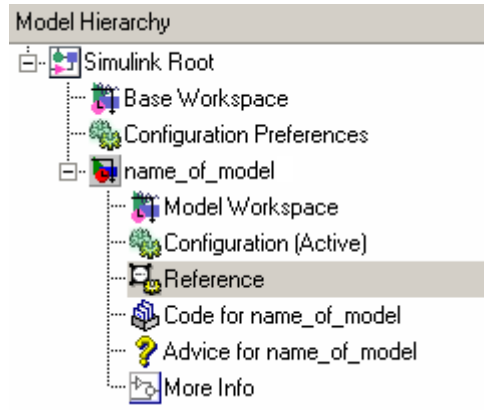
To use a configuration reference, it must point to freestanding configuration set. Create a freestanding configuration set before creating a configuration reference, see "Create a Configuration Set in the Base Workspace" on page 10-12.

To create a configuration reference:

1. In the Model Explorer, in the Model Hierarchy pane, select the model.
2. Click the **Add Reference** tool  or select **Add > Configuration Reference**. The Create Configuration Reference dialog box opens.
3. Specify the **Configuration set name** of the configuration set object in the base workspace to be referenced.
4. Click **OK**. If you chose to create a configuration reference without first creating a configuration set object, a dialog box opens asking if you would like to continue. If you choose:

- **Yes**, an unresolved configuration reference is created. For more information, see “Unresolved Configuration References” on page 10-30. Follow the instructions in“Resolve a Configuration Reference” on page 10-19.
- **No**, then the configuration reference is not created. Follow the instructions in“Create a Configuration Set in the Base Workspace” on page 10-12, and then return to step 1 above.

5 A new configuration reference appears in the Model Hierarchy under the selected model. The default name of the new reference is `Reference`.



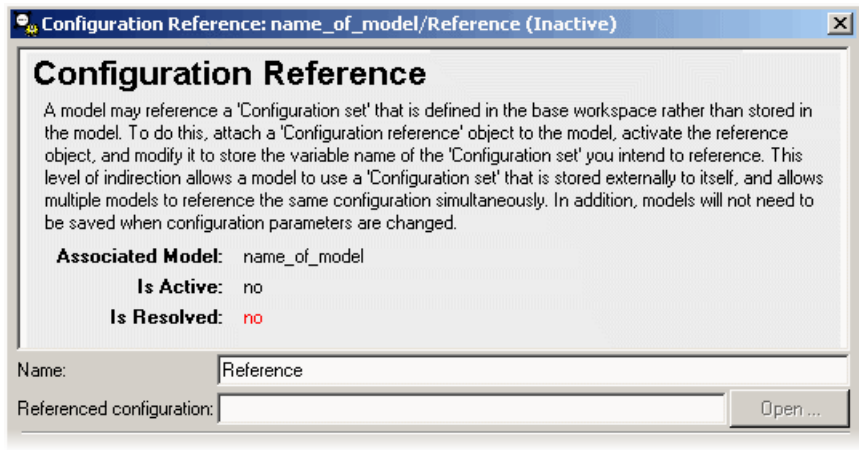
Resolve a Configuration Reference

An unresolved configuration reference is a configuration reference that is not pointing to a valid configuration set object.

To resolve a configuration reference:

1 In the Model Hierarchy pane, select the unresolved configuration reference or right-click the configuration reference, and select **Open** from the context menu.

The Configuration Reference dialog box opens in the Dialog pane or a separate window.



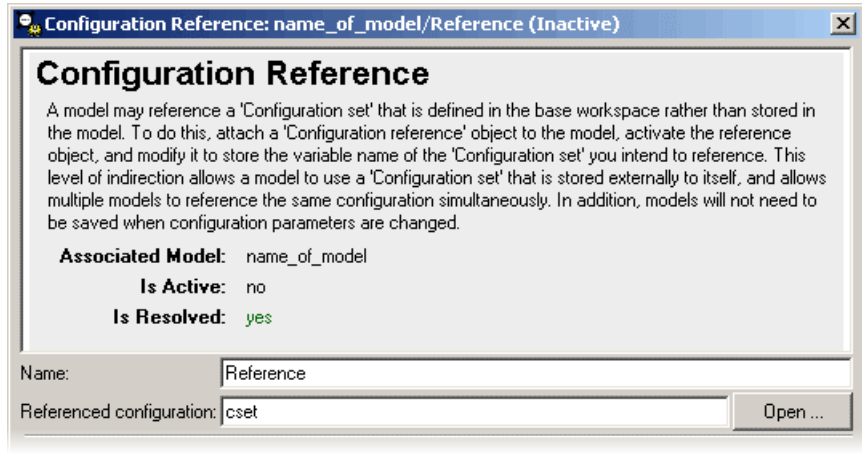
2 Specify the **Referenced configuration** set to be a configuration set object already in the base workspace. If one does not exist, see "Create a Configuration Set in the Base Workspace" on page 10-12.

Tip Do not specify the name of a configuration reference. If you nest a configuration reference, an error occurs.

---

3 Click **OK** or **Apply**.

If you specified a Referenced configuration that exists in the base workspace, the **Is Resolved** field in the dialog box changes to `yes`.

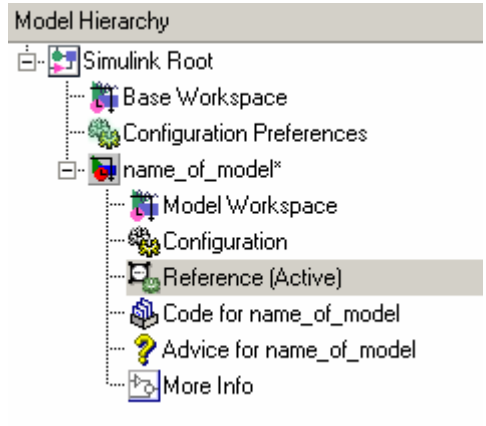


Activate a Configuration Reference

After you create a configuration reference and attach it to a model, you can activate it so that it is the active configuration.

- In the GUI, from the context menu of the configuration reference, select **Activate**.
- 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 changes to `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.

Manage Configuration Reference Across Referenced Models

In a model hierarchy, you can share a configuration reference across referenced models. Using the Configuration Reference Propagation dialog box, you can propagate a configuration reference of a top model to an individual referenced model or to all referenced models in the model hierarchy. The dialog box provides:

- A list of referenced models in the top model.
- The ability to select only specific referenced models for propagation.
- After propagation, the status for the converted configuration for each referenced model.
- A view of the changed parameters after the propagation.
- The ability to undo the configuration reference and restore the previous configuration settings for a referenced model.

To open the dialog box, in the Model Explorer, in the model hierarchy pane, right-click the configuration reference node of a model. In the context menu,

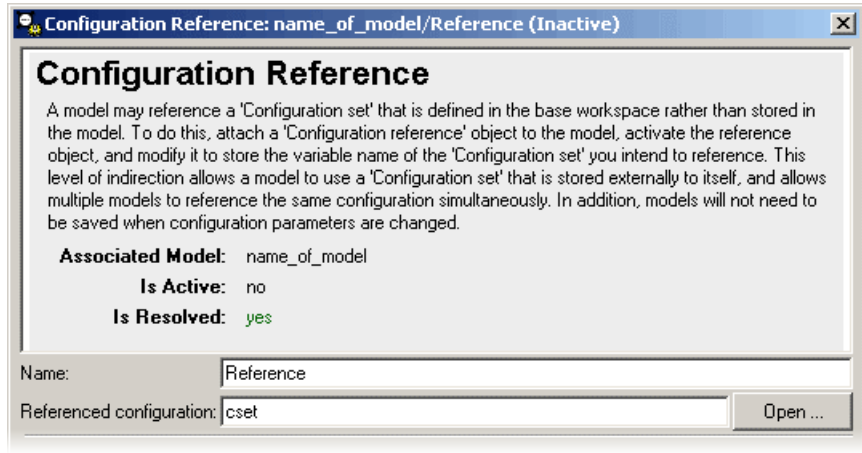
select `Propagate to Referenced Models`. For an example, see “Share a Configuration Across Referenced Models” on page 10-6.

Change Parameter Values in a Referenced Configuration Set

To obtain a referenced configuration set:

1. In the Model Hierarchy pane, select the configuration reference, or right-click the configuration reference, and select **Open** from the context menu.

   The Configuration Reference dialog box appears in the Dialog pane or in a separate window.



2. To the right of the **Referenced configuration** field, click **Open**. The Configuration Parameters dialog box opens. You can now change and apply parameter values as you would for any configuration set.

Save a Referenced Configuration Set

If your model uses a configuration reference to specify the model configuration, before closing your model, you need to save the referenced configuration set to a MAT-file or MATLAB script.

1. In the Model Explorer, in the Model Hierarchy, select **Base Workspace**.
2. In the Contents pane, right-click the name of the referenced configuration set object.
3. From the context menu, select **Export Selected**.
4. Specify the filename for saving the configuration set as either a MAT-file or a MATLAB script.

Tip When you reopen the model you must load the saved configuration set, otherwise, the configuration reference is unresolved. To set up your model to automatically load the configuration set object, see "Callback Functions" on page 4-54.

Load a Saved Referenced Configuration Set

If your model uses a configuration reference to specify the model configuration, you need to load the referenced configuration set from a MAT-file or MATLAB script to the base workspace.

1. In the Model Explorer, in the Model Hierarchy, right-click **Base Workspace**.
2. From the context menu, select **Import**.
3. Specify the filename for the saved configuration set and select OK. The configuration set object appears in the base workspace.

Tip When you reopen the model you must load the saved configuration set, otherwise, the configuration reference is unresolved. To set up your model to automatically load the configuration set object, see "Callback Functions" on page 4-54.

Why is the Build Button Not Available for a Configuration Reference?

The Code Generation 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. Click 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 capability as its equivalent in the Configuration Parameters dialog box. It operates on the model that contains the configuration reference.

About Configuration Sets

In this section...

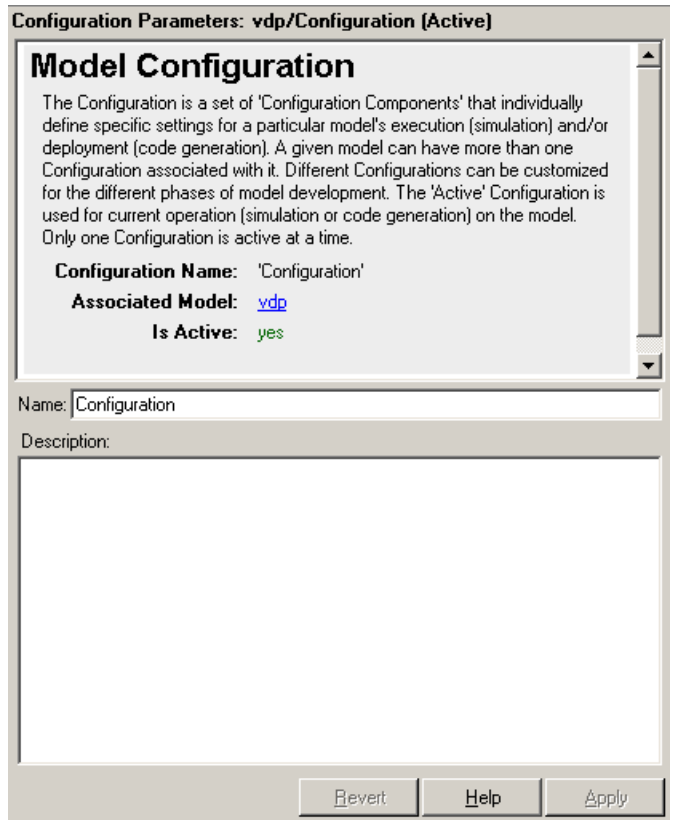
What Is a Configuration Set?

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 Simulink Coder, define additional components. If such a product is installed on your system, the configuration set also contains the components that the product defines.

When you select any model configuration, the Model Configuration dialog appears in the Model Explorer **Dialog** pane. In this location, you can edit the name and description of your configuration.



What Is a Freestanding Configuration Set?

A freestanding configuration set is a configuration set object, `Simulink.ConfigSet`, stored in the base workspace. To use a freestanding configuration set as the configuration for a model, you must create a configuration reference in the model that references it. You can create a freestanding configuration set in the base workspace in these ways:

- Create a new configuration set object.
- Copy a configuration set that resides within a model to the base workspace.
- 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 MATLAB variable.

Note 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. Using it in a configuration reference causes an error.

Model Configuration Preferences

Model Configuration Preferences are the preferred configuration for new models. You can change the preferred configuration by editing the settings in the Model Explorer.

1. Select **View > Show Configuration Preferences** to display the **Configuration Preferences** node in the expanded **Simulink Root** node.
2. Under the **Simulink Root** node, select **Configuration Preferences** . The Model Configuration Preferences dialog box opens in the **Dialog** pane.
3. In the **Contents** pane, select components and change any parameter values.

About Configuration References

In this section...

What Is a Configuration Reference?

A configuration reference in a model is a reference to a configuration set object in the base workspace. A model that has a configuration reference that points to a freestanding configuration set uses that configuration set when configuration reference is active. The model then has the same configuration parameters 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. For more information, see "Why Use Configuration References?" on page 10-29. For an example on how to use configuration references, see "Share a Configuration for Multiple Models" on page 10-4 or "Create and Attach a Configuration Reference" on page 10-18.

Tip Save or export the configuration set object. Otherwise, when you reopen your model the configuration reference is unresolved. To set up your model to automatically load the configuration set object, see "Callback Functions" on page 4-54.

Why 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. 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.

Unresolved Configuration References

When a configuration reference does not reference 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.

For more information, see “Resolve a Configuration Reference” on page 10-19.

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 "Use `refresh` When Replacing a Referenced Configuration Set" on page 10-41.
- 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 occurs, even if an active configuration reference points to that target. For more information about `ActivateCallback` functions, see "rtwgensettings Structure" in the Simulink Coder documentation.

Configuration References for Models with Older Simulation Target Settings

Suppose that you have a nonlibrary model that contains one of these blocks:

- MATLAB Function
- Stateflow chart
- Truth Table
- Attribute Function

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 of the software that you use:

- A copy of the configuration set in the base workspace attaches to the model.
- The simulation target settings migrate to the corresponding parameters in this new configuration set.
- The new configuration set becomes active.
- 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.

Model Configuration Command Line Interface

In this section...

Overview

An application programming interface (API) lets you create and manipulate configuration sets at the command line or in a script. The API includes the `Simulink.ConfigSet` and `Simulink.ConfigSetRef` classes 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 preceding functions and the `Simulink.ConfigSet` class, see the function and class reference pages.

Load and Activate a Configuration Set at 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, use the `setActiveConfigSet` function to activate the configuration set.

Alternatively, to load a configuration set at 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.

Save a Configuration Set at 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.

Alternatively, to save the active configuration set:

1. Open the model.
2. Use the `Simulink.BlockDiagram.saveActiveConfigSet` function to save the active configuration set.

Create a Freestanding Configuration Set at the Command Line

Copy a Configuration Set Stored in a Model

Create a freestanding configuration set to be referenced by a configuration reference in several models. You must copy any configuration set obtained from an existing model, otherwise, *cset* refers to the existing configuration set stored in the model, rather than a new freestanding configuration set in the base workspace. For example, use one of the following:

- ```
  cset = copy (getActiveConfigSet(model))
  ```

- ```
  cset = copy (getConfigSet(model, ConfigSetName))
  ```

model is any open model, and *ConfigSetName* is the name of any configuration set attached to the model.

Read 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, then save the variable to the MAT-file:

```
save (workfolder/ConfigSetName.mat, cset)
```

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

Create and Attach a Configuration Reference at the Command Line

To create and populate a configuration reference, Simulink.ConfigSetRef, 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(model, cref, true)
   ```

   The third argument is optional and authorizes renaming to avoid a name conflict.

Using a configuration reference with an invalid configuration set, `WSVarName`, generates an error and is called an unresolved configuration reference. The GUI equivalent of `WSVarName` is **Referenced configuration**. You can later use the API or GUI to provide the name of a freestanding configuration set. For more information, see “Unresolved Configuration References” on page 10-30.

Attach a Configuration Reference to Multiple Models at the Command Line

After you create a configuration reference and attach it to a model, you can attach copies of the reference to any other models. Each model has its own copy of any configuration reference attached to it, just as each model has its own copy of any attached configuration set.

If you use the GUI, attaching an existing configuration reference to another model automatically attaches a distinct copy to the model. 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(model, ConfigSetRefName))
attachConfigSet (model, 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 from 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 an extra copy, you can remove it with `detachConfigSet`, as shown in the last line of the example.

```
open_system('model1')
% Get handle to local cset
cset = getConfigSet('model1', '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'
```

```
% Attach the configuration reference to the model
attachConfigSet('model1', cref1, true)

% In a second model, create a configuration
% reference to the same cset
open_system('model2')
% Rename if name conflict occurs
attachConfigSetCopy('model2', cref1, true)

% Delete original cset from first model
detachConfigSet('model1', 'Configuration')
```

Get 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')
```

Change Values in a Referenced Configuration Set

By operating on only a configuration reference, you cannot change the referenced configuration set parameter values. 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.

To obtain a referenced configuration set using the API:

1. Follow the instructions in “Obtain a Configuration Reference Handle” on page 10-40.

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.

Obtain a Configuration Reference Handle

Most functions and methods that operate on a configuration reference take a handle to the reference. When you create a configuration reference:

```
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(model, 'ConfigSetRefName')
```

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 technique you use to obtain a configuration set handle. Wherever the same operation applies to both configuration sets and configuration references, applicable functions and methods overload to perform correctly with either class.

Use `refresh` When 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 invalid. To avoid this situation, execute:

```
cref.refresh
```

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 configuration  reference
cref1 = Simulink.ConfigSetRef;

% Resolve the configuration reference to the configuration set
cref1.WsVarName = 'cset1';

% Attach the configuration reference 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.

11

Configuring Models for Targets with Multicore Processors

Introduction to Concurrent Execution

In this section...

About Configuring Models for Concurrent Execution

Configuring your model for concurrent execution in the Simulink environment enables you to capture and simulate the effects of deploying your design to a multicore system. A model that is configured for concurrent execution gives you control over how a design should execute on a multicore target. It allows the design to be mapped into concurrently executing tasks. Subsequently, the Simulink environment enables the simulation of the mapped design by identifying data transfer points and by simulating the mapped design in conjunction with data transfer latencies. You can deploy the design to a multicore system using Simulink Coder, Embedded Coder, and xPC Target™ software.

You can use simulation results to identify whether a mapping scheme is suitable with respect to the functional characteristics of the design. You can also explore alternate partitioning schemes using a mapping interface. In addition, you can use profiling results on the deployed design to validate if the mapping scheme is efficiently using the multicore system.

- Create a new model configuration or extend existing configurations for concurrent execution.
- Use the Model block to define potential opportunities for concurrency in your design.
- Set up and configure concurrent on-target tasks using a task editing interface.
- Use either the GUI or command-line interface to iteratively map design partitions (based on Model blocks) to tasks and find optimal concurrent execution scenarios.

- Generate code that uses threading APIs on Windows, Linux, or xPC Target platforms for on-target execution.

Supported Targets

You can build and download concurrent execution models for the following targets using system target files:

- Linux, Windows, and Mac OS using `ert.tlc` and `grt.tlc`.
- xPC Target using `xpctarget.tlc` and `xpctargetert.tlc`.
- Linux and Windows using `idelink_ert.tlc` and `idelink_grt.tlc`.
- Embedded Linux and VxWorks® using `idelink_ert.tlc` and `idelink_grt.tlc`.

Note Deploying to embedded Linux and VxWorks targets requires the Embedded Coder product.

You cannot build and download a model, configured for concurrent execution, for field-programmable gate arrays (FPGAs) and programmable logic controllers (PLCs). For FPGA optimization and hardware utilization techniques, see the "Streaming, Resource Sharing, and Delay Balancing" chapter of the *HDL Coder™ User's Guide*.

Helpful Terms

Task — Object that corresponds to a thread of execution on a target. From within the Simulink environment, you can specify tasks, configure their properties, and map Model blocks to them.

Task configuration — Configuration properties that apply to the set of tasks set up for your multicore system.

Trigger — Abstraction of operating system timers, signals, interrupts, and system events.

Aperiodic trigger — Event trigger that has no inherent periodicity, such as an interrupt. When multiple triggers coexist, the software assumes that they are asynchronous to each other.

Periodic triggers — Periodic event trigger such as an operating system trigger.

Software Requirements

- To build and download your model, you must have Simulink Coder software installed.
- To build and download your model to an xPC Target system, you must have xPC Target software installed. You must also have a multicore target system supported by the xPC Target product.

Design Considerations

In this section...

Modeling for Concurrency

A model configured for concurrent execution is defined as a model designed to execute concurrently on a real-time multicore target. In this situation, different pieces of the model ultimately execute in concurrent threads on the target environment. Modeling for concurrent execution allows the designer to factor in the effect of the concurrent execution semantics within the model, to simulate and to provide initial conditions for data transfer points.

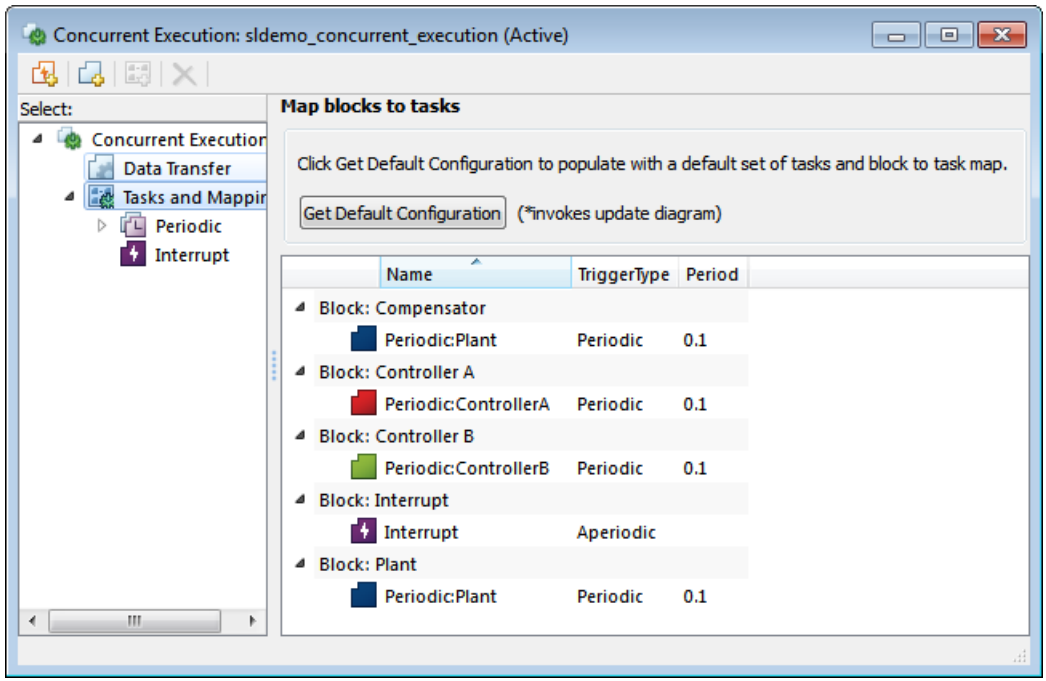
Note The simulation itself does not require a multicore host. The current simulation engine uses only one thread to simulate.

Modeling for concurrency is an iterative process. It ultimately deploys a model on a multicore target environment while making the best use of the computational power provided by the multiple cores. To support the iterative workflow, Simulink provides a mapping interface that allows you to map the potential concurrency in the design to the actual concurrency available on the target. A model configured for concurrent execution consists of three parts:

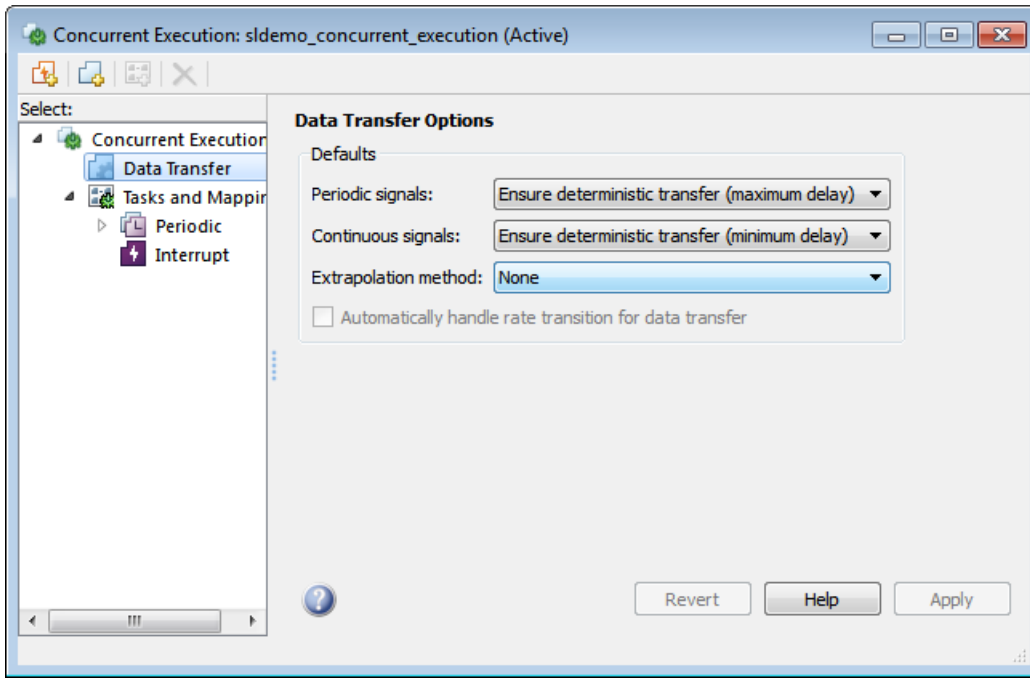
- A model that has identified blocks for concurrent execution
- A description of the available concurrency in terms of the number of tasks and their periodicities
- A mapping that places the identified blocks in the model into actual tasks for concurrent execution

These parts constitute a mapped model. To manage mapped models, Simulink software provides:

- Explicit control over task configuration and how blocks are mapped to tasks



- Control over how data is communicated between tasks



- Simulation of a mapped model that allows you to validate a desired functionality against the data transfer requirements of a particular mapping

To validate if a particular mapping is an acceptable design, first validate that the mapped model produces the desired simulation traces. Simulation results vary from mapping to mapping because each mapping imposes communication (data transfer) requirements that might cause the Simulink software to treat certain signal lines as delays for data transfer. Ultimately, however, you must evaluate the mapping on the target, and profile the behavior to measure whether the mapping meets the computational requirements and makes good use of the available computational power of the target platform. This evaluation and profiling are beyond the scope of the software.

Identifying Opportunities for Concurrent Execution

To use the software mapping interface, a model must first specify opportunities for concurrency by identifying blocks for concurrent execution.

Use Model blocks (referenced models) to identify potential opportunities for concurrent execution. A Model block defines a unit of functionality that the software can map for execution in one or more target tasks. More precisely, you can map a multirate Model block that contains *N* rates to exactly *N* tasks, the periodicity of which agree with the respective rates. You can map several Model blocks to the same task. Map a Model block that contains continuous blocks to a task, the period of which agrees with the fundamental sample time of the model. You can specify the fundamental sample time of the model in the **Fixed-step size (fundamental sample time)** of the **Solver** pane in the Configuration Parameters dialog box.

Because Model blocks must be used to express opportunities for concurrency, a design must consist entirely of Model blocks. You can also use virtual connectivity blocks to organize the block diagram, including:

- Goto and From blocks
- Ground and Terminator blocks
- Inport and Outport blocks
- Virtual subsystem blocks that contain permitted blocks

A model configured for concurrent execution reports an error diagnostic if any other blocks are detected. Place all other blocks in one or more referenced models.

Also consider signal lines when designing for concurrent execution. Depending on the mapping, any signal line can potentially be identified as a data transfer point. In particular, if the source port of a signal originates in a block from one task and the destination port is to a block in another task, the Simulink software identifies that signal as a data transfer point.

Algebraic Loops

An algebraic constraint or algebraic loop might impose tight coupling between tasks and can lead to severe computational penalties. Therefore, a model configured for concurrent execution cannot contain algebraic loops or algebraic constraints that originate from physical modeling in a referenced model. This condition makes an algebraic loop fully contained in a task.

However, the use of Model blocks might lead to artificial algebraic loops. This condition might occur if Simulink cannot identify if a break point is encapsulated within a referenced model. In such situations, use one of the following methods to remove artificial algebraic loops:

- In the referenced model Configuration Execution dialog box, select **Model Referencing > Minimize algebraic loop occurrences**.
- Insert a Memory or Unit Delay block as the first block at the relevant input port of the referenced model.

Additionally, if the model is configured for the Embedded Coder target (`ert.tlc`), in the Configuration Parameters dialog box, clear the **Code Generation > Interface > Single output/update function** check box. This last operation prevents optimizations that can lead to artificial algebraic loops.

Simulation Limitations

When modeling for concurrent execution, configure the model to use the fixed-step solver.

Do not use the following modes of simulation for models in the concurrent execution environment:

- External mode
- Logging to MAT-files
- Processor-in-the-loop (PIL) simulation mode
- Software-in-the-loop (SIL) simulation mode
- If you are simulating your model using Rapid Accelerator mode, the top-level model cannot contain a root level Inport block that outputs function calls.

In the Configuration Parameters dialog box, set the **Diagnostics > Sample Time > Multitask conditionally executed subsystem** and **Diagnostics > Data Validity > Multitask data store** parameters to `error`.

In addition, for all Rate Transition blocks within the Model blocks:

- Select the **Ensure data integrity during data transfer** check box.
- Clear the **Ensure deterministic data transfer (maximum delay)** check box.

Modeling Process for Concurrent Execution

You can model for concurrent execution using the following general workflow. These steps assume that you have a model that meets the modeling guidelines in “Design Considerations” on page 11-5.

1. Configure your model for concurrent execution.
2. Perform baseline analysis of your model for concurrent execution.
3. Explicitly set configuration values in the concurrent execution configuration.
4. Simulate the model and evaluate the results
5. As necessary, refine the results.
6. Build and download the model to the multicore target and evaluate the results.
7. As necessary, refine the results.

Configure Your Model

You can use configuration references or configuration sets to configure a model for concurrent execution.

If Your Model Has...	Create...
A single-level model, or if it has multiple descendants, such as reference models, and the descendants do not share the same configuration settings.	A configuration set for a single model. For more information, see "Creating a Concurrent Execution Configuration Set" on page 11-12.
A top-level model and multiple descendants, such as referenced models, all of which share the same configuration settings.	A configuration reference object that can be shared between all models in the hierarchy. For more information, see "Creating and Propagating a Configuration Reference" on page 11-13.

Creating a Concurrent Execution Configuration Set

You can create a concurrent execution configuration set from an existing configuration set, or create a new configuration set:

1. In the Simulink model editor, select **View > Model Explorer**.

   The Model Explorer window is displayed.

2. In the Model Explorer window:

To...	Do...
Preserve existing configuration settings for your model, convert an existing configuration set to a concurrent execution configuration set.	Expand the node for the model. Under the model, right-click **Configuration**, then select **Show Concurrent Execution options**.
Create new configuration settings, add a new concurrent execution configuration set.	Expand the node for the model. Right-click the model node and select **Configuration > Add Configuration for Concurrent Execution**. Activate the configuration set by right-clicking it and selecting **Activate**.

3. In the third column of the Model Explorer window, the Solver pane is updated to display an **Allow tasks to execute concurrently on target** check box. Click the **Configure Tasks** button.

If you want to create a configuration reference, see "Creating and Propagating a Configuration Reference" on page 11-13. Otherwise, to begin configuring the model for concurrent execution, see "Baseline Analysis Using Configuration Defaults" on page 11-17.

Creating and Propagating a Configuration Reference

This topic assumes that you have an existing concurrent execution configuration. If you have not yet created one, see "Creating a Concurrent Execution Configuration Set" on page 11-12.

For more information on configuration references, see "About Configuration References" on page 10-29. This topic describes one way to create and propagate a configuration reference.

1. In the Simulink model editor, select **View > Model Explorer**.

   The Model Explorer window is displayed.

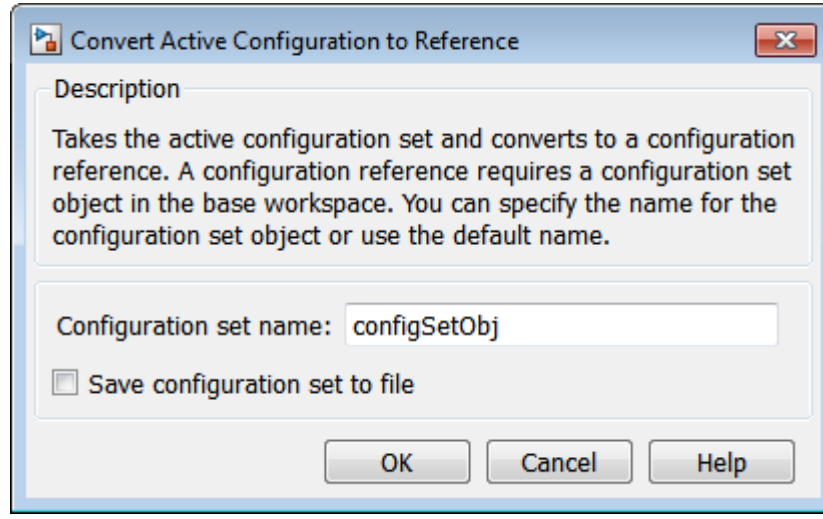
2 In the Model Explorer window, expand the node for the model and do one of the following:

To...	Do...
Preserve existing configuration settings for your model, convert an existing configuration set to a concurrent execution configuration set.	Right-click and select **Configuration > Show Concurrent Execution options**.
Create new configuration settings, add a new concurrent execution configuration set.	Right-click and select **Configuration > Add Configuration for Concurrent Execution**.

3 Activate the configuration set by right-clicking it and selecting **Activate**.

4 In the Model Hierarchy column, right-click **Configuration > Convert to Configuration Reference**.

A Convert Active Configuration to Reference dialog box is displayed.

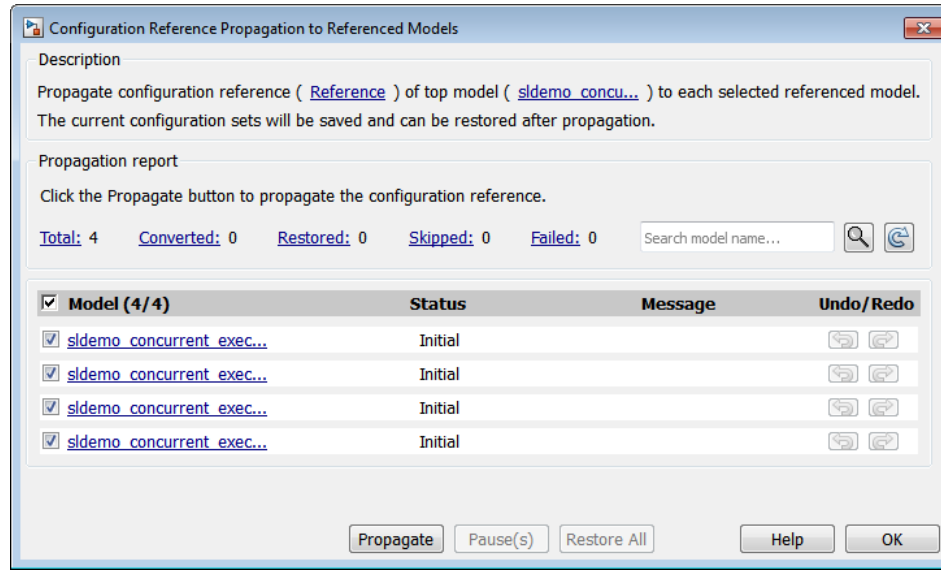


5 Click **OK** to accept the default name for the configuration reference.

The configuration is converted to a configuration reference.

6 To share the configuration reference with the other referenced models in the model hierarchy, activate the configuration reference, then right-click it and select **Configuration > Propagate to Referenced Models**.

A Propagate to Referenced Models dialog box is displayed.



7 Click **Propagate** to propagate the configuration reference.

A propagation confirmation dialog box is displayed.

8 Click **OK** to continue.

The hierarchy of each referenced model is updated with the configuration reference.

9 Click **OK**.

10 In the Model Explorer, in the left column, select the **Reference (Active)** node.

The right column changes to display the Configuration Parameters reference pane.

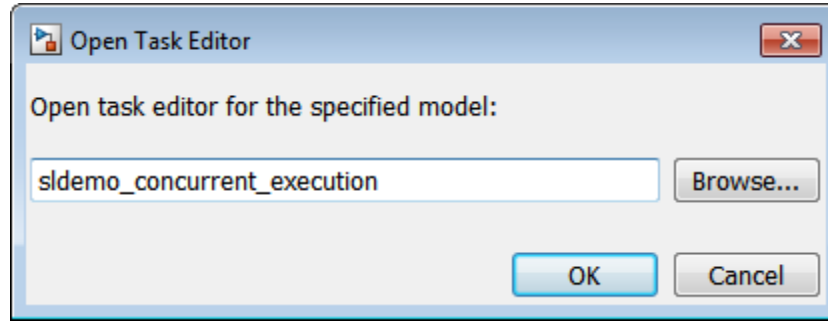
11 In the Configuration Parameters reference pane, click the **Open** button of the **Referenced configuration** parameter.

The Configuration Parameters dialog box is displayed.

12 Navigate to the Solver node.

13 Click the **Allow tasks to execute concurrently on target** check box and click **Configure Tasks** button.

The Open Task Editor dialog window is displayed.



Consider saving the configuration reference to MAT-file if you want to use it in future MATLAB sessions. To save the configuration reference named `configSetObj`, enter the following command in the MATLAB Command Window:

```
save configsetobj.mat configSetObj
```

To load the saved configuration reference into another MATLAB session, enter the following command in the MATLAB Command Window:

```
load configsetobj.mat
```

To begin configuring the model for concurrent execution, see “Baseline Analysis Using Configuration Defaults” on page 11-17.

Baseline Analysis Using Configuration Defaults

Perform an automatic baseline analysis of the model. This step allows you to identify initial bottlenecks in the model execution.

1. In the Concurrent Execution dialog box, select the Tasks and Mapping node.

   The **Map blocks to tasks** pane is displayed.

2. Click the **Get Default Configuration** button.

3. Select **Yes** in the resulting dialog box.

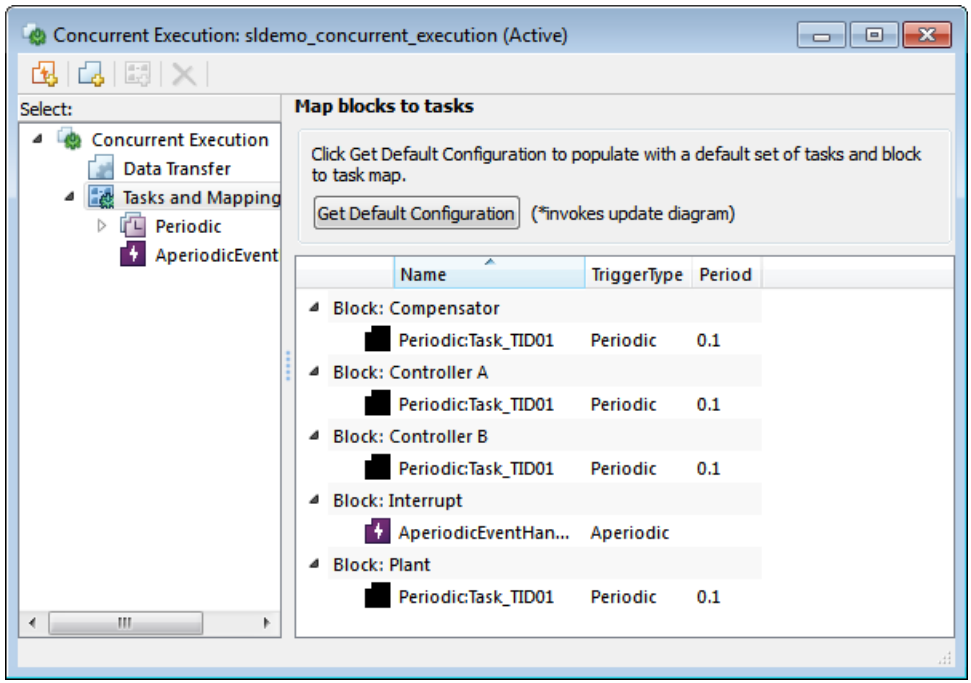
   This button updates the diagram.

Upon a successful update, the software:

- Creates one periodic task for each periodic sample time in the model.
- Creates one aperiodic trigger for each function-call input in the model.
- Configures the block-to-task mapping so that each block maps to a task based on sample time analysis.

If the software reports a diagnostic during the update phase, the analysis might not complete. In this case, address the modeling issues reported in the diagnostics before continuing.

The following is the automatic baseline analysis for the `sldemo_concurrent_execution` model.



When the analysis is complete, decide on your next step.

To...	Go to...
Explicitly configure how data is transferred to override the settings detected by automatic analysis.	"Customize Concurrent Execution Settings" on page 11-19
Simulate the model.	"Interpret Simulation Results" on page 11-26

Customize Concurrent Execution Settings

After you set configuration defaults using automatic analysis, you might want to fine-tune simulation results by performing operations such as explicitly creating a different number of tasks or setting data transfer parameters.

Note If you do not want to customize concurrent execution settings, in the **Concurrent Execution** pane clear the **Enable explicit model partitioning for concurrent behavior** check box. Clearing this check box allows the model to use rate-based tasks and ignores task-to-block mappings.

Configuring Data Transfer Communications

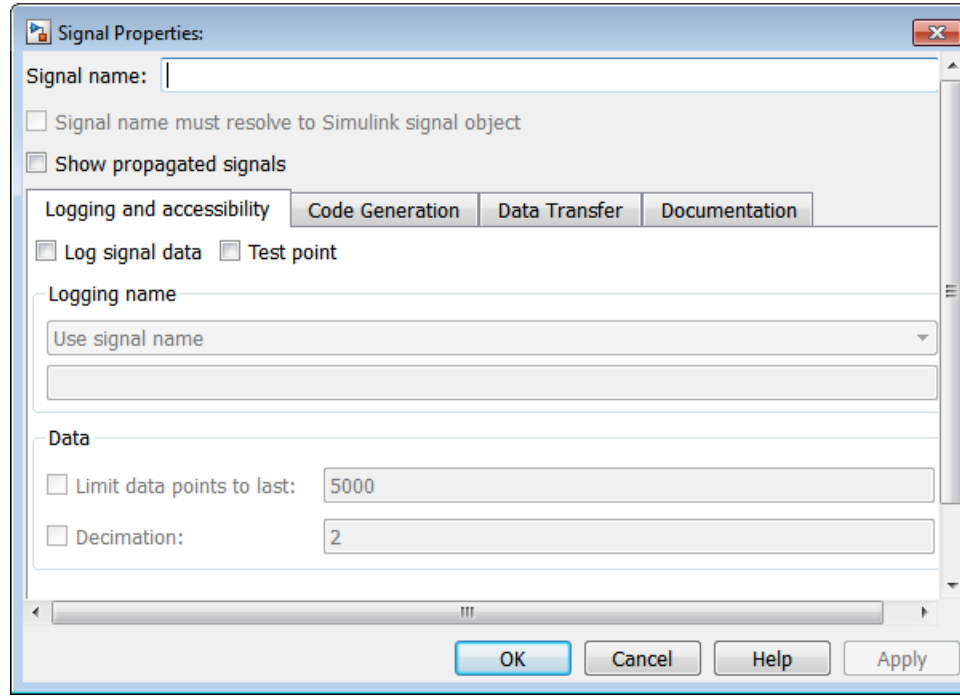
Use the **Data Transfer Options** pane to define communications between tasks.

Data Transfer Options

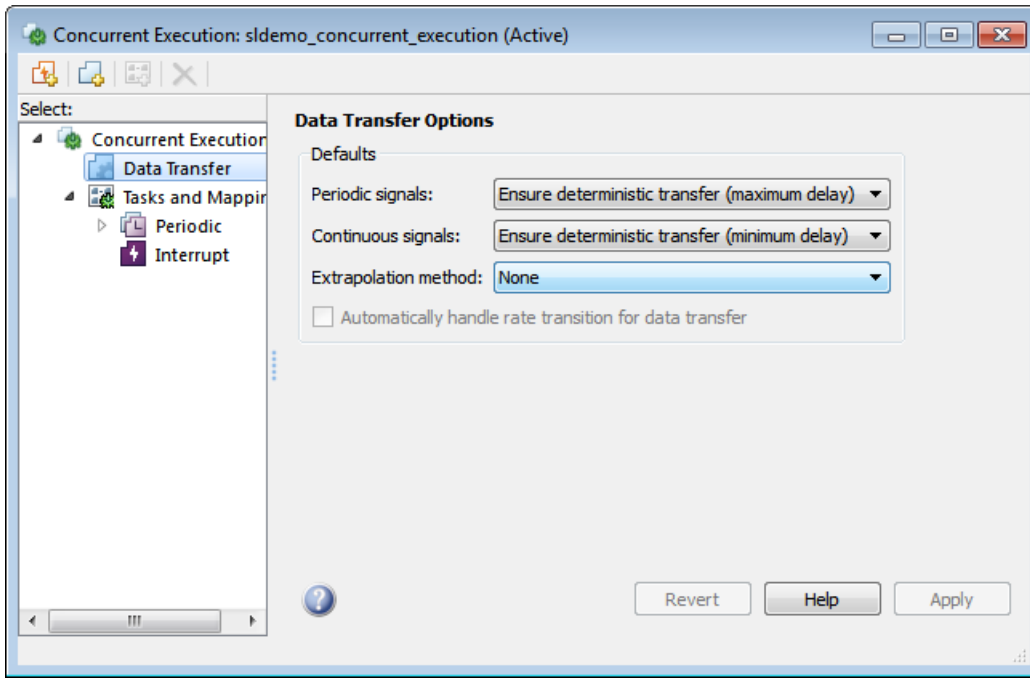
Data Transfer Type	Simulation	Deployment
Ensure data integrity only.	Data transfer is simulated using a one-step delay.	Simulink Coder ensures data integrity during data transfer. Data is transferred as soon as possible.
Ensure deterministic transfer (maximum delay).	Data transfer is simulated using a one-step delay.	Simulink Coder ensures data transfer is identical with simulation.
Ensure deterministic transfer (minimum delay).	Data transfer occurs within the same step.	

- For continuous signals, the Simulink software uses extrapolation methods to compensate for numerical errors that were introduced due to delays and discontinuities in data transfer.
- For signals that are configured for `Ensure Data Integrity Only` and `Ensure deterministic transfer (maximum delay)` data transfers, you

might need to provide an initial condition to avoid numerical errors. You can specify this initial condition in the **Data Transfer** tab of the Signal Properties dialog box. To access this dialog box, right-click the signal line and select **Properties** from the context menu. A dialog box like the following is displayed.



1. From the Data Transfer Options on page 11-19 table, determine how you want your tasks to communicate.
2. In the Concurrent Execution dialog box, select Data Transfer defaults and apply the settings from step 1.



3 Apply your changes.

Configuring Periodic Tasks

If you want to explore the effects of increasing the concurrency on your model execution, you can create additional periodic tasks in your model.

1 In the Concurrent Execution dialog box, right-click on the Periodic node and select **Add task**.

A task node appears in the Configuration Execution hierarchy.

2 Select the task node and enter a name and period for the task, then click **Apply**.

The task node is renamed to the name you enter.

3 Optionally, specify a color for the task. The color illustrates the block-to-task mapping. If you do not assign a color, Simulink chooses a

default color. If you enable sample time colors for your model, the software honors the setting.

4 Click **Apply** as necessary.

When the periodic tasks are complete, configure the aperiodic (interrupt) tasks as necessary. If you do not need aperiodic tasks, continue to "Mapping Blocks to Tasks" on page 11-24.

Configuring Aperiodic Triggers and Tasks

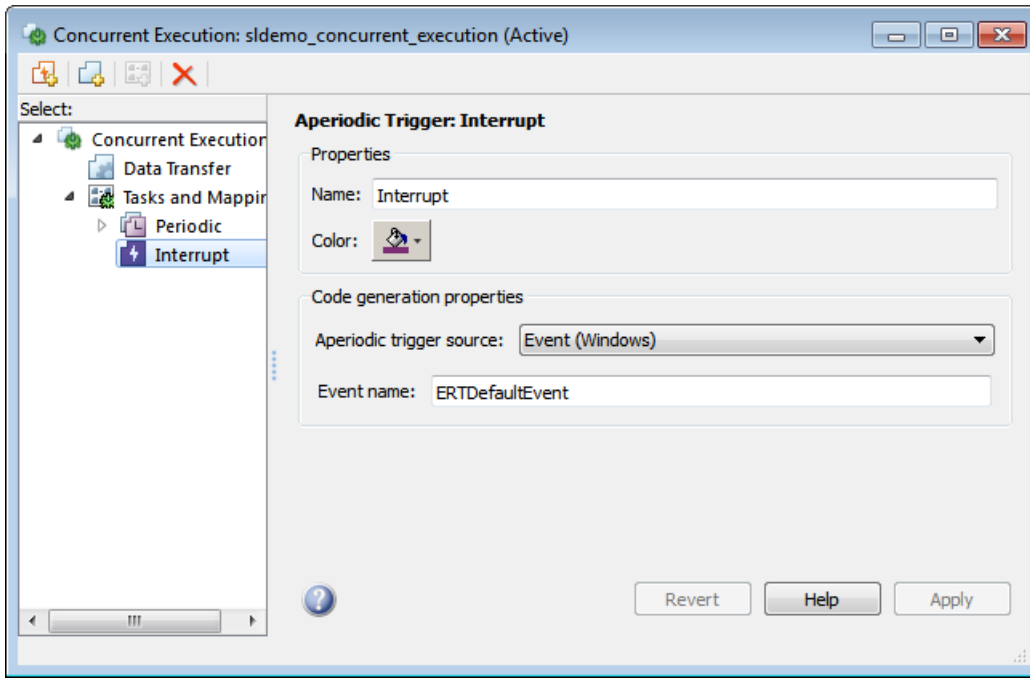
1 To create an aperiodic trigger, in the Concurrent Execution dialog box, right-click the Concurrent Execution node and click the **Add aperiodic trigger** icon.

A node named **Interrupt***N* appears in the configuration tree hierarchy.

2 Select **Interrupt**.

This node represents an aperiodic trigger for your system.

3 Specify the name of the trigger and configure the aperiodic trigger source. Depending on your deployment target, choose either `Posix Signal (Linux/VxWorks 6.x)` or `Event (Windows)`. For POSIX® signals, specify the signal number to use for delivering the aperiodic event. For Windows events, specify the name of the event.



4 Click **Apply**.

The software services aperiodic triggers as soon as the system can respond to the trigger. If you want to process the trigger response using a task:

1 Right-click the **Interrupt** node and select **Add task**.

A new task node appears under the **Interrupt** node.

2 Specify the name of the new task node.

3 Optionally, specify a color for the task. The color illustrates the block-to-task mapping. If you do not assign a color, Simulink chooses a default color.

4 Click **Apply**.

You can delete tasks (both periodic and aperiodic) as well as triggers by right-clicking them in the pane and selecting **Delete**.

When the aperiodic tasks are complete, continue to "Mapping Blocks to Tasks" on page 11-24.

Mapping Blocks to Tasks

After you simulate and evaluate a model that has automatic analysis defaults, you are likely to want to redo the block-to-task mappings. If you have specified new tasks and triggers explicitly, you must map the blocks to the newly created tasks and triggers.

1. In the Concurrent Execution dialog box, click the Tasks and Mapping node.

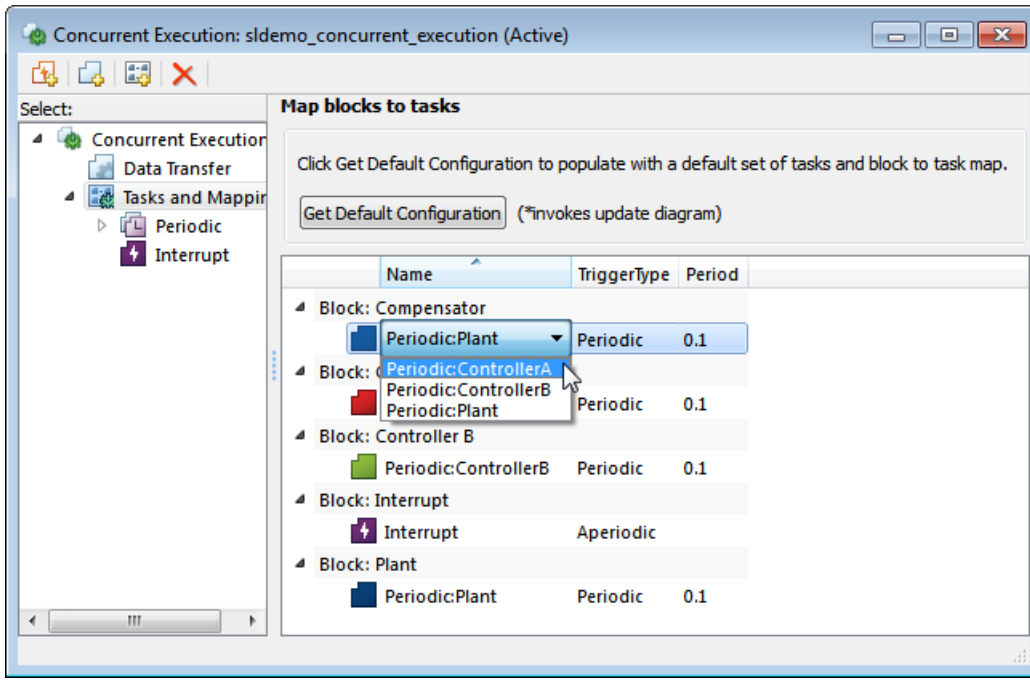
   The **Map blocks to tasks** pane appears.

2. If you changed the model by adding or removing blocks, consider using automatic analysis by clicking the **Get Default Configuration** button.

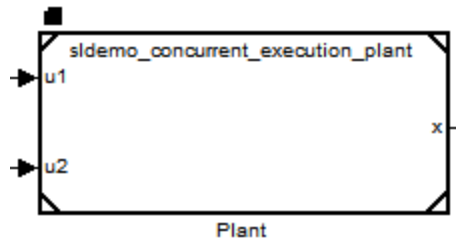
   If you added a new Model block, a **select task** entry appears under the block.

3. If you want to add a new task to a block, in the **Name** column, right-click a task under the block and select **add new entry**.

4. To assign a task for the entry, left-click the box in the **Name** column and select a task from the list. For example:



The block-to-task mapping icon appears on the top-left corner of the Model block. If a Model block is assigned to multiple tasks, multiple task icons are displayed in the top-left corner. For example:



5 Click **Apply**.

When the mapping is complete, simulate the model again (see “Interpret Simulation Results” on page 11-26).

Interpret Simulation Results

In this section...

Introduction

A model configured for concurrent execution is a model that is designed to execute concurrently on a real-time multicore target. Simulink enables you to simulate such models and observe the effects of task-to-task data transfer. You can also observe how this transfer can impact the numerical characteristics of the model.

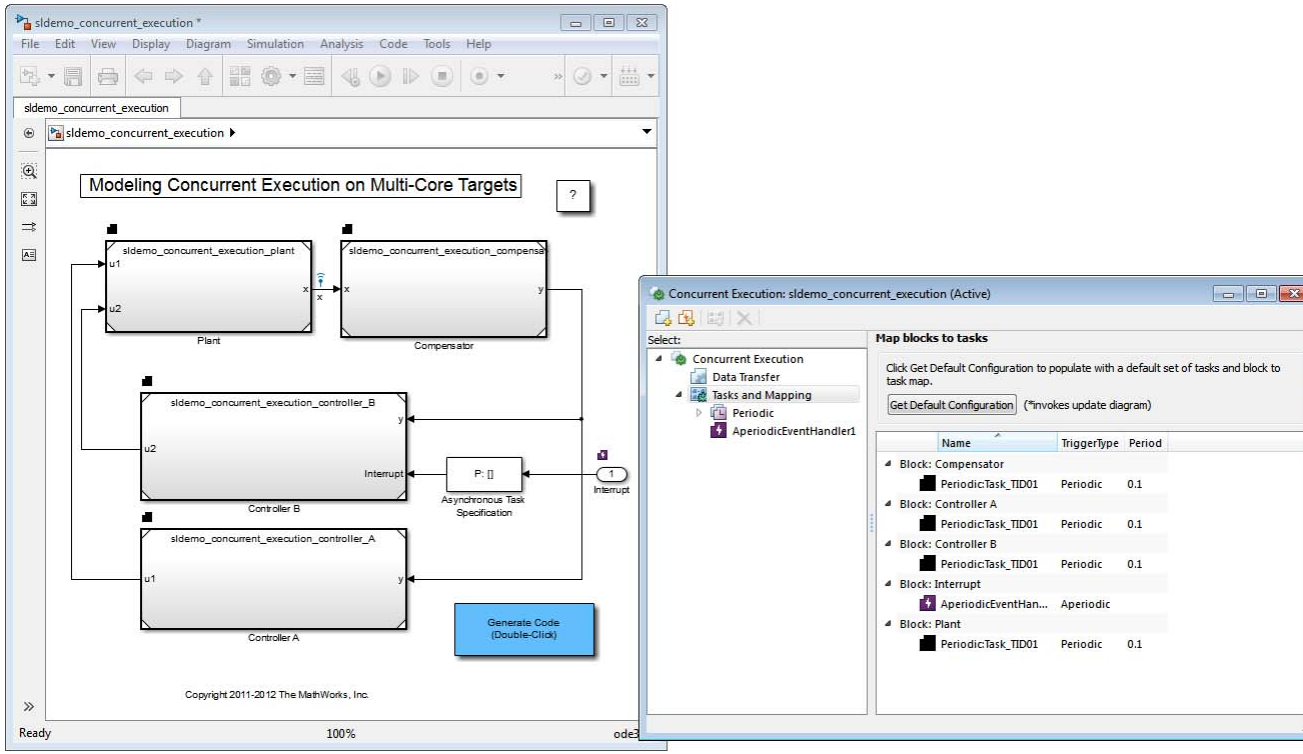
Note The simulation itself does not require a multicore target. The number of tasks that you use to simulate the design is determined by other factors and does not impose any requirements on the number of tasks modeled by the design. Factors that influence the concurrency of the simulation include the use of the Basic Linear Algebra Subprograms (BLAS) library, Rapid Accelerator mode, and the MATLAB `parfor` command.

Consider the model `sldemo_concurrent_execution`. To understand simulation results, compare the signal x in two scenarios:

- Default configuration — The target has exactly one periodic task and all blocks are mapped to execute within this task. In this configuration, the target does not allow for any concurrent execution.
- Sample configuration — The target has three periodic tasks and all blocks are mapped to execute concurrently in these tasks.

Default Configuration

In the following example, the model is configured as described in “Baseline Analysis Using Configuration Defaults” on page 11-17. Because this model contains only one sample time (continuous sample time), the automatic analysis configures the target with one task and maps all blocks to run in that task. The period of the task is selected as 0.1, which agrees with the fixed-step size of the model. Because the design has only one task, no task-to-task data transfer is needed. Therefore, simulation of the model should produce the same numeric results as if the model is not configured for concurrent execution.



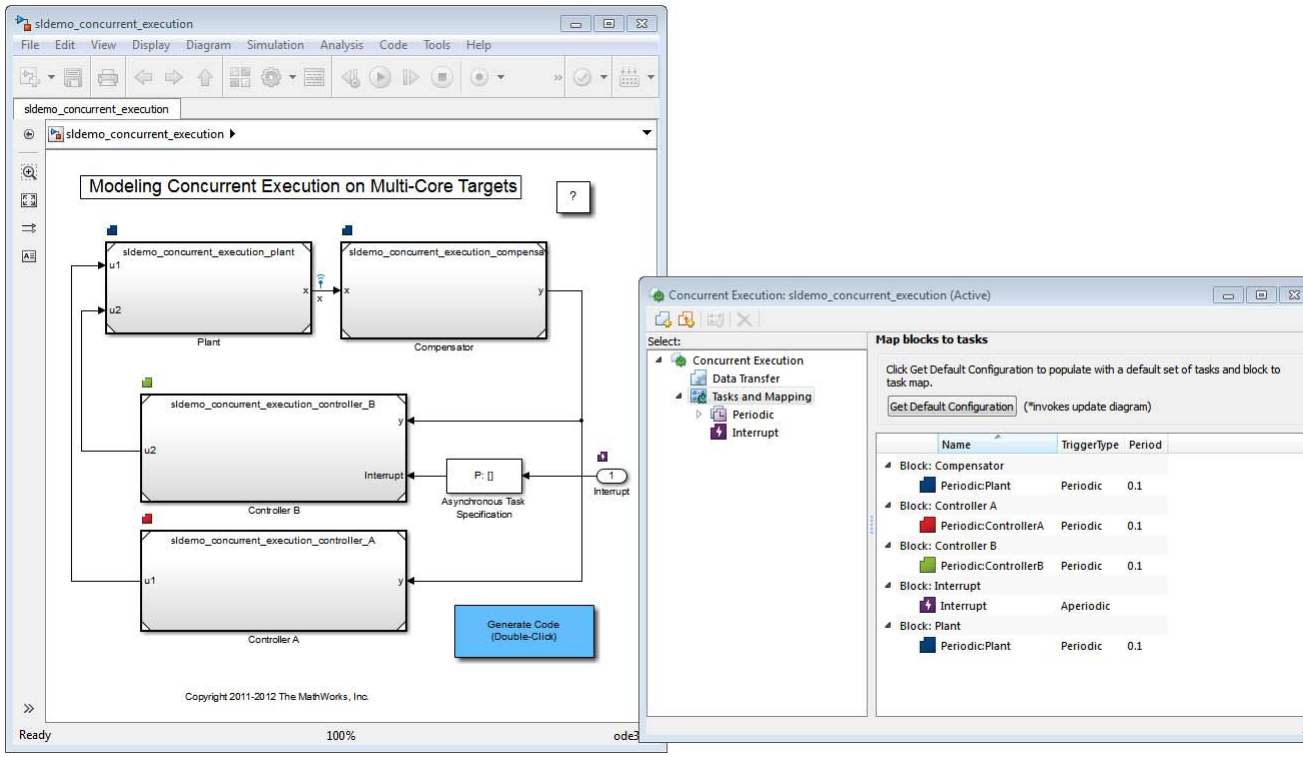
Note Configuring a model with automatic analysis always configures a model to minimize task-to-task communication requirements. In particular, only those communications that require rate transitions are included in the design.

Configure the model to inspect data using the Simulation Data Inspector by clicking the **Record & Inspect Simulation Output** button in the toolbar. (Alternatively, in the Configuration Parameters dialog box, select the **Data Input and Output > Record and inspect simulation output** button). After you enable the Simulation Data Inspector, click **Simulate > Run** to simulate the model using the single task configuration. After simulation, launch the Simulation Data Inspector as directed in the editor. Observe that the tool has recorded the simulation results for the signal labeled `x`.

Sample Configured Model with Multiple Target Tasks

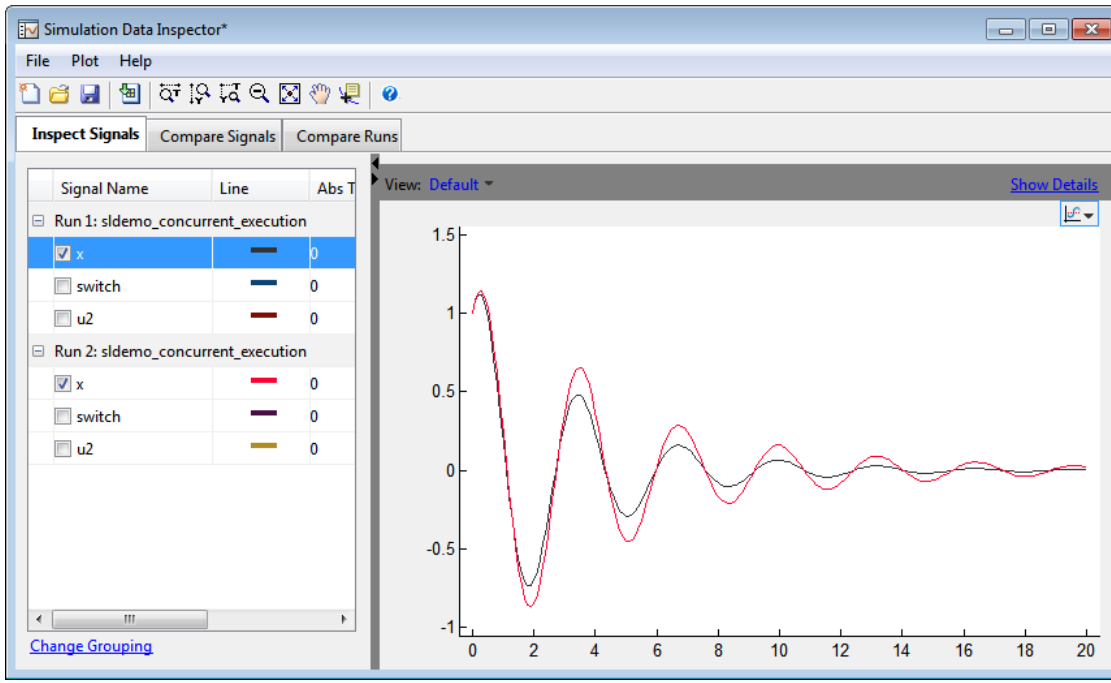
In the Concurrent Execution dialog box, create two additional tasks and map the ControllerA block to the first additional task and the ControllerB block to the second additional task.

1. Open the Concurrent Execution dialog box.
2. Click the **Add Task** button twice.
3. Select the first added task and label it `ControllerA`.
4. Select the second added task and label it `ControllerB`.
5. In the **Map blocks to tasks** pane, check that the ControllerA block is assigned to execute within the ControllerA task and the ControllerB block is assigned to execute within the ControllerB task.



6 Simulate the model again.

7 After simulation completes, compare the results for the default and custom configurations using the Simulation Data Inspector.



To understand the source of the phase margin, observe that:

- For the first run of the model, signal *x*, identified by the black line, shows a default task configuration.
- In the second run of the model, signal *x*, identified by the red line, shows a custom task configuration and the effects of communication latencies from lines crossing task boundaries. This is different from the first run, which has only one periodic task and therefore, no communication latencies.
- The default setting for data transfer is to ensure determinism, so the data transfer is deterministic (see Data Transfer Options on page 11-19).

Because the data transfer is deterministic, the simulated model takes into account a unit delay to capture the effects of data transfer. This delay causes a small phase margin in the mapped design. The delay agrees with the step size of the model, which is 0.1. This delay is the least possible delay that the software can impose on the signal.

How Simulink Determines Data Transfer Requirements

The software determines data transfer based on how the blocks are mapped to tasks. When a model is simulated, either from an update diagram or upon code generation, Simulink software examines the block-to-task mapping and determines which signals must be configured for task-to-task data transfer. The software considers only the signals where the source of the signal originates from one task and the destination of the signal resides in a different task. You can specify global options that control data transfer (see Data Transfer Options on page 11-19). You can also override these options for each signal from the **Data Transfer** pane of the Signal Properties dialog box.

Therefore, the block-to-task mapping dictates which blocks execute in which tasks. Consequently, this mapping also dictates which signals you configure for task-to-task data transfer.

Build and Download to a Multicore Target

In this section...

Generating Code

To generate code, in the Simulink editor window, select **Tools > Code Generation > Build Model**. This code can run concurrently on a multicore target with Simulink Coder or Embedded Coder software. The coder generates all target-dependent code for thread creation, thread synchronization, interrupt service routines, and signal handlers and data transfer. The source files of the mapped model (for example, *`model`*`.c` and *`model`*`.h`) do not contain target-dependent code for setting up the execution of threads. However, target-dependent code might exist for data transfer types, which generate target-specific data protection or semaphore application programming interface (API) calls.

For each periodic task, Simulink Coder combines the output and update methods of the blocks mapped to that task and binds these methods to a target-specific thread. Additionally, for each periodic task that contains continuous states, a separate solver instance is generated in the source file of the mapped model. This mapped model can concurrently run the continuous parts of the model. (The generated solver instances share the solver type specified in the **Solver** of the Configuration Parameters dialog box of the mapped model.)

For each aperiodic task or aperiodic trigger, Simulink Coder combines the output and update methods of the blocks mapped to that task and binds these to a target-specific Interrupt Service Routine (ISR) or to a target-specific event handler.

Following is an example of generated code in the source file of a mapped model. This code shows the functions generated for the mapped model:

- Two solver instances
- Three periodic tasks with two of them having continuous states
- Two aperiodic tasks
- Two aperiodic triggers

```
/*
 * This function updates continuous states using the ODE3 fixed-step
 * solver algorithm
 */
static void Periodic_Task1_rt_ertODEUpdateContinuousStates(RTWSolverInfo  *si )
{   }

/*
 * This function updates continuous states using the ODE3 fixed-step
 * solver algorithm
 */
static void Periodic_Task2_rt_ertODEUpdateContinuousStates(RTWSolverInfo  *si )
{   }


/* OutputUpdate for Task: Periodic_Task1 */
void Periodic_Task1_step(void)                   /* Sample time: [0.1s, 0.0s] */
{
    Periodic_Task1_rt_ertODEUpdateContinuousStates(&task_M[0]->solverInfo);

}

/* OutputUpdate for Task: Periodic_Task2 */
void Periodic_Task2_step(void)                  /* Sample time: [0.2s, 0.0s] */
{
    Periodic_Task2_rt_ertODEUpdateContinuousStates(&task_M[1]->solverInfo);

}

/* OutputUpdate for Task: Periodic_Task3 */
void Periodic_Task3_step(void)                  /* Sample time: [0.1s, 0.0s] */
{   }
```

```
/* OutputUpdate for Task: Periodic_Task4 */
void Periodic_Task4_step(void)                  /* Sample time: [0.2s, 0.0s] */
{   }

/* OutputUpdate for Task:Interrupt1_asyncTask1 */
void Interrupt1_asyncTask1(void)
{   }

/* OutputUpdate for Task:Interrupt2_asyncTask2 */
void Interrupt2_asyncTask2(void)
{   }

/* OutputUpdate for Task:Interrupt3 */
void Interrupt3(void)
{   }

/* OutputUpdate for Task:Interrupt4 */
void Interrupt4(void)
{   }
```

In addition, for continuous signals, the coder produces code for the extrapolation method that you select. There are four types of extrapolation methods: zero-order hold, linear, quadratic, and none. None is an ideal case when the two communicating tasks synchronize in minor steps.

The following code snippets contain the generated task functions in the source file of the mapped model. The `sldemo_concurrent_execution` model has been modified so that:

- ControllerA/u1 uses `Ensure data Integrity only` option in the Signal Properties dialog box.
- Plant is remapped to a new task that executes concurrently with Compensator. The data transfer from Plant to Compensator is `Ensure deterministic transfer (minimum delay)`.

The coder makes sure that the data transfer between concurrently executing tasks behave as described Data Transfer Options on page 11-19.

Generate Code to Share Data in a Concurrent Environment

For `Ensure data integrity only`, the generated code allows data to be shared in a concurrent environment. This is achieved with a double-buffer algorithm (for same rate data transfer) and a triple buffer algorithm (for rate-transition data transfer) and target-specific protection code for the buffer flag management. The following example shows code generated using the `sldemo_concurrent_execution` model:

1. Open the Signal Properties dialog box for ControllerA/u1 and select `Data Integrity Only` as the data transfer handling option from the **Data Transfer** pane.
2. To generate code, select **Code > C/C++ Code > Build Model**.

The coder generates code like the following. This code is for ControllerA/u1 on the Linux platform.

```
/* Output for Task: Periodic_ControllerA */
void Periodic_ControllerA_output(void) /* Sample time: [0.1s, 0.0s] */
{

  /* TaskTransBlk: '<Root>/TaskTransAtController AOut1' */
  sldemo_concurrent_execution_DWork.
    TaskTransAtControllerAOut1_buf_3[sldemo_concurrent_execution_DWork.fw_buf_3]
    = sldemo_concurrent_execution_B.ControllerA;
  rtw_pthread_mutex_lock(sldemo_concurrent_execution_DWork.mw_buf_3);
  sldemo_concurrent_execution_DWork.fw_buf_3 = 1 -
    sldemo_concurrent_execution_DWork.fw_buf_3;
  rtw_pthread_mutex_unlock(sldemo_concurrent_execution_DWork.mw_buf_3);
}
/* Output for Task: Periodic_Plant */
void Periodic_Plant_output(void)       /* Sample time: [0.0s, 0.0s] */
{

  if (rtmIsMajorTimeStep(task_M[2])) {
    /* TaskTransBlk: '<Root>/TaskTransAtPlantIn1' */
    rtw_pthread_mutex_lock(sldemo_concurrent_execution_DWork.mw_buf_3);
    wrBufIdx = 1 - sldemo_concurrent_execution_DWork.fw_buf_3;
    rtw_pthread_mutex_unlock(sldemo_concurrent_execution_DWork.mw_buf_3);
    sldemo_concurrent_execution_B.TaskTransAtPlantIn1 =
```

```
      sldemo_concurrent_execution_DWork.TaskTransAtControllerAOut1_buf_3[wrBufIdx];

  }

}
void MdlInitialize(void)
{

  sldemo_concurrent_execution_DWork.fw_buf_3 = 0;
  rtw_pthread_mutex_init(&sldemo_concurrent_execution_DWork.mw_buf_3);

}
```

Generate Code for Maximum Capacity During Data Transfer

For `Ensure deterministic transfer (maximum delay)`, the generated code for the task transition is ANSI® C code with writing and reading to and from double buffers. In the Signal Properties dialog box, you provide a value for the **Initial Condition** value that initializes the buffer used for the first read operation.

The software generates code like the following. This example is for ControllerB/u1 on the Linux platform.

```
/* Output for Task: Periodic_ControllerB */
void Periodic_ControllerB_output(void) /* Sample time: [0.1s, 0.0s] */
{

  sldemo_concurrent_execution_DWork.
    TaskTransAtControllerBOut1_buf_4[sldemo_concurrent_execution_DWork.fw_buf_4]
    = sldemo_concurrent_execution_B.ControllerB;
  sldemo_concurrent_execution_DWork.fw_buf_4 = 1 -
    sldemo_concurrent_execution_DWork.fw_buf_4;
}
/* Output for Task: Periodic_Plant */
void Periodic_Plant_output(void)       /* Sample time: [0.0s, 0.0s] */
{

  if (rtmIsMajorTimeStep(task_M[2])) {
```

```
    /* TaskTransBlk: '<Root>/TaskTransAtPlantIn2' */
    sldemo_concurrent_execution_B.TaskTransAtPlantIn2 =
      sldemo_concurrent_execution_DWork.
      TaskTransAtControllerBOut1_buf_4[sldemo_concurrent_execution_DWork.fr_buf_4];
    sldemo_concurrent_execution_DWork.fr_buf_4 = 1 -
      sldemo_concurrent_execution_DWork.fr_buf_4;
  }


}

void MdlInitialize(void)
{


  /* InitializeConditions for TaskTransBlk: '<Root>/TaskTransAtController BOut1' */
  sldemo_concurrent_execution_DWork.fw_buf_4 = 0;


}
```

Generated Code for Maximum Data Integrity During Data Transfer

For `Ensure deterministic transfer (minimum delay)`, the generated code for the data transfer makes sure that the task reading the data is waiting for the task writing the data to complete its computation of the data. This behavior produces target-specific code for data synchronization (for example, semaphores).

The software generates code like the following. This example code is for Plant/x on the Linux platform.

```
/*
 * This function updates continuous states using the ODE3 fixed-step
 * solver algorithm
 */
```

```
static void Periodic_Compensator_rt_ertODEUpdateContinuousStates(RTWSolverInfo
  *si )
{

  /* TaskTransBlk: '<Root>/TaskTransAtCompensatorIn1' */
  if (sldemo_concurrent_execution_DWork.br_buf_5) {
    sldemo_concurrent_execution_DWork.br_buf_5 = FALSE;
  } else {
    rtw_pthread_sem_wait(sldemo_concurrent_execution_DWork.sw_buf_5);
    sldemo_concurrent_execution_B.TaskTransAtCompensatorIn1 =
      sldemo_concurrent_execution_DWork.TaskTransAtPlantOut1_buf_5;
    rtw_pthread_sem_post(sldemo_concurrent_execution_DWork.sr_buf_5);
    if (rtmIsMajorTimeStep(task_M[0])) {
      sldemo_concurrent_execution_DWork.br_buf_5 = TRUE;
    }
  }
  /* End of TaskTransBlk: '<Root>/TaskTransAtCompensatorIn1' */

}
/* Output for Task: Periodic_Plant */
void Periodic_Plant_output(void)       /* Sample time: [0.0s, 0.0s] */
{

  if (rtmIsMajorTimeStep(task_M[3])) {

  /* TaskTransBlk: '<Root>/TaskTransAtPlantOut1' */
  rtw_pthread_sem_wait(sldemo_concurrent_execution_DWork.sr_buf_5);
  sldemo_concurrent_execution_DWork.TaskTransAtPlantOut1_buf_5 =
    sldemo_concurrent_execution_B.x;
  rtw_pthread_sem_post(sldemo_concurrent_execution_DWork.sw_buf_5);
}
void MdlInitialize(void)
{

  /* InitializeConditions for TaskTransBlk: '<Root>/TaskTransAtPlantOut1' */
  sldemo_concurrent_execution_DWork.fw_buf_5 = 0;
  rtw_pthread_sem_create(&sldemo_concurrent_execution_DWork.sw_buf_5, 0);
}
```

Threading APIs

For Embedded Coder targets and generic real-time targets, the generated code from a mapped model creates a thread for each task and automatically leverages the threading APIs supported by the operating system running on the host machine.

- If the host machine is a Windows platform, the generated code will create and run Windows threads.
- If the host machine is Linux or Mac OS platform, the generated code will create and run POSIX pthreads.

Aspect of Concurrent Execution	Linux Implementation	Windows Implementation	Mac OS Implementation
Periodic triggering event	POSIX timer	Windows timer	Not applicable
Aperiodic triggering event	POSIX real-time signal	Windows event	POSIX non-real-time signal
Aperiodic trigger	For blocks mapped to an aperiodic task: thread waiting for a signal For blocks mapped to an aperiodic trigger: signal action	Thread waiting for an event	For blocks mapped to an aperiodic task: thread waiting for a signal For blocks mapped to an aperiodic trigger: signal action
Threads	POSIX	Windows	POSIX

Aspect of Concurrent Execution	Linux Implementation	Windows Implementation	Mac OS Implementation
Threads priority	Assigned based on sample time: fastest task has highest priority	Priority class inherited from the parent process. Assigned based on sample time: fastest task has highest priority for the first three fastest tasks. The rest of the tasks share the lowest priority.	Assigned based on sample time: fastest task has highest priority
Example of overrun detection	Yes	Yes	No

The data transfer between concurrently executing tasks behave as described in Data Transfer Options on page 11-19. The coders use the following APIs on supported targets for this behavior:

Data Protection and Synchronization APIs that Embedded Coder and Generic Real-Time Targets Use

API	Linux Implementation	Windows Implementation	Mac OS Implementation
Data protection API	• pthread_mutex_init • `pthread_mutex_-destroy` • `pthread_mutex_lock` • `pthread_mutex_-unlock`	• `CreateMutex` • `CloseHandle` • `WaitForSingleObject` • `ReleaseMutex`	• `pthread_mutex_init` • `pthread_mutex_-destroy` • `pthread_mutex_lock` • `pthread_mutex_-unlock`
Synchronization API	• `sem_init` • `sem_destroy`	• `CreateSemaphore` • `CloseHandle`	• `sem_open` • `sem_unlink`

Data Protection and Synchronization APIs that Embedded Coder and Generic Real-Time Targets Use (Continued)

API	Linux Implementation	Windows Implementation	Mac OS Implementation
	• sem_wait • sem_post	• WaitForSingle-Object • ReleaseSemaphore	• sem_wait • sem_post

The `main()` code is always dynamically generated. The general structure of the generated main file is depicted in the following pseudocode:

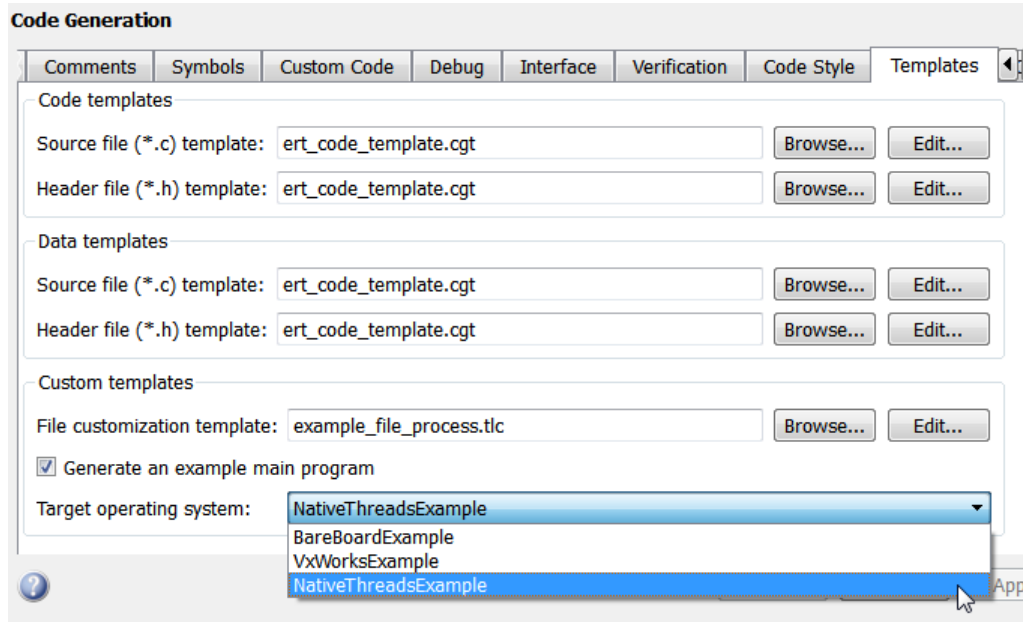
```
main()
{
  Model_initialize();
 For_each_periodic_task
 {
  Create_synchronization_event(periodic_task);
  Create_thread(periodic_task);
 }
           For_each_aperiodic_task
 {
  Create_external_event(aperiodic_task);
  Create_thread(aperiodic_task);
 }

      Create_timer();
Create_thread(Periodic_task_scheduler);

For_each_aperiodic_trigger
{
 Hookup_isr_to_aperiodic_event();
}

Wait_for_stopping();
 Cleanup();
 Model_terminate();
 return 0;
```

```
}

Periodic_task_scheduler()
{
 Wait_for_event_from_timer(clock);
 For_each_periodic_task
 {
     If periodic_task has a sample time hit
     Set the event to run the task
 }
}

Periodic_Task()
{
 Wait_for_event(Periodic_task_scheduler);
 Run the appropriate periodic_task();
}

Aperiodic_Task()
{
 Wait_for_aperiodic_event();
 Run the appropriate aperiodic_task();
}

Isr()
{
    Run the appropriate aperiodic_trigger ();
}
```

Configuring Embedded Coder for Native Threads Example

To generate code for an Embedded Coder target, in the Configuration Execution dialog box:

- Select the **Code Generation > Templates > Generate an example main program** check box.
- From the **Code Generation > Templates > Target Operating System** list, select `NativeThreadsExample`.



Build and Download

You can build and download concurrent execution models for the following targets using system target files:

- Linux, Windows, and Mac OS using `ert.tlc` and `grt.tlc`.
- xPC Target using `xpctarget.tlc` and `xpctargetert.tlc`.
- Linux and Windows using `idelink_ert.tlc` and `idelink_grt.tlc`.
- Embedded Linux and VxWorks using `idelink_ert.tlc` and `idelink_grt.tlc`.

Note Deploying to embedded Linux and VxWorks targets requires the Embedded Coder product.

You cannot generate code for C++ (Encapsulated) language option.

Profile and Evaluate

Profile the execution of your code on the multicore system using a profiling tool like that provided in the xPC Target software. Profiling lets you identify the areas in your model that are execution bottlenecks. You can analyze the execution time of each task and find the task that takes most of the execution time. For example, if you are using the xPC Target profiling tool, you can compare the average execution times of the tasks. If a task is computation-intensive, or does not satisfy real-time requirements and overruns, you can break it into multiple tasks that are less computation-intensive and that can run concurrently.

Based on this analysis, you can then explicitly change the mapping of Model blocks to efficiently use the concurrency available on your multicore system (see “Mapping Blocks to Tasks” on page 11-24).

Concurrent Execution Example Model

For an interactive example of a model that has been configured to work in a concurrent execution environment:

1. In the MATLAB Command Window, click the question mark.

   The Documentation Center window opens.

2. Navigate to **Simulink > Examples > Modeling Features > Modeling Concurrency > Modeling Concurrent Execution on Multi-Core Targets**.

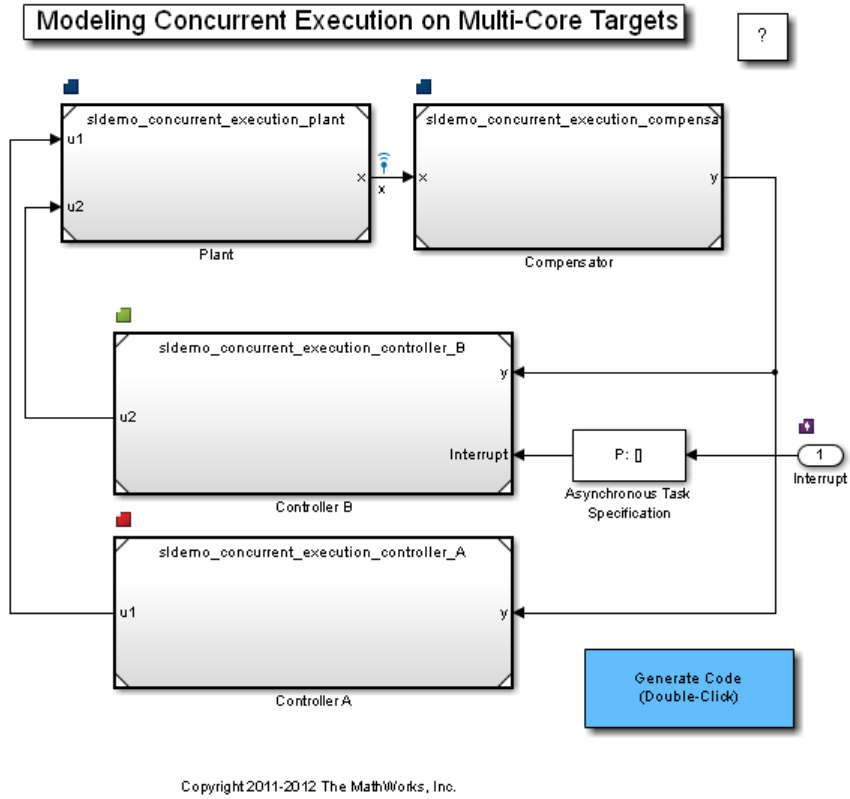
Modeling Concurrent Execution on Multi-Core Targets

This model shows how you can use Simulink and Simulink Coder™ to realize concurrent execution of a model on a multicore target. Additionally, the example also illustrates how simulation captures effects of on-target concurrent execution, such as the transfer of data between tasks.

Example Requirements

If you want to generate code for this model, ensure that Simulink Coder™ is installed. Note, when you simulate the example, Simulink and Simulink Coder™ might generate code in a Simulink project folder created in the current working folder. If you do not want to (or cannot) generate files in this folder, change the current working folder to a suitable folder.

```
topmdl = 'sldemo_concurrent_execution';
open_system(topmdl);
curDir = pwd;
cd(tempdir);
```



Overview of the Model

To take advantage of the concurrent execution feature, use Model blocks to partition your model into portions that can potentially execute concurrently. Open the model and examine its partitioning into four Model blocks: Plant, Compensator, ControllerA, and ControllerB. This example also shows how you can specify and simulate the effects of asynchronous external inputs to your system via the root input port Interrupt of ControllerB.

Starting with a Default Configuration

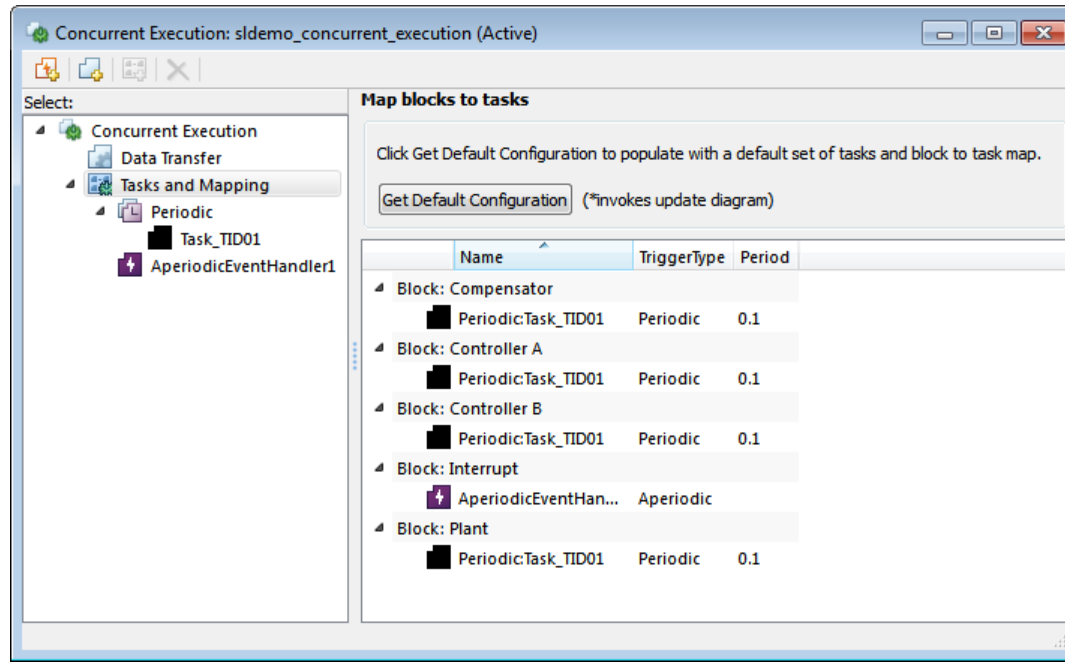
This model has been configured for concurrent execution on a target. For more information, see the documentation.

Use the Concurrent Execution dialog to configure your model for concurrent execution on the target. Open the Concurrent Execution dialog.

Each element of the Concurrent Execution dialog tree-view allows configuration of the following model aspects:

- Data Transfer - Allows default configuration of the data transfer options between tasks (you can override these by configuring each signal through the signal properties dialog)
- Tasks and Mapping - Allows explicit mapping of blocks to tasks
- Periodic - Allows specification and configuration of periodic tasks
- Interrupt - Allows specification and configuration of aperiodic tasks

As a first step, set up the model to behave in non-concurrent fashion to identify bottlenecks in execution. You can use the **Get Default Configuration** button in the **Tasks and Mapping** pane to do this. Alternatively, click on the following link. You can now simulate the default configuration of the model with all Model blocks mapped to a single periodic task `Task_TID01` and a single aperiodic trigger `AperiodicEventHandler1`. Observe the outputs of ControllerB in the scope.



Exploring Concurrent Execution

This example is a fairly simple model illustrating the basic elements of concurrent execution. In a real-world application model, you might see bottlenecks due to all blocks mapped to a single periodic task as with the default configuration for this example.

Assume that you have significant computation in all four Model blocks which needs to be mapped to separate tasks on a multicore target platform. To experiment with a different mapping for the Model blocks, change the task configuration to create new tasks, and map the blocks to the newly created tasks. Do this automatically using the following link or by following the instructions below.

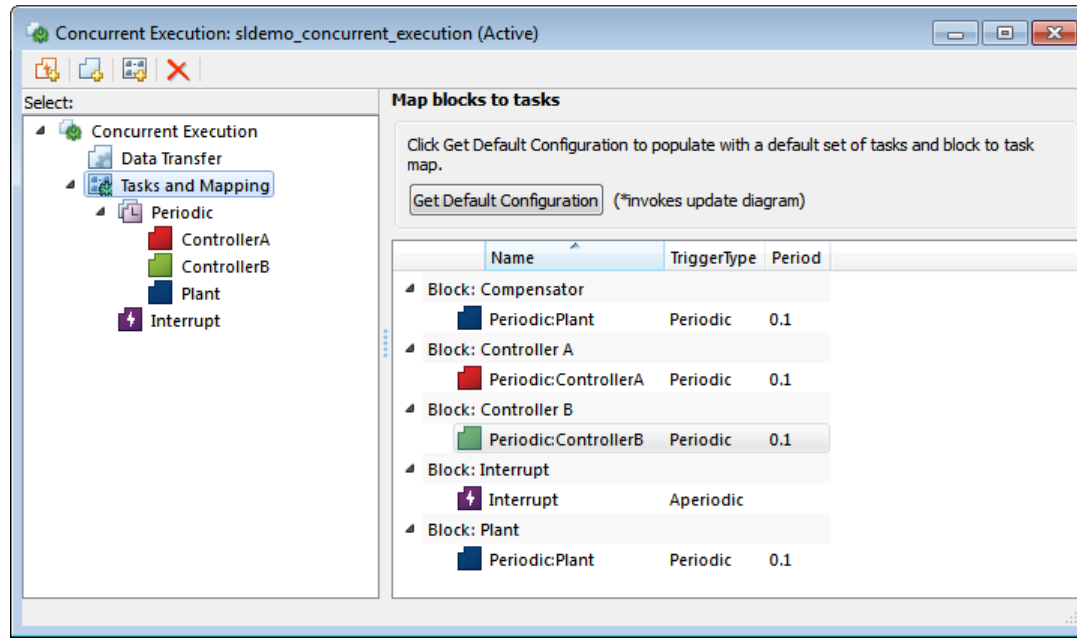
To change the task mapping, first create tasks. Both periodic and aperiodic tasks (not used in this model) are supported. Refer to the documentation for more information about configuring aperiodic tasks.

1. Click the **Add Task** button on the toolbar to create a new task. You can configure **Name**, **Period** (i.e., sample time) and **Color** of the newly created task. Rename the task to `Plant`. Change the period attribute of the task to be `0.1`. Click the Apply button to save your changes. Similarly, create two more tasks named `ControllerA` and `ControllerB`, both with period `0.1`.

2. Click the **Add aperiodic trigger** button on the toolbar to create a new aperiodic trigger. You can configure an aperiodic trigger to generate an aperiodic event, e.g., to simulate the effects of an interrupt on the system. You can also configure the behavior of aperiodic triggers during simulation and code generation. To configure the simulation behavior, open the Configuration Parameters dialog box for the top-level model, select the Data Import/Export pane, and select the Input check box. This parameter specifies the time points at which the external aperiodic trigger is generated. This example is pre-configured to generate the aperiodic trigger at time points 4 and 7.

3. Click **Tasks and Mapping** node. Change the mapping of **Block:Compensator** by clicking the task `Periodic:Task_TID01` in the **Name** column and changing it to `Periodic:Plant` from the task drop-down list. Similarly, change the mapping of **Block:ControllerA** to `Periodic:ControllerA`, **Block:ControllerB** to `Periodic:ControllerB`, **Block:Plant** to `Periodic:Plant`, and **Block:Interrupt** to `AperiodicEventHandler1`.

Now, simulate the model and examine the effects of your mapping. The Simulink editor shows the inter task communication via the new z^{-1} icons on the signals between the Model blocks. The z^{-1} icon on the signal indicates that inter task communication introduces a unit delay in the communication between each pair of tasks.



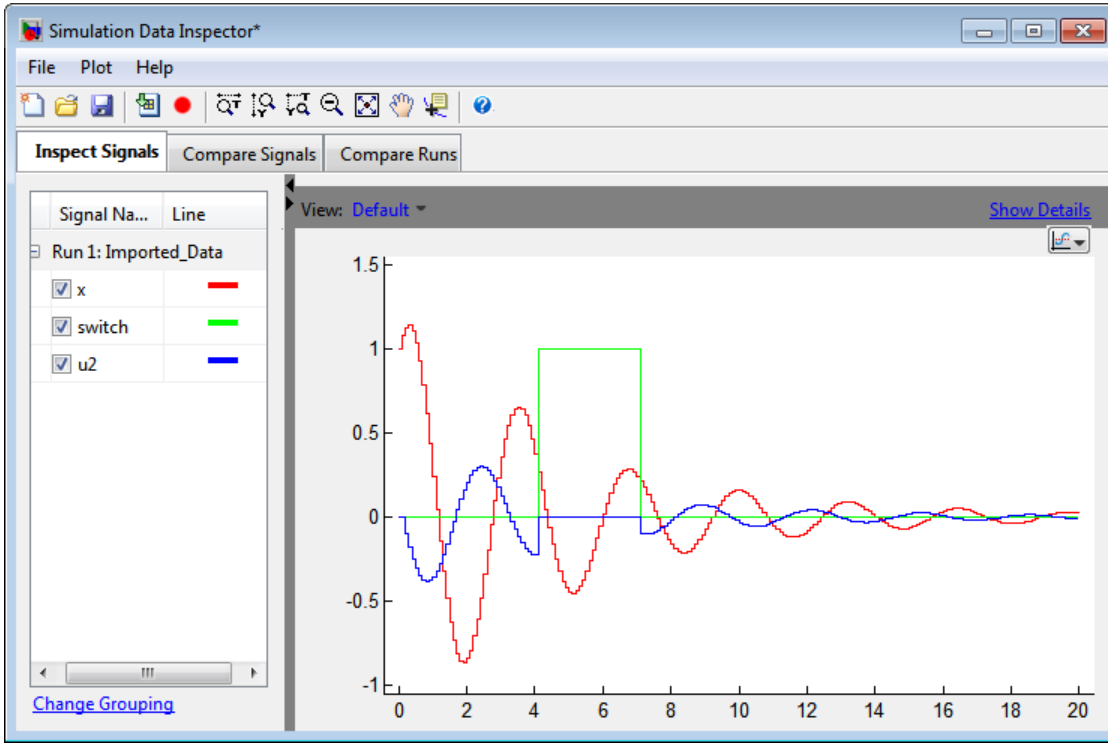

```
% Enable the external inputs to the system.
set_param(topmdl, 'LoadExternalInput', 'on');

%Get Active Configuration Set
csTop = getActiveConfigSet(topmdl);

% Get the task configuration.
tc = csTop.concurrentExecutionComponents;

% Get the block handles for mapping.
plantBlkH        = get_param([topmdl '/Plant'], 'Handle');
compensatorBlkH  = get_param([topmdl '/Compensator'], 'Handle');
controlABlkH     = get_param([topmdl '/Controller A'], 'Handle');
controlBBlkH     = get_param([topmdl '/Controller B'], 'Handle');
interruptBlkH    = get_param([topmdl '/Interrupt'], 'Handle');

% Delete any previously created tasks
periodicTrigger = tc.Triggers(1);
```

```
periodicTasks   = periodicTrigger.Tasks;
tnames          = {periodicTasks.Name};
for i = 1:length(periodicTasks)
    periodicTrigger.deleteTask(tnames{i});
end

% Delete Aperiodic Trigger
aperiodicTrigger = tc.Triggers(2);
tc.deleteTrigger(aperiodicTrigger);

% Create and configure new tasks.
plant           = periodicTrigger.addTask('Plant');
controlA        = periodicTrigger.addTask('ControllerA');
controlB        = periodicTrigger.addTask('ControllerB');
interruptSource = tc.addAperiodicTrigger('Interrupt');

plant.Period    = '0.1';
controlA.Period = '0.1';
controlB.Period = '0.1';

% Perform mapping of blocks to tasks.
tc.map(plantBlkH, plant);
tc.map(compensatorBlkH, plant);
tc.map(controlABlkH, controlA);
tc.map(controlBBlkH, controlB);
tc.map(interruptBlkH, interruptSource);

% Launch Concurrent Execution dialog
Simulink.SoftwareTarget.concurrentExecution(topmdl, ...
                                            'OpenDialog', ...
                                            'Configuration');

sim(topmdl);
```

Viewing Simulation Results

You can use the Simulation Data Inspector to view the simulation results. Note that the output of **Block:ControllerB** (u2) becomes zero around points 4 and 7 because of the occurrence of the aperiodic event (switch). After the event, the output continues to settle down to zero. To further observe the

effect of the aperiodic trigger on the system, alter the time points at which the aperiodic event trigger is generated.



Configuring Inter Task Communication

You can change the modes of the inter task communication between the Model blocks in the model to better suit design criteria. Do this by clicking the following link or by following these instructions:

Click on **Data Transfer** node of the Concurrent Execution dialog. In the **Data Transfer Options** pane, change **Defaults > Periodic signals** to `Ensure data integrity only` by selecting it. Click Apply to save the changes.

Now, simulate the model. The lock icon on the signals between the Model blocks indicates that data transfer between concurrent tasks is performed in

data-integrity-only mode. For fine-grained control on the data transfer modes between tasks at the level of individual signals, see the documentation.

Generating Code

1. To generate code for the model, save the model after performing the preceding steps. You can change to a temporary folder so that the original example model remains unchanged.

2. Depending on the host platform that you use for running this example, you might need to change the code generation properties of the aperiodic trigger. You can configure aperiodic triggers to generate code using POSIX signals or Windows events. To generate code using POSIX signals to represent the aperiodic triggers, select the `AperiodicEventHandler1` node in the Concurrent Execution dialog. For the 'Aperiodic trigger source' parameter, choose 'POSIX Signal (Linux/VxWorks 6.x)'. For the 'Signal number' parameter, enter a valid signal number, [2, SIGRTMAX-SIGRTMIN-1], to represent the POSIX signal to represent this aperiodic trigger. To generate aperiodic triggers using Windows Events, for the 'Aperiodic trigger source' parameter, choose 'Event (Windows)'. Enter a name to represent this aperiodic trigger.

3. Generate code from the model.

4. In the code generation report, click `grt_main.c` to view the threads created for tasks. Because you created three tasks in the task configuration, you will see three threads created in the `main()` function. Depending on the platform that you are using to view this example, you will see that either Windows or POSIX threads are used for tasks. You will also see that either Windows events or POSIX signal handlers are generated corresponding to the aperiodic trigger.

5. Open `sldemo_concurrent_execution.c` to view the output/update functions that are mapped to tasks. For example, `Periodic_Plant_output` corresponds to the task **Plant**, `Periodic_ControllerA_output` corresponds to the task **ControllerA**, etc. Observe that a function `AperiodicEventHandler1` is generated for the aperiodic trigger. This function is associated with a signal handler `sigHandler_AperiodicEventHandler1` generated in `grt_main.c`. If you chose Windows events, you will observe a similar function generated for the aperiodic trigger.

Closing the Models

```
close_system(topmdl, 0);
close_system([topmdl,'_plant'], 0);
close_system([topmdl,'_compensator'], 0);
close_system([topmdl,'_controller_A'], 0);
close_system([topmdl,'_controller_B'], 0);
cd(curDir);
```

Conclusion

This example illustrates a simple workflow using Simulink and Simulink Coder™ to examine the effects of concurrent execution on a multicore target. You can iteratively apply this workflow to optimize performance of a real-world application on a multicore xPC Target™ environment, along with the on-target profiling capability of xPC Target™.

Command-Line Interface

The previous topics describe how to configure models for concurrent execution using the Simulink Configuration Execution dialog box. You can also perform the configuration using a command-line interface. The following classes, their methods and properties, and the `Simulink.SoftwareTarget.concurrentExecution` function comprise this interface:

To...	Use...
Create a configuration set for concurrent execution	`Simulink.SoftwareTarget.concurrentExecution`
Specify aperiodic trigger	`Simulink.SoftwareTarget.AperiodicTrigger`
Specify periodic trigger	`Simulink.SoftwareTarget.PeriodicTrigger`
Specify aperiodic trigger for POSIX targets	`Simulink.SoftwareTarget.PosixSignalHandler`
Specify task that models unit of concurrent execution	`Simulink.SoftwareTarget.Task`
Configure model for concurrent execution	`Simulink.SoftwareTarget.TaskConfiguration`
Specify base class for PeriodicTrigger and AperiodicTrigger	`Simulink.SoftwareTarget.WindowsEventHandler`
Describe aperiodic trigger for Windows target	`Simulink.SoftwareTarget.Trigger`
Configure concurrent execution data transfers	`Simulink.GlobalDataTransfer`

12

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 "Model a Continuous System" on page 12-8) 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 7-30 for a description of function-call subsystems)
- Self-triggering subsystems and loops containing non-latched triggered subsystems (see "Triggered Subsystems" on page 7-20 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:

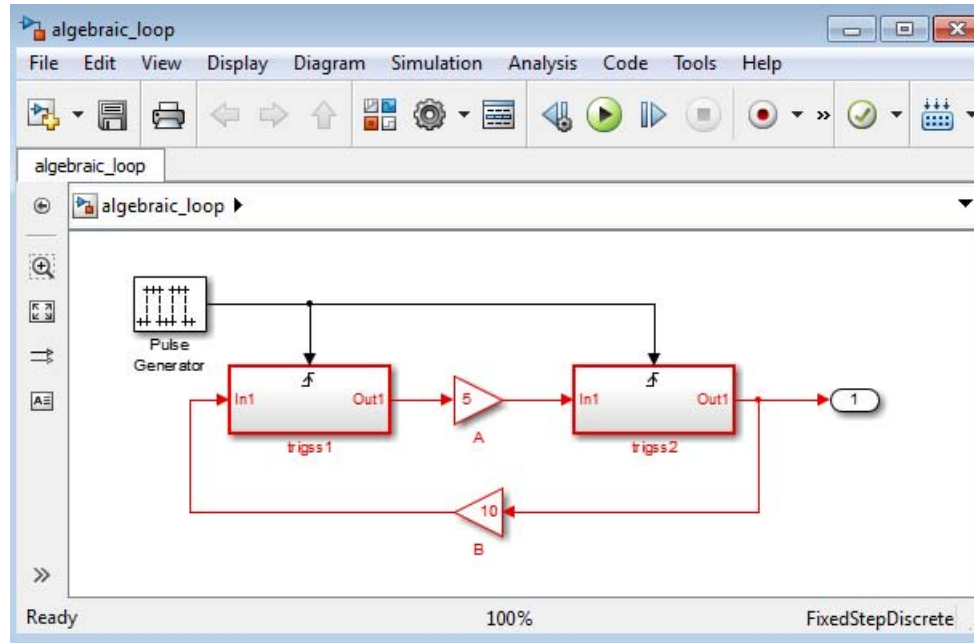
- `simulink/Ports&Subsystems/sl_subsys_semantics/Triggered subsystem/sl_subsys_trigerr1` (`sl_subsys_trigerr1`)
- `simulink/Ports&Subsystems/sl_subsys_semantics/Triggered subsystem/sl_subsys_trigerr2` (`sl_subsys_trigerr2`)

- `simulink/Ports&Subsystems/sl_subsys_semantics/Function-call systems/sl_subsys_fncallerr3` (`sl_subsys_fncallerr3`)

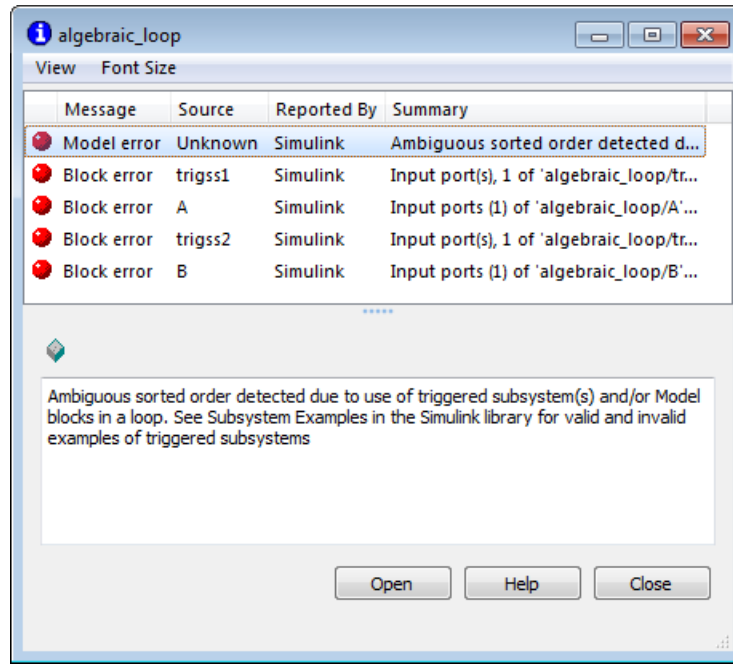
You might find it useful to study these examples to avoid creating invalid loops in your own models.

Detecting Invalid Loops

To detect whether your model contains invalid loops, select **Update Diagram** from the model's **Simulation** 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.slx`) 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 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.slx` 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.slx` is being used. To see which file called `mylibrary.slx` is loaded into memory, enter:

```
 which mylibrary

C:\work\Model1\mylibrary.slx
```

To see all the files called `mylibrary` which are on the MATLAB path, including MATLAB scripts, enter:

```
which -all mylibrary

C:\work\Model1\mylibrary.slx
C:\work\Model2\mylibrary.slx  % 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 "Create a Subsystem" on page 4-36. The Model Browser provides useful information about complex models (see "Model Browser" on page 9-80).

- 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 "Signal Names and Labels" on page 47-19 and "Annotate Diagrams" on page 4-23.

- 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.

Model a Continuous System

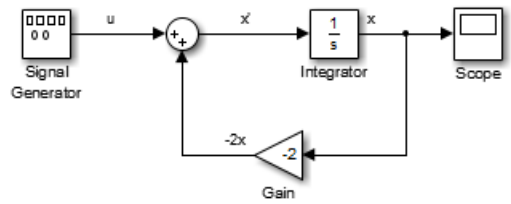
To model the differential equation

$$x' = -2x(t)+u(t),$$

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.

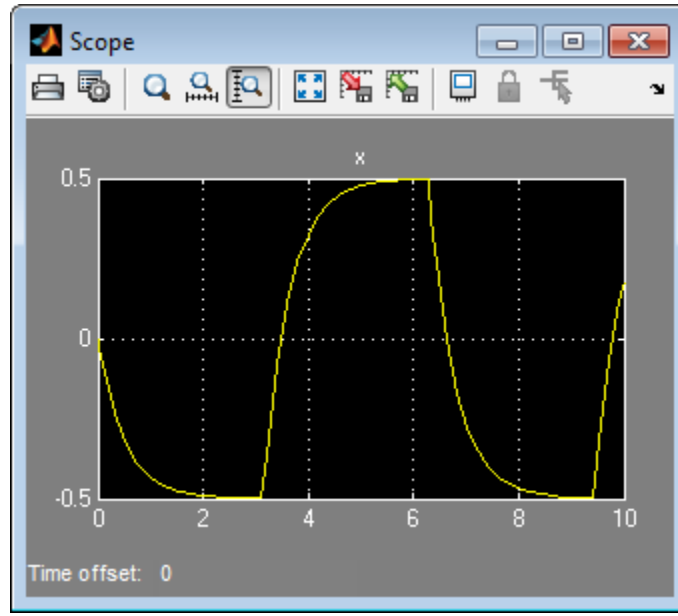
In this model, to reverse the direction of the Gain block, select the block, then use the **Diagram > Rotate & Flip > Flip Block** command. To create the branch line from the output of the Integrator block to the Gain block, hold down the **Ctrl** key while drawing the line. For more information, see "Draw a Branch Line" on page 4-16.

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

$$x = u/(s + 2)$$

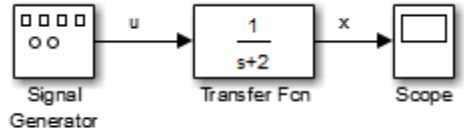
or,

$$x/u = 1/(s + 2).$$

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]`.



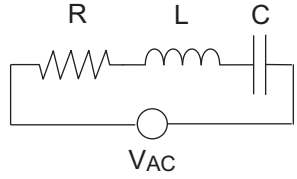
The results of this simulation are identical to those of the previous model.

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

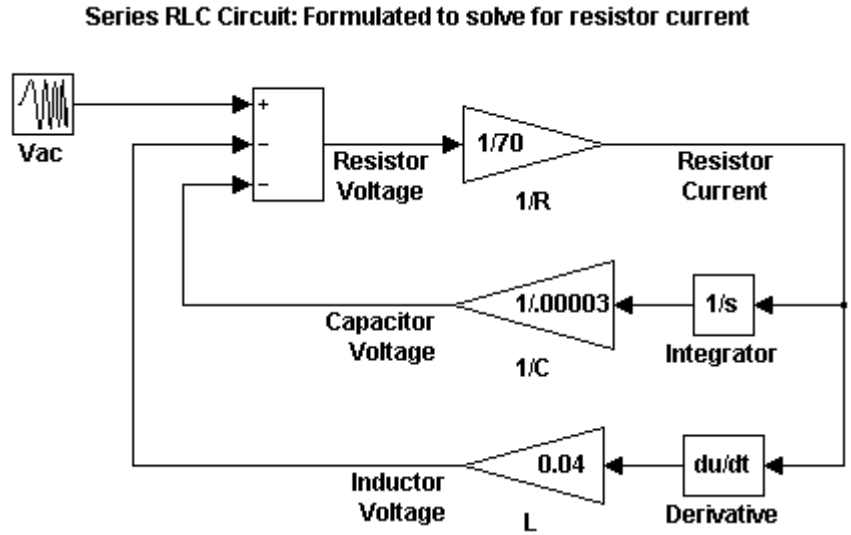
Solving the RLC circuit for the resistor voltage yields

$$V_R = Ri$$

$$Ri = V_{AC} - L\frac{di}{dt} - \frac{1}{C}\int_{-\infty}^{t} i(t)dt$$

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 3-39 for more information.

Solving Series RLC Using Inductor Voltage

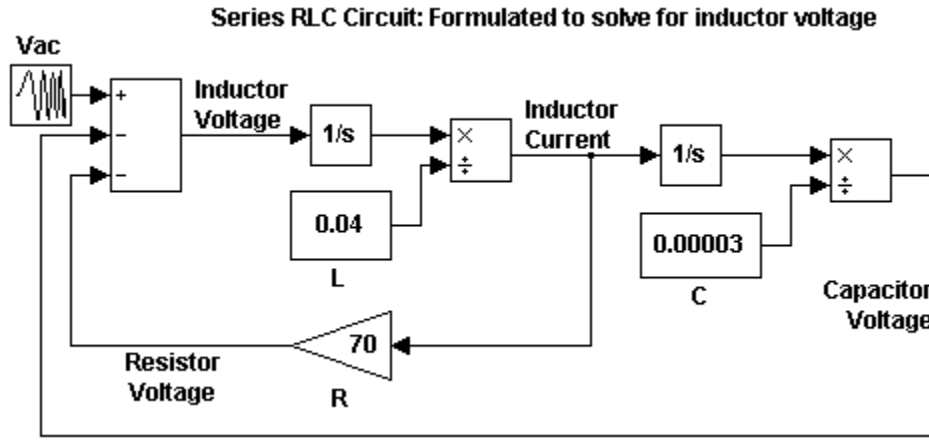
To avoid using a Derivative block, formulate the equation to solve for the inductor voltage.

$$V_L = L\frac{di}{dt}$$

$$L\frac{di}{dt} = V_{AC} - Ri - \frac{1}{C}\int_{-\infty}^{t} i(t)dt$$

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.

Model a Simple Equation

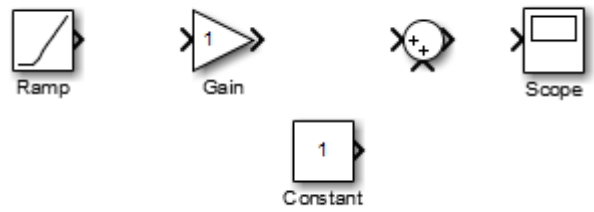
To model the equation that converts Celsius temperature to Fahrenheit

$T_F = 9/5(T_C) + 32$

First, consider the blocks needed to build the model:

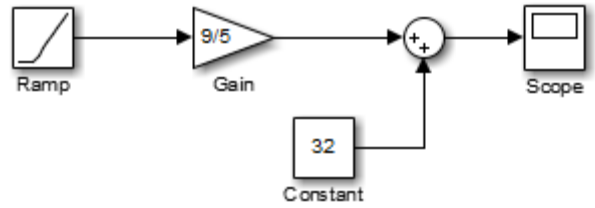
- A Ramp block to input the temperature signal, from the Sources library
- A Constant block to define a constant of 32, also from the Sources library
- A Gain block to multiply the input signal by 9/5, from the Math Operations library
- A Sum block to add the two quantities, also from the Math Operations 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 **Run** from the **Simulation** menu to run the simulation. The simulation runs for 10 seconds.

Componentization Guidelines

Componentization

A component is a piece of your design, a unit level item, or a subassembly, that you can work on without needing the higher level parts of the model.

Componentization involves organizing your model into components. Componentization provides many benefits for organizations that develop large Simulink models that consist of many functional pieces. The benefits include:

- Meeting development process requirements, such as:
  - Component reuse
  - Team-based development
  - Intellectual property protection
  - Unit testing
- Improving performance for:
  - Model loading
  - Simulation speed
  - Memory usage

Componentization Techniques

Key componentization techniques that you can use with Simulink include:

- Subsystems
- Libraries
- Model referencing

These componentization techniques support a wide range of modeling requirements for models that vary in size and complexity. Most large models use a combination of componentization techniques. For example, you can include subsystems in referenced models, and include referenced models in subsystems. As another example, a large model might use model reference

Accelerator blocks at the top level component partitions and blend model reference Accelerator and atomic subsystem libraries at lower levels.

Simulink provides tools to convert from subsystems to model referencing. Because of the differences between subsystems and model referencing, switching from subsystems to model referencing can involve several steps (see Converting a Subsystem to a Referenced Model). Consider scalability and support for anticipated future modeling requirements, such as how a model is likely to grow in size and complexity and possible code generation requirements. Designing a scalable architecture can avoid later conversion costs.

General Componentization Guidelines

This table provides high-level guidelines about the kinds of modeling goals and models for which subsystems, libraries, and model referencing are each particularly well suited.

Componentization Technique	Modeling Goals for Which the Technique Is Well Suited
Subsystems	• Add hierarchy to organize and visually simplify a model. • Maximize design reuse with inherited attributes for context-dependent behavior.
Libraries	• Provide a frequently used, and infrequently changed, modeling utility. • Reuse components repeatedly in a model or in multiple models.
Model referencing	• Develop a referenced model independently from the models that use it. • Obscure the contents of a referenced model, allowing you to distribute it without revealing the intellectual property that it embodies. • Reference a model multiple times without having to make redundant copies.

Componentization Technique	Modeling Goals for Which the Technique Is Well Suited
	• Facilitate changes by multiple people, with defined interfaces for top-level components. • Improve the overall performance by using incremental model loading, update diagram, simulation, and code generation for large models (for example, a model with 10,000 blocks). • Perform unit testing. • Simplify debugging for large models. • Generate code that reflects the model structure.

For a more detailed comparison of these modeling techniques, see "Summary of Componentization Techniques" on page 12-19.

Summary of Componentization Techniques

This section compares subsystems, libraries, and model referencing. The table includes recommendations and notes about a range of modeling requirements and features.

To see more information about a specific requirement or feature, click a link in a table cell.

Modeling Requirement or Feature	Subsystems	Libraries	Model Referencing
Development Process			
Component reuse	Not supported	Well suited	Well suited
Team-based development	Not supported	Supported, with limitations	Well suited

Modeling Requirement or Feature	Subsystems	Libraries	Model Referencing
Intellectual property protection	Not supported	Not supported	Well suited
Unit testing	Supported, with limitations	Supported, with limitations	Well suited
Performance			
Model loading speed	Supported, with limitations	Well suited	Well suited
Simulation speed for large models	Supported, with limitations	Supported, with limitations	Well suited
Memory	Supported, with limitations	Supported, with limitations	Well suited
Artificial algebraic loop avoidance	Well suited	Well suited	Supported, with limitations
Features			
Signal property inheritance	Well suited	Well suited	Supported, with limitations
State initialization	Well suited	Well suited	Supported, with limitations
Tunability	Well suited	Well suited	Supported, with limitations
Buses	Well suited	Well suited	Supported, with limitations
S-functions	Well suited	Well suited	Supported, with limitations

Modeling Requirement or Feature	Subsystems	Libraries	Model Referencing
Model configuration settings	Well suited	Well suited	Supported, with limitations
Tools	Well suited	Well suited	Supported, with limitations
Code generation	Supported, with limitations	Supported, with limitations	Well suited

For each modeling technique, you can see a summary table that includes the more detailed information included in the links in the above summary table of componentization techniques:

- "Subsystems Summary" on page 12-21
- "Libraries Summary" on page 12-25
- "Model Referencing Summary" on page 12-29

Subsystems Summary

This section provides guidelines for using subsystems for each of the modeling requirements and features highlighted in the "Summary of Componentization Techniques" on page 12-19.

For additional information about subsystems, see:

- Creating Subsystems
- "Conditional Subsystems"

Modeling Requirement or Feature	Guidelines for Subsystems
Development Process	
Component reuse	**Not supported** • Copy a subsystem to reuse it in a model. • Subsystem copies are independent of each other. • Save a subsystem by saving the model that contains the subsystem. • Configuration management for subsystems is difficult.
Team-based development	**Not supported** • For subsystems in a model, Simulink provides no direct interface with source control tools. • To create or change a subsystem, you need to open the parent model's file. This can lead to file contention when multiple people want to work on multiple subsystems in a model.
Intellectual property protection	**Not supported** Use model referencing protected models instead.
Unit testing	**Supported, with limitations** • For coverage testing, use Signal Builder and source blocks. • Each time a subsystem changes, you need to copy the subsystem to a harness model. • The test harness may have different Simulink sort orders, due to virtual boundaries. • Test harness files require configuration management overhead.
Performance	

Modeling Requirement or Feature	Guidelines for Subsystems
Model loading speed	**Supported, with limitations** Loading a model loads all subsystems at one time. There is no incremental loading.
Simulation speed for large models	**Supported, with limitations** • To speed simulation, use Accelerator or Rapid Accelerator simulation mode. • Simulation mode applies to the whole model. Model referencing provides a finer level of control for simulation modes.
Memory	**Supported, with limitations** Memory use for simulation and code generation is comparable for subsystems and libraries. For models with over 500 blocks, model reference Accelerator mode can significantly reduce memory usage for simulation and code generation.
Artificial algebraic loop avoidance	**Well suited** • Virtual subsystems avoid artificial algebraic loops. • For nonvirtual subsystems, consider enabling the Subsystem block parameter **Minimize algebraic loop occurrences**.
Features	
Signal property inheritance	**Well suited** • Inheriting signal properties from outside of the subsystem boundary avoids your having to specify properties for every signal. • Propagation of signal properties can lead to Simulink using signal properties that you did not anticipate.

Modeling Requirement or Feature	Guidelines for Subsystems
State initialization	**Well suited** You can initialize states of subsystems.
Tunability	**Well suited** • Tune subsystems using a block parameterization or masked subsystems. • Control tunability using **Configuration Parameters > Optimization > Signals and Parameters > Inline parameters**.
Buses	**Well suited** Subsystems do not require the use of bus objects for virtual buses.
S-functions	**Well suited** Subsystems support inlined or noninlined S-functions.
Model configuration settings	**Well suited** A subsystem uses the model configuration settings of the model that contains the subsystem.
Tools	**Well suited** Subsystems provide extensive support for Simulink tools.
Code generation	**Supported, with limitations** • To generate code for a subsystem by itself, right-click the Subsystem block and select a code generation option. • As an optimization, Simulink attempts to recognize identical subsystems. For detected identical subsystems, the generated code includes only one copy of code for the multiple subsystems.

Modeling Requirement or Feature	Guidelines for Subsystems
	• For virtual subsystems, you cannot specify file or function code partitions for code generation.

Libraries Summary

This section provides guidelines for using libraries for each of the modeling requirements and features highlighted in the "Summary of Componentization Techniques" on page 12-19.

For additional information about libraries, see "Libraries".

Modeling Requirement or Feature	Guidelines for Libraries
Development Process	
Component reuse	**Well suited** • Access a collection of well-defined utility blocks. • Create a component once and reuse it in models. • Link to the same library block multiple times without creating multiple copies. • Link to the same library block from multiple models. • Restrict write access to library components. • Maintain one truth: propagate changes from a single library block to all blocks that link to that library. • Disable a link to allow independent changes to a linked block. • Managing library links adds some overhead.

Modeling Requirement or Feature	Guidelines for Libraries
	• Save library in a file similar to a Simulink model, but you cannot simulate the file contents.
Team-based development	**Supported, with limitations** • Place library files in source control for version control and configuration management. • Maintain one truth: propagate changes from a single library block to all blocks that link to that library. • To reduce file contention, use one subsystem per library. • Link to the same library block from multiple models. • Restrict write access to library component. • See General Reusability Limitations.
Intellectual property protection	**Not supported** Use model referencing protected models instead.
Unit testing	**Supported, with limitations** • For coverage testing, use Signal Builder and source blocks. • Test harness may have different Simulink sort orders, due to virtual boundaries. • Test harness files require configuration management overhead.
Performance	

Modeling Requirement or Feature	Guidelines for Libraries
Model loading speed	**Well suited** Simulink incrementally loads a library at the point needed during editing, updating a diagram, or simulating a model.
Simulation speed for large models	**Supported, with limitations** • To speed simulation, use Accelerator or Rapid Accelerator simulation mode. • Simulation mode applies to the whole model. Model referencing provides a finer level of control for simulation modes.
Memory	**Supported, with limitations** • Simulink incrementally loads libraries at the point needed during editing, updating a diagram, or simulating a model. • Simulink duplicates library block instances during block update. • Memory usage for simulation and code generation is comparable for subsystems and libraries. For models with over 500 blocks, model reference Accelerator mode can significantly reduce memory usage for simulation and code generation.
Artificial algebraic loop avoidance	**Well suited** • Virtual subsystems avoid artificial algebraic loops. • For nonvirtual subsystems, consider enabling the Subsystem block parameter **Minimize algebraic loop occurrences**.
Features	

Modeling Requirement or Feature	Guidelines for Libraries
Signal property inheritance	**Well suited** • Inheriting signal properties from outside of the library block boundary avoids your having to specify properties for every signal. • Propagation of signal properties can lead to Simulink using signal properties that you did not anticipate.
State initialization	**Well suited** You can initialize states of library blocks.
Tunability	**Well suited** • Tune library blocks using block parameterization or masked subsystems. • Control tunability using **Configuration Parameters > Optimization > Signals and Parameters > Inline parameters**.
Buses	**Well suited** Libraries do not require the use of bus objects for virtual buses.
S-functions	**Well suited** Libraries support inlined and noninlined S-functions.
Model configuration settings	**Well suited** • Library models do not have model configuration settings. • A referenced library block uses the model configuration setting of the model that contains that block.

Modeling Requirement or Feature	Guidelines for Libraries
Tools	**Supported, with limitations** There are some limitations for using some Simulink tools, such as the Model Advisor, with libraries.
Code generation	**Supported, with limitations** • As an optimization, Simulink attempts to recognize identical subsystems. For detected identical subsystems, the generated code includes only one copy of code for the multiple subsystems. • For virtual subsystems, you cannot specify file or function code partitions for code generation.

Model Referencing Summary

This section provides guidelines for using model referencing for each of the modeling requirements and features highlighted in the "Summary of Componentization Techniques" on page 12-19.

For additional information about model referencing, see:

- "Model Reference"
- Simulink Model Referencing Requirements
- Model Referencing Limitations

Modeling Requirement or Feature	Guidelines for Model Referencing
Development Process Requirements	
Component reuse	**Well suited** • Create a standalone component once and reuse it in multiple models. • Reference the same model multiple times without creating multiple copies. • Reference the same model from multiple models. • Model referencing uses specified boundaries for preserving component integrity.
Team-based development	**Well suited** • For version control and configuration management, you can place model reference files in a source control system. • Design, create, simulate, and test a referenced model independently from the model that references it. • Link to the same model reference from multiple models. • Changes made to a referenced model apply to all instances of that referenced model. • Simulink does not limit access for changing a model reference. • You save a referenced model in a separate file from the model that references it. Using separate files helps to avoid file contention.

Modeling Requirement or Feature	Guidelines for Model Referencing
Intellectual property protection	**Well suited** • Use the protected model feature to obscure contents of a referenced model in a distributed model. • Creating a protected model feature requires a Simulink Coder license. Using a protected model does *not* require a Simulink Coder license.
Unit testing	**Well suited** • Test components independently to isolate behaviors, by simulating them standalone. • You can eliminate unit retest for unchanged components. • Use a data-defined test harness, with MATLAB test vectors and direct coverage collection. • For coverage testing, use root inports and outports.
Performance	
Model loading speed	**Well suited** • Simulink incrementally loads a referenced model at the point needed during editing, updating a diagram, or simulating a model. • If a simulation target build is required, first-time loading can be slow.

Modeling Requirement or Feature	Guidelines for Model Referencing
Simulation speed for large models	**Well suited** • Simulate a referenced model standalone. • The Model block has an option for specifying the simulation mode. • You can improve rebuild performance by selecting the appropriate setting for the **Configuration Parameters > Model Referencing > Rebuild** parameter. • Simulation through code generation can have a slow start-up time, which might be undesirable during prototyping. • See "Limitations on Normal Mode Referenced Models" on page 6-83, "Limitations on Accelerator Mode Referenced Models" on page 6-84, and "Limitations on PIL Mode Referenced Models" on page 6-87.
Memory	**Well suited** • Simulink loads a referenced model at the point that model is needed for navigation during editing, updating a diagram, or simulating a model. • Use model reference Accelerator mode to reduce memory usage, incrementally loading a compiled version of a referenced model.
Artificial algebraic loop avoidance	**Supported, with limitations** Consider enabling **Configuration Parameters > Model Referencing > Minimize algebraic loop occurrences**.
Features	

Modeling Requirement or Feature	Guidelines for Model Referencing
Signal property inheritance	**Supported, with limitations** • Inherit sample time when the referenced model is sample-time independent. You cannot propagate a continuous sample time to a Model block that is sample-time independent. • Model block is context-independent, so it cannot inherit signal properties. Explicitly set input and output signal properties. • Use a bus object to define the signal data type of a bus signal that is passed into a referenced model. • Goto and From block lines cannot cross model referencing boundaries. • • See Index Base Limitations.
State initialization	**Supported, with limitations** • You can initialize states from the top model. • Use either the structure format or structure with time format to initialize the states of a top model and the models that it references. • To use the `SimState` (simulation state) feature with model referencing, simulate all Model blocks in Normal mode. • See “Import and Export State Information for Referenced Models” on page 45-120.

Modeling Requirement or Feature	Guidelines for Model Referencing
Tunability	**Supported, with limitations** • To have each instance of a referenced model use different values, use model arguments in the Model block. • To have each instance of a referenced model use the same values, use `Simulink.Parameter` objects. • To have each instance of a referenced model use the same values, use `Simulink.Parameter` objects. By default, all other parameters are inlined.
Buses	**Supported, with limitations** You must use bus objects for bus signals that cross referenced model boundaries (for example, global data stores, root inports, root outports).
S-functions	**Supported, with limitations** Model referencing generally supports inlined or noninlined S-functions. See "S-Function Limitations" on page 6-86.
Model configuration settings	**Supported, with limitations** • To apply the same model configuration settings to all models in a model hierarchy, use a referenced configuration set. • Configuration settings for the root model and referenced models must be consistent. However, not all configuration settings need to be the same across the model hierarchy.

Modeling Requirement or Feature	Guidelines for Model Referencing
Tools	**Supported, with limitations** • There are some limitations for using some Simulink tools, such as the Simulink Debugger, with model referencing. • For details, see "Simulink Tool Limitations" on page 6-82.
Code generation	**Well suited** • By default, model referencing generates code incrementally. • You can improve rebuild performance by selecting the appropriate setting for the **Configuration Parameters > Model Referencing > Rebuild** parameter. • Model referencing requires the use of bus objects. For information about the impact of bus objects for code generation, in the Embedded Coder documentation, see "Buses".

Modeling Complex Logic

To model complex logic in a Simulink model, consider using Stateflow software.

Stateflow extends Simulink with a design environment for developing state charts and flow graphs. Stateflow provides the language elements required to describe complex logic in a natural, readable, and understandable form. It is tightly integrated with MATLAB and Simulink products, providing an efficient environment for designing embedded systems that contain control, supervisory, and mode logic.

For more information on Stateflow software, see “Stateflow”.

Modeling Physical Systems

To model physical systems in the Simulink environment, consider using Simscape software.

Simscape extends Simulink with tools for modeling systems spanning mechanical, electrical, hydraulic, and other physical domains as physical networks. It provides fundamental building blocks from these domains to let you create models of custom components. The MATLAB based Simscape language enables text-based authoring of physical modeling components, domains, and libraries.

For more information on Simscape software, see “Simscape”.

Modeling Signal Processing Systems

To model signal processing systems in the Simulink environment, consider using DSP System Toolbox™ software.

DSP System Toolbox provides algorithms and tools for the design and simulation of signal processing systems. These capabilities are provided as MATLAB functions, MATLAB System objects, and Simulink blocks. The system toolbox includes design methods for specialized FIR and IIR filters, FFTs, multirate processing, and DSP techniques for processing streaming data and creating real-time prototypes. You can design adaptive and multirate filters, implement filters using computationally efficient architectures, and simulate floating-point digital filters. Tools for signal I/O from files and devices, signal generation, spectral analysis, and interactive visualization enable you to analyze system behavior and performance. For rapid prototyping and embedded system design, the system toolbox supports fixed-point arithmetic and C or HDL code generation.

For more information on DSP System Toolbox software, see “DSP System Toolbox”.

13

Managing Projects

Organize Large Modeling Projects

In this section...

What Are Simulink Projects?

You can use Simulink Projects to help you organize your work. Find all your required files; manage and share files, settings, and user-defined tasks; and interact with source control.

Projects can promote more efficient team work and individual productivity by helping you to:

- Find all the files that belong with your project.
- Share projects using built-in integration with the Subversion client, an external source control tool.
- View and label modified files for peer review workflows.
- Create standard ways to initialize and shut down a project.
- Create, store, and easily access common operations.

See the Web page `http://www.mathworks.com/products/simulink/simulink-projects/` for the latest information, downloads, and videos.

Get Started with Your Project

To get started with managing your files in a project:

1. Try an example project to see how the tools can help you organize your work. See "Try Simulink Project Tools with the Airframe Project" on page 13-4.
2. Create a new project. See "Create a New Simulink Project" on page 13-23.

3. Use the Dependency Analysis view to analyze your project and check required files. See "Analyze Project Dependencies" on page 13-32.

4. Explore views of your files. See "Manage Project Files" on page 13-44.

5. Create shortcuts to save and run frequent tasks. See "Automate Project Startup and Run Frequent Tasks" on page 13-52.

6. Run operations on batches of files. See "Run Batch Functions on Project Files" on page 13-58.

7. If you use a source control integration, you can use the Modified Files view to review changes, compare revisions, and commit modified files. If you want to use source control with your project, see "Use Source Control with Projects" on page 13-60.

Try Simulink Project Tools with the Airframe Project

In this section...

Explore the Airframe Project

Try an example Simulink project to see how the tools can help you organize your work. Projects can help you to manage:

- Your design (model and library files, `.m`, `.mat`, and other files, source code for S-functions, data)
- A set of actions to use with your project (run setup code, open models, simulate, build, run shutdown code).
- Working with files under source control (check out, compare revisions, tag or label, and check in)

The Airframe example shows how to:

1. Set up and browse some example project files, under local revision control.
2. Examine project shortcuts to run setup and shutdown tasks, and access frequently used files and tasks.

3. Analyze dependencies in the example project and locate required files that are not yet in the project.

4. Modify some project files, find and review modified files, compare to an ancestor version, and commit modified files to source control.

5. Explore views of project files only, modified files, and all files under the project root folder.

Follow the steps below to explore the example project.

Set Up the Project Files and Open the Simulink Project Tool

Run this command to create a working copy of the project files and open the project:

```
sldemo_slproject_airframe
```

The project example copies files to your temporary folder so that you can edit them and put them under local revision control.

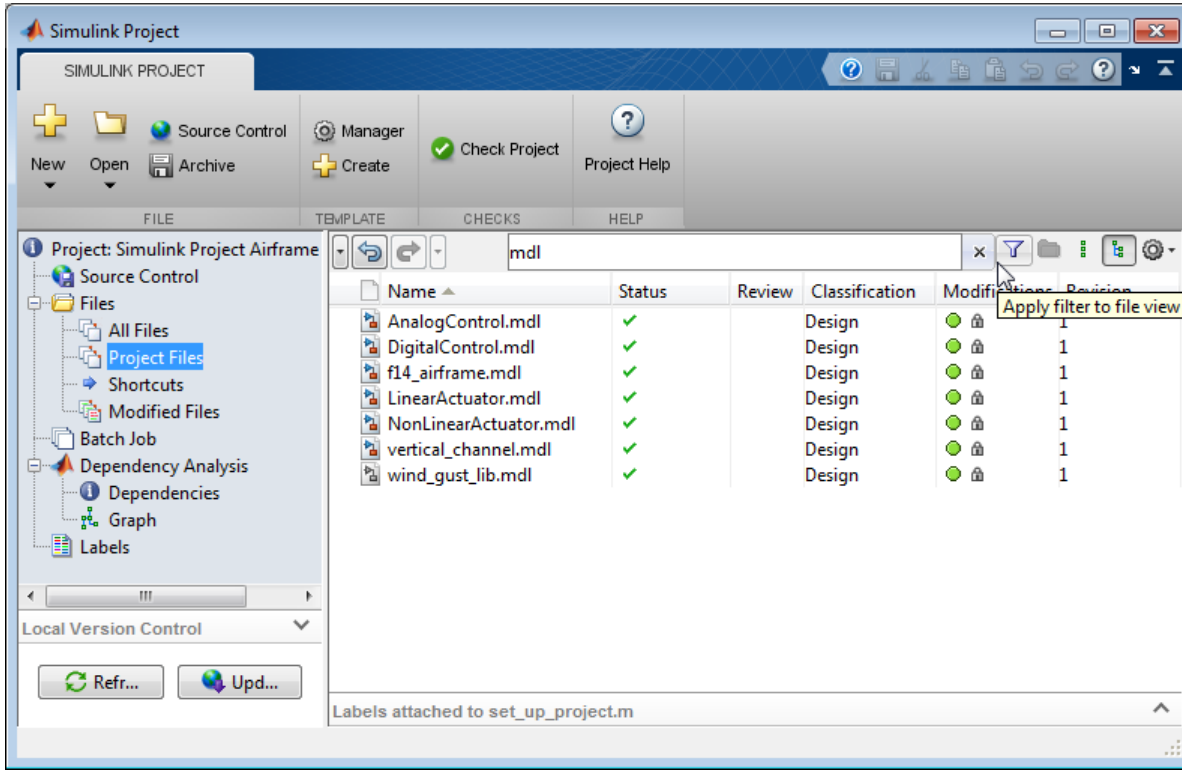
The Simulink Project Tool opens and loads the project. The project is configured to run some startup tasks, including changing the current working folder to the project root folder.

View, Search, and Sort Project Files

1. Click the Project Files view to manage the files within your project. Only the files that are in your project are shown.

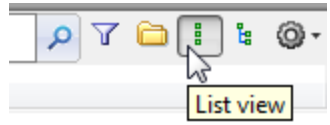
2. Click the All Files view to see all the files in your sandbox. This view shows all the files that are under the project root, not just the files that are in the project. This view is useful for adding files to the project that exist within your sandbox, but which are not yet part of the project.

3. To find particular files or file types, in any file view, type in the search box or click the Filter button next to the search box.



Click the **x** to clear the search.

4 To view files as a list instead of a tree, click the List view button at the top right.



5 To sort files and to customize the columns that you want to show, click the "cog" icon Actions button at the far right of the search box.

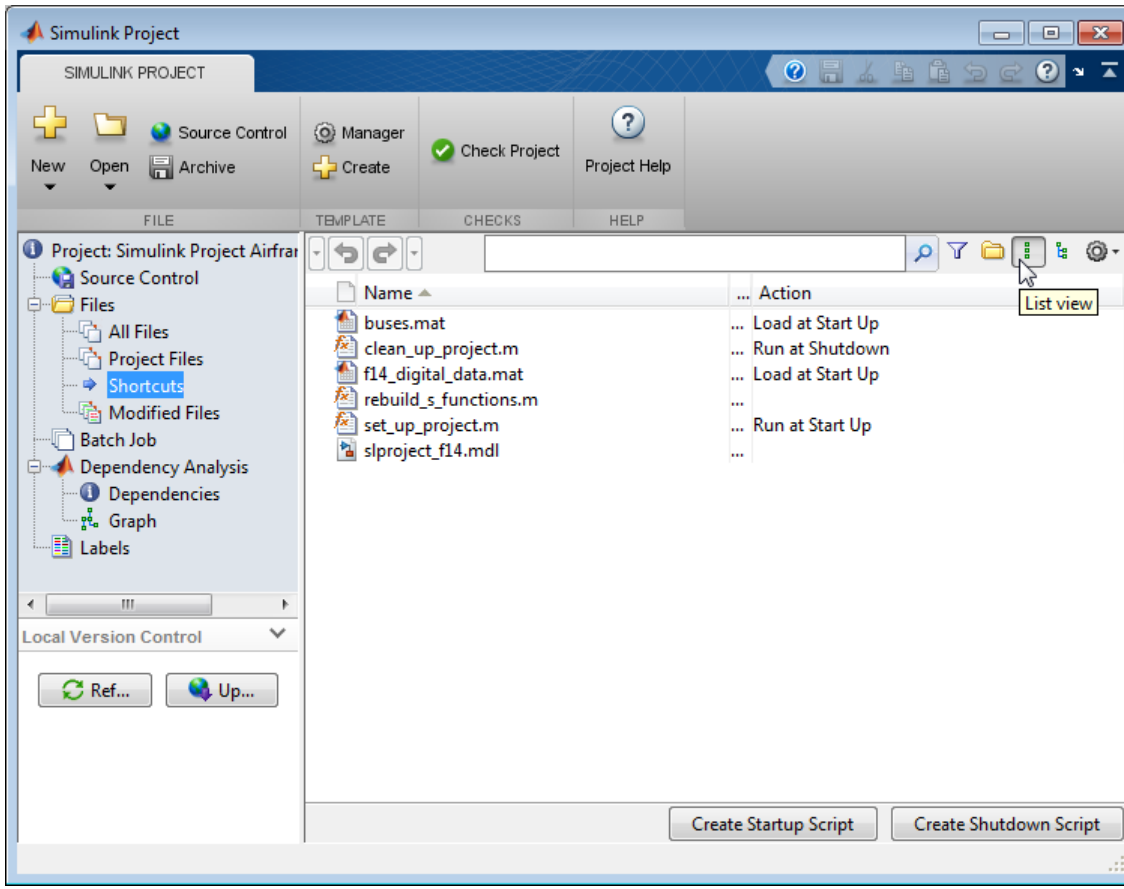
6 You can dock and undock the Simulink Project Tool into the MATLAB Desktop. If you want to maximize space for viewing your project files, undock the Simulink Project Tool.

Automate Project Startup and Shutdown Tasks

You can use *shortcuts* to automatically run startup or shutdown tasks, and to easily find files within a large project.

1 Click the Shortcuts node to view the startup tasks and other shortcuts.

2 If you see a tree view, click the List view button at the top right of the Simulink Project Tool to view the shortcuts as a list of files.



In this example, you can see that:

- Some files are set as **Run at Startup** shortcuts. Startup shortcut files automatically run (`.m` files), load (`.mat` files), and open (Simulink models) when you open the project. You can use these shortcuts to set up the environment for your project. The file `set_up_project.m` sets the MATLAB path, and defines where to create the `slprj` folder. Open the `set_up_project.m` file to view how it works. The following lines use the project API to get the current project:

  ```
  p = Simulink.ModelManagement.Project.CurrentProject;
  projectRoot = p.getRootDirectory;
  ```

- Another file is set as a **Run at Shutdown** shortcut. This type of file runs before the current project closes. In this example, the file `clean_up_project.m` resets the environment changes made by `set_up_project.m`.

To create new startup or shutdown shortcuts, select the Project Files view, right-click a file, and select **Create Shortcut**. Go to the Shortcuts view to set an existing shortcut to **Run at Startup** or **Run at Shutdown**.

Open and Run Frequently Used Files

You can use shortcuts to make scripts easier to find in a large project. In this example, the script that regenerates S-Functions is a shortcut so that a new user of the project can easily find it. You can also make the top-level model, or models, within a project easier to find. In this example, the top-level model, `slproject_f14.mdl`, is a shortcut.

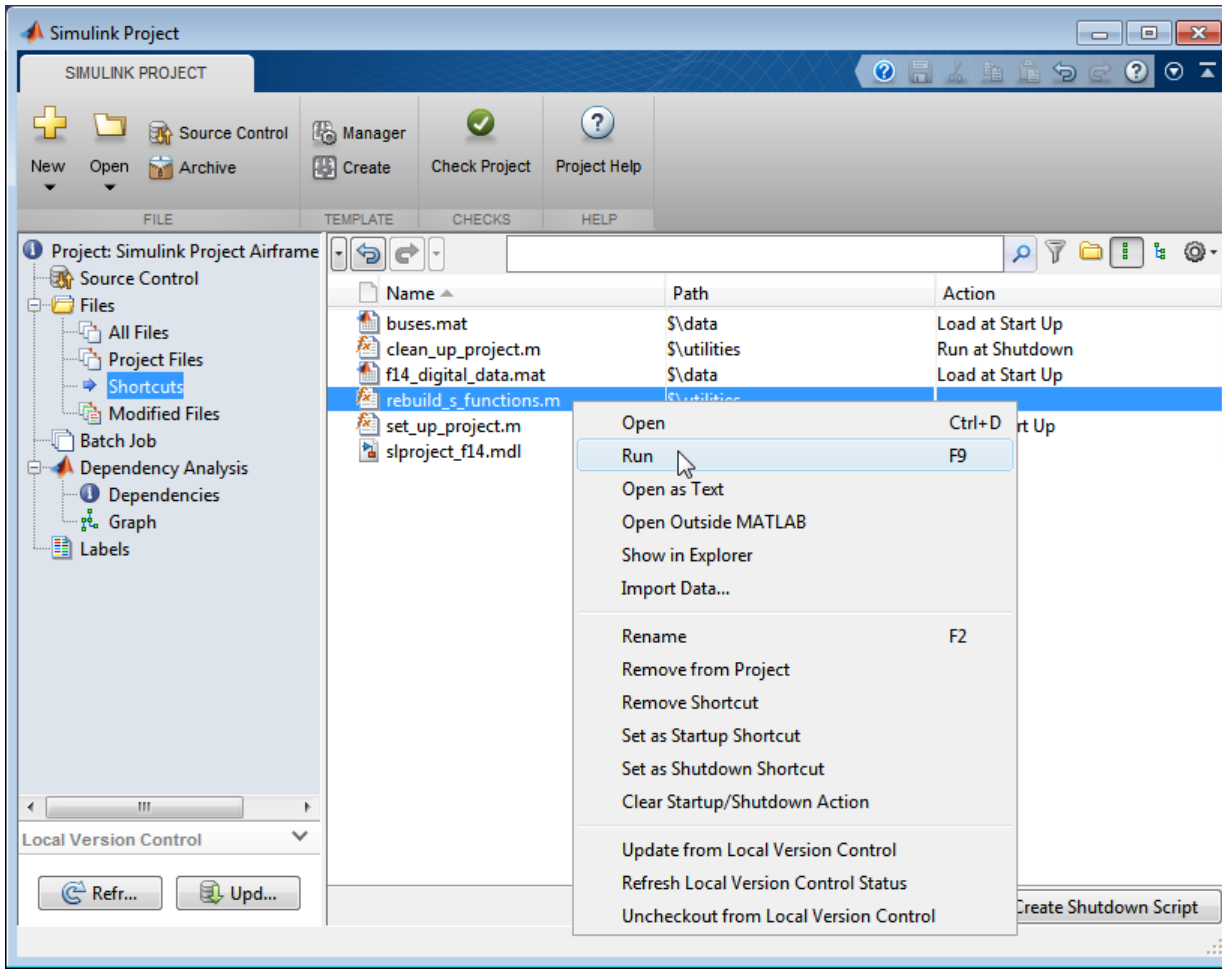
Use the example shortcuts:

1. Double-click the shortcut `slproject_f14.mdl` to open the root model for this project. This model will not run until you compile a required S-Function.

2. Right-click the shortcut `rebuild_s_functions.m` and select **Run** to generate the S-Function. Open this file to view how it works.

Note This shortcut builds a MEX-file. If you do not have a compiler set up, then first run the following command:

```
mex -setup
```



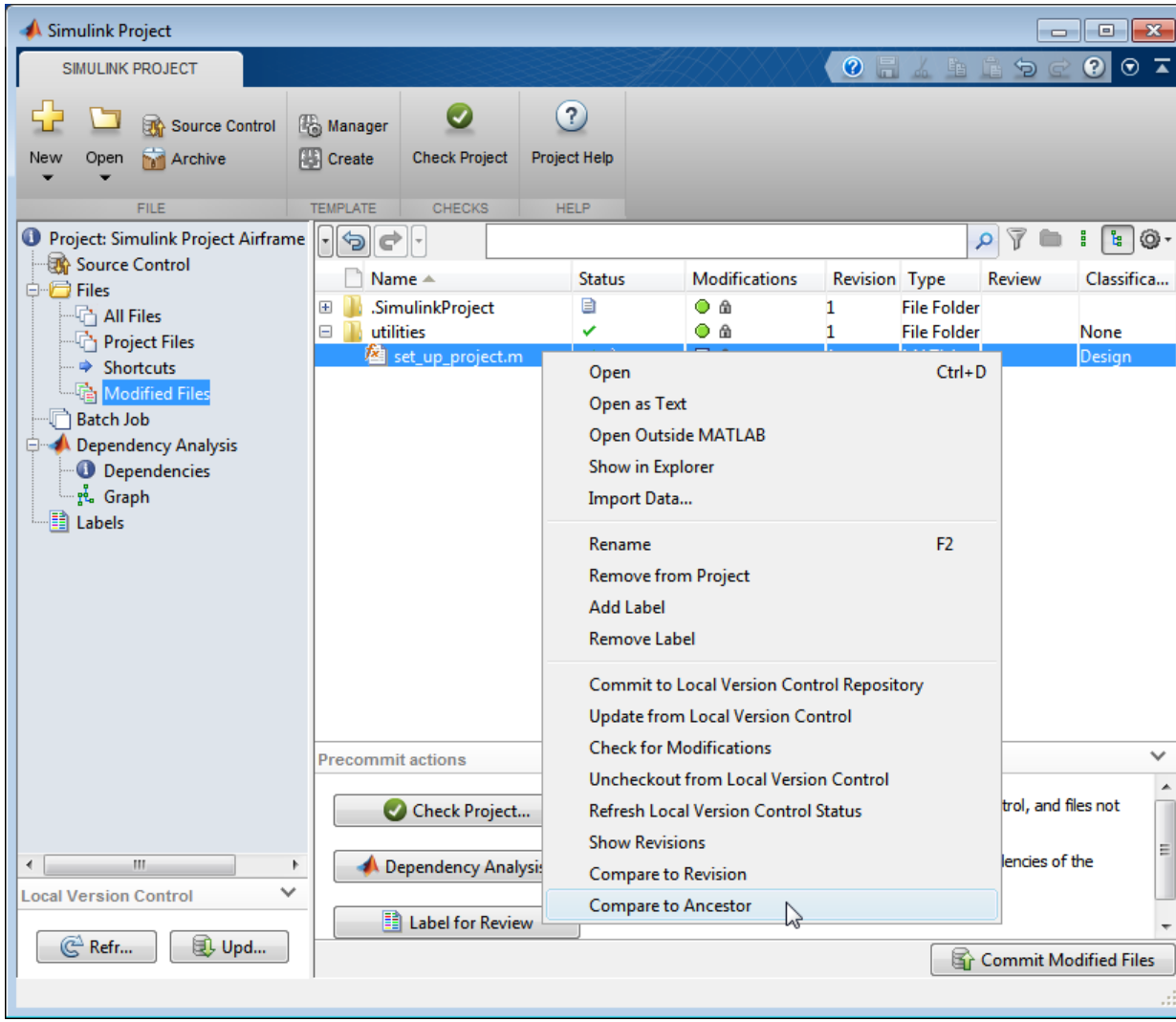
3 To create new shortcuts, select the Project Files view, right-click a file, and select **Create Shortcut**.

Review Changes in Modified Files

1 Open and make changes to one of the utility MATLAB files. You can double-click to open files for editing from the Simulink Project, or right-click and select **Open**. Make a change in the Editor and save the file.

2 In the Simulink Project Tool, click the Modified Files node to see the files that you have modified.

3 To review changes, right-click a file in the Modified Files view and select **Compare to Ancestor**.



The MATLAB Comparison Tool opens a report comparing the modified version of the file in your sandbox against its ancestor stored in the version control tool. Comparison type depends on the file you select. If you select a Simulink model, and you have Simulink Report Generator installed, this command runs a Simulink XML comparison.

Run Project Integrity Checks

In the Modified Files view, click **Check Project** to run the project integrity checks to look for missing files, files that should be added to source control or retrieved from source control, and other issues. The checks dialog can offer automatic fixes to problems found. Click the **Fix** button to view recommended actions and decide whether to make the changes.

Close the Project Integrity Checks dialog box.

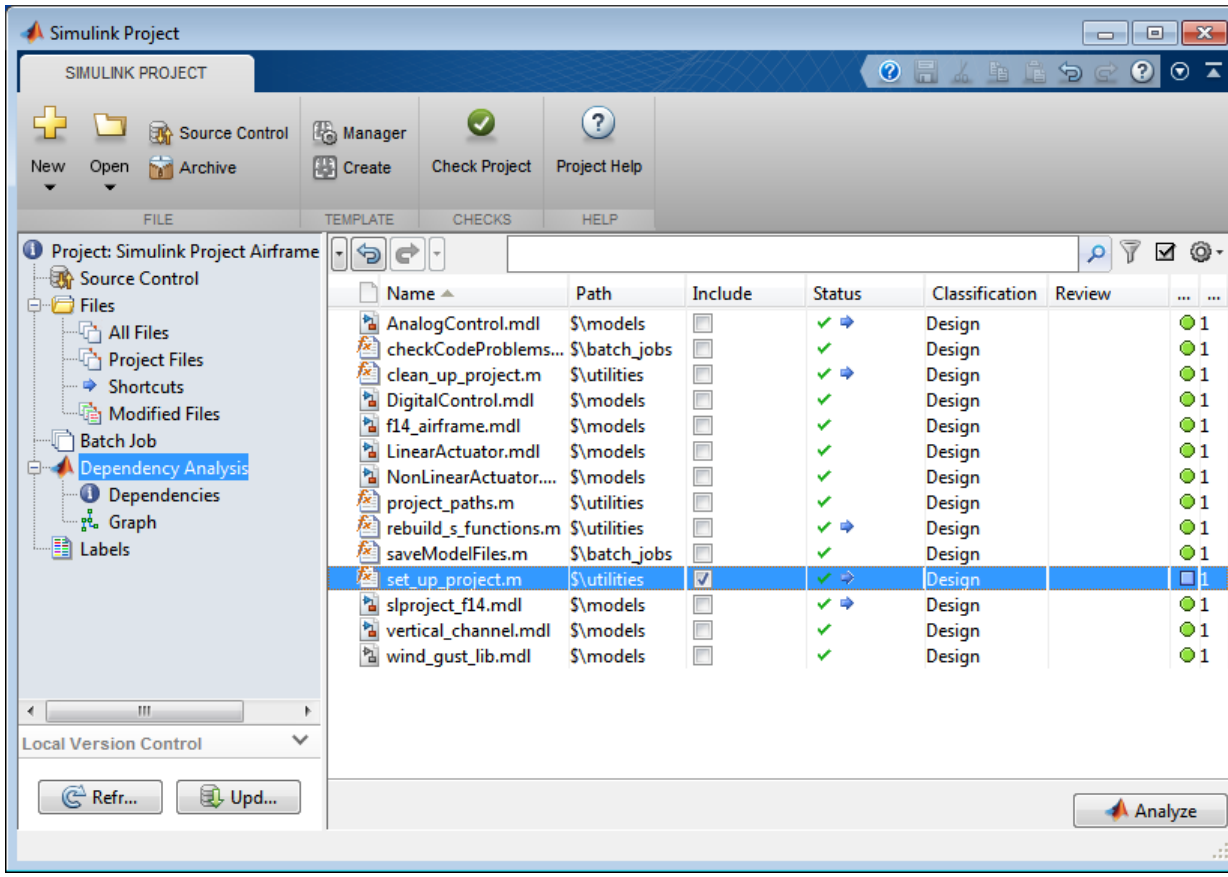
For an example using the project checks to fix issues, see the later steps in "Upgrade Model Files to SLX and Preserve Revision History" on page 13-15.

Run Dependency Analysis

Run a file dependency analysis on the modified files in your project, to check that you have all the required files added to the project.

1. In the Modified Files view, click the Dependency Analysis button to perform analysis on the modified files.

   The Simulink Project Tool opens the Dependency Analysis view with your modified files selected for analysis.

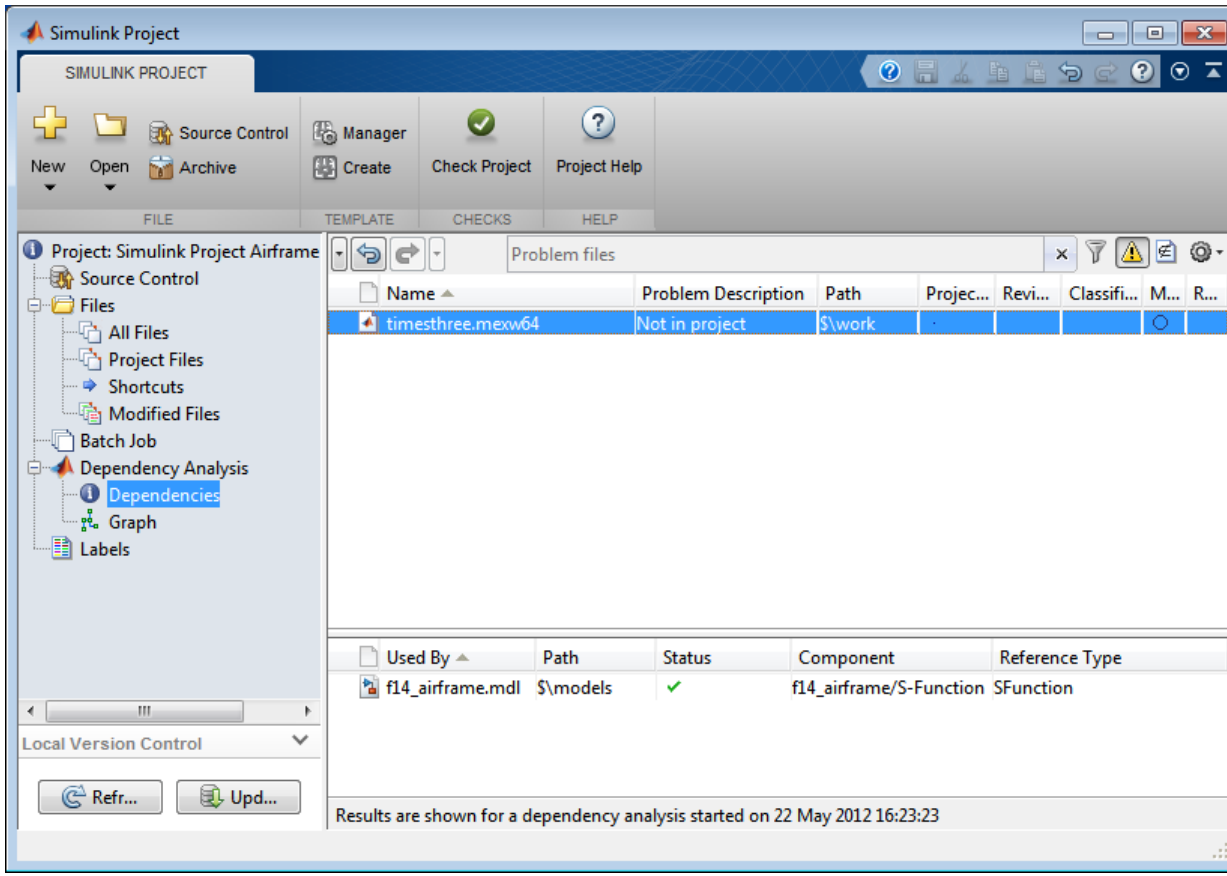


2 Add all files to the analysis. Click the list of files, and then press **Ctrl+A** to select all files. Right-click and select **Include**.

3 Click the **Analyze** button.

4 Review reported problem files. Observe that `Problem files` automatically appears in the search box for filtering your file views.

5 Observe that the S-Function binary file, `timesthree.mexw64`, is required by the project but is not currently part of it. Click the problem file to view where it is used in the table below, in the **Used By** column.



You might want to add binary files to your project or, as in this project, provide a utility script that regenerates them from the source code that is part of the project.

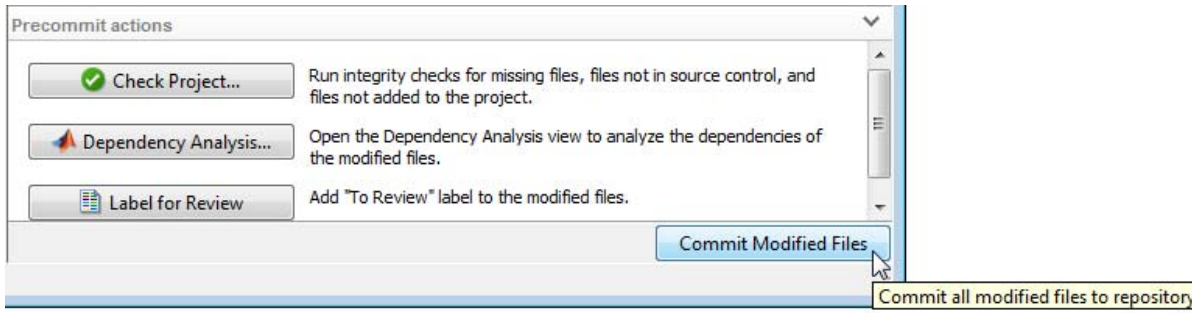
6 Right-click the problem file and select **Add External File**. You remove the file from the problem files list, and the next time you run dependency analysis, this file will not be marked as a problem file.

7 Click the **Graph** node to view the dependency graph of the project structure. Try some right-click options to customize the graph.

Commit Modified Files

1. Return to the Modified Files view, and click **Check Project** again to make sure your changes are ready to commit. When you are satisfied with the results of the checks, commit your modified files.

2. To commit your changes to source control, click the **Commit Modified Files** button.



   The Modified Files list includes a `.SimulinkProject` folder. The files stored in the `.SimulinkProject` folder are internal project definition files generated by your changes. These definition files allow you to add a label to a file without checking it out. You should never need to view the definition files directly unless you need to merge them, but they are shown so that you know about all the files being committed to the source control system. See “Project Definition Files” on page 13-91.

3. Enter a comment for your submission, and click **Submit**.

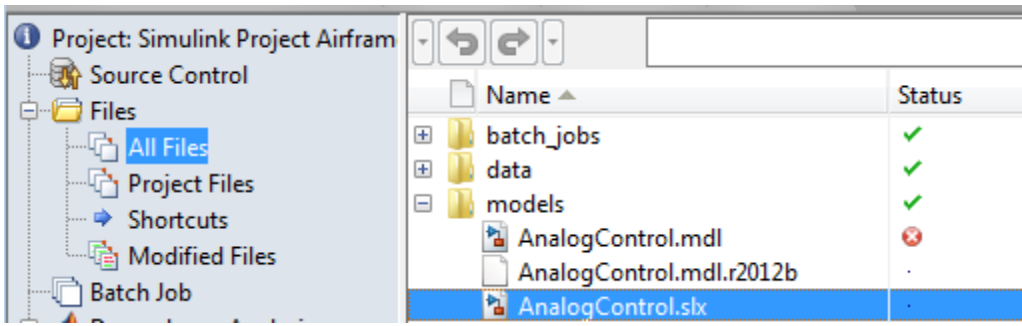
Upgrade Model Files to SLX and Preserve Revision History

Simulink Projects help you upgrade model files from MDL format to SLX format. You can use the Project Integrity checks to automatically add the new SLX file to your project, remove the MDL file from the project, and preserve the revision history of your MDL file with the new SLX file. You can then commit your changes to source control and maintain the continuity of your model file history.

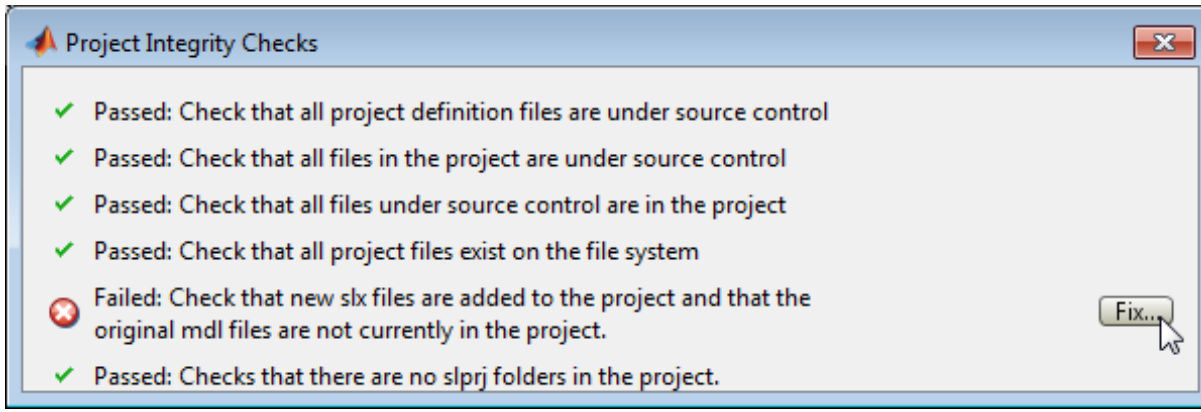
The following steps show how the project tools can help you migrate files to SLX, using the Airframe example project. If you have not done the previous example steps, you can run this command to open a new copy of the project:

```
sldemo_slproject_airframe
```

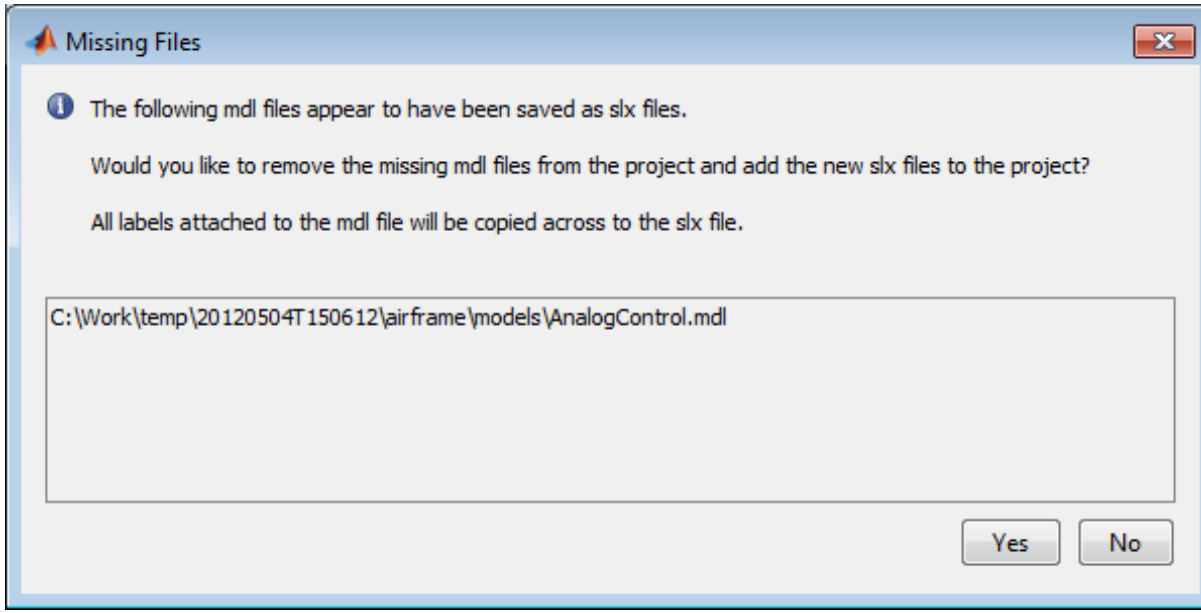
1. In the Project Files view, right-click the model file `AnalogControl.mdl`, and select **Open**.
2. Select **File > Save As**.
3. Ensure that **Save as type** is SLX, and click **Save**. SLX is the default unless you change your preferences.
4. Select the All Files view to see the results. Click the tree view button and expand the `models` folder. Simulink saves your model in SLX format, and creates a backup file by renaming the MDL file to `mymodel.mdl.`*`releasename`*. The project also reports the original name of the MDL file as missing.



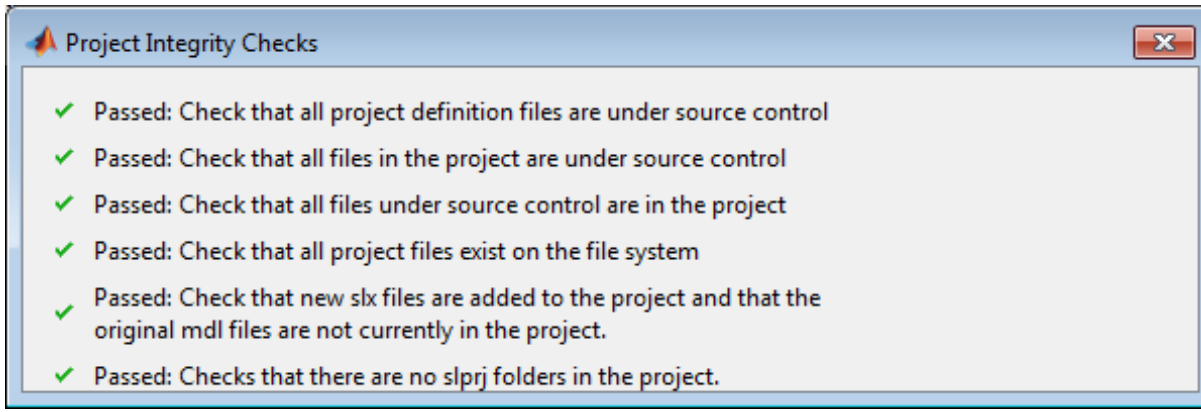
5. To resolve these issues, click **Check Project** on the **Simulink Project** tab to run the project integrity checks. The checks look for MDL files converted to SLX, and offer automatic fixes if that check fails.
6. Click the **Fix** button to view recommended actions and decide whether to make the changes.



When you click **Fix**, the Missing Files dialog box offers to remove the missing MDL file from the project and add the new SLX file to the project. Click **Yes** to perform the fix.

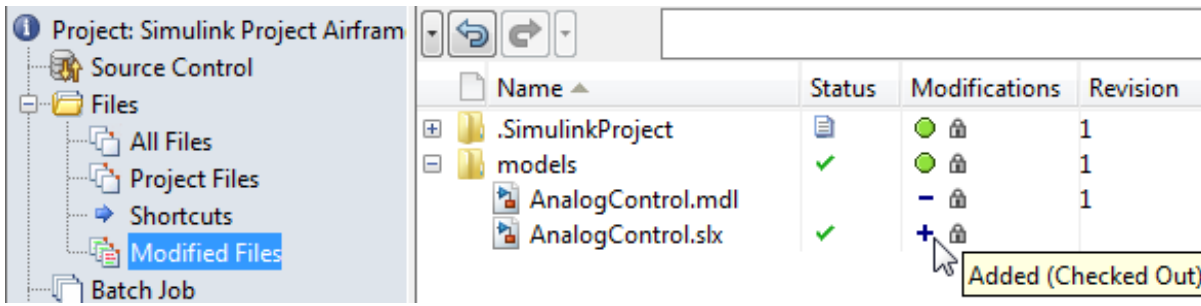


Project checks rerun after you click **Fix**, in case there are remaining issues.



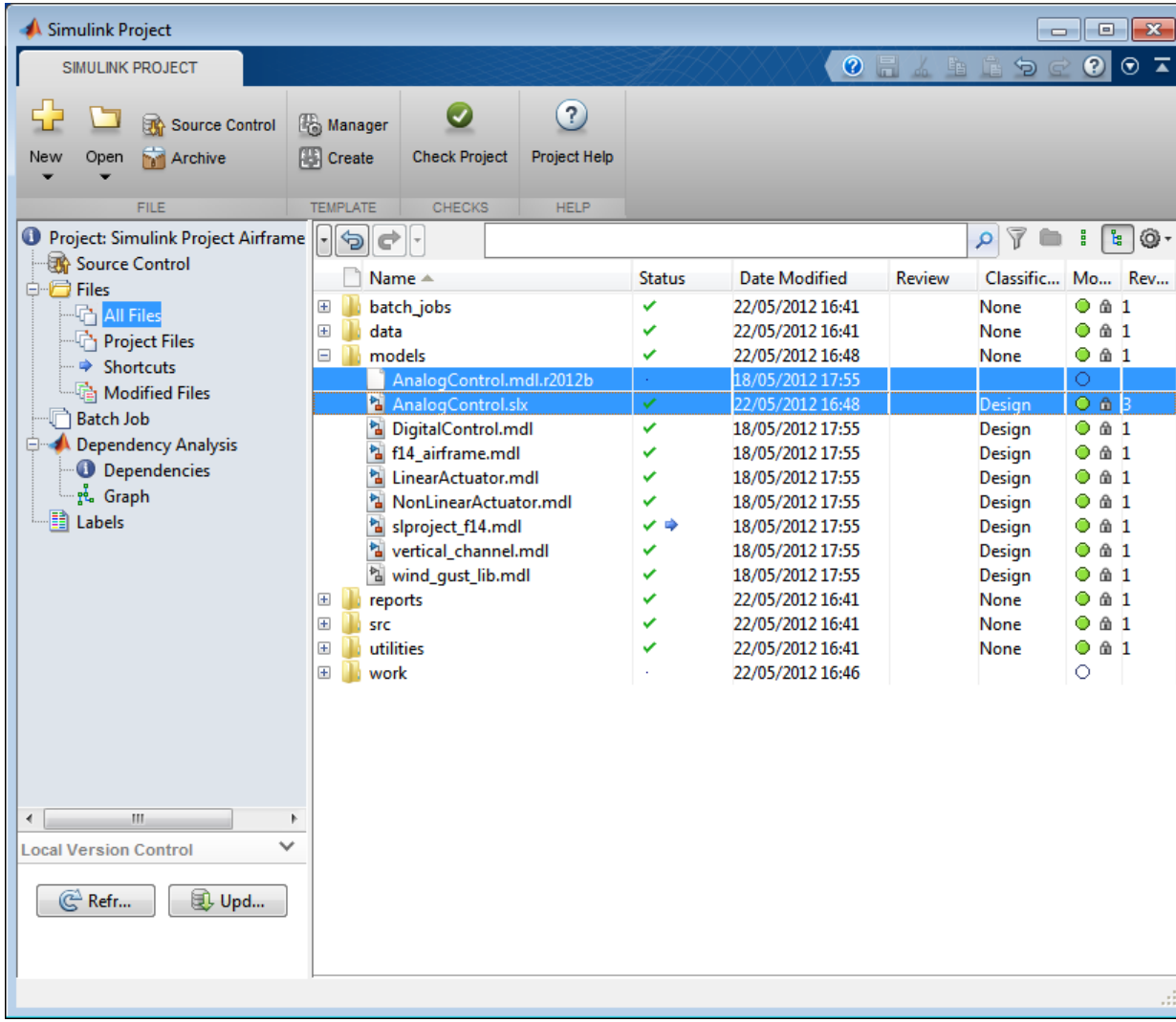
Close the Project Integrity Checks dialog.

7 Select the Modified Files view. Expand the `models` folder and check the Modifications column to see that the newly created SLX file has been added to the project, and the original MDL file is scheduled for removal.

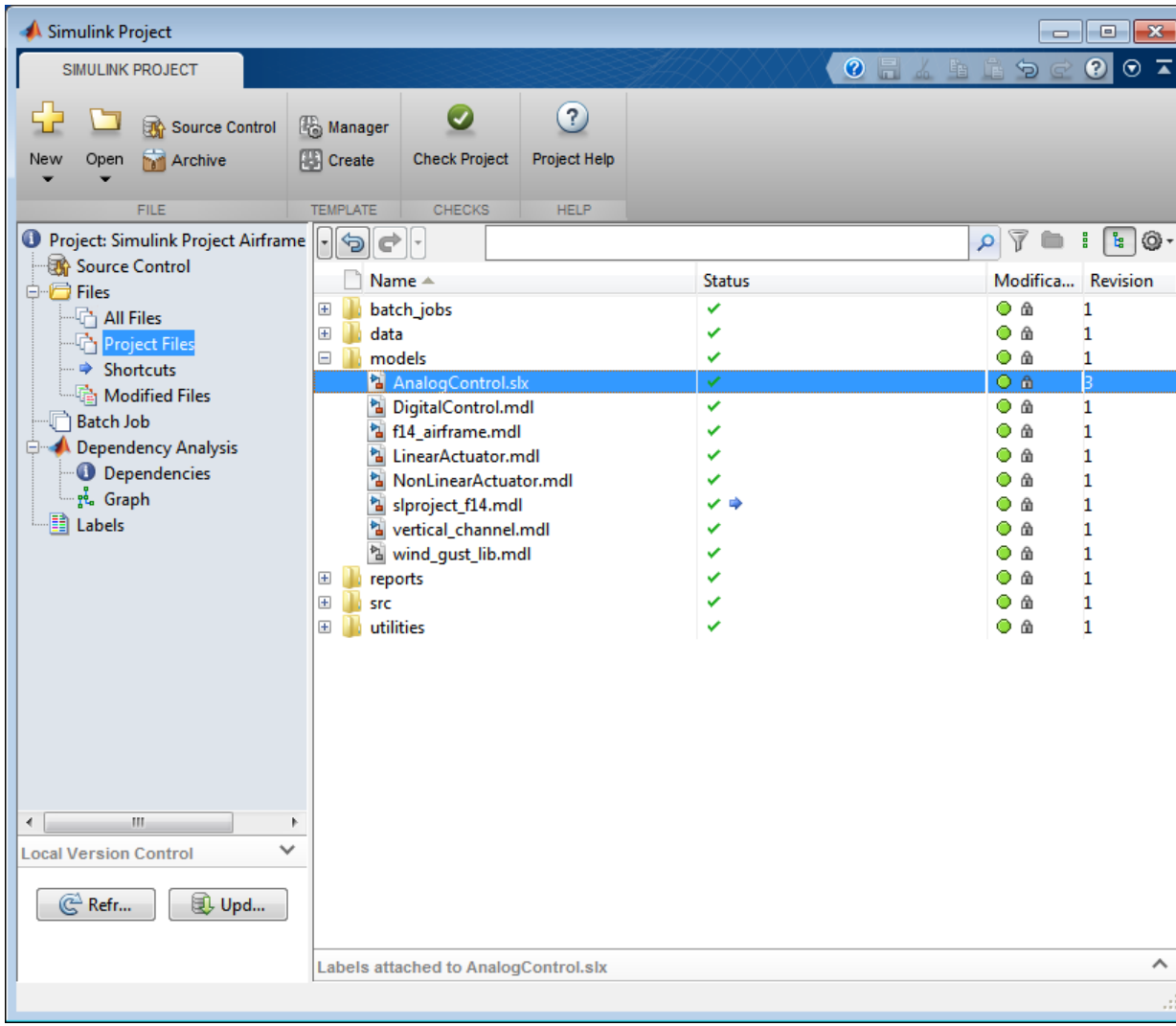


8 Click **Commit Modified Files**. Enter a comment for your submission in the dialog, for example, `Convert to SLX`, and click **Submit**.

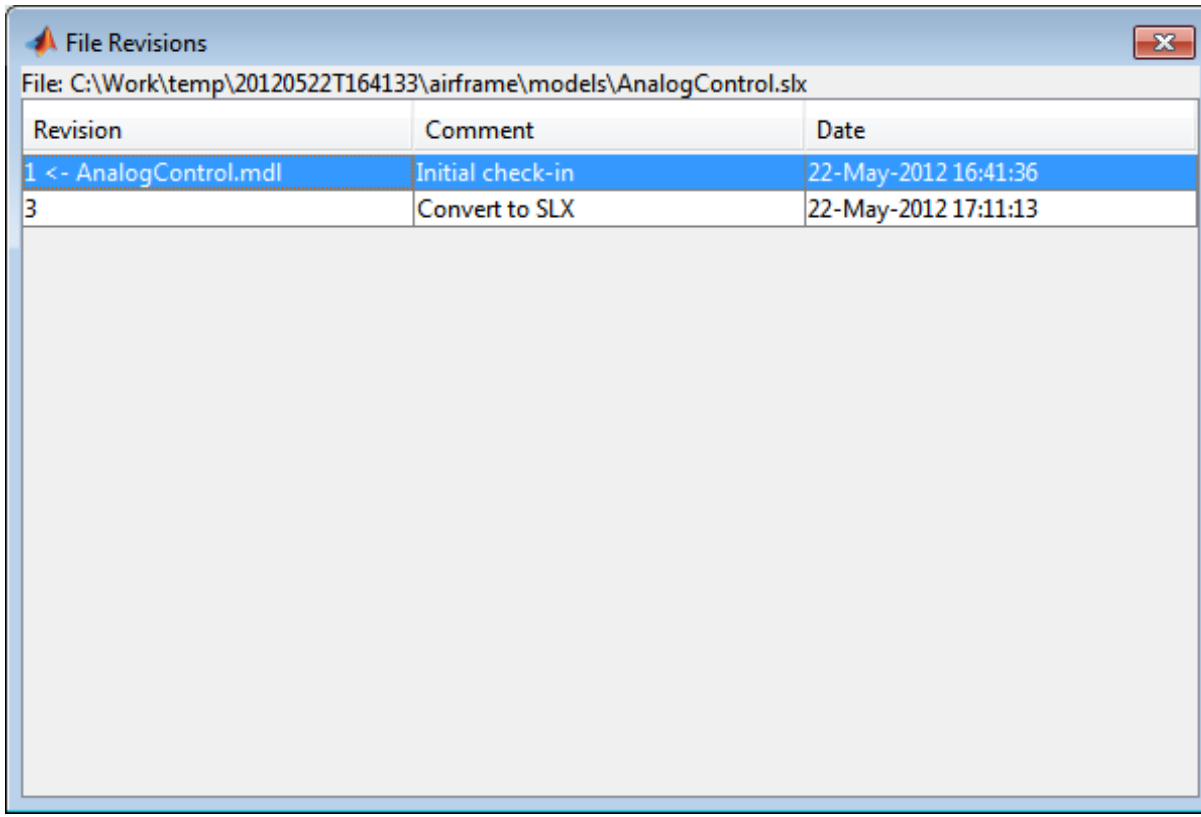
9 Select the All Files view to see that your backup file `AnalogControl.mdl.r2012b` is still present, along with the new SLX file.



10 Select the Project Files view to see that only the new SLX file is now included in the project, and the backup file is not included in the project.

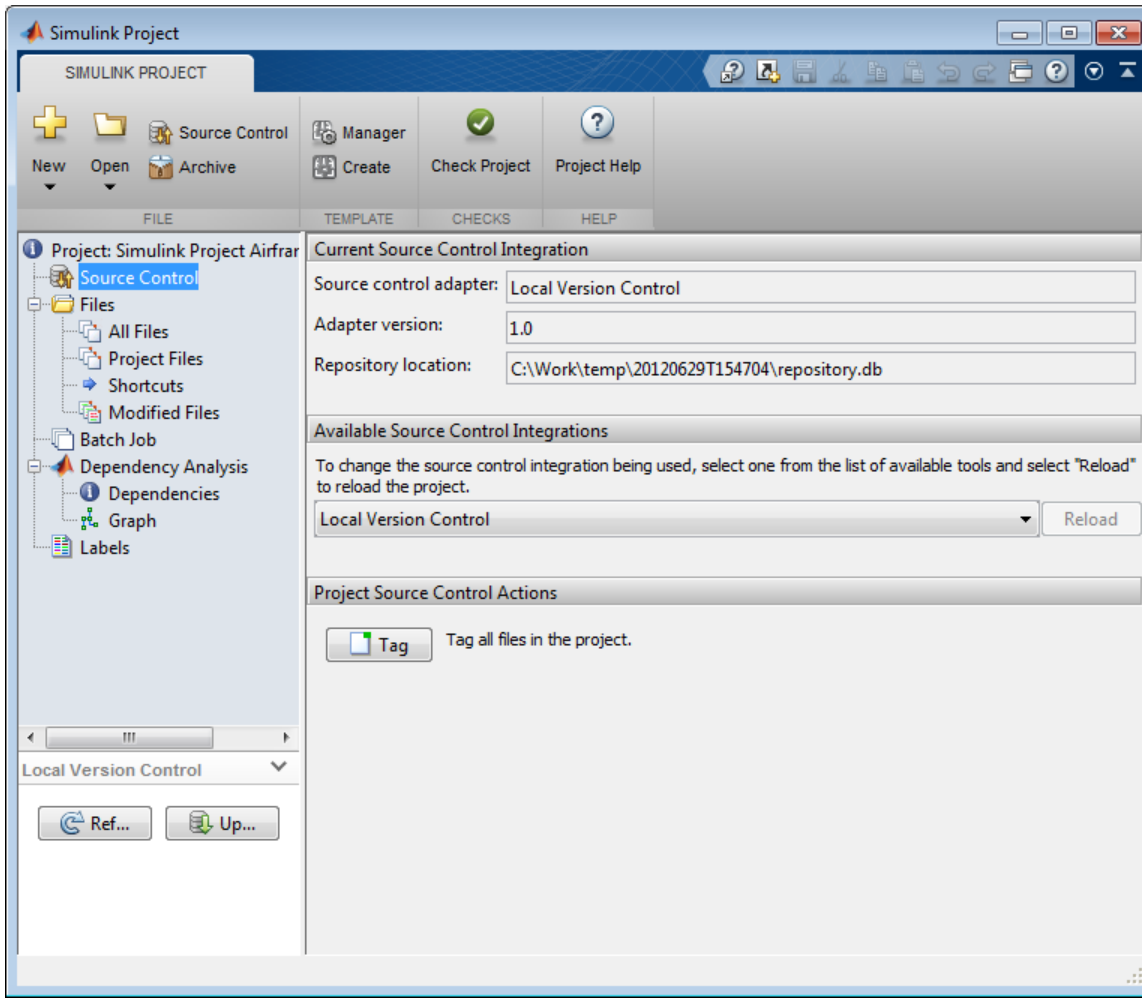


11 Right-click the model file `AnalogControl.slx` and select **Show Revisions**. The File Revisions dialog box opens, and you can verify that the previous revision is `AnalogControl.mdl`. The revision history of your previous model file is preserved with the new SLX file.



View Source Control and Project Information

1 Click the **Source Control** node to see information about the source control tool being used by the current project. The Airframe example project is under the control of the Local Version Control tool.



For source control information on individual files (e.g., modified, checked out), see the Modifications column in the Files views.

2 Click the root tree node **Project: Simulink Project Airframe** to see information about the currently open project, including a description and the location of the project root folder.

Create a New Simulink Project

In this section...

Create a New Project to Manage Existing Files

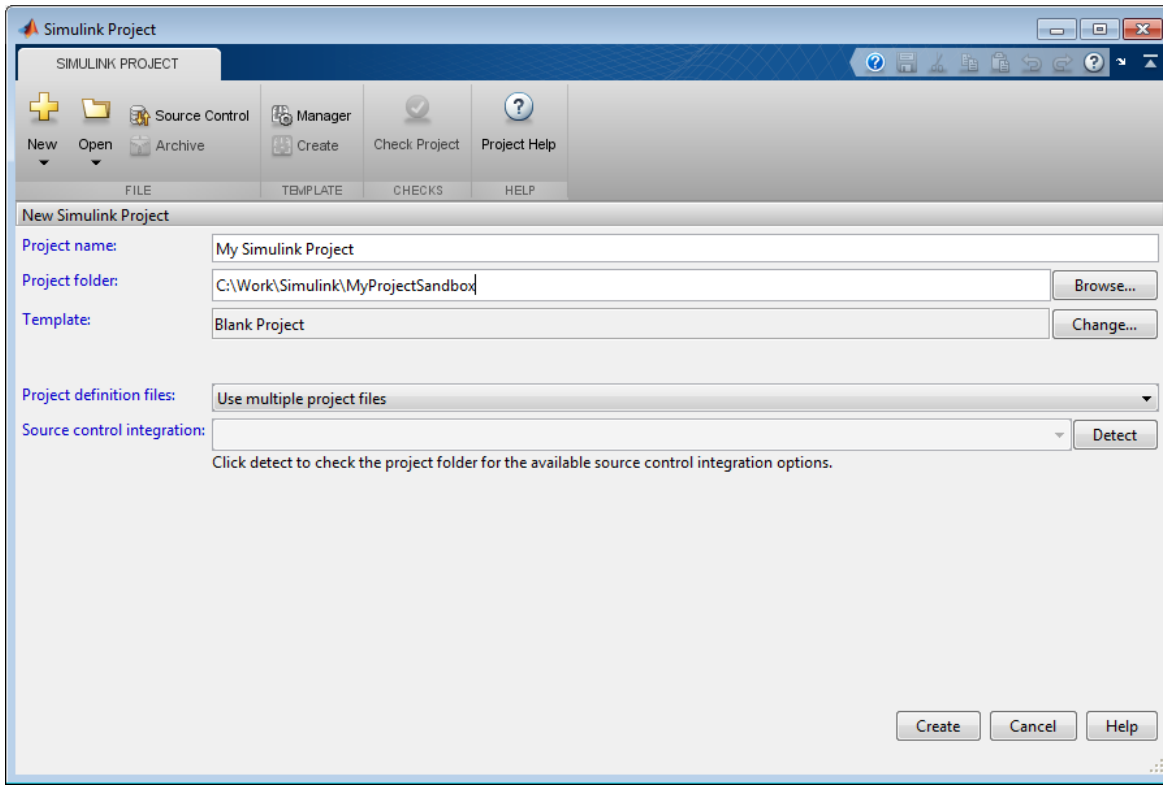
If you already have files that you want to organize into a project, with or without source control, use the following steps for a new project.

Note If you want to retrieve your project from a source control repository, see instead "Retrieve a Working Copy of a Project from Source Control" on page 13-76.

To create a new project to manage your files, either:

- From MATLAB, on the **Home** tab, in the **File** section, select **New > Simulink Project > Blank**.
- From the Model Editor, select **File > New > Simulink Project**.
- From the Simulink Project Tool, on the **Simulink Project** tab, in the **File** section, select **New**.

The Create Simulink Project dialog box appears.



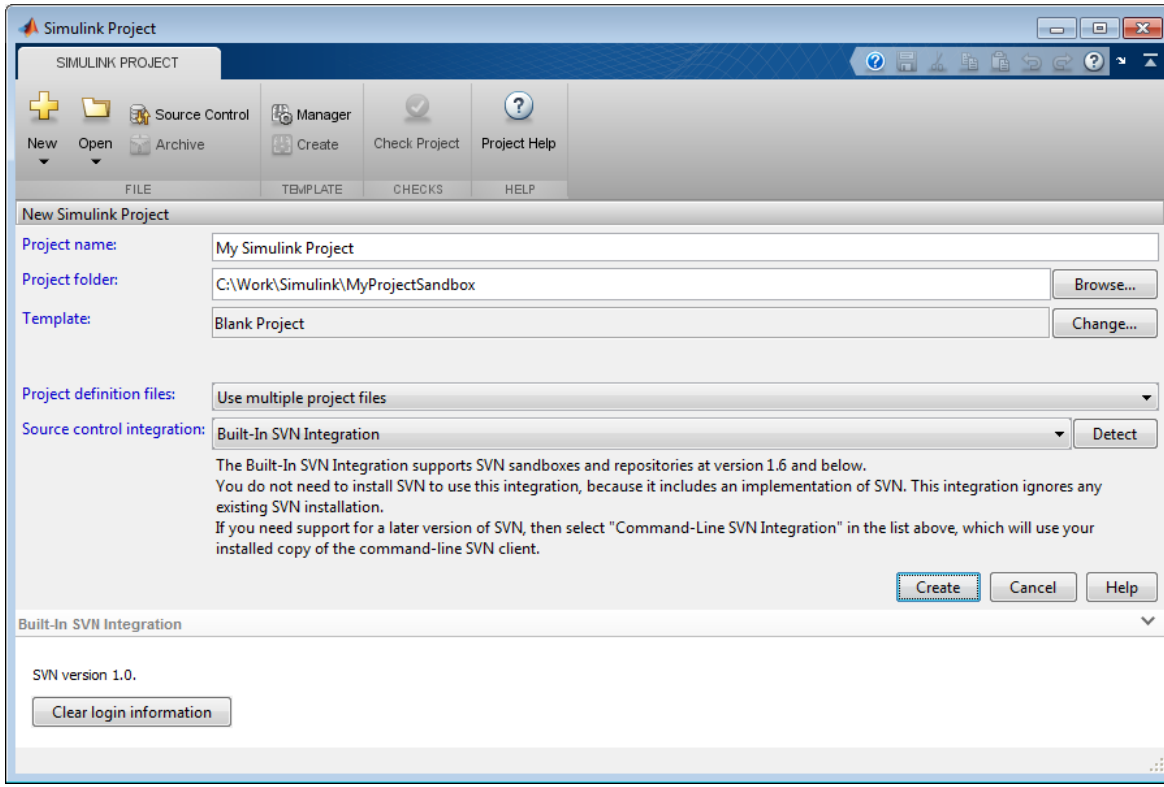
1 Enter the project name.

2 Select a project folder. The default is your current folder.

3 (Optional) Click **Detect** to check the project folder for source control integration options. If your selected folder is under source control that the project can recognize, the **Source control integration** field reports the detected source control. You can change available source control tools here.

Note You can put the project under source control later by using the Source Control node in the Project tree. See "Use Source Control with Projects" on page 13-60.

The next example shows the project has detected SVN in the selected project folder, and so the project selects Built-In SVN Integration.



4 (Optional) Change the template.

- Leave the default `Blank Project` template if you want to create a blank project without any preconfigured structure or utilities. Use the blank template if you are creating a project in a folder that already contains files.
- Change the template if you want to create a project with some preconfigured settings to guide you with setting up your project.
  - Try the `Project Environment` template if you are creating a project in a new folder and intend to add files later. Click **Change** next to **Template** to open a dialog box and select the `Project Environment`

template. You can view information about the template settings in the description field. The `Project Environment` template can create a new project with a preconfigured structure, and utilities to configure the path and environment with startup and shutdown shortcuts. For example, the path utilities help set up your search path to ensure dependency analysis can detect project files. You can modify any of these files, folders, and settings later.

- Similarly, try the `Code Generation Example` template to set up a project with settings for production code generation of a plant and controller. This template requires Simulink Coder and Embedded Coder. See "Example Templates" on page 13-101.
- If you create your own templates, you can select them in the Select a Template dialog box. See "Use Templates to Create Standard Project Settings" on page 13-97.

Note A warning tells you when your chosen template will overwrite any files in the chosen location.

---

5. (Optional) Change project definition files.

   `Use multiple project files` is better for avoiding merging issues on shared projects.

   `Use a single project file` is faster but is likely to cause merge issues when multiple users submit changes in the same project to a source control tool. See "Project Definition Files" on page 13-91.

6. Click **Create** to create your new project.

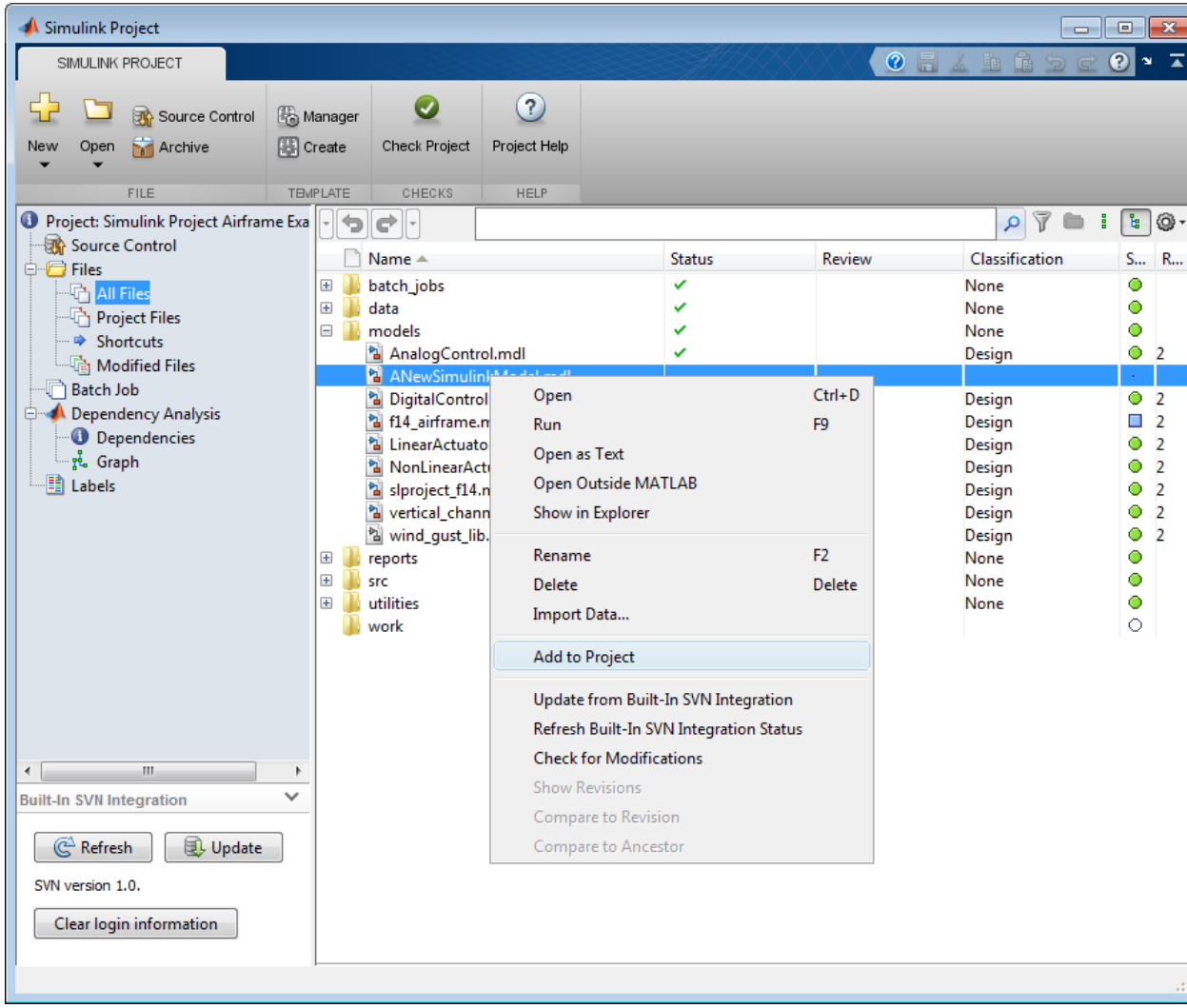
The Simulink Project Tool displays the empty Project Files list for your chosen project root. Your project does not yet contain any files. You need to select files to add. For next steps, see "Add Files to the Project" on page 13-26.

Add Files to the Project

The All Files node in the Project tree shows all files in your project folder. Files under your chosen project root are not included in your project until you

add them. You might not want to include all files in your project. You can add files to your project from the All Files view.

In the All Files view, select files or folders, right-click and select **Add to Project** or **Add to Project (including child files)**.



To add and remove project files at the command line, see the Simulink.ModelManagement.Project.CurrentProject reference page.

To help you set up your project with all required files, see “Choose Files and Run Dependency Analysis” on page 13-33.

To configure your project to automatically run startup and shutdown tasks, see “Automate Project Startup and Run Frequent Tasks” on page 13-52.

Create a New Project from an Archived Project

To create a new project from an archived project, either:

- From MATLAB, on the **Home** tab, in the **File** section, select **New > Simulink Project > From Archive**.
- From the Simulink Project Tool, on the **Simulink Project** tab, select **New > New Project from Zip Archive**

Open Recent Projects

Note You can have one project open. If you open another project, any currently open project closes. Having multiple projects open could cause conflicts.

To open recent projects:

- From MATLAB, on the **Home** tab, in the **File** section, select **Open** and then select your project under the **Recent Simulink Projects** list.

  From the Current Folder browser, you can open projects by double-clicking your `.prj` file.

- From the Simulink Project Tool, on the **Simulink Project** tab, select a recent project to open from the **Open > Recent** list.

  Alternatively, to browse for a project from the Simulink Project Tool:

  - For projects created or saved in Release 2012b or later, select **Open > Open Project File**. Browse and select your project `.prj` file, and click **OK** to load the project.
  - For projects last saved in Release 2012a or earlier, select **Open > Open Project by Folder**. Navigate to the folder containing the `.SimulinkProject` folder, and click **OK** to load the project. Subsequently, you can use **Open Project File**.

To open the Simulink Project Tool:

- From the MATLAB command line, enter:

  ```
  simulinkproject
  ```

- From the Library Browser or Simulink Editor, select **View > Simulink Project**.

Tip Create a MATLAB shortcut for opening or giving focus to the Simulink Project Tool by dragging this command to the toolstrip from the Command History or Command Window:

```
simulinkproject
```

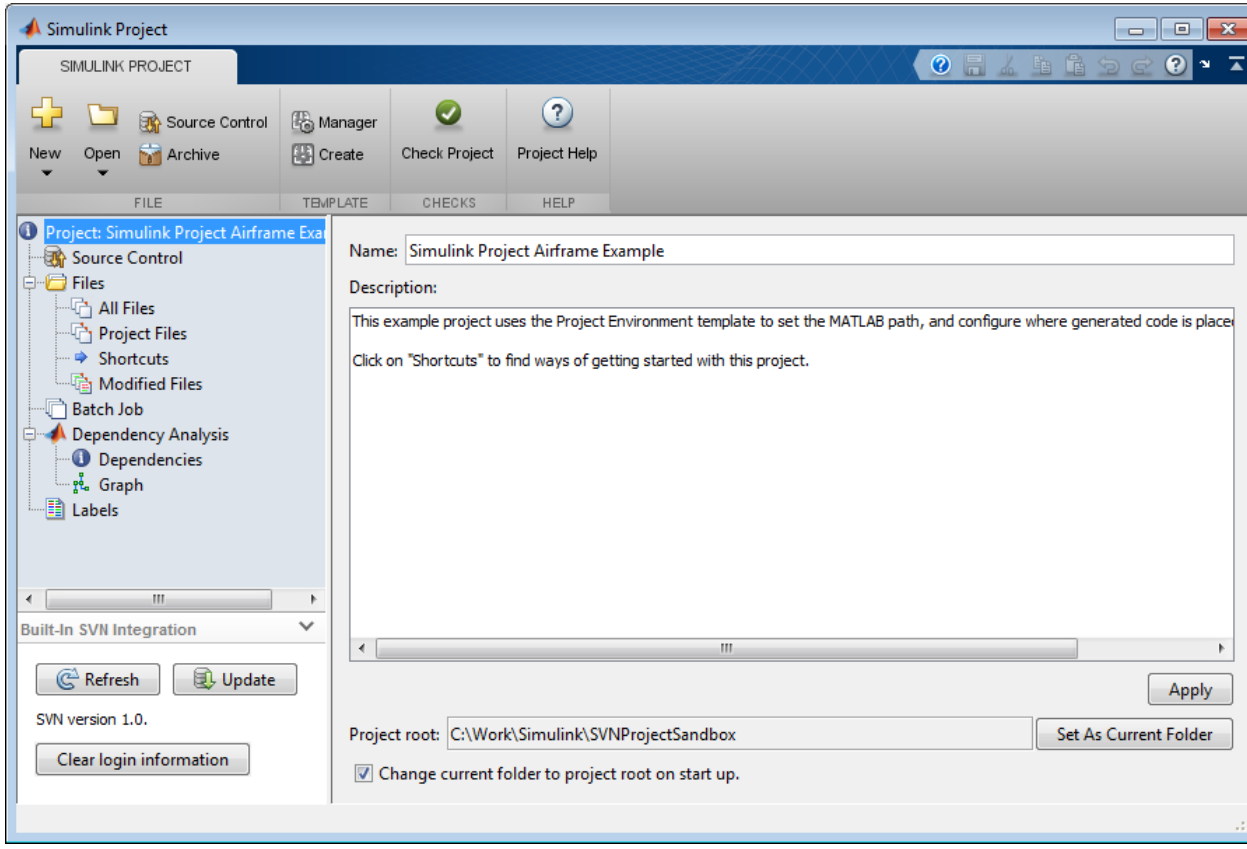
Change the Project Name, Root, Description, and Startup Folder

Use the Project tree node if you want to edit the project name or add a description. If you edit the name or description, click **Apply** to save your changes.

You can view the project root folder, and click **Set as Current Folder** to change the current working folder to your project root. You can change your project root by moving your entire project on your file system, and reopening your project in its new location. All project file paths are stored as relative paths.

The check box option **Change current folder to project root on start up** is selected by default. Clear the check box if you do not want to change to the project root folder on startup.

You can also configure startup shortcut scripts that set the current folder and perform other setup tasks. If you configure startup shortcuts to set the current folder, your shortcut setting takes precedence over the check box at the Project node. To set up shortcuts, see "Automate Project Startup and Run Frequent Tasks" on page 13-52.


Simulink Project
SIMULINK PROJECT
New
Open
Source Control
Archive
Manager
Create
Check Project
Project Help
FILE
TEMPLATE
CHECKS
HELP
Project: Simulink Project Airframe Exa
Source Control
Files
All Files
Project Files
Shortcuts
Modified Files
Batch Job
Dependency Analysis
Dependencies
Graph
Labels
Built-In SVN Integration
Refresh
Update
SVN version 1.0.
Clear login information
Name: Simulink Project Airframe Example
Description:
This example project uses the Project Environment template to set the MATLAB path, and configure where generated code is place
Click on "Shortcuts" to find ways of getting started with this project.
Apply
Project root: C:\Work\Simulink\SVNProjectSandbox
Set As Current Folder
Change current folder to project root on start up.

Analyze Project Dependencies

In this section...

What Is Dependency Analysis?

You can analyze project structure and discover files required by your project with the Dependency Analysis view.

- You can use dependency analysis to help you set up your project with all required files. For example, you can add a top-level model to your project, analyze the model dependencies, and then add all dependent files to your project.
- You can run dependency analysis at any point in your workflow when you want to check that all required files are in the project. For example, you can check dependencies again before submitting a version of your project to source control.
- You can use the Graph view of your dependency analysis to analyze the structure of your project visually. From the graph, you can examine your project structure and perform file operations such as adding labels and opening files.

Note You can analyze only files within your project. If your project is new, you must add initial files to the project before running dependency analysis. Click the All Files node under Management in the Project tree. Select the files you want to analyze, right-click, and select **Add to Project**.

Choose Files and Run Dependency Analysis

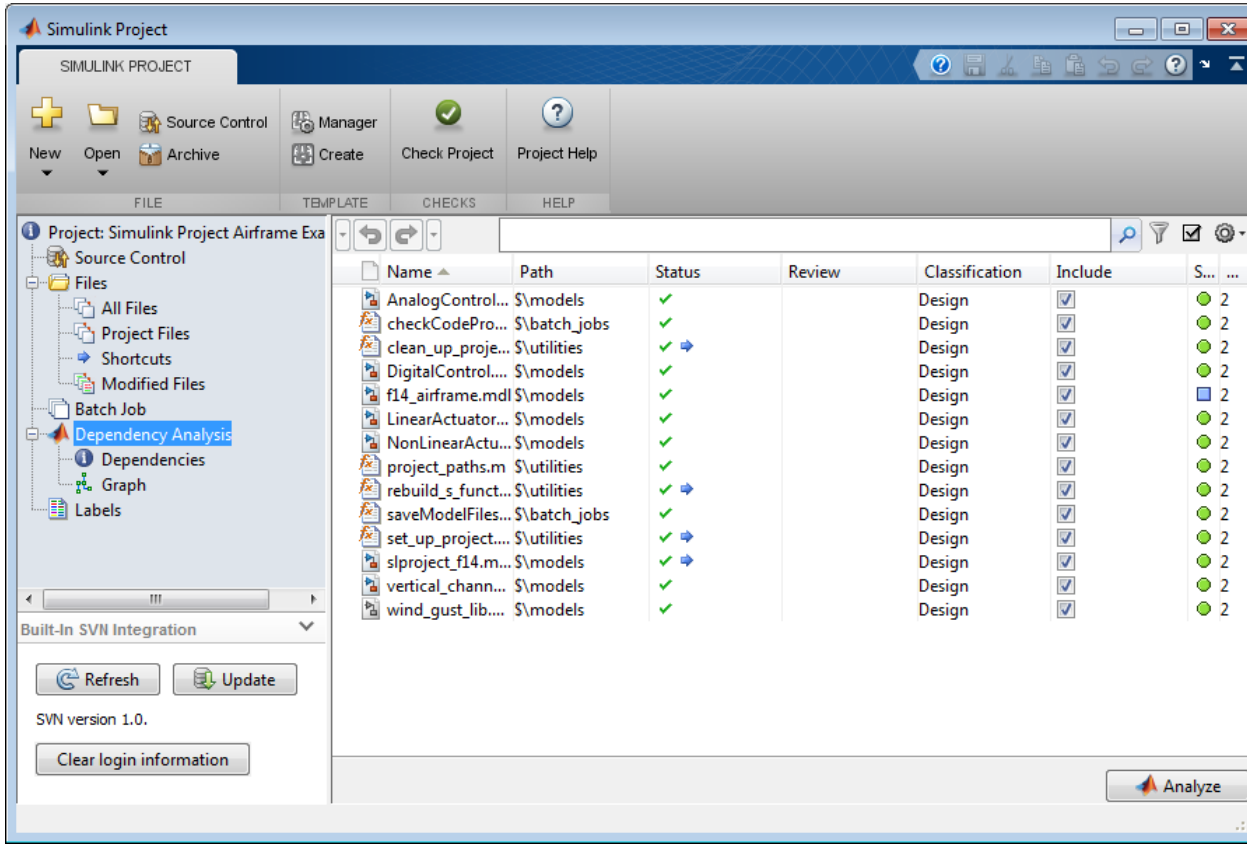
1. In the Project tree, click Dependency Analysis.

   Files in your project are shown in the list.

2. To specify which files to analyze, select the check boxes in the **Include** column.

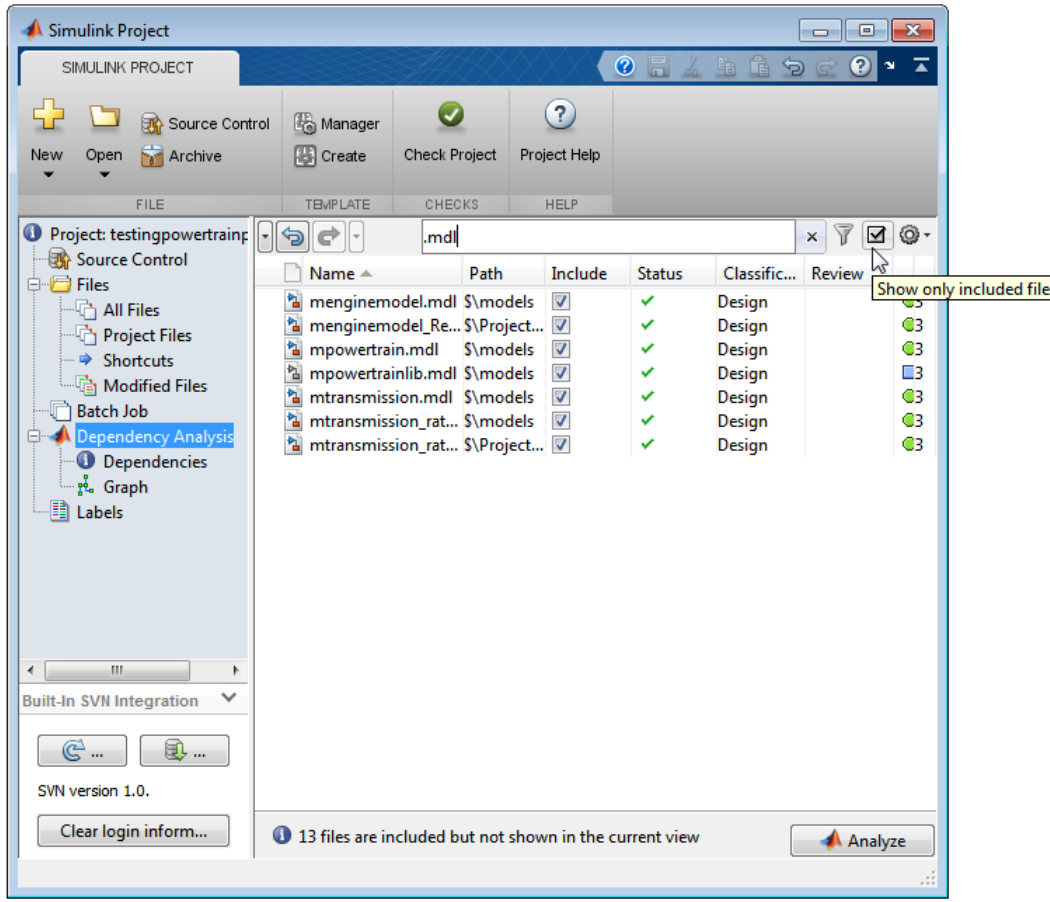
   If you click the Dependency Analysis button in the Modified Files view, you open the Dependency Analysis view with your modified files preselected.

   To include or exclude all files, press **Ctrl+A** to select all files, then right-click and select **Include** or **Exclude**.



3 If desired, use the search box or Filter button to alter the list of files displayed.

You see a message under the list if your filtering hides some of the files selected for dependency analysis. To show all files selected for analysis, click the button to the right of the search box to show only included files.



4 Click **Analyze** to discover required files.

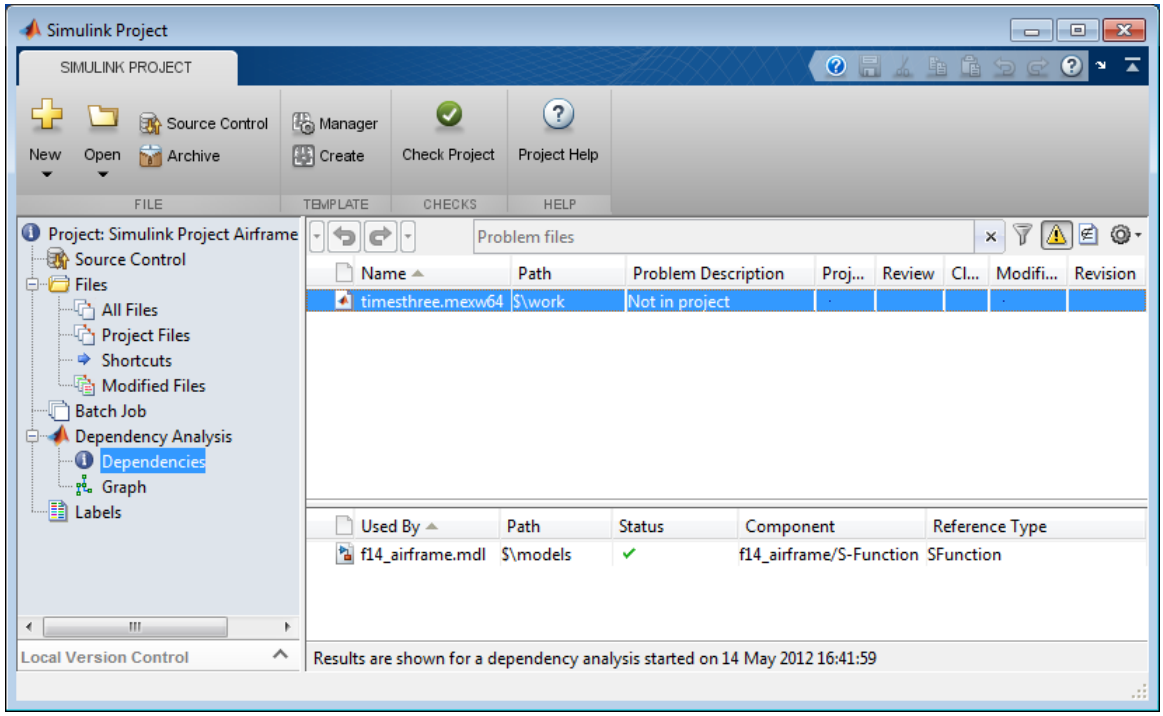
The view changes to the Dependencies node to show your results in list form.

Check Dependencies Results and Resolve Problems

If dependency analysis finds any problems, the Simulink Project Tool displays the problem files. The search box shows that the list is filtered to show only `Problem files`.

The list reports dependent files that you should review because they are required by the project but not currently in the project or missing.

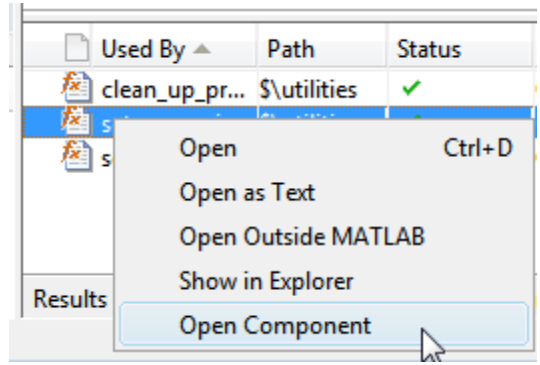
1 Click each file in the Problem list to see where they are being used by other files in the project, under **Used By** in the lower pane.



Note If you clear the search box, you can return to viewing only problem files or external files by clicking the toolbar buttons to the right of the search box.

2. In the dependencies table, check the Problem Description and Project Status of dependent files, and if desired right-click to add any required files that are not in the project. You can select multiple files. For example, press **Ctrl+A** to select all files in the dependent files list, right-click, and select **Add to Project**.

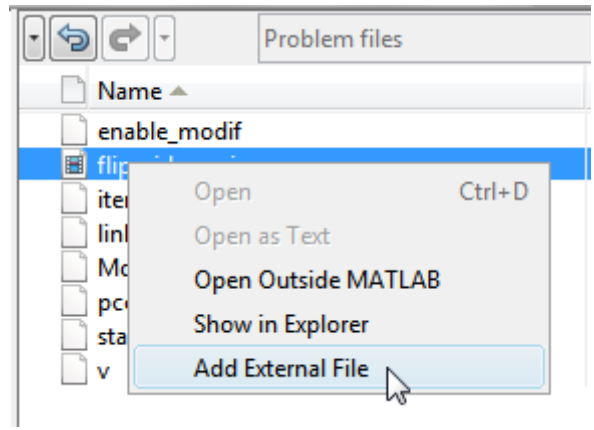
3. To open the referencing component for editing, right-click a file in the **Used By** table and select **Open Component**. The referencing file opens. MATLAB files open in the MATLAB Editor, and Simulink models open in the Model Editor with the block highlighted.



4. If you want to remove files from the Problem list but not add them to the project, you can right-click to select **Add External File**. The file disappears from the Problem list. Next time you run dependency analysis, this file will not appear in the Problem list. To view all external files, click the Show only external files button to the right of the search box.

   You might not want to add all required files to the project. For example, you might want to exclude derived S-Function binary files that the source code in your project can generate. See “Work with Derived Files in Projects” on page 13-96.

   Check the **Status** message and the **Path** for dependent files, where $ indicates the project root. Check if required files are outside your project root—you cannot add such files to your project. This dependency might not indicate a problem if the file is on your path and is a utility or other resource that is not part of your project. Use dependency analysis to ensure that you understand your design’s dependencies.



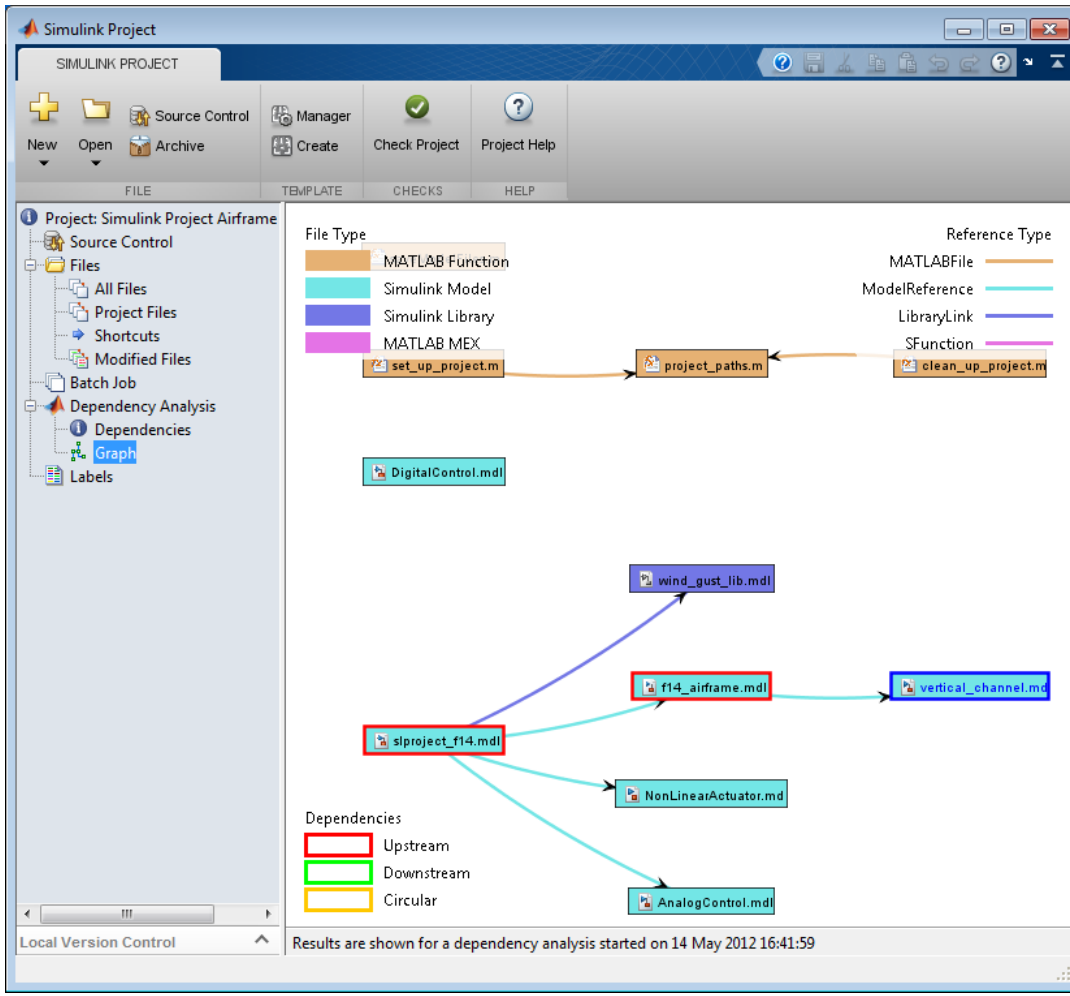
5 If you decide the file needs to be part of your project, copy or move it within the project root, add it the project and the path, and remember to remove the original from the path.

6 Clear the search box to view all identified dependencies. Click files to view where they are used. Also try the Graph view to investigate your project dependencies graphically. See “Investigate Dependencies Graph” on page 13-38.

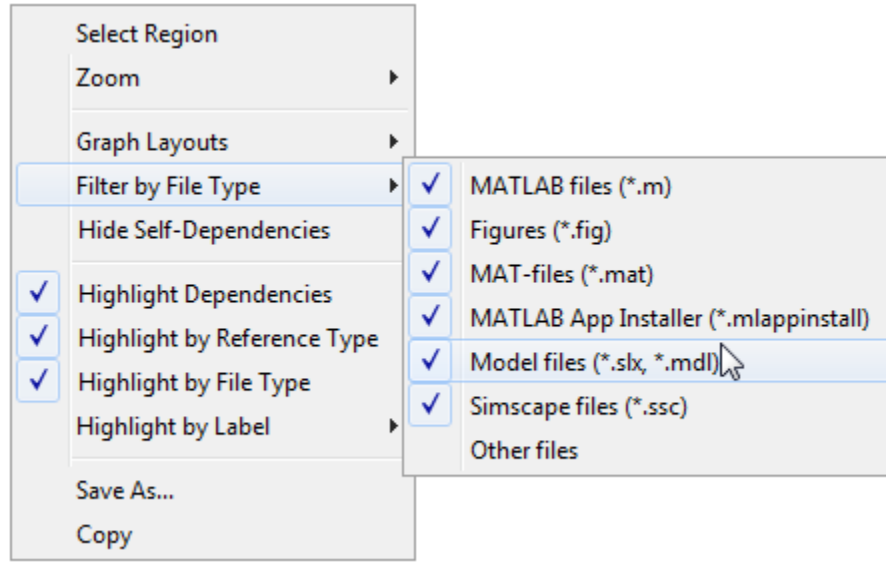
Investigate Dependencies Graph

To investigate dependencies visually, click Graph in the tree under Dependency Analysis.

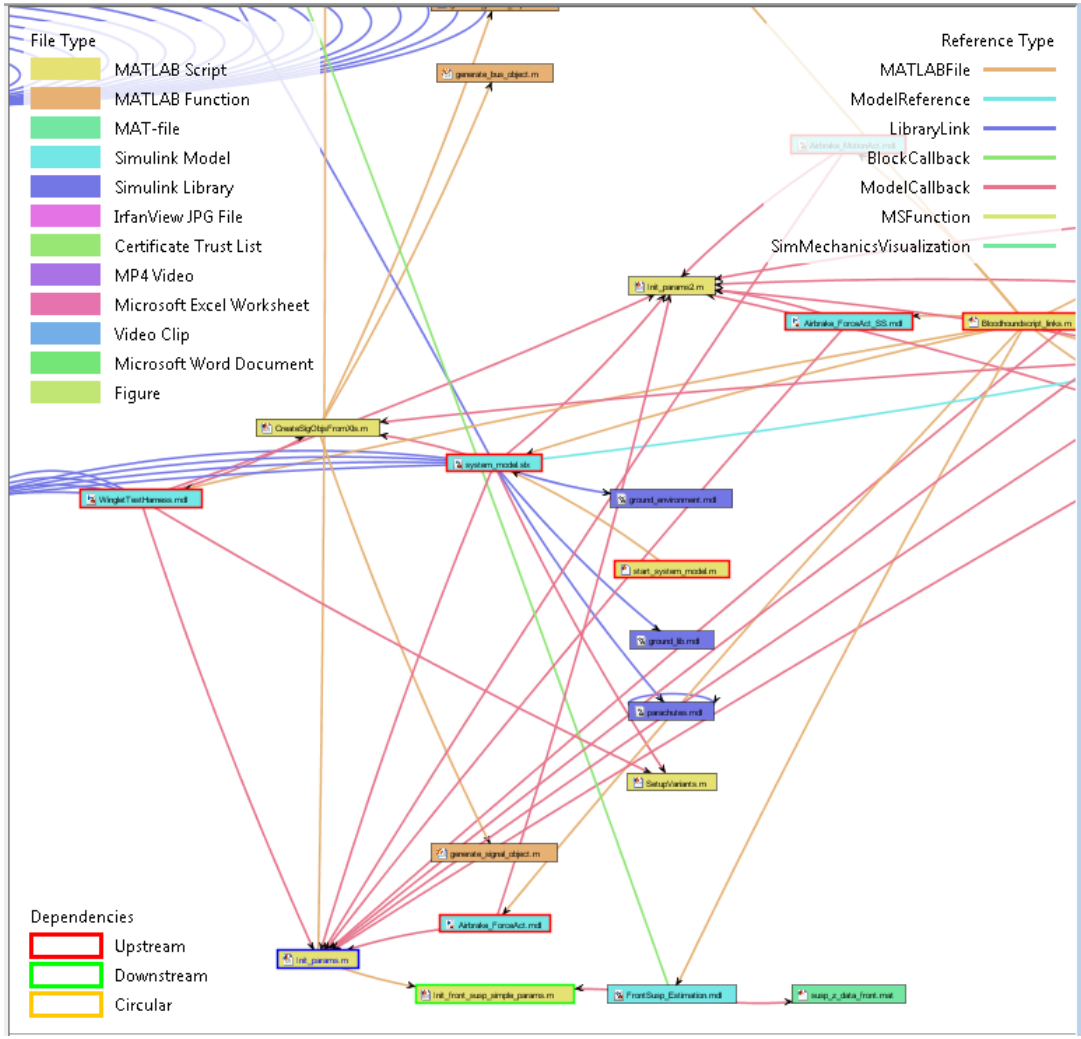
1 To highlight dependencies of selected files, right-click the graph canvas and select **Highlight Dependencies**, and then click graph items to view their highlighted dependencies. You can highlight upstream, downstream, and circular dependencies.



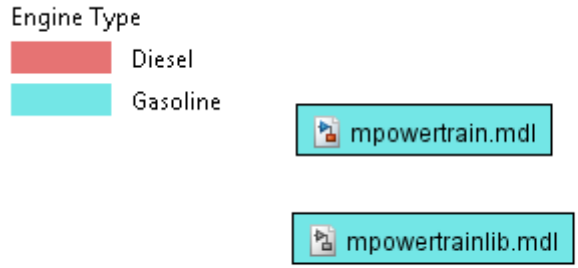
2 Right-click the graph canvas to **Filter by File Type**, and select the file types you want to display or hide.



3 Right-click the graph canvas to highlight all graph items by file type and reference type. The following example shows a project dependency graph with many file types and reference types highlighted.

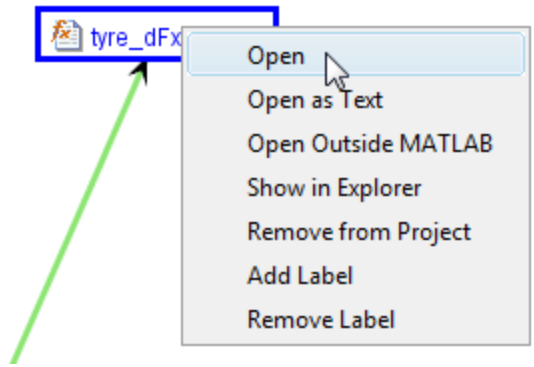


4 Right-click the graph canvas to **Highlight by Labels**, and select a category of labels to use for highlighting. For example, you might want to see which files have the label To Review. The following example shows highlighting of custom labels to show `Engine Type` in the project.



5 Right-click the graph canvas to try different graph layouts and change zoom. You can also control zoom with a mouse wheel, or use the keyboard. Press **+** and – to zoom in or out, press space to fit to view.

6 Right-click files in the graph to perform operations such as **Open**, **Add Label**, or **Remove from Project**. You can also double-click to open a file.



You can perform file operations on multiple files. To select multiple files, press **Shift** and drag the mouse to enclose the files. Hold down **Ctrl** to multiselect and add to any existing selection. Press **F** to fit the view to the currently selected files.

7 You can select **Hide Self-Dependencies** if you want a simpler view of other graph items. For example, a library that contains multiple blocks that use another block in the same library shows many self-references.

Self-referencing files do not introduce any new file dependencies, so you can hide these self-dependencies if you want to simplify the graph. The layout regenerates whenever you change the graph.

8 To save the graph as a `.png` image file, right-click and select **Save As**, or select **Copy** to copy the image to your clipboard for pasting into other documents.

Options for Analyzing Model Dependencies

You can use the Simulink Project Tool to analyze file dependencies for your entire project. For detailed dependency analysis of a *specific* model, use the manifest tools instead to control more options. Use the manifest tools if you want to:

- Save the list of the model dependencies to a manifest file.
- Create a report to identify where dependencies arise.
- Control the scope of dependency analysis.
- Identify required toolboxes.

See “Analyze Model Dependencies” on page 13-104.

Manage Project Files

In this section...

Choose Views of Files to Manage

Use the Project Files views to explore project files, interact with source control, view modified or labeled files, and save tasks or shortcuts.

1. In the Project tree, use the nodes under Files to choose the view with the files you want to manage:
   - **All Files** — View all files within your project folder (or `projectroot`). This list can be different from the list in the Project Files node. For example, you might want to exclude some files under `projectroot` from your project, such as SVN or CVS source control folders.
   - **Project Files** — View only files added to your project. This list can be different from the list of all files within your project folder.
   - **Shortcuts** — View files you have specified as shortcuts for frequent tasks, such as opening top-level models, running startup or shutdown code and other tasks, or simulating models. You can set up shortcuts to run when you open or close your project, or to run manually. The Shortcuts node is blank until you create shortcuts from the All Files or Project Files views. See "Automate Project Startup and Run Frequent Tasks" on page 13-52.
   - **Modified Files** — View only files with changes. This view is available only if you are using a source control integration with your project. See "Review Changes and Commit Modified Files" on page 13-89.

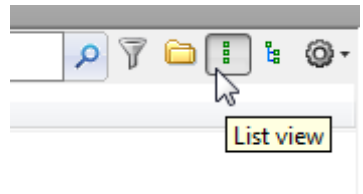
Note To access previous projects, see “Open Recent Projects” on page 13-29.

Group and Sort File Views

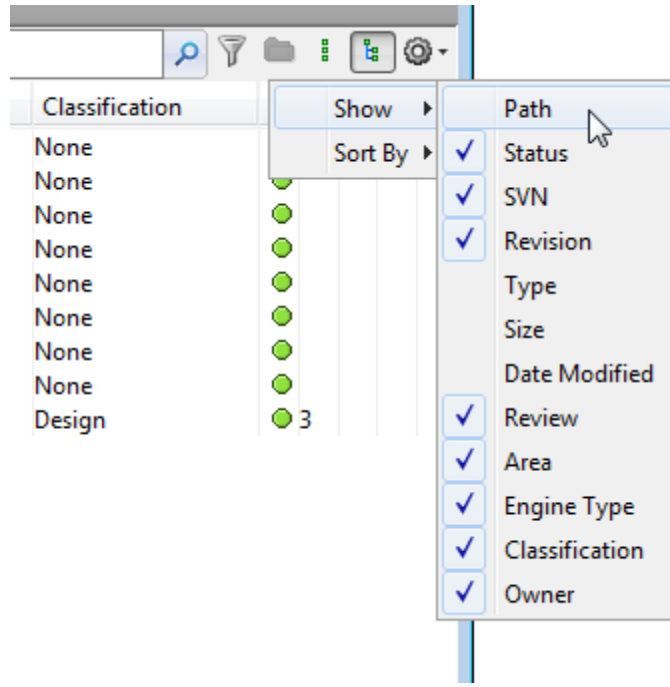
To group and sort the views in all Files nodes:

- Use the List view or Tree view buttons at top right to switch between a flat list of files and a hierarchical tree of files.

  In a list view, you can click the **Hide Folders** button if you want to view only files.



- Click the Actions cog button at top right (next to the Tree view button) to select the columns to show and select groupings, for example, to sort by Review Status labels or any labels you have defined.



Search and Filter File Views

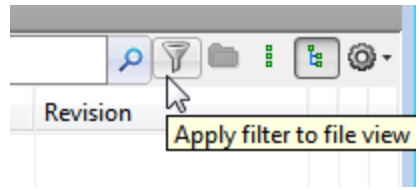
Use the search box or Filter button to alter the list of files displayed. In all the file views, and in batch job and dependency analysis nodes, you can use the search box and filtering tools.

- Type a search term in the search box, for example, part of a file name, or a file extension. You can use wildcards, such as `*.m` to find only MATLAB files, or `*.m*` to find both MATLAB and model files.

  Click the `x` to clear the search.

- Click the filter button to the right of the search box to build a filter for the current view.

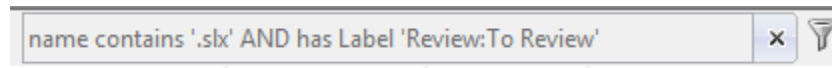


In the Filter Builder dialog box you can select multiple filter criteria to apply using names, project status, and labels. Press **Ctrl** to multiselect labels.

The dialog reports the resulting filter at the bottom, for example:

```
Filter = file name contains '.mdl' AND project status
 is 'In project' AND has Label 'Engine Type:Diesel'
```

When you click **OK**, the search box shows the filter you are applying.



Click the `x` to clear the filter.

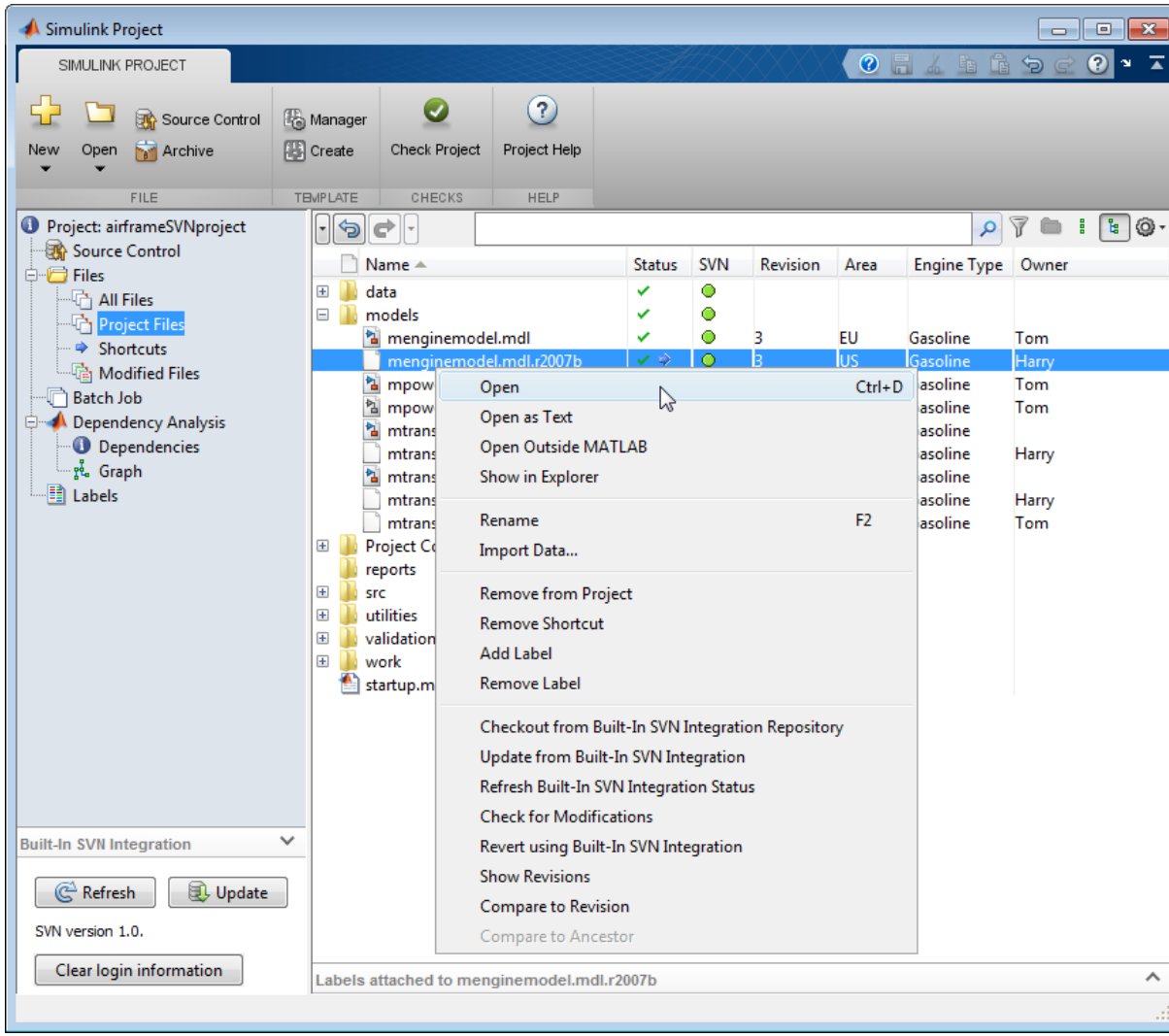
Work with Project Files

In all Files nodes, use the right-click menus to perform actions on the files that you are viewing. Right-click a file (or selected multiple files) to perform project options such as:

- Open or run files.
- Add and remove files from the project.
- Add, change and remove labels. See “Label Files” on page 13-49.
- Create entry point shortcuts (for example, code to run at startup or shutdown, open models, simulate, or generate code). See “Automate Project Startup and Run Frequent Tasks” on page 13-52.
- If a source control interface is enabled, you can also:
  - Refresh source control status.
  - Update from source control.
  - Check for modifications.

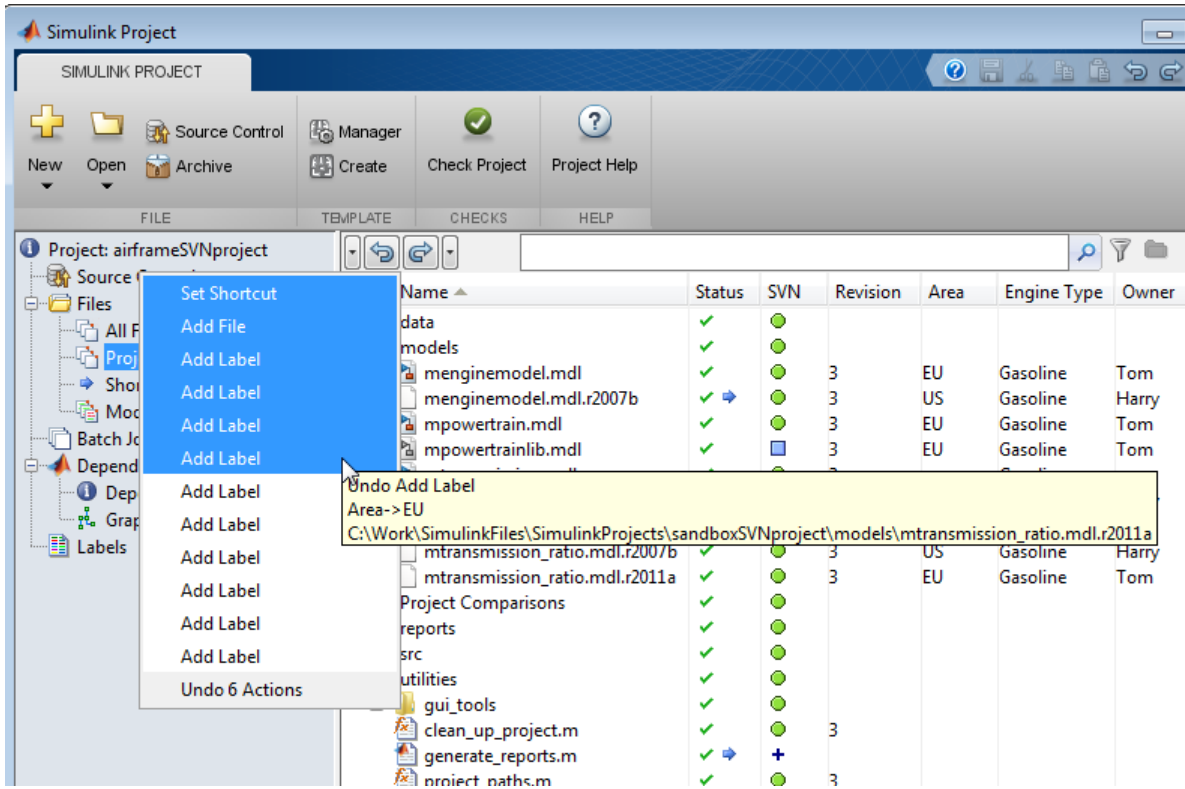
- Revert.
- Compare against revision (select a version to compare)

See “Use Source Control with Projects” on page 13-60.



Back Out Changes

Use the Undo buttons to back out recent changes. Use the Undo or Redo buttons and their drop-down list buttons to undo or redo recent actions in the project. You can select multiple actions to undo. Hover over each action to view details in a tooltip.

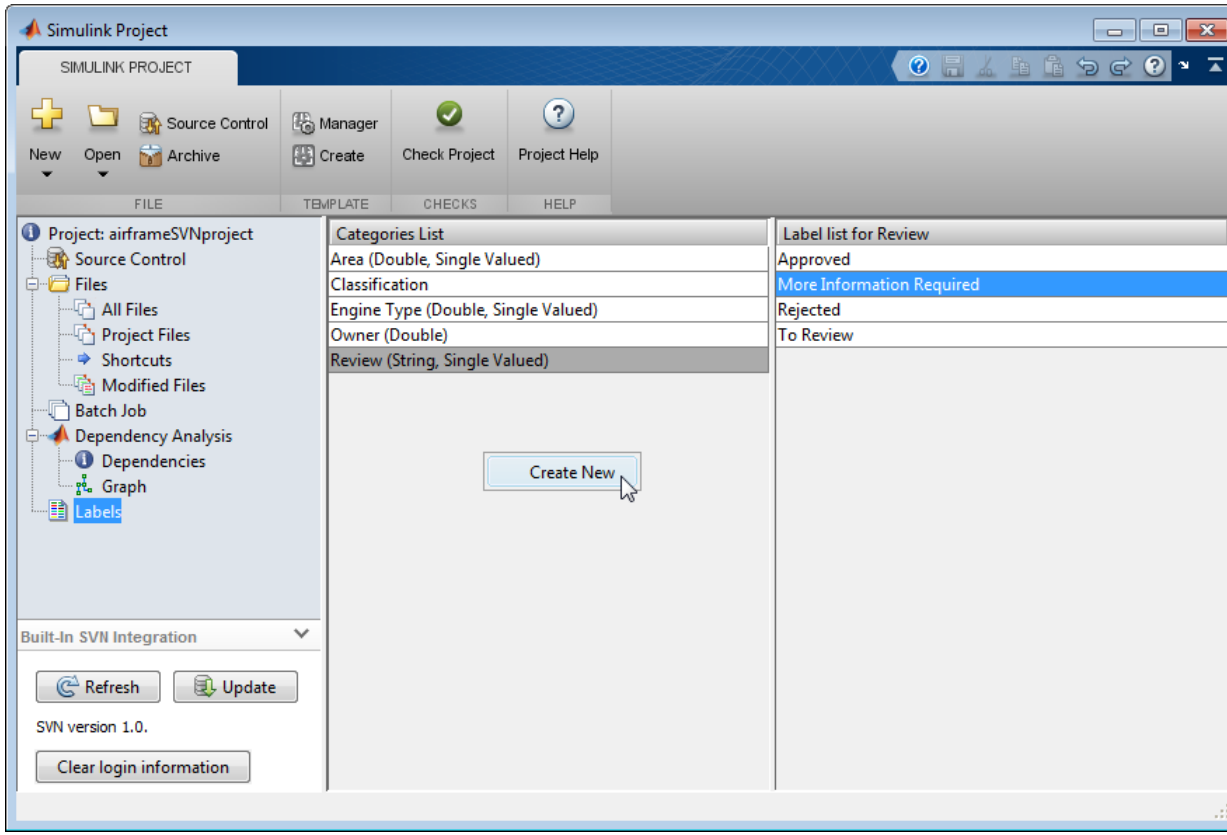


Label Files

Use labels to organize your files. The project automatically applies built-in labels for file categories. You can create your own labels.

- In the Files views, right-click a file (or multiple selected files) to add or remove labels. Once added to a file, a label persists across revisions of the file.

- In the Files views, you can organize lists by labels. Use the Actions button (cog icon at top right) and select Sort By.
- Use the Labels tree node to create new label categories.



1 To add a new category of labels, right-click in the blank areas of the Categories list and select **Create New**.

   a In the dialog box, enter a name for the new category.

   b If only one label of the category can be attached to a file at a time, then select the check box **Single Valued**.

For example, if you want to create a category with labels for Prototype and Release and want to apply only one of those labels to any specific file, then select **Single Valued** to ensure only one label can be attached.

   c If desired, change the **Type** selection to change the data type that can be stored in the label, e.g., `double`, `logical`, `integer`, `string`, or `none`.

   d Click **Create** to create your new category.

2. To add a new label in your new category, right-click in the blank areas of the Labels list and select **Create New**.

   a In the dialog box, enter a name for the new label.

   b Click **OK** to create the label.

   c Repeat to create more labels in your selected category.

3. To delete labels, right-click user-defined categories and labels and select **Remove**. You cannot delete built-in labels.

To add labels at the command line, see the Simulink.ModelManagement.Project.CurrentProject reference page.

Automate Project Startup and Run Frequent Tasks

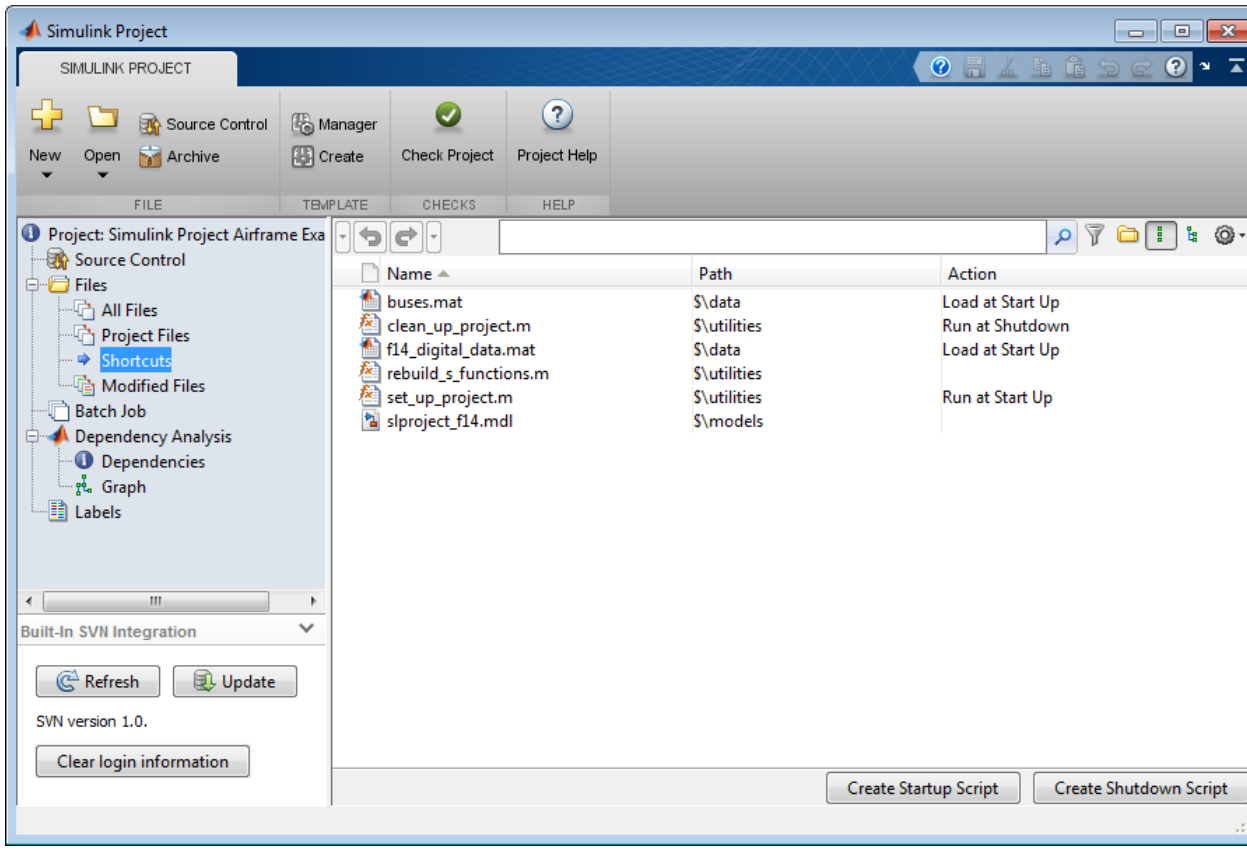
In this section...

Create Shortcuts

Use shortcuts for your common project tasks and to make it easy to find and access important files and operations. For example, find and open top models, run startup code (e.g., change the path or load data), simulate models, or run shutdown code. The Shortcuts node is blank until you add shortcuts. You can create shortcuts from the Files node, in the All Files or Project Files view.

1. To add a shortcut, right-click a file in the All Files or Project Files view and select **Create Shortcut**.

2. After you add shortcuts, use the Shortcuts node to use, change, or remove your shortcuts. You can specify Startup, Shutdown, or basic shortcuts.
   - Startup shortcuts run when you open your project.
   - Shutdown shortcuts run when you close your project.
   - Run basic shortcuts manually by right-clicking.



Use Shortcuts to Find and Run Frequent Tasks

Use shortcuts to make it easy to find and access important files and operations, for yourself and any other project users. You can use shortcuts to make top models or scripts easier to find in a large project, so that a new user of the project can easily find it.

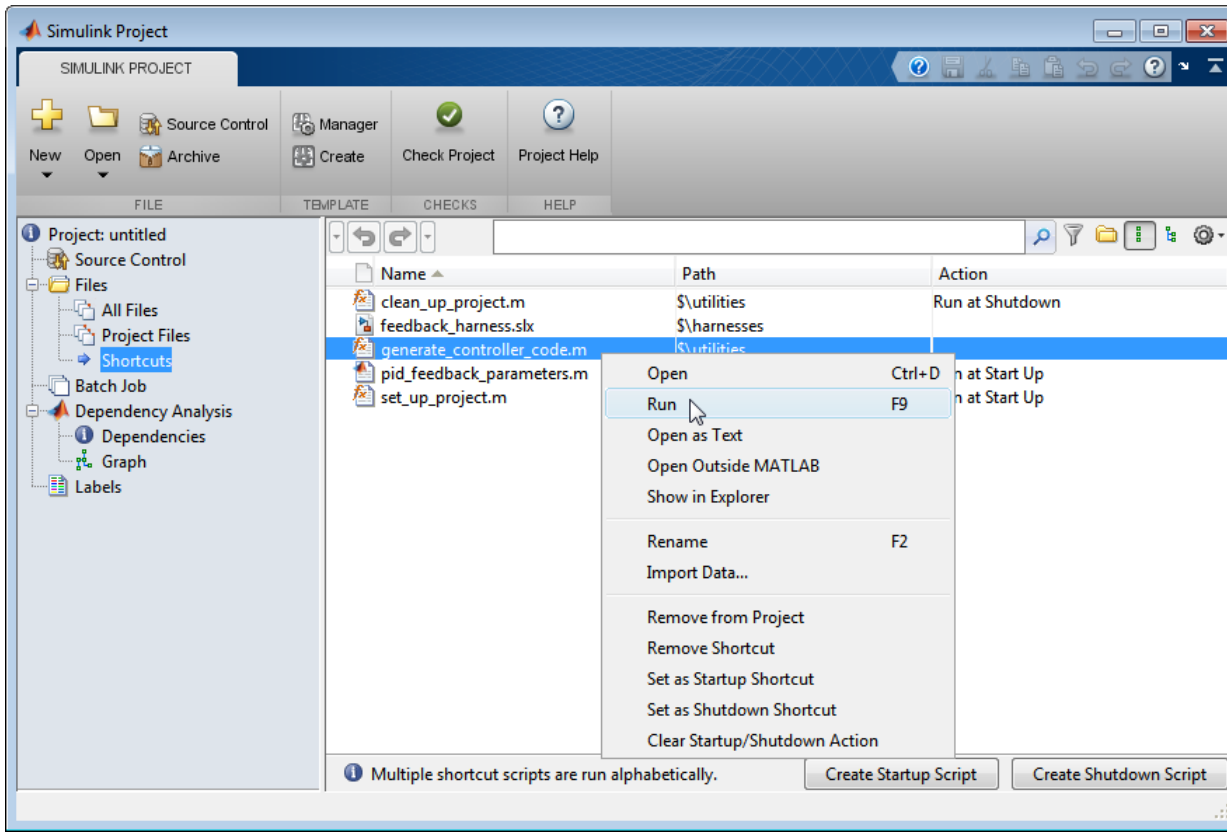
Note Shortcuts are included when you commit your modified files to source control, so you can share shortcuts with other project users.

To use your shortcuts:

1. Click the Shortcuts node.

   In the Shortcuts view, it can be useful to switch to List view. Click the List view button at top right.

2. Right-click the shortcut file and select an action, e.g., **Open** or **Run**.



Automate Startup Tasks with Shortcuts

You can use startup shortcuts to set up the environment for your project.

To configure your shortcut to run when you open your project:

1. Click the Shortcuts node.
2. Right-click the shortcut file and select **Set as Startup Shortcut**.

   The Action column displays `Run at Start Up`.

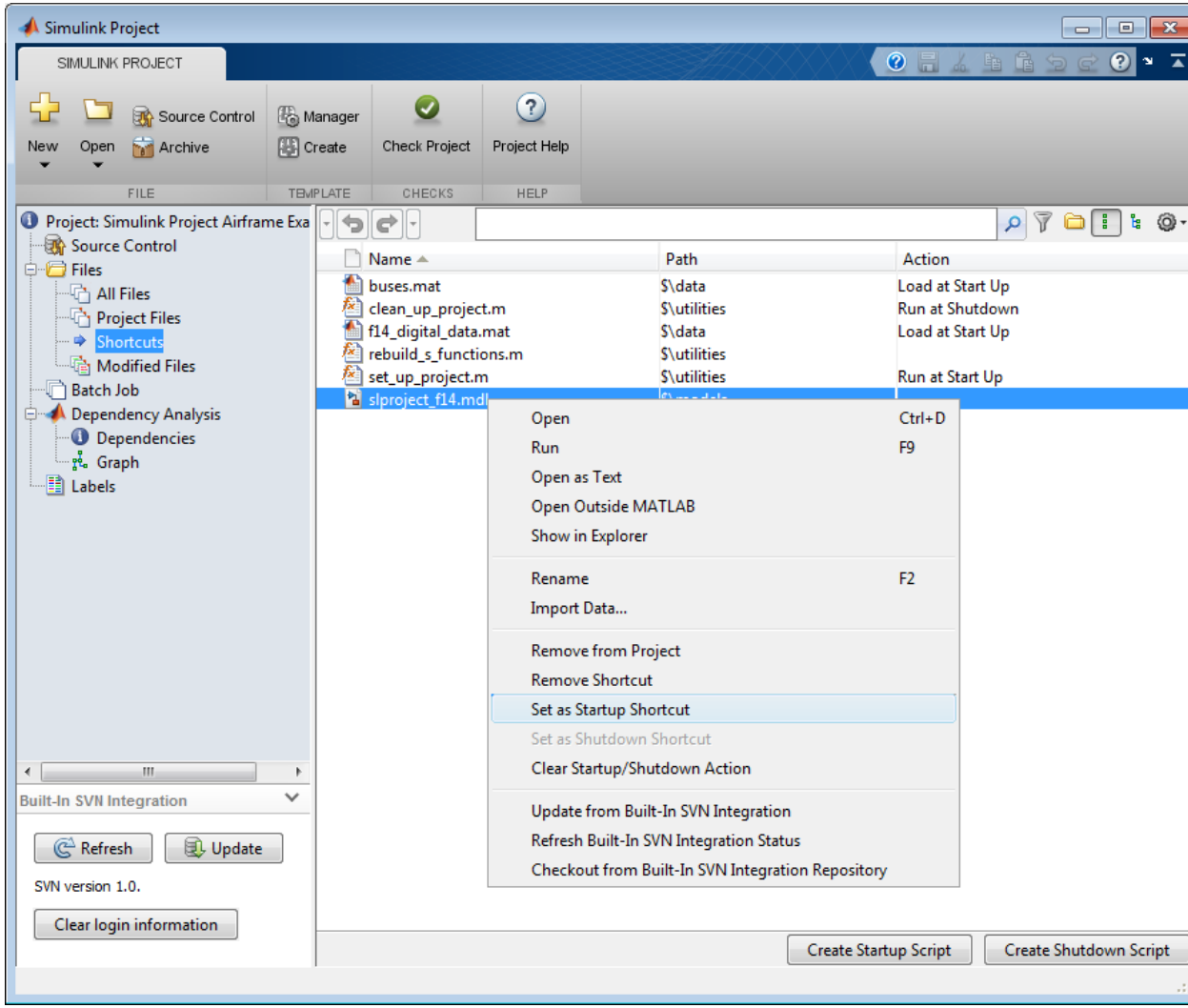
Startup shortcut files are automatically run (`.m` files), loaded (`.mat` files), and opened (Simulink models) when you open the project.

Startup shortcut scripts can have any name. You do not need to use `startup.m`.

Note Remember that files named `startup.m` on the MATLAB path run when you start MATLAB. If your `startup.m` file calls the project with the `CurrentProject` class, you might see an error because no project is loaded yet. To avoid the error, rename the file and use it as a project startup shortcut instead.

You can view an example in the `sldemo_slproject_airframe` project, where the file `set_up_project.m` sets the MATLAB path, and defines where to create the `slprj` folder.

You can change back to a basic shortcut by selecting **Clear Startup/Shutdown Action**.



Projects warn if you have more than one startup shortcut, because they run in alphabetical order, which you might not want. If execution order is important, consider creating another script that calls all the others, and use that script as your only startup shortcut.

Note Be aware that shortcuts are included when you commit your modified files to source control, so any startup shortcuts you create will also run for any other project users.

Automate Shutdown Tasks with Shortcuts

To configure your shortcut to run when you close your project:

1. Click the Shortcuts node.
2. Right-click the shortcut file and select **Set as Shutdown Shortcut**.

   The Action column displays `Run at Shutdown`.

You can use shutdown shortcuts to clean up the environment for the current project when you close it. Shutdown shortcuts should undo the settings applied in startup shortcuts. You can view an example in the `sldemo_slproject_airframe` project.

You can change back to a basic shortcut by selecting **Clear Startup/Shutdown Action**.

Note Be aware that shortcuts are included when you commit your modified files to source control, so any shutdown shortcuts you create will also run for any other project users.

Run Batch Functions on Project Files

Select the Batch Job view to create and run functions on selected project files.

To create a batch function to use on your files:

1. Click **Create**.

   The MATLAB Editor opens a new untitled file containing a simple example batch job. The instructions guide you to create a batch job with the correct function signature.

2. Edit the function to perform the desired action on each file.

3. Save the function file on your MATLAB path.

To use the batch job from the Simulink Project Tool:

1. In the Batch Job view, select the check boxes of project files you want to include in the batch job. Only selected files are included in the batch job.

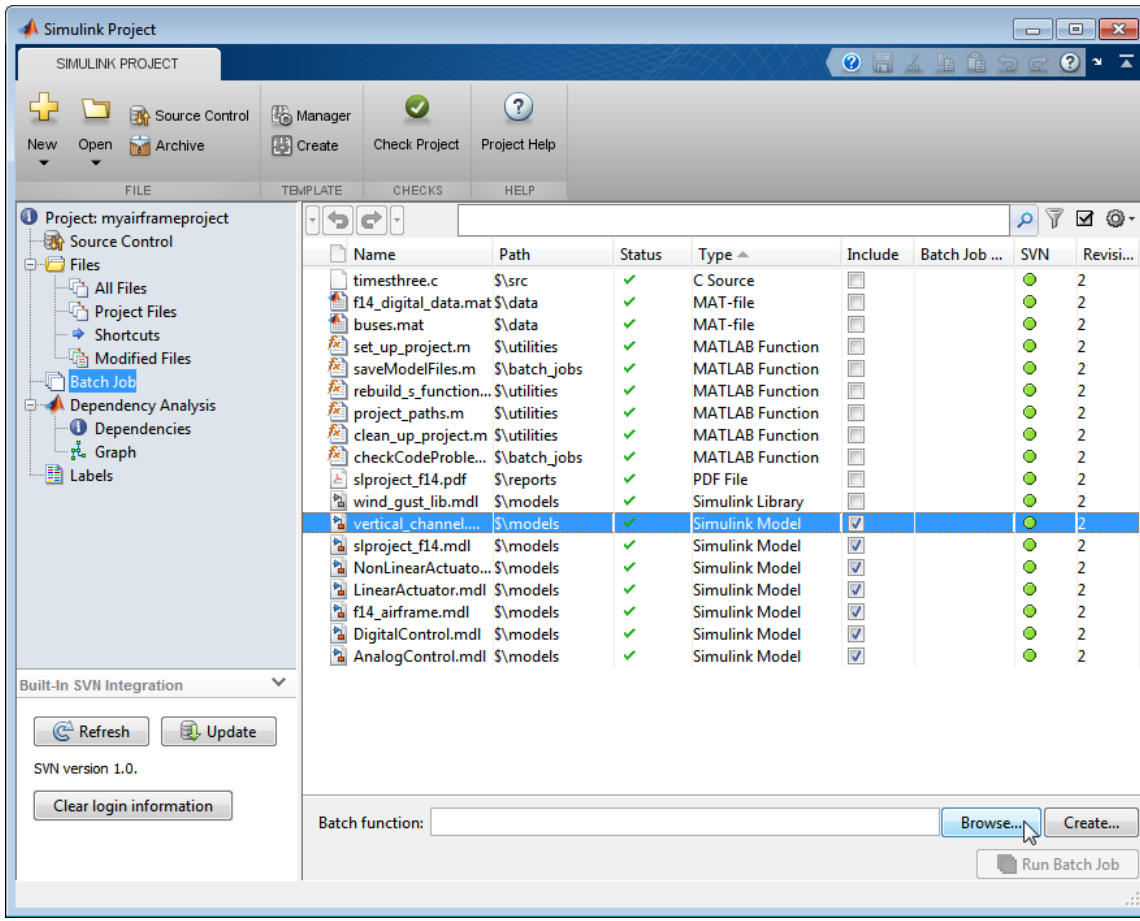
   If the batch function can determine if a file it is given is appropriate, you might want to include all files. The batch function operates only on the appropriate subset of the included files. For example, the batch job function `saveModelFiles` in the `airframe` project checks that the file is a Simulink model, and does nothing if it is not. Include all files if you want your batch function to check all files.

   To select multiple files, **Shift** or **Ctrl**+click, and then right-click a file and select **Include** or **Exclude**.

2. Click **Browse** to locate your batch job function file, or enter the name of your batch function.

3. Click **Run Batch Job**.

   The Simulink Project Tool displays the results in the Batch Job Results column.



For example batch jobs, see Running Batch Jobs with a Simulink Project. This example shows how to apply a batch job function to a set of files managed by a Simulink Project. The example batch job function `saveModelFiles` identifies and saves any loaded Simulink model files that contain unsaved changes. This action can be useful to perform before committing changes to source control.

Open the example `airframe` project to view example batch job files `saveModelFiles` and `checkCodeProblems`. See “Try Simulink Project Tools with the Airframe Project” on page 13-4.

Use Source Control with Projects

In this section...

About Source Control with Projects

You can use the Simulink Project Tool to work with source control.

Projects automatically recognize supported source control applications when you create a new project in a folder under source control and click **Detect**.

Simulink projects contain interfaces to:

- Subversion® (SVN) — See "Subversion Integration with Projects" on page 13-70.
- A local version control tool — Project examples use the light-weight local version control tool so you can try out source control operations after a single command. The local version control tool is designed for a single user for example purposes only. See "Try Simulink Project Tools with the Airframe Project" on page 13-4.

You can add your project to source control to use the built-in SVN integration that comes with Simulink projects.

When your project is under source control, you can use these project features:

- "Retrieve and Check Out Files Under Source Control" on page 13-76
- "Review Changes and Commit Modified Files" on page 13-89

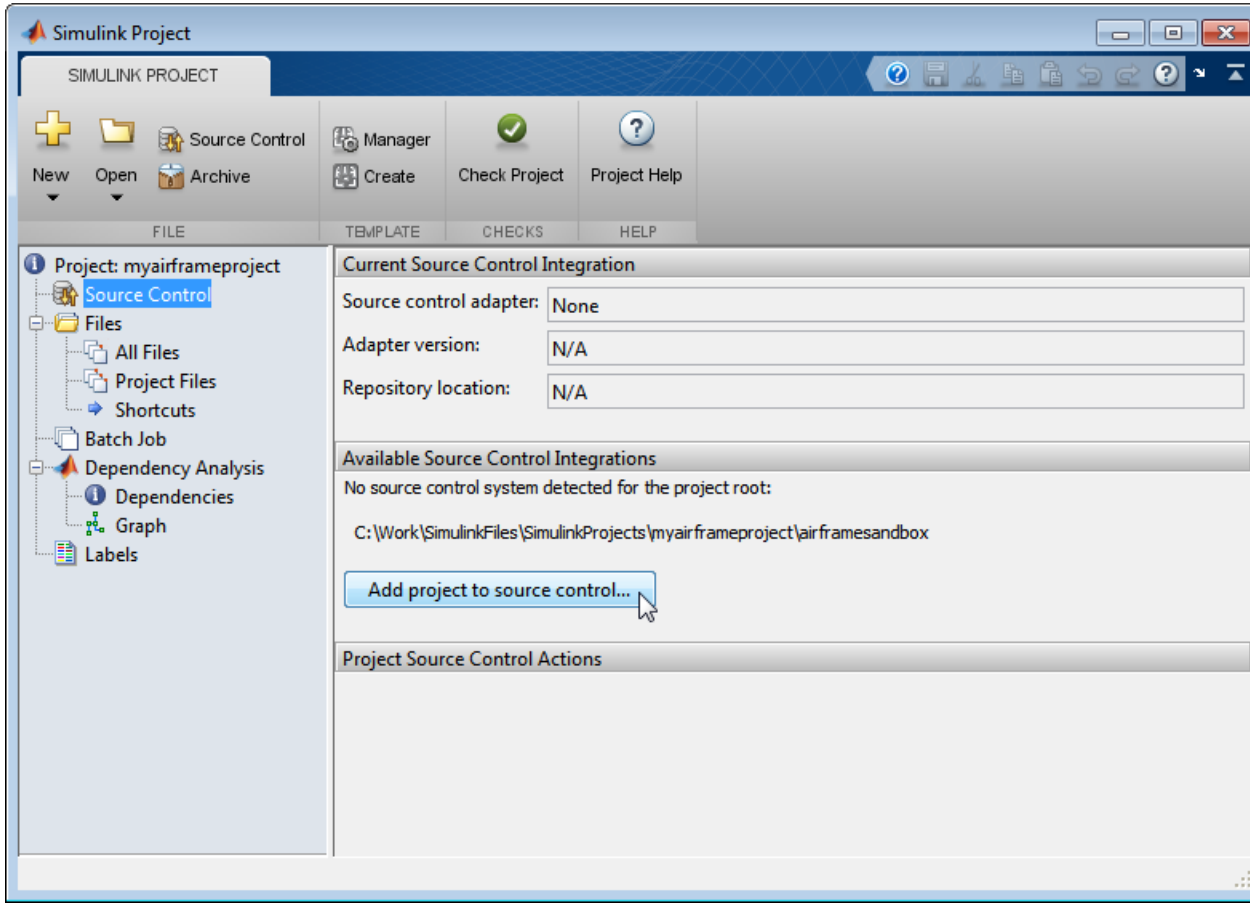
Add a Project to Source Control

Check your sandbox folder is on a local hard disk, not a network location.

Caution Using a network folder with SVN is slow and currently has known bugs, e.g., http://subversion.tigris.org/issues/show_bug.cgi?id=3053. Instead, use local sandbox folders.

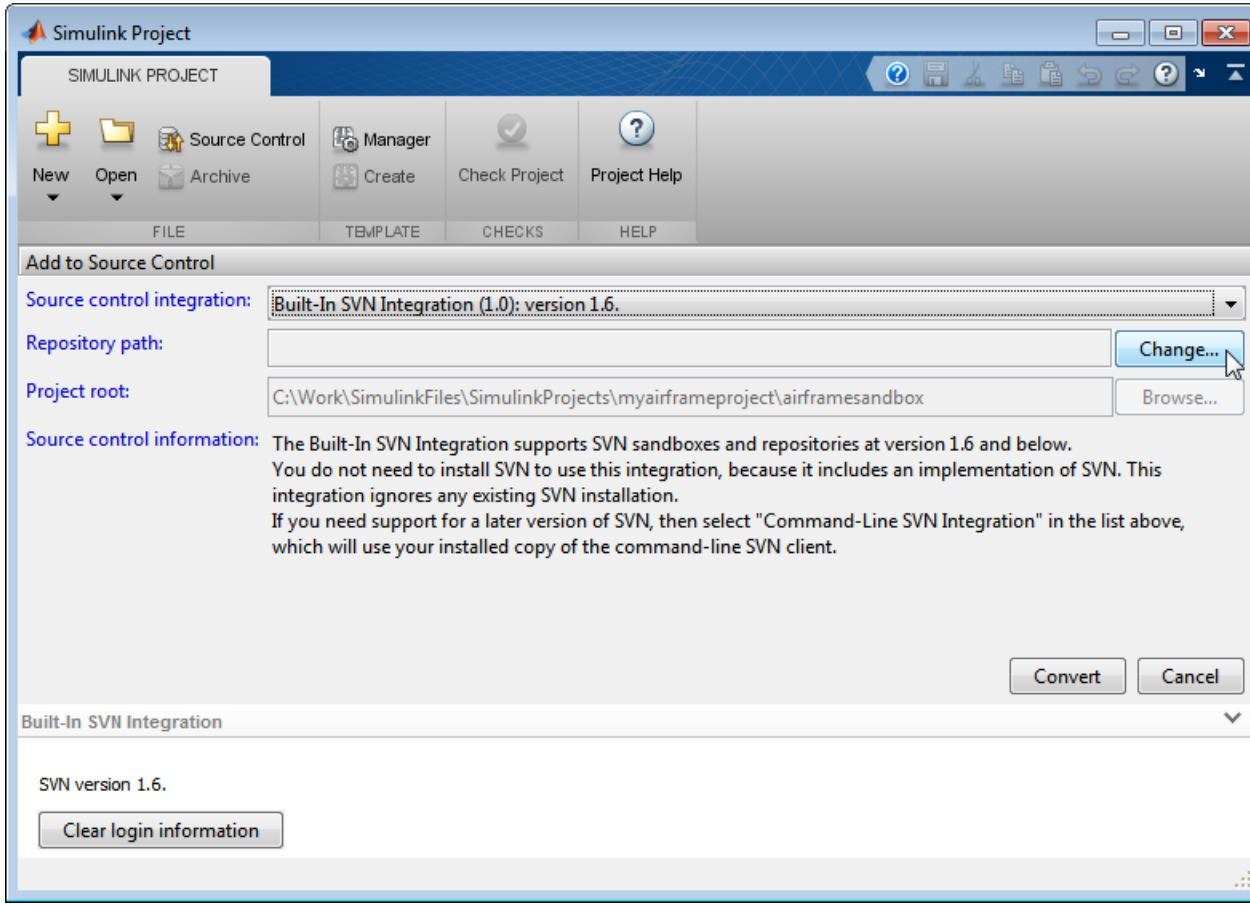
To add source control to a newly created project or an existing one:

1. Select the Source Control node in the project tree.
2. Under **Available Source Control Integrations**, click **Add project to source control**.

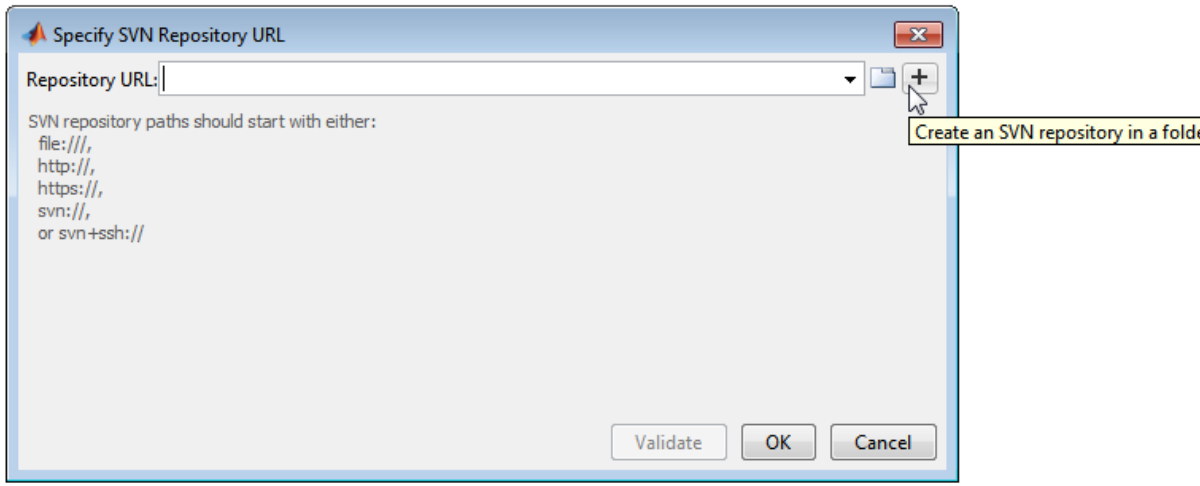


3 On the Add to Source Control dialog box, leave the default **Source control integration** selected to use `Built-In SVN Integration`.

4 Next to **Repository path**, click **Change**.



5 On the Specify SVN Repository URL dialog box, either select an existing repository or create a new one.



- To specify an existing repository, click the Browse button to the right of the **Repository URL** box, paste a URL into the box, or use the drop-down list to select a recent repository.
- To create a new repository, click the Create button to the right of the **Repository URL** box. A file browser opens. Create a new folder where you want to create the new repository and click **Select Folder**. Do not place the new repository inside the existing project folder.

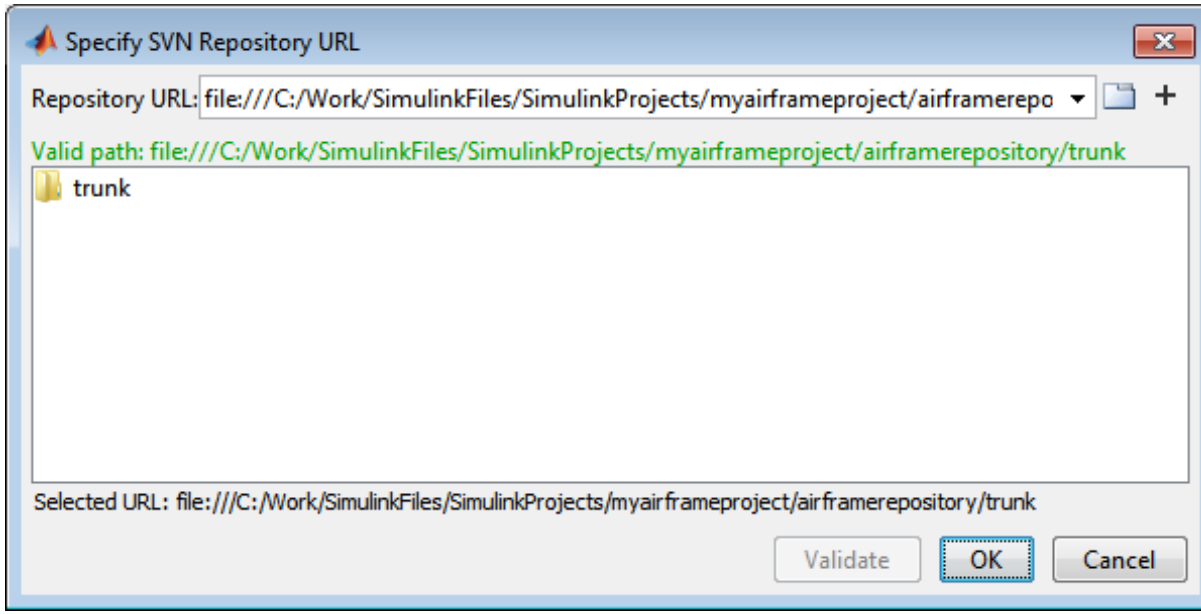
Caution Create new repository is for single users only. See "Create Subversion Repository" on page 13-74.

The Simulink Project Tool creates a repository in your folder and you return to the Specify SVN Repository URL dialog box. The URL of your new repository is specified in the **Repository URL** box, and the project automatically selects the `trunk` folder.

6 Click **Validate** to check the path to your selected repository. If you have problems, check the dialog messages for required path styles.

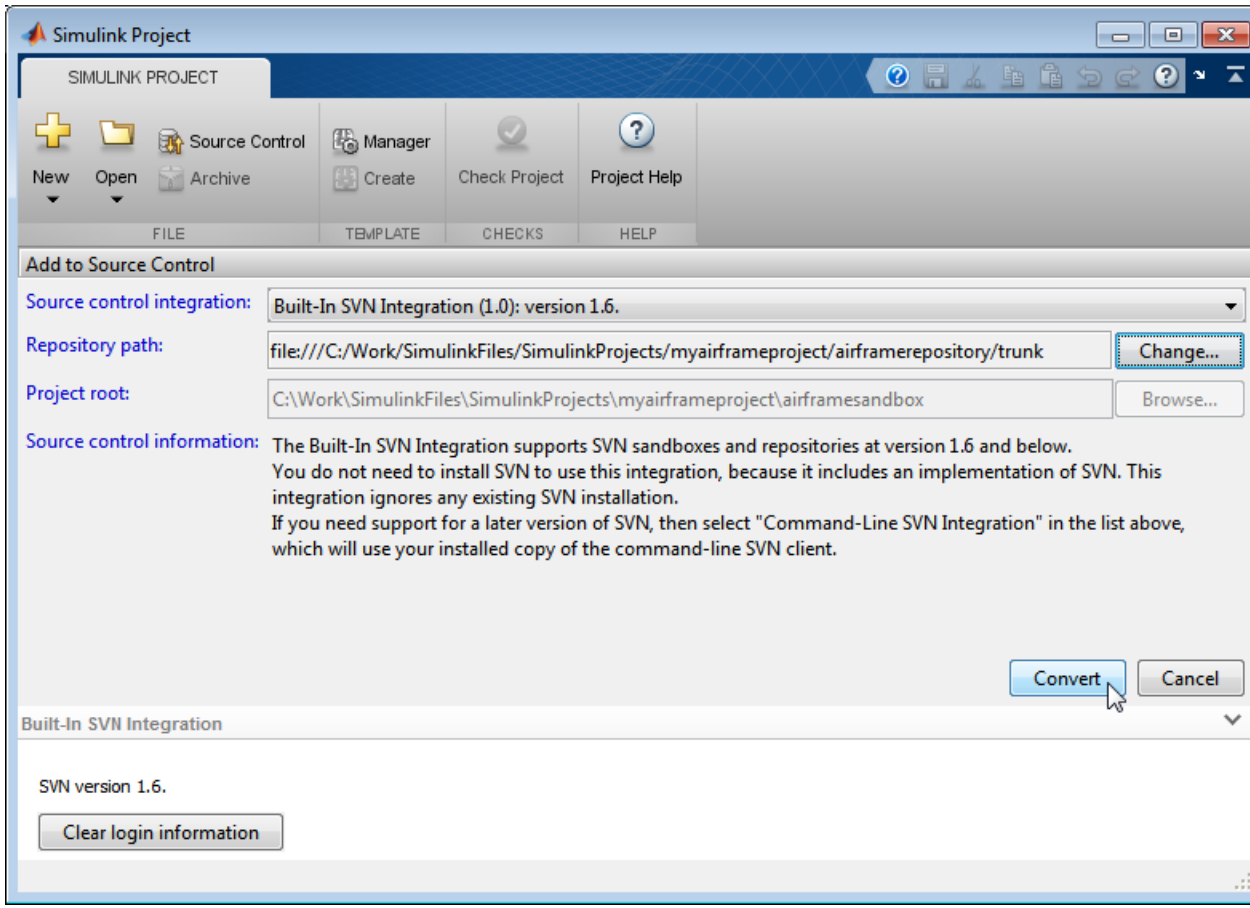
Caution Use `file://` URLs only for single user repositories. For more information, see "Create Subversion Repository" on page 13-74.

When your path is valid, you can browse the repository folders. Select the `trunk` folder if needed, and verify the selected URL at the bottom of the dialog box. If you created a new repository, `trunk` is automatically selected.

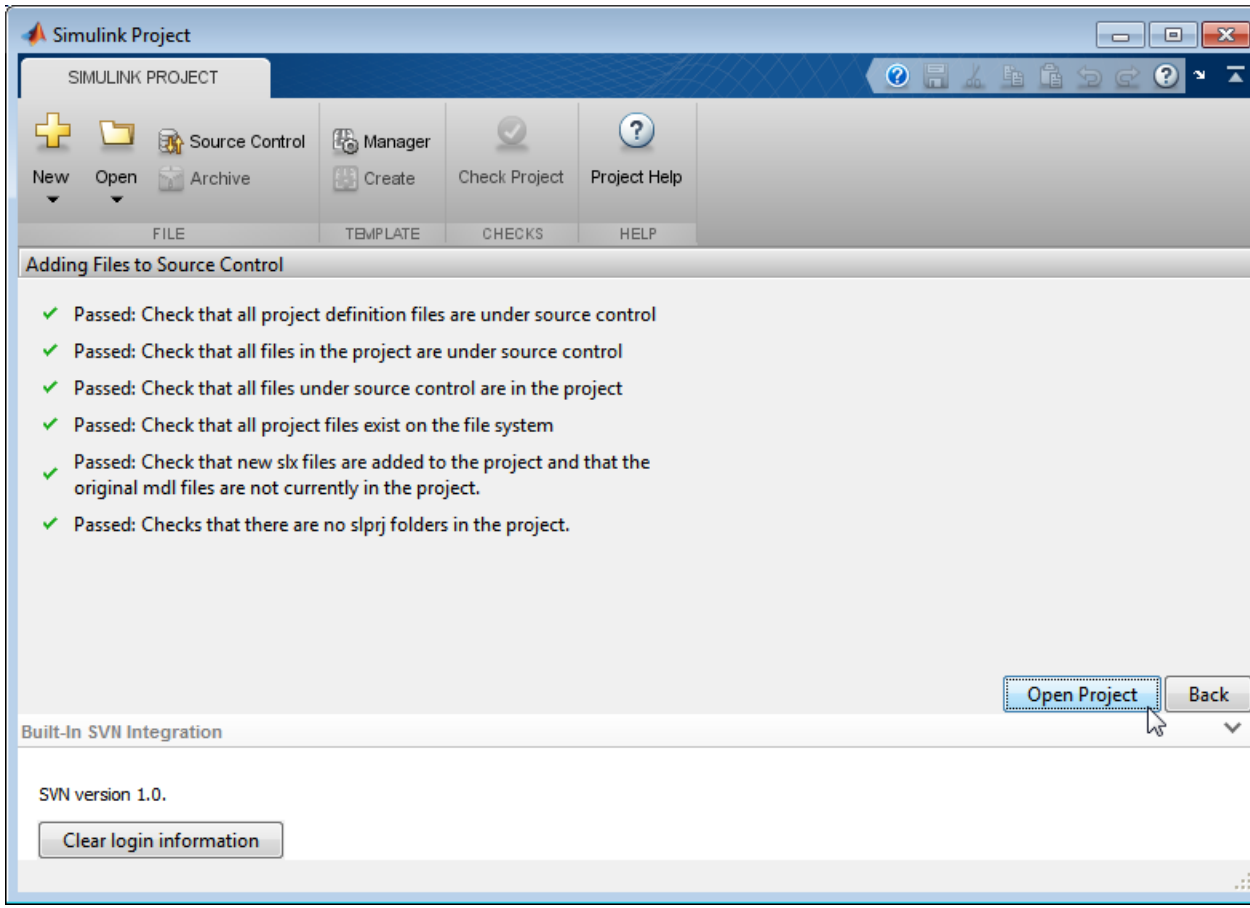


7 Click **OK** to return to the Add to Source Control dialog box.

8 Click **Convert** to finish adding the project to source control.



The project runs integrity checks.

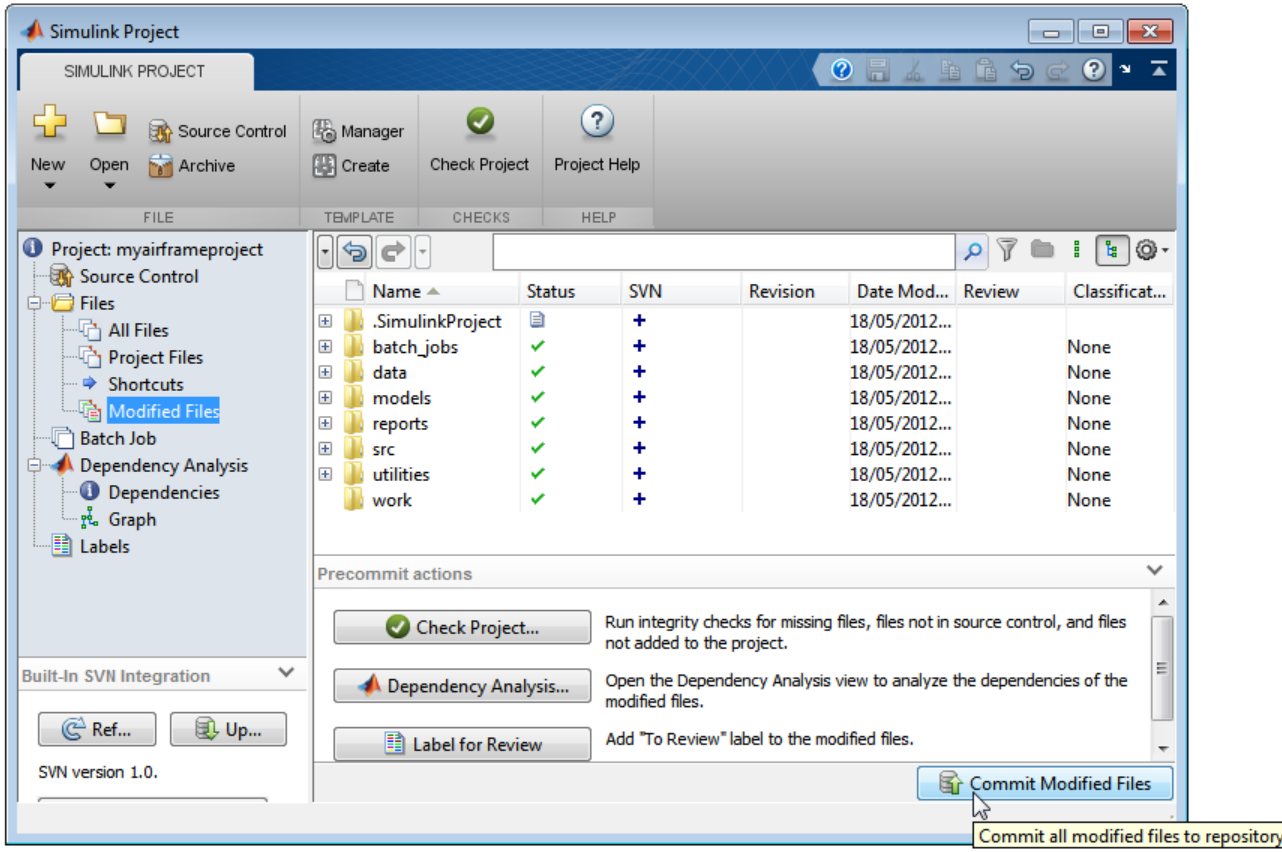


9 Click **Open Project** to return to your project.

10 If you created a new repository, you need to add your files to it. To commit files to your new repository:

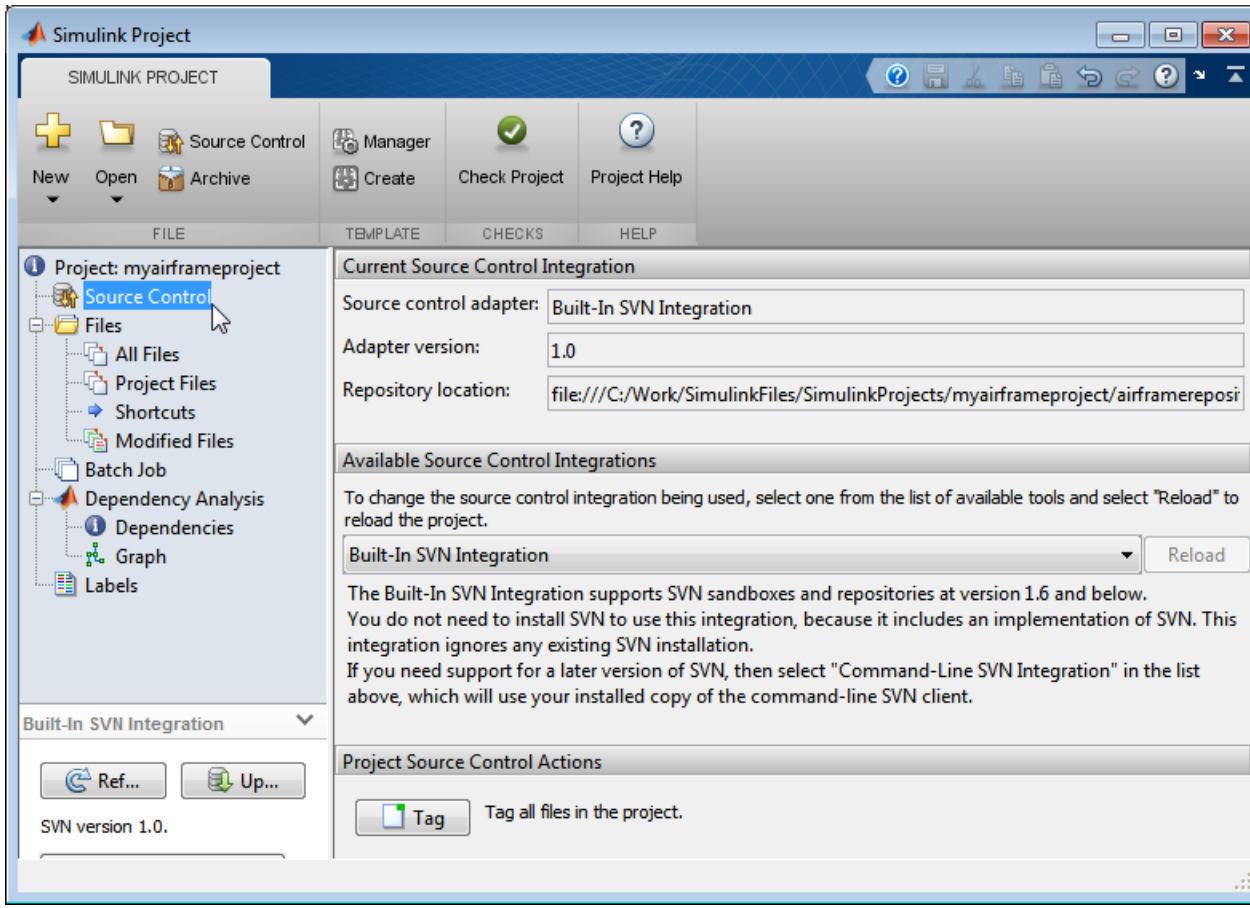
   a Select the Modified Files view. All your project files should be in the Modified Files list.

   b Click **Commit Modified Files** to commit the first version of your files to the new repository. A dialog box opens, where you can enter a comment and click **Submit**.



For more information about the default Built-In SVN Integration, see “Select Subversion Source Control” on page 13-71.

View or Change Project Source Control



Viewing Source Control Type and Repository

The Source Control node in the project tree shows details of the current source control tool, the adapter interfacing to source control in your current project, and the repository location.

Adding, Changing, or Removing Source Control

To add source control to a newly created project or an existing one, under **Available Source Control Integrations**, select **Add project to source control**. See “Add a Project to Source Control” on page 13-61.

Use the same control to remove a project from source control by selecting `No source control integration` and clicking **Reload**. For example, this action might be useful when you are preparing a project to create a template from it, and you want to avoid accidentally committing unwanted changes. You can later select your previous source control from the list again.

Tagging Files

Use *tags* to identify specific revisions of all project files. In the Source Control node, click the **Tag** button under Project Source Control Actions. Specify the text for the tag. This action adds your tag to every project file.

Not every source control has the concept of tags. To use tags with SVN, you need the standard folder structure in your repository and you need to check out your files from `trunk`. See "Create Subversion Repository" on page 13-74

Register Model Files with Source Control Tools

If you use third-party source control tools, be sure to register your model file extensions (`.mdl` and `.slx`) as binary formats. If you do not, these third-party tools might corrupt your model files when you submit them, by changing end-of-line characters, expanding tokens, keyword substitution, or attempting to automerge. Corruption can occur whether you use the source control tools outside of Simulink or if you try submitting files from the Simulink Project Tool without first registering your file formats.

You should also check that other file extensions are registered as binary to avoid corruption at check-in for files such as `.mat`, `.xlsx`, `.jpg`, `.pdf`, `.docx`, etc.

For instructions, see "Register Model Files with Subversion" on page 13-73

Subversion Integration with Projects

- "Create Subversion Repository" on page 13-74

Select Subversion Source Control

To use SVN in your project, you can use any of the following workflows:

- Create a new project in a folder already under SVN source control and click **Detect**. See "Create a New Project to Manage Existing Files" on page 13-23.
- Add source control to a project. See "Add a Project to Source Control" on page 13-61.
- Retrieve files from an existing SVN repository and create a new project. See "Retrieve a Working Copy of a Project from Source Control" on page 13-76.

When you add to source control or retrieve from source control, you can optionally change the SVN integration in the **Source control integration** list.

SVN Version You Want to Use	SVN Integration to Select
SVN version 1.7 or below (no installation steps required)	"Built-In SVN Integration" on page 13-71
Other SVN version (requires additional installation steps)	"Command-Line SVN Integration (Compatibility Mode)" on page 13-72

Note Also, you can check for updated downloads on the Simulink Projects Web page: `http://www.mathworks.com/products/simulink/simulink-projects/`

Built-In SVN Integration

Select the `Built-In SVN Integration` for use with SVN sandboxes and repositories at version 1.7 and below.

You do not need to install SVN to use this integration because `Built-In SVN Integration` includes an implementation of SVN. This integration ignores

any existing SVN installation. If you need support for a later version of SVN, then select `Command-Line SVN Integration (compatibility mode)` instead.

The `Built-In SVN Integration` supports secure logins and moving @ folders.

Command-Line SVN Integration (Compatibility Mode)

Note Select `Command-Line SVN Integration (compatibility mode)` only if you need to use a later version of SVN than 1.7. Otherwise, use `Built-In SVN Integration` instead, for more features, improved performance, and no need to install an additional command-line SVN client.

If you select `Command-Line SVN Integration (compatibility mode)`, you must also install a command-line SVN client.

Command-line SVN integration communicates with any Subversion (SVN) client that supports the command-line interface. Install an SVN client that supports the command-line interface, and then you can use this integration with the Simulink Project Tool.

TortoiseSVN does not support the command-line interface. However, you can continue to use TortoiseSVN from Windows Explorer after installing another SVN client that supports the command-line interface. Ensure that the major version numbers match, e.g., both clients should be SVN 1.7.

You can find Subversion clients on this Web page:

```
http://subversion.apache.org/packages.html
```

.

If you try to rename a file in a project under SVN source control, and the folder name contains an @ character, you see an error because command-line SVN treats all characters after the @ symbol to be a peg revision value.

Register Model Files with Subversion

If you do not register your model file extension as binary, Subversion may add annotations to conflicted Simulink files and attempt automerge. This corrupts model files so you cannot load the models in Simulink.

To avoid this problem when using Subversion, follow these steps to register your file extensions:

1. Locate your SVN config file, e.g.: `C:\Users\myusername\AppData\Roaming\Subversion\config`, or `C:\Documents and Settings\username\Application Data\Subversion\config` on Windows, or in `~/.subversion` on Linux or Mac OS X.

2. Add the following lines to the end of the config file, and SVN will no longer add annotations to Simulink files on conflict, and will never attempt an automerge.

```
*.mdl = svn:mime-type= application/octet-stream
*.mat = svn:mime-type=application/octet-stream
*.slx = svn:mime-type= application/octet-stream
```

Create Subversion Repository

You can create an SVN repository when adding a project to source control. See "Add a Project to Source Control" on page 13-61.

Caution Creating new repositories is provided for local single-user access only, for testing and debugging. Do *not* use for multiple users or you risk corrupting the repository.

When you use Simulink Projects to create a repository, you create a repository using the `file://` protocol. Subversion documentation strongly recommends only single users access a repository directly via `file://` URLs. See the Web page:

```
http://svnbook.red-bean.com/en/1.7/svn-book.html#svn.serverconfig.choosing.recomme
```

It is *not* recommended to allow multiple users to access a repository directly via `file://` URLs. You risk corrupting the repository. Use `file://` URLs only for single user repositories.

When you want to share a repository, you need to set up a server. You can use `svnserve` or the Apache™ SVN module. See the Web page references:

```
http://svnbook.red-bean.com/en/1.7/svn-book.html#svn.serverconfig.svnserve
http://svnbook.red-bean.com/en/1.7/svn-book.html#svn.serverconfig.httpd
```

On Windows, search the Web for Subversion servers that you can set up in a few clicks.

To enable tagging within projects when using SVN, create your repository with the standard `tags`, `trunk`, and `branch` folders, and check out your files from `trunk`. This structure is recommended by the Subversion project. See the Web page:

```
http://svn.apache.org/repos/asf/subversion/trunk/doc/user/svn-best-practices.html
```

.

You can create an SVN repository with the standard structure from the project, and the project automatically selects the `trunk` folder.

After you create a repository with this structure, you can use the **Tag** button in the Project Source Control node to add tags to all your project files. Tag errors if you do not create a `tags` folder in your repository.

Write a Source Control Adapter with the SDK

Simulink provides a Software Development Kit (SDK) that you can use to integrate Simulink Projects with third-party source control tools.

The SDK provides instructions for writing an adapter to a source control tool that has a published API that can be called from Java™.

You must create a `.jar` file which implements a collection of Java interfaces and a Java Manifest file, which defines a set of required properties.

The SDK also provides example source code, Javadoc, and files for validating, building, and testing your source control adapter. Build and test your own interfaces using the example as a guide, then you can use your source control adapter with Simulink Projects.

1. To extract the contents of the SDK, enter:

   ```
   run(fullfile(matlabroot,'toolbox','simulink','simulink','slproject',...
       'adapterSDK','extractSDK'))
   ```

   Select a folder to place the `cm_adapter_SDK` folder and files inside, and click **OK**.

2. Locate the new folder `cm_adapter_SDK`, and open the file `cm_adapter_SDK_guide.pdf` for instructions.

Retrieve and Check Out Files Under Source Control

In this section...

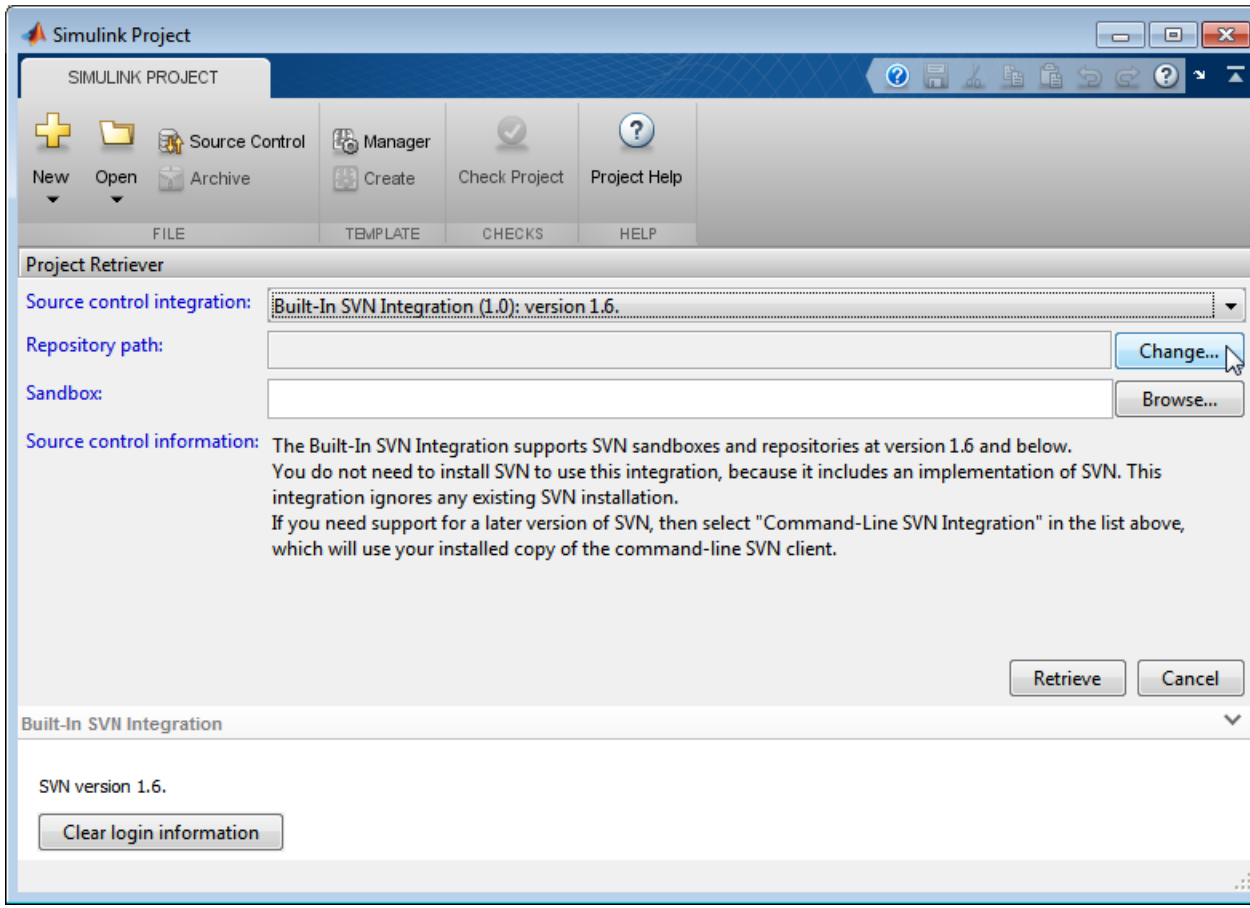
Retrieve a Working Copy of a Project from Source Control

To create or update a new local copy of a project by retrieving files from source control:

1 From MATLAB, on the **Home** tab, in the **File** section, select **New > Simulink Project > From Source Control**.

Alternatively, from the Simulink Project Tool, on the **Simulink Project** tab, select **Source Control**.

The Source Control dialog box appears.



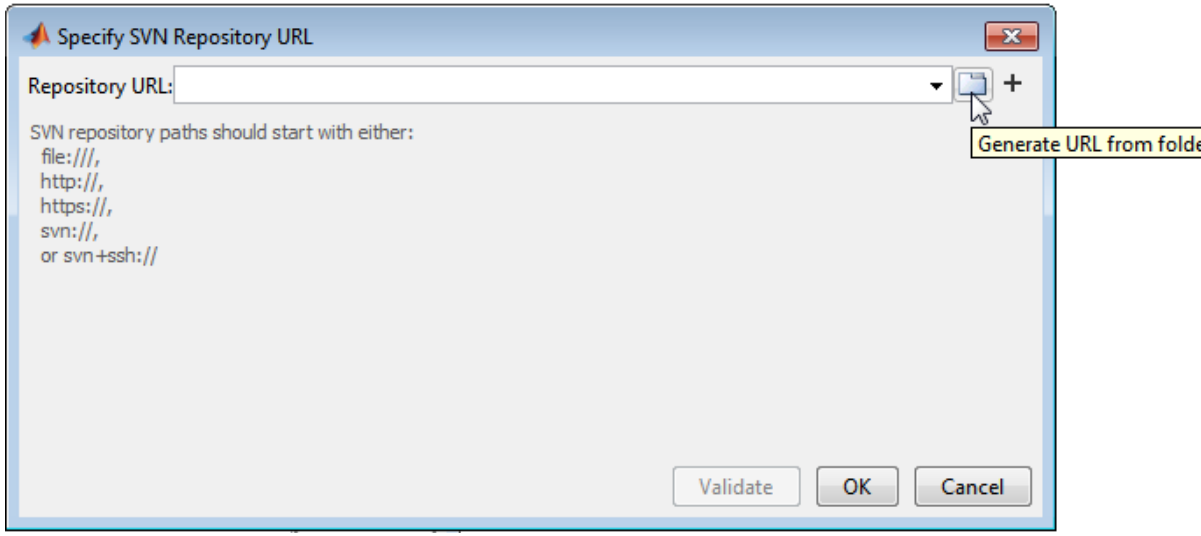
2 (Optional) Select your source control interface from the **Source Control Adapters** drop-down list.

Leave the default `Built-In SVN Integration` to use the default SVN integration with your project. For more information on SVN support, see “Select Subversion Source Control” on page 13-71.

3 Click **Change** to select the Repository Path that you want to retrieve files from.

The Specify Repository URL dialog box opens.

a Click the Generate URL from folder button to the right of the **Repository URL** box to browse for your repository location.



Select the folder containing your repository and click **OK**.

The retriever generates a URL for you in the **Repository URL** field.

Alternatively, manually enter or paste the **Repository URL**.

b Click **Validate** to check the repository path.

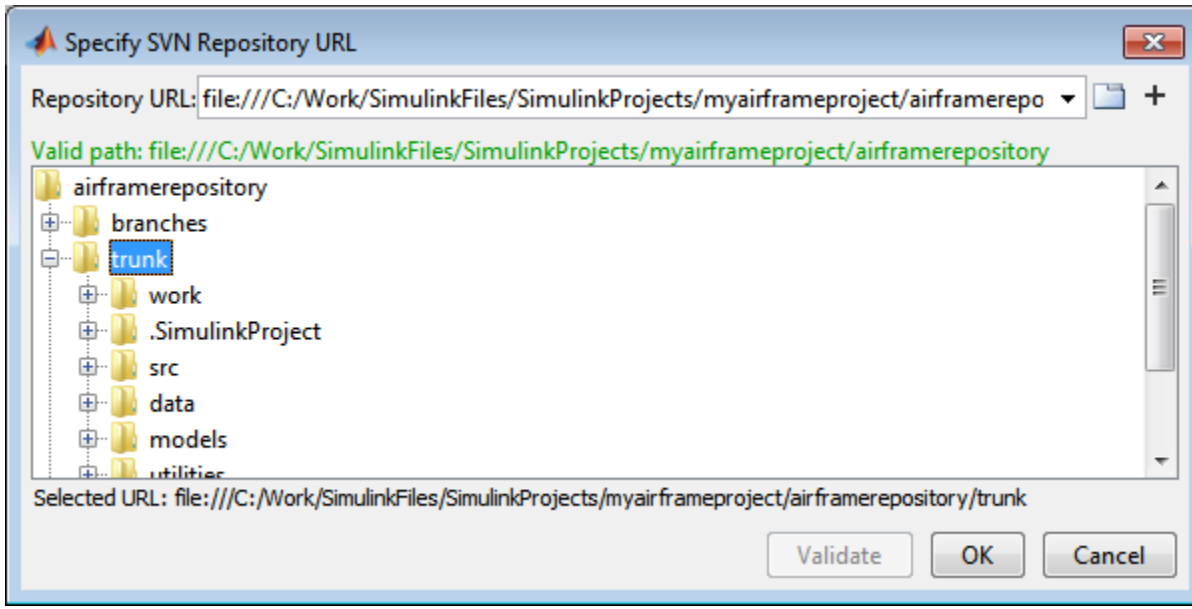
If the path is invalid, check the URL against your source control repository browser.

Caution Use `file://` URLs only for single user repositories. For more information, see “Create Subversion Repository” on page 13-74.

---

c If necessary, select a deeper folder in the repository tree. The example shows `trunk` selected, and the **Selected URL** displays at the bottom of the dialog box.

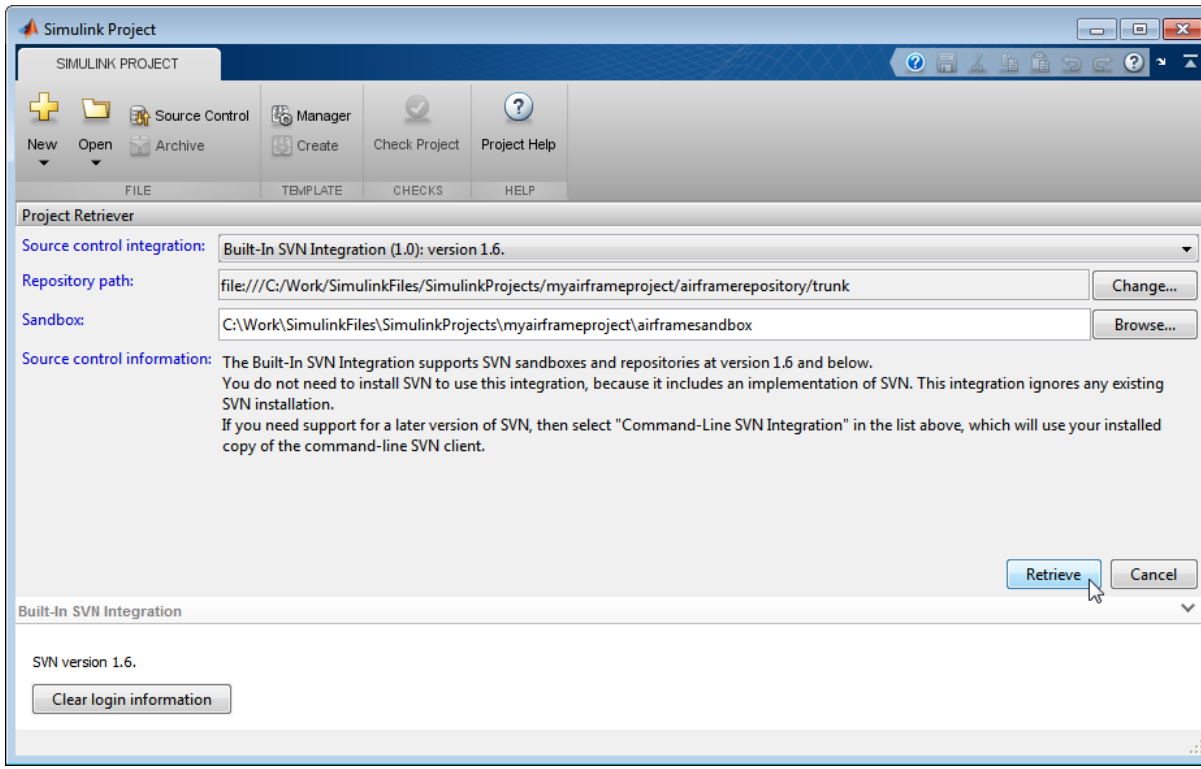
The retriever uses the **Selected URL** when you click **OK**.



d Click **OK** to continue and return to the Project Retriever.

4 Click **Browse** to select the sandbox folder where you want to put the retrieved files for your new project.

Caution Using a network folder with SVN is slow and currently has known bugs e.g., http://subversion.tigris.org/issues/show_bug.cgi?id=3053. Instead, use local sandbox folders.



5 Click **Retrieve**.

6 Watch the **Built-In SVN Integration** pane for messages as the project retrieves your files from source control.

   If you are retrieving files to update an existing project, your project opens.

7 If you are retrieving files to a new sandbox, a dialog appears to report that the files in the repository have been checked out to your selected sandbox folder, and to check whether you want to create a project in the folder. Click **Yes** to continue creating the project. Click **No** to leave the files on disk and return to the retriever.

8 When you click **Yes**, the new project controls appear.

   a Enter a project name.

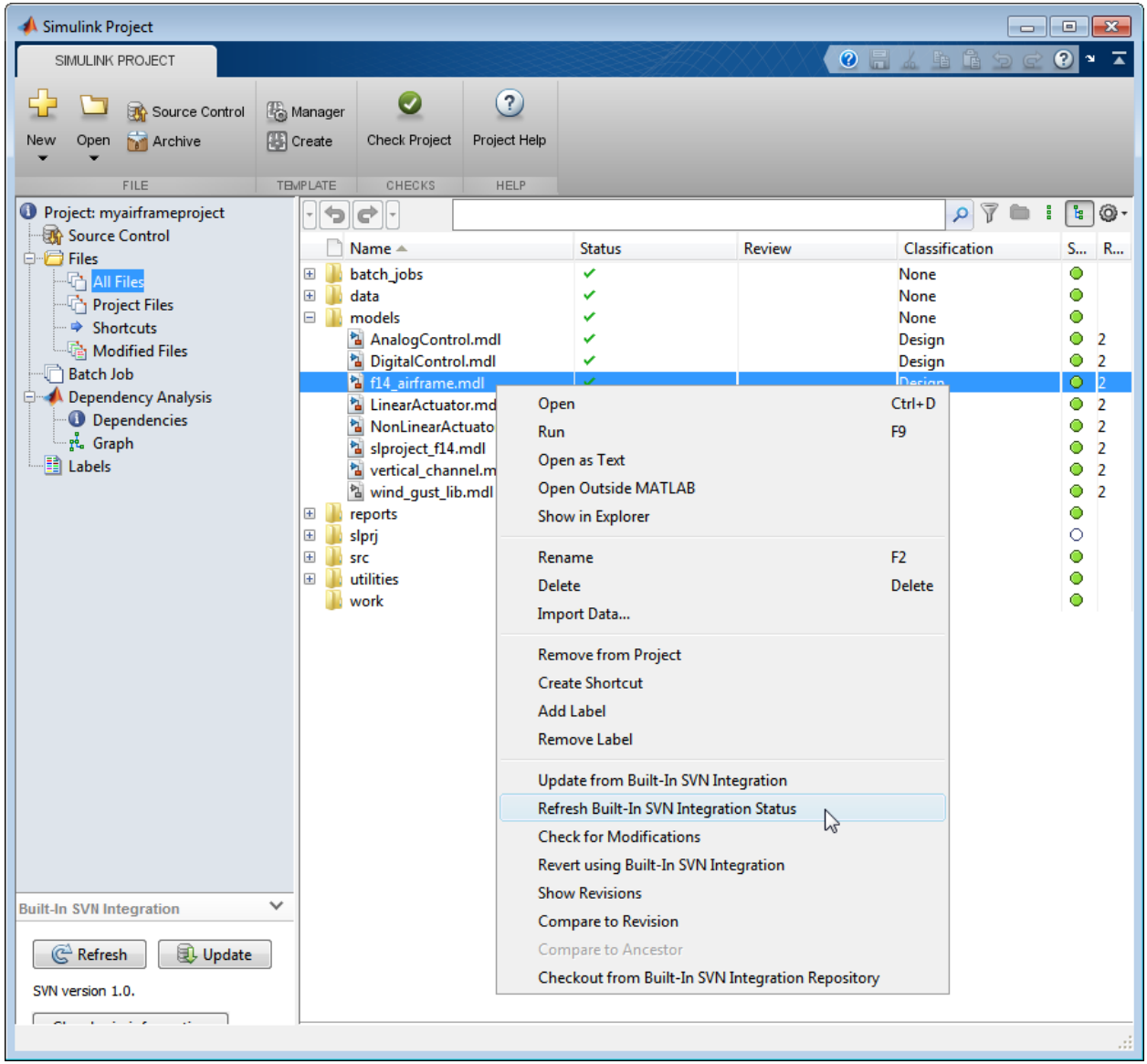
b Click **Detect** to identify the source control in the project folder.

c Click **Create** to finish creating the new project in your new sandbox.

The Simulink Project Tool displays the empty Project Files list for your chosen project root. Your project does not yet contain any files. You need to select files to add. For next steps, see "Add Files to the Project" on page 13-26.

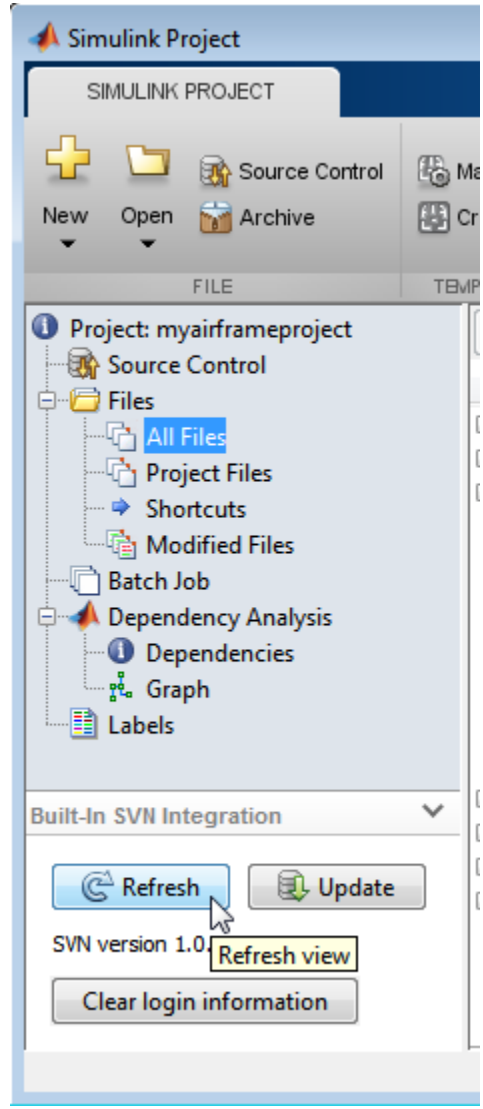
Refresh Status of Project Files

To check the status of individual files, right-click files in any view to select **Refresh**. This action queries the local sandbox state and checks for changes made with another tool. For SVN, **Refresh** does not contact the repository.



To check source control status of *all* project files, click the **Refresh** button in the source control pane at bottom left. The source control pane title depends

on your source control, for example, **Built-In SVN Integration**. The source control pane reports source control messages, and the buttons in the pane apply to the whole project.

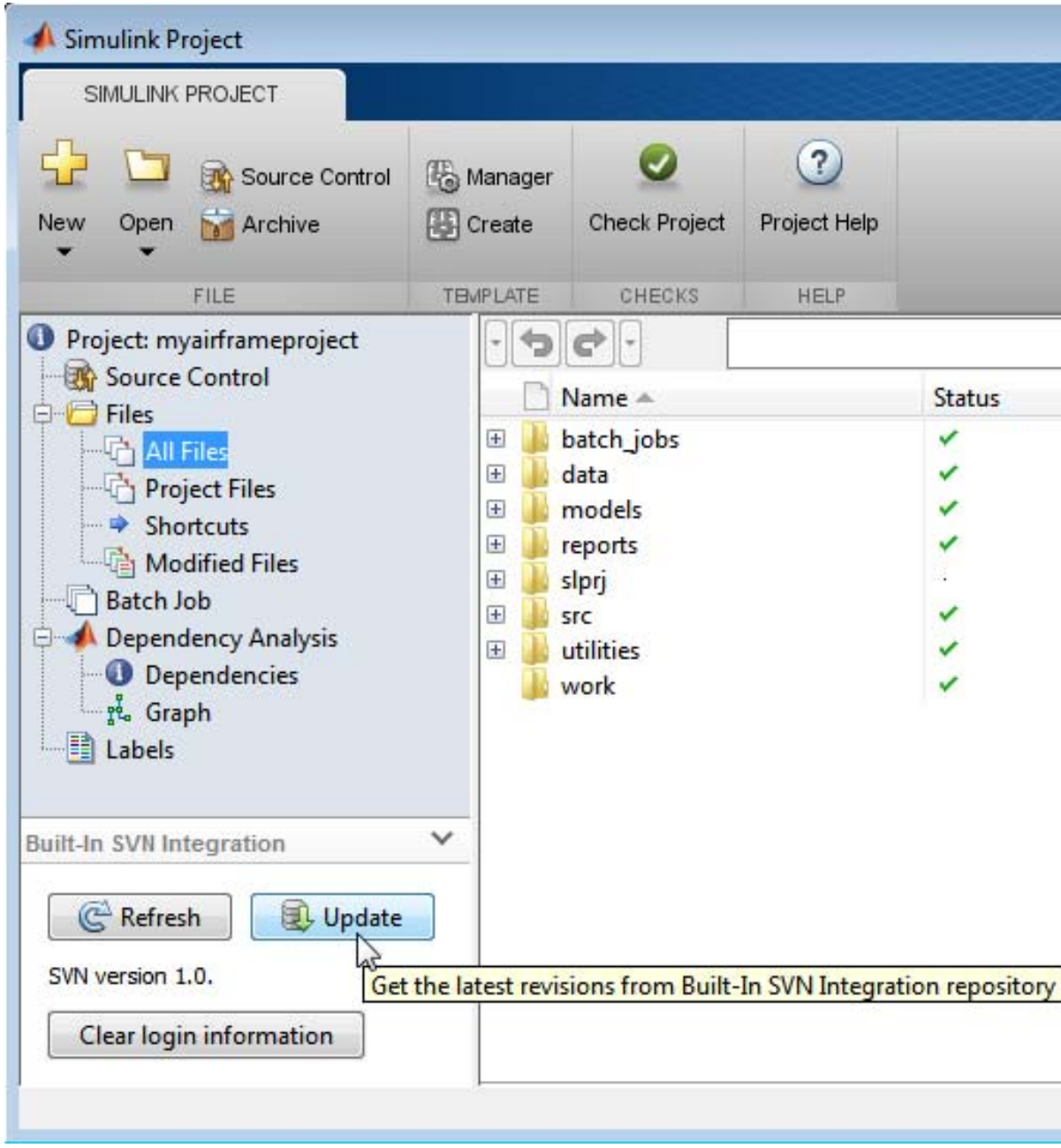


Refresh refreshes the view of the source control status for all files under `projectroot`. When you click **Refresh**, this updates the information shown in the **Revision** column and the source control status column (e.g., **SVN** or **Modifications** column). Hover over the **Modifications** row to see the tooltip showing the source control status of a file, e.g., **Modified (Checked Out)**.

For SVN repositories that require login, you can click **Clear login information** to clear your login information.

Update Revisions of Project Files

To get the latest revisions of *all* project files from the source control repository, click the **Update** button in the source control pane. The source control pane title depends on your source control, for example, **Built-In SVN Integration**.


Simulink Project
SIMULINK PROJECT
New
Open
Source Control
Archive
Manager
Create
Check Project
Project Help
FILE
TEMPLATE
CHECKS
HELP
Project: myairframeproject
Source Control
Files
All Files
Project Files
Shortcuts
Modified Files
Batch Job
Dependency Analysis
Dependencies
Graph
Labels
Name
Status
batch_jobs
data
models
reports
slprj
src
utilities
work
Built-In SVN Integration
Refresh
Update
SVN version 1.0.
Clear login information
Get the latest revisions from Built-In SVN Integration repository

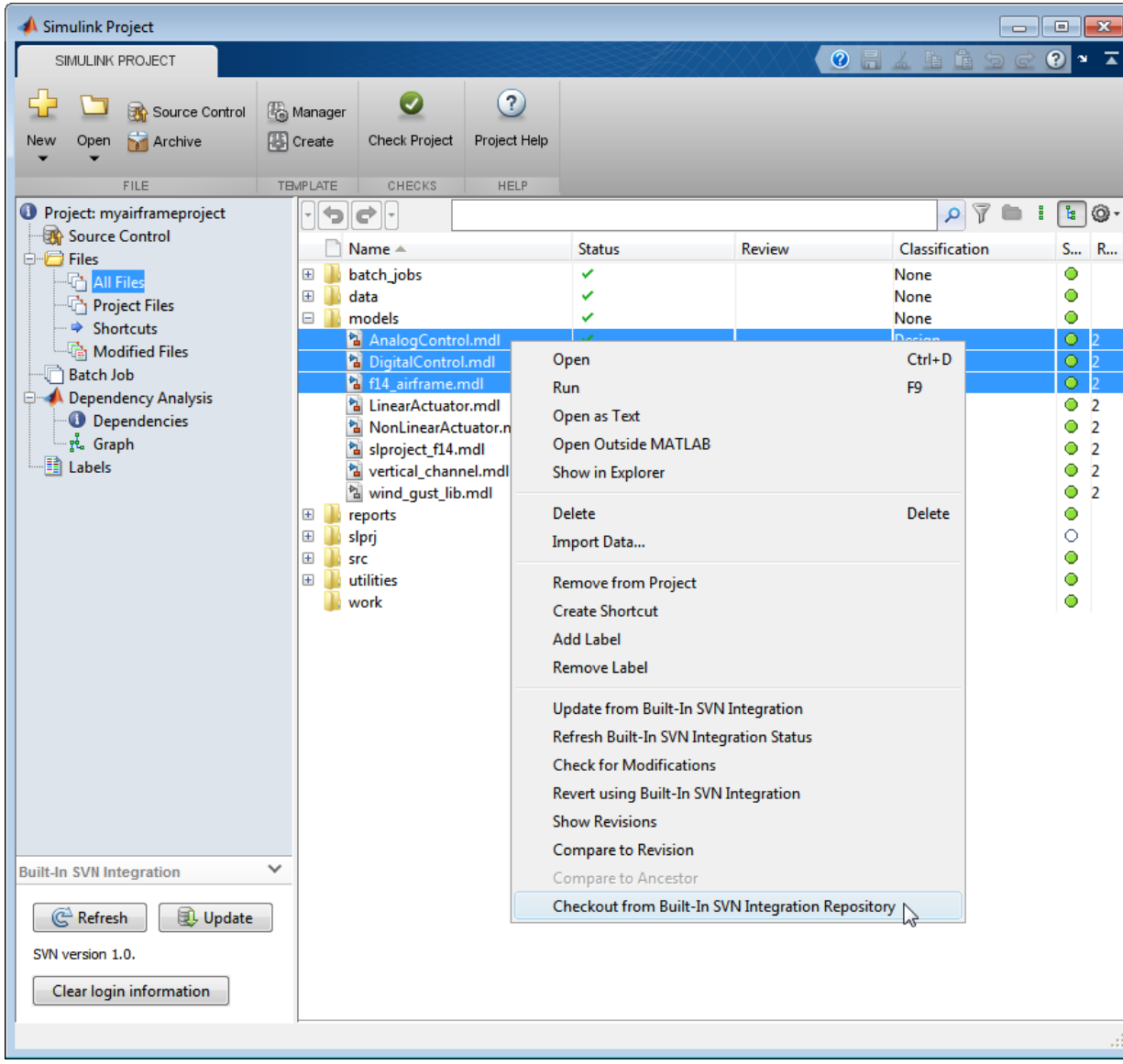
To update selected files, right-click and select **Update from Built-In SVN Integration Repository** to get fresh local copies of the selected file from the repository.

Check Out Files

To check out files,

1. In any Files view, click to select a file, or press **Shift**+click to select multiple files.
2. Right-click the selected files and select **Checkout from *`Source Control`***.

   The menu wording for *`Source Control`* is specific to your selected source control, e.g., for SVN, **Checkout from Built-In SVN Integration Repository**.


Simulink Project
SIMULINK PROJECT
New
Open
Source Control
Archive
Manager
Create
Check Project
Project Help
FILE
TEMPLATE
CHECKS
HELP
Project: myairframeproject
Source Control
Files
All Files
Project Files
Shortcuts
Modified Files
Batch Job
Dependency Analysis
Dependencies
Graph
Labels
Name
Status
Review
Classification
S...
R...
batch_jobs
data
models
AnalogControl.mdl
DigitalControl.mdl
f14_airframe.mdl
LinearActuator.mdl
NonLinearActuator.n
slproject_f14.mdl
vertical_channel.mdl
wind_gust_lib.mdl
reports
slprj
src
utilities
work
None
Open Ctrl+D
Run F9
Open as Text
Open Outside MATLAB
Show in Explorer
Delete Delete
Import Data...
Remove from Project
Create Shortcut
Add Label
Remove Label
Update from Built-In SVN Integration
Refresh Built-In SVN Integration Status
Check for Modifications
Revert using Built-In SVN Integration
Show Revisions
Compare to Revision
Compare to Ancestor
Checkout from Built-In SVN Integration Repository
Built-In SVN Integration
Refresh
Update
SVN version 1.0.
Clear login information

Note With SVN, use **Checkout from Built-In SVN Integration Repository** to get a lock on a file. This option does not modify the file in your local sandbox.

To get a fresh local copy of the file from the repository, select **Update from Built-In SVN Integration Repository**.

For next steps, see "Review Changes and Commit Modified Files" on page 13-89.

Review Changes and Commit Modified Files

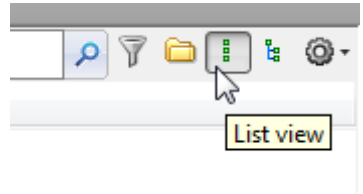
In this section...

View Modified Files

The Modified Files node is visible only if you are using source control integration with your project.

Use the Modified Files node to review, analyze, label, and commit modified files. Lists of modified files are sometimes called *changesets*. The Modified Files node aids the reviewing process.

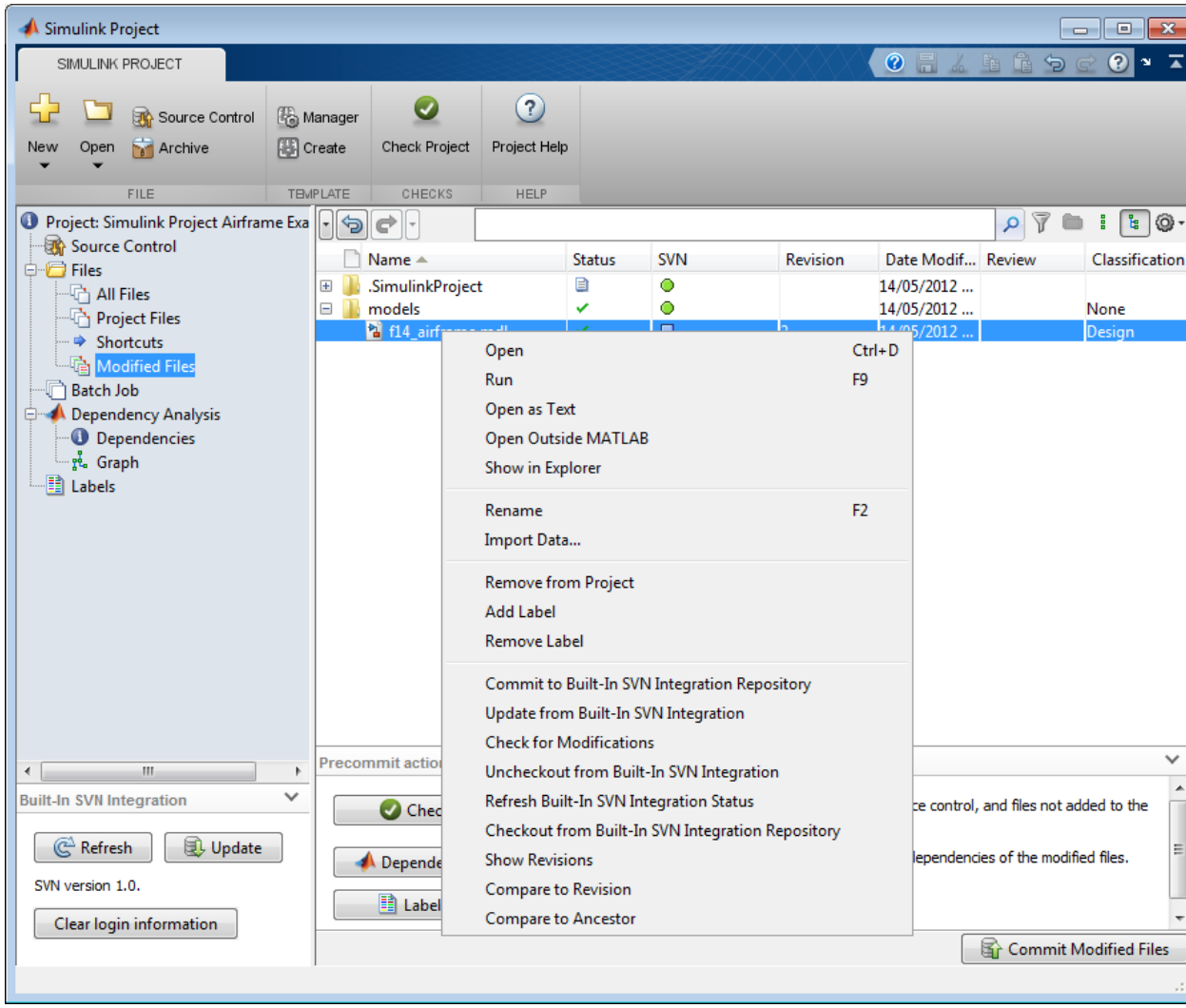
In the Modified Files view, it can be useful to switch to List view. Use the List view or Tree view buttons at top right.



As in the other Files nodes, in the Modified Files view you can right-click files or multiple selected files to:

- Add and remove labels.
- Update from source control.

- Uncheckout from source control.
- Commit to repository.
- Refresh source control status.
- Compare against selected revision or ancestor.



Project Definition Files

The files in `.SimulinkProject` are project definition files generated by your changes. The project definition files allow you to create shortcuts and add labels to files without checking them out, and add other metadata such as a project description. Project definition files also define which files are added to your project.

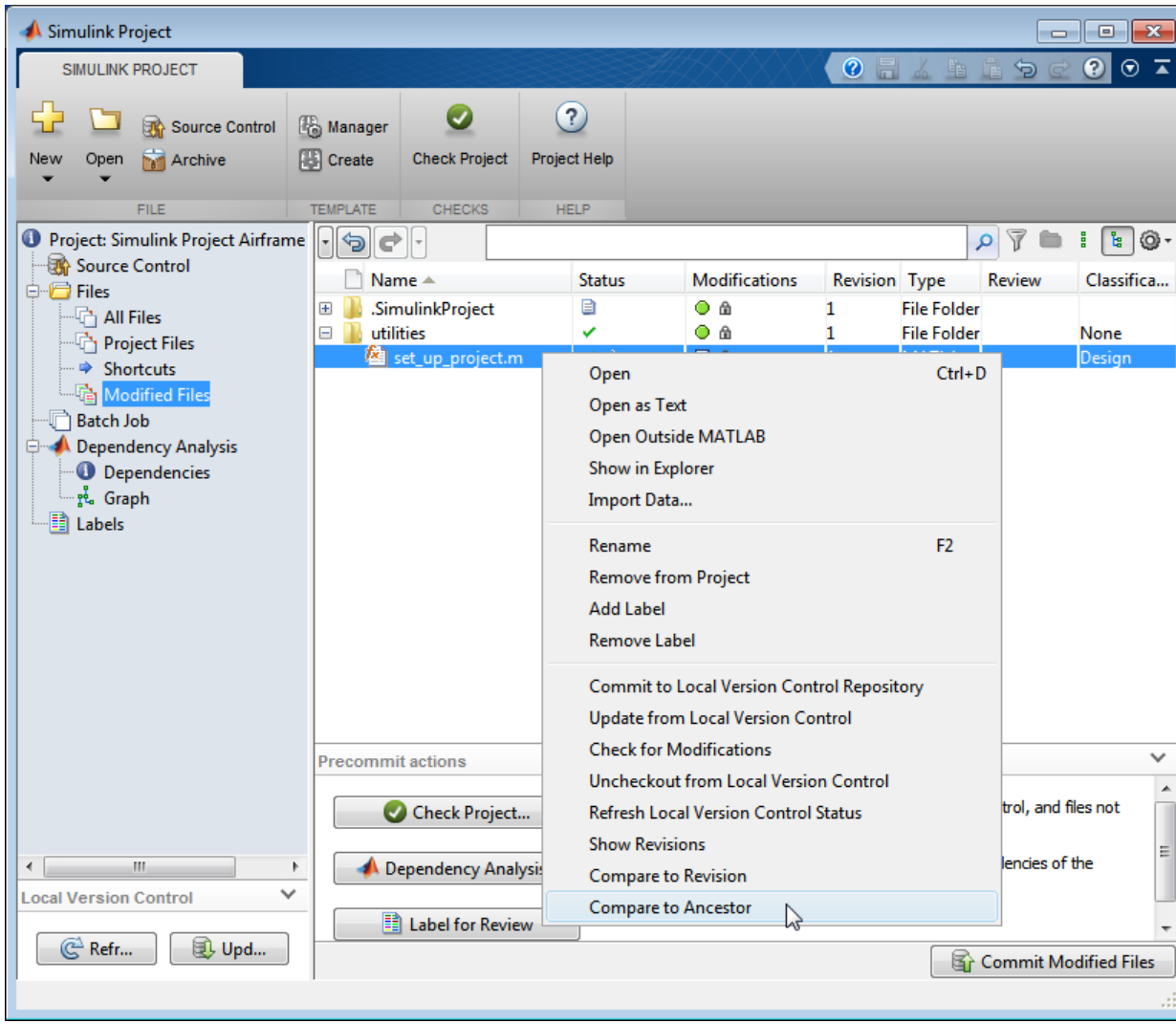
Any changes you make to your project (e.g., to shortcuts, labels, categories, or files in the project) generate changes in the `.SimulinkProject` folder. These files store the definition of your project in XML files whose format is subject to change.

You should never need to view project definition files directly, except when the source control tool requires a merge. The files are shown so that you know about all the files being committed to the source control system. See "Resolve Conflicts" on page 13-95.

Review Changes

To review changes in modified files, right-click selected files to view revision logs and compare against another revision or ancestor.

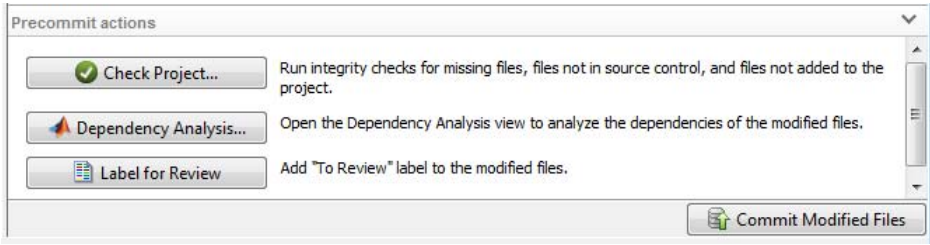
- Select **Show Revisions** to open the File Revisions dialog box and browse the history of a file. In the table, you can view SVN information about who previously committed the file, when they committed it, and the log messages.
- Select **Compare to Revision** to open a dialog where you can select the revision you want to compare. You can select multiple files and select a revision to compare against for each file. When you click **Compare**, your comparisons run and the Comparison Tool displays reports.
- Select **Compare to Ancestor** to run a comparison with the last checked out version in the sandbox. The Comparison Tool displays a report.



When reviewing changes, you can merge Simulink models from the Comparison Tool report (requires Simulink Report Generator).

Precommit Actions

The Precommit actions pane in the Modified Files view contains tools you might want to use before committing your changes to source control.



- Click the **Check Project** button to check the integrity of the project. For example, is everything under source control in the project? Are all project files under source control? A dialog box reports results. You can click for details and follow prompts to fix problems, e.g., if you would like to add files to your repository.

  For an example showing how the checks can help you, see "Upgrade Model Files to SLX and Preserve Revision History" on page 13-15.

  This function is also in the **Simulink Project** tab (**Check Project**) so you can run the checks from any project view.

  For more information on some problems the checks can fix, see "Work with Derived Files in Projects" on page 13-96.

- If you want to check for required files, click the **Dependency Analysis** button to open the Dependency Analysis view, with your modified files selected for analysis. You can optionally change the check box selections before clicking **Analyze**. You can use the dependency tools to analyze the structure of your project. See "Analyze Project Dependencies" on page 13-32.

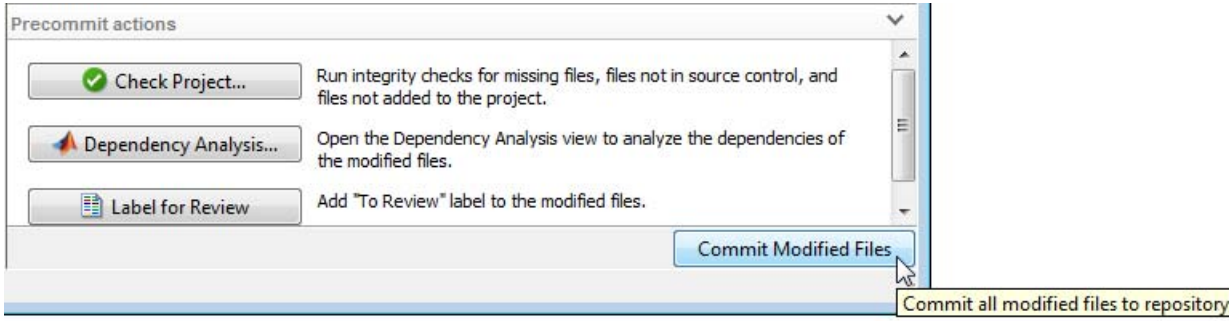
- If you want to add the label **To Review** to all files in your changeset, click the **Label for Review** button.

Note The files in `.SimulinkProject` are project definition files generated by your changes, and these files are not labeled. See "Project Definition Files" on page 13-91.

Commit Modified Files

To commit your changes to source control:

1. Click the **Commit Modified Files** button to check in all files in the modified files list.



2. A dialog prompts you to enter comments for your submission.

3. Click **Submit** or **Cancel**.

Revert Local Changes and Release Locks

If you want to roll back local changes, right-click a file and select **Uncheckout from Built-In SVN Integration Repository** to release locks and revert to the version in the last sandbox update (e.g., the last version you synchronized or retrieved from the repository).

Select **Revert using Built-In SVN Integration Repository** to choose a revision to revert to.

Resolve Conflicts

If two people both change the same file in different sandboxes, you get a conflict message when you try to commit your modified files. You can also get conflicts in your project definition files. For example, if two people both change the labels attached to a file, you can get a conflict in one of the project definition files in the `.SimulinkProject` folder.

To resolve conflict problems:

1. Look for conflicted files in the Modified Files view.
2. It can be useful to switch to List view. Click List view at the top right.
3. Check the source control status column (e.g., the **SVN** or **Modifications** column) for files with a red icon. The tooltip shows **Conflicted**.

4. Examine the conflict. You might want to select **Compare to Ancestor** to run a comparison with the last checked out version in the sandbox, or **Compare to Revision** to select revisions for comparison.

   In the Comparison Tool, examine the report to see how the files have changed.

5. Resolve the conflict. In the Comparison Tool report, you can merge changes between revisions (requires Simulink Report Generator). For example, you can merge project file labels and shortcuts.

   You might want to open files from the project to make changes and resolve the conflict. If you need to change labels manually, see “Label Files” on page 13-49, or to change the project description, see the Project node.

6. When you are satisfied that you have resolved the changes and want to commit the version in your sandbox, right-click the file and select **Mark Conflict Resolved**. You can now commit your file.

Work with Derived Files in Projects

You might not want to include derived and temporary files in your project or commit them to source control. Use **Check Project** in the Precommit Actions pane or the **Simulink Project** tab to check the integrity of the project. If you add the `slprj` folder to a project, the project checks advise you to remove this from the project and offer to make the fix. The checks recommend a best practice of not adding derived and temporary files to source control.

You might not want to commit derived files, such as `.mex*`, the contents of the `slprj` folder, `sccprj` folder, or other code generation folders, because they can cause problems. For example:

- With a source control that can do file locking, users can encounter conflicts. If `slprj` is under source control and a user generates code, this changes most of the files under `slprj` and locks those files. Other users then cannot generate code because they get file permission errors. The `slprj` folder is also used for simulation via code generation (e.g., with model reference or Stateflow), so locking these files can have a big impact on a team. The same problems arise with binaries, such as `.mex*`.
- Deleting `slprj` is quite commonly required. However, deleting `slprj` causes problems such as “not a working copy” errors if the folder is under some source control tools (e.g., SVN).
- If you want to check in the generated code as an artifact of the process, then it is common to copy some of the files out of the `slprj` cache folder and into a separate location that is part of the project. That way the temporary cache folder can be deleted whenever required. See the `packNGo` function to discover the list of generated code files, and use the project API to add to the project with appropriate metadata.
- The `slprj` folder can contain a large number of small files. This can have a performance impact with some source control tools when each of those files has to be checked to see if it is up-to-date.

Use Templates to Create Standard Project Settings

In this section...

Use Templates for Standard Project Setup

You can use templates to create and reuse a standard project structure. You can use templates to make consistent projects across teams. You could use templates to create new projects that:

- Use a standard folder structure.
- Set up a company standard environment, for example, with company libraries on the path.
- Have access to tools such as company Model Advisor checks.
- Use company standard startup and shutdown scripts.
- Share labels and categories.

When your existing project is in a state that others would find useful, or you want to reuse, then you can create a template from it and use it when creating new projects.

Create a Template from Your Current Project

You can create a template from an existing project, and then use the template to create new projects.

To create a template from your current project, on the **Simulink Project** tab, in the **Template** section, select **Create**.

To use the template when creating new projects, you must put the template on the template path. If the folder where you create the new template is not already on the template path, you can add folders to the path later in the Template Manager.

When you create a new template, it contains the structure and *all* the contents of the current project, so that you can reuse scripts and other files for your standard project setup. Before creating the template, create and edit a new copy of the project to contain only the files you want to reuse.

To create a template from an existing project that is under version control:

1. Get a new working copy of the project. See "Retrieve a Working Copy of a Project from Source Control" on page 13-76.
2. To avoid accidentally committing changes to your project that you have made only to create the template, you might want to stop using source control with this sandbox. In the Source Control view, click `Select an available source control integration` and select `None` to remove this sandbox from source control.
3. Remove the files that you do not want in the template. For example, you might want to reuse only the utility functions, startup and shutdown scripts, and labels. In the Project Files view, right-click unwanted files and select **Remove from Project**.
4. On the **Simulink Project** tab, in the **Template** section, click **Create**.
5. To verify that your template behaves as you expect, create a new empty project that uses your new template.

To make changes to an existing template:

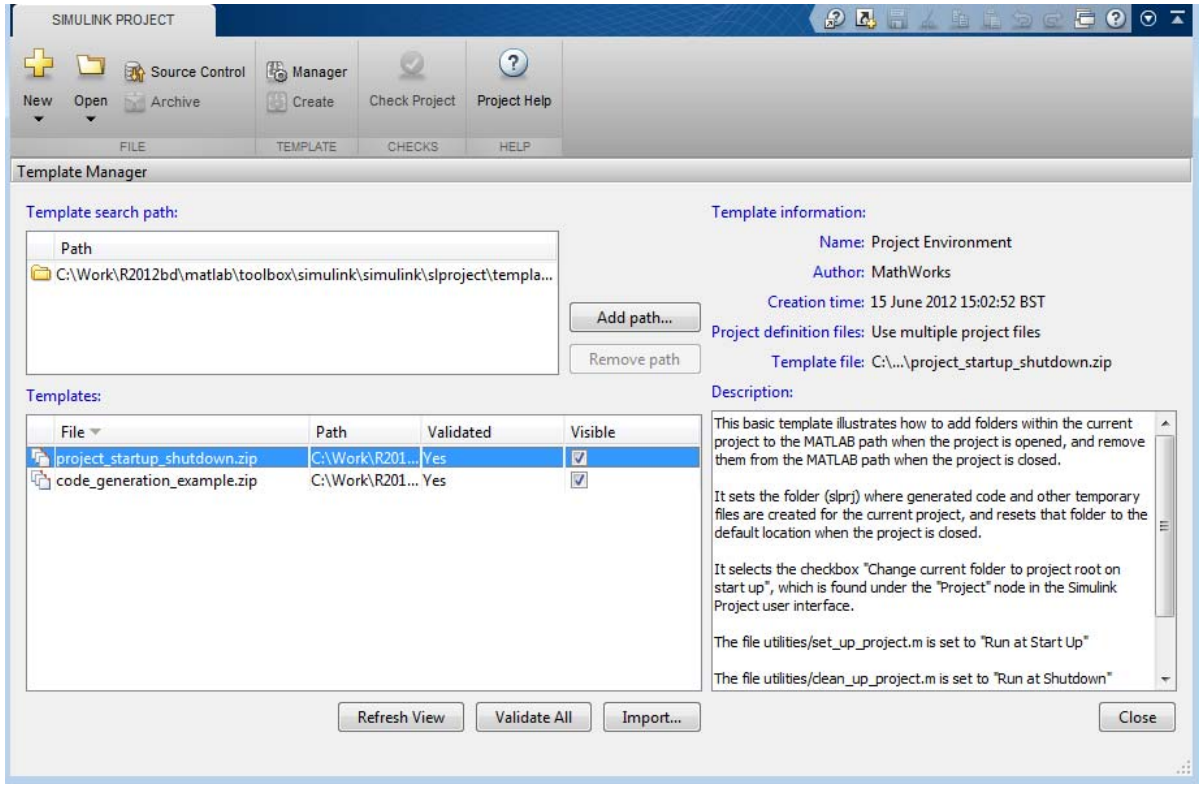
1. Create a new empty project using the template you want to modify.
2. Make the desired changes to the project.
3. On the **Simulink Project** tab, in the **Template** section, click **Create**.

   Either create a new template, or overwrite the existing template.

View and Validate Templates

Use the Template Manager to view a default template, or locate and validate template files. On the **Simulink Project** tab, in the **Template** section, click **Manager**.

Click the templates in the **Templates** pane to view the **Description**.



For example, the `Project Environment` template shows you how to specify options to:

- Set up and reset the folders on the path when you open or close the project.

- Define the location of the folder (`slprj`) for generated code and other temporary files.
- Run standard scripts at startup and shutdown.
- Include information in a template about names, authors, and description.

See also “Example Templates” on page 13-101.

In the Template Manager you can:

- Validate that a template is usable to create new projects.
- Add folders to the template path to make templates visible in the New Project dialog **Templates** list.
- Specify which templates to make visible in the **Templates** list.

Create a New Project Using a Template

To try using the Project Environment template, select it when creating a new project.

Use the Templates list to select a template during project creation. Only templates on the template path appear in the dialog.

Note If you create a project in a folder that already contains files, you are warned if there are any collisions with the template. The template will overwrite the existing files if you choose to continue.

Import New Templates

You can use templates to share information and best practices. New templates can be created by you, your colleagues, or downloaded from MATLAB Central:

```
http://www.mathworks.com/matlabcentral/
```

.

You need to import a new template to make it available for use in new projects.

1. On the **Simulink Project** tab, in the **Template** section, click **Manager**.
2. Click **Import**.
3. Browse to the zip file that contains the new template.
4. Select a location on the template path to save the new template. Click **Import** to validate the template and import it. If validation fails, then it will not be imported.

Example Templates

Project Environment Template

Try the `Project Environment` template if you are creating a project in a new folder and intend to add files later. You can view information about the template settings in the description field of the Template Manager. The `Project Environment` template can create a new project with a preconfigured structure, and utilities to configure the path and environment with startup and shutdown shortcuts. For example, the path utilities help set up your search path to ensure dependency analysis can detect project files. You can modify any of these files, folders, and settings later. To try the template, select the `Project Environment` template when creating a new project.

The utilities `set_up_project.m`, `clean_up_project.m` and `project_paths.m` configure the path and settings when you open and close the project. The startup shortcut changes current folder to the project root. The utilities set the folder (`slprj`) where generated code and other temporary files are created for the current project, and reset that folder to the default location when the project is closed. Shortcuts provide quick access to frequently required models and tasks.

Code Generation Example Template

Try the `Code Generation Example` template to set up a project with settings for production code generation of a plant and controller. This template requires Simulink Coder and Embedded Coder. To try the template, select the `Code Generation Example` template when creating a new project.

The utilities `set_up_project.m`, `clean_up_project.m` and `project_paths.m` configure the path and settings when you open and close the project, as

in the Project Environment template. These utilities set the folder (`slprj`) where generated code and other temporary files are created for the current project, and reset that folder to the default location when the project is closed. The startup shortcut also changes the current folder to the project root. Other shortcuts define the controller parameters as a tunable structure in the generated code. Shortcuts provide quick access to frequently required models and tasks.

The settings of the model `feedback_control` are changed to be suitable for production code generation. Settings are changed as the Model Advisor recommends in the checks for both **By Product > Embedded Coder** and **By Task > Code Efficiency**, including:

- **System Target File** is set to `ert.tlc`.
- Code Generation reporting is enabled.
- The following diagnostics are set:
  - **Bus Signals Treated As Vectors**, Connectivity pane, set to `Error`.
  - **Model Initialisation**, **Underspecified initialization detection** set to `Simplified`
- The following optimizations are enabled:
  - All Data Initialisation Optimizations
  - Saturation maths operations for floating point to integer conversion (and vice versa)
  - Inline parameters, Inline Invariant Signals

After you create the project, open the model `feedback_harness` to examine the controller and plant models.

Right-click to run the project shortcut `generate_controller_code.m` to generate code for the controller and display a code generation report.

Archive Projects in Zip Files

To package and share project files, you can export all project files to a zip file. For example, you can share a zipped project with people who do not have access to the connected source control tool.

1. On the **Simulink Project** tab, select **Archive**. A file browser opens.
2. (Optional) Edit the zip file name and change the destination folder. By default, the file *`myprojectname`*`.zip` is created in the current working folder.
3. Click **Save**.

The archive command exports a complete project.

To create a new project from an archived project, on the **Simulink Project** tab, select **New > New Project from Zip Archive**.

Locate the archive zip file to extract.

Analyze 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*.

Dependency Analysis Requirements	Tools to Choose
Find required files for an entire project	Use dependency analysis from the Simulink Project Tool. See "Analyze Project Dependencies" on page 13-32.
Detailed dependency analysis of a specific model with control of more options	Use the manifest tools from your model. See "Generate Manifests" on page 13-105. Generate a manifest if you want to: • Save the list of the model dependencies to a manifest file. • Create a report to identify where dependencies arise.

Dependency Analysis Requirements	Tools to Choose
	• Control the scope of dependency analysis. • Identify required toolboxes.

After you generate a manifest for a model to determine its dependencies, you can:

- View the files required by your model in a manifest file.
- Trace dependencies using the report to understand why a particular file or toolbox is required by a model.
- 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 "Model Dependency Viewer" on page 9-83.

Generate Manifests

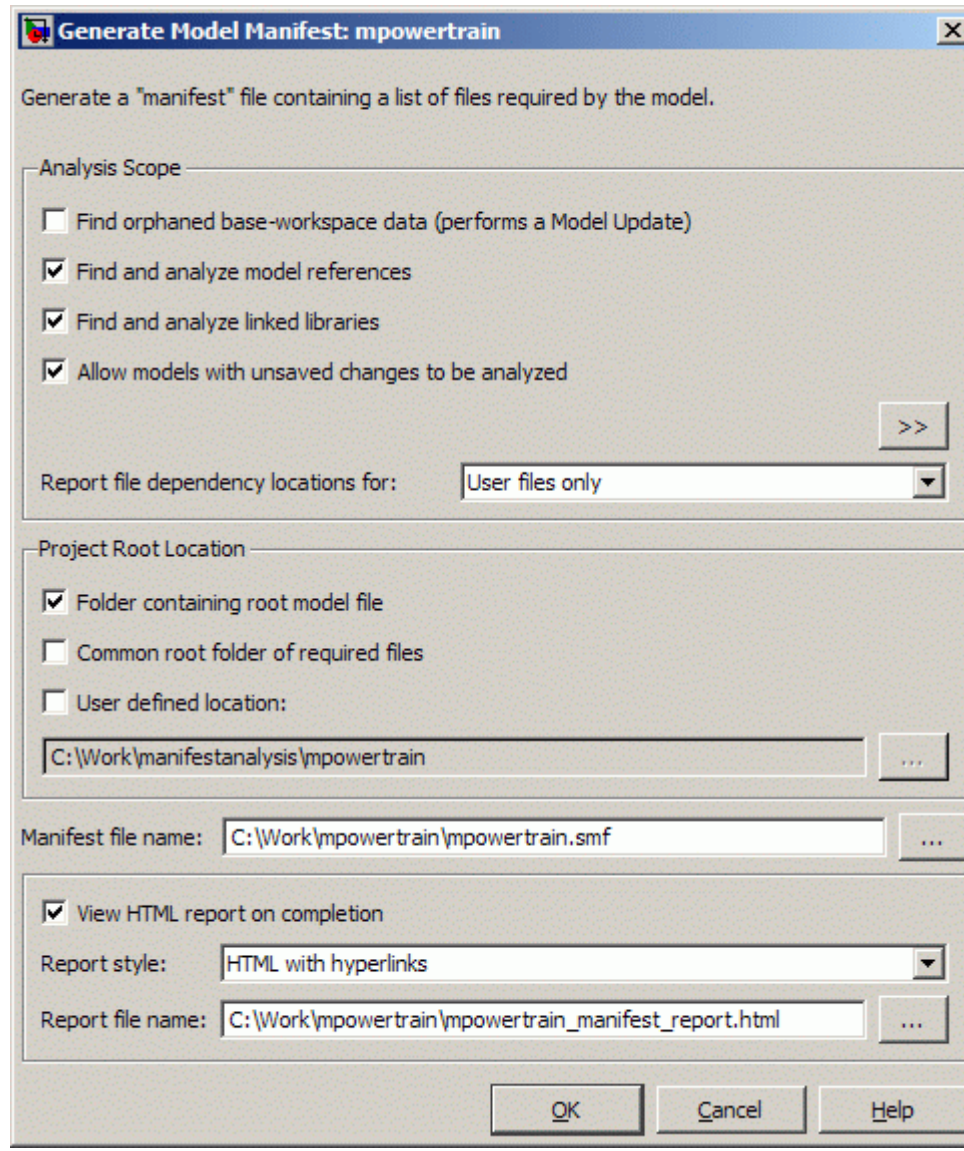
Generating a manifest performs the dependency analysis and saves the list of model dependencies to a manifest file. You must generate the manifest before using any of the other Simulink Manifest Tools.

Note The model dependencies identified in a manifest depend upon the **Analysis Scope** options you specify. For example, performing an analysis without selecting **Find Library Links** might not find all the Simulink blocksets that your model requires, because they are often included in a model as library links. See "Manifest Analysis Scope Options" on page 13-109.

To generate a manifest:

1 Select **Analysis > 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 13-109).
- 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 "Use the Model Manifest Report" on page 13-124 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 13-122.
Analyze model and block callbacks (including Interpreted MATLAB Function blocks)	Searches for file dependencies introduced by the code in Interpreted MATLAB Function blocks, block callbacks, and model callbacks. For more detail on how callbacks are analyzed, see "Code Analysis" on page 13-121.
Find files required for code generation	Searches for file dependencies introduced by Simulink Coder custom code, and 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 Code Replacement Library definition files (.m or .mat). See also "Required Toolboxes" on page 13-126, and the source code item in "Special Cases" on page 13-122.
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 13-122.
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 MATLAB Functions blocks	Searches for MATLAB Function blocks in the model, and identifies any file dependencies (outside toolboxes) introduced in the code. Toolbox dependencies introduced by a 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 "Links Between Models and Requirements" 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 13-122.
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 13-121.
Store MATLAB code analysis warnings in manifest	Saves any warnings in the manifest.

See also "Scope of Dependency Analysis" on page 13-120 for more information.

Command-Line Dependency Analysis

Check File Dependencies

To programmatically check for file dependencies, use the function `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`* — returns the full path of the user dependencies (`.smd`) file, if it exists, 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. See "Edit Manifests" on page 13-114.
- *`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 an example model, it returns an empty list of required files because the standard MathWorks installation includes all the files required for the example models.

Check Toolbox Dependencies

To check which toolboxes are required, use the function `dependencies.toolboxDependencyAnalysis` as follows:

```
[names,dirs] = dependencies.toolboxDependencyAnalysis(files_in)
```

files_in must be a cell array of strings containing `.m` or model files on the MATLAB path. Simulink model names (without file 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'
   missing =
        []
   depfile =
        []
   manifestfile =
        []
   ```

2. Call `toolboxDependencyAnalysis` on the `files` output of step 1.

   For example:

```
tbxes = dependencies.toolboxDependencyAnalysis(files)

tbxes =
[1x24 char]    'MATLAB'    'Simulink Coder'    'Simulink'
```

To view long product names examine the `tbxes` cell array as follows:

```
tbxes{:}

ans =
Image Processing Toolbox

ans =
MATLAB

ans =
Simulink Coder

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 Simulink Coder is always reported as required. See "Required Toolboxes" on page 13-126 for more examples of how your installed products and analysis scope settings can affect reported toolbox requirements.

Edit Manifests

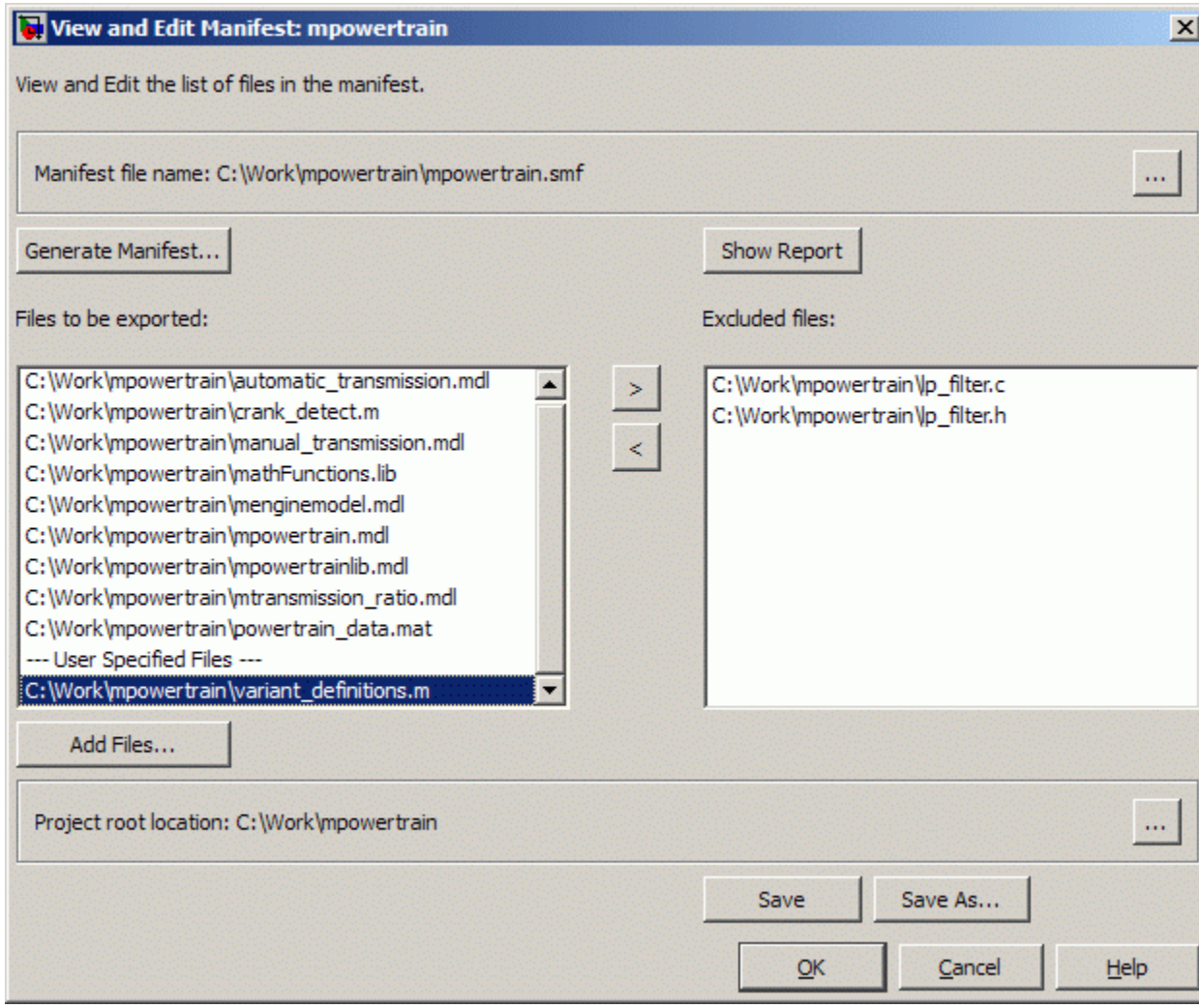
After you generate a manifest, you can view the list of files identified as dependencies, and manually add or delete files from the list.

To edit the list of required files in a manifest:

1. Select **Analysis > Model Dependencies > 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 "Generate Manifests" on page 13-105).

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, so you do not need to repeat manual editing. For example, you might want to exclude source code or include a copyright document every time you generate a manifest for exporting to a customer. 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 "Use the Model Manifest Report" on page 13-124 for an example.

8 When you are finished editing the manifest, click **OK**.

Compare 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 **Analysis > 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.

Export Files in a Manifest

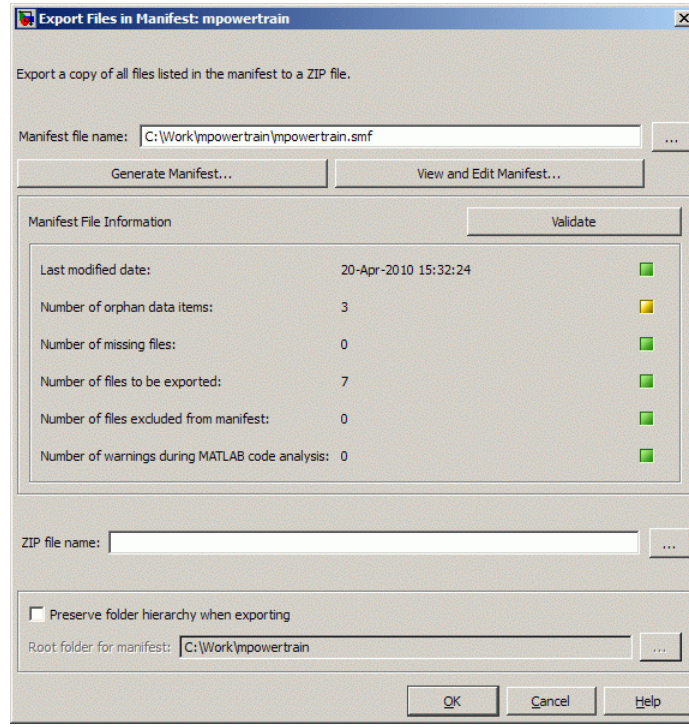
You can export copies of the files listed in the manifest to a ZIP file. Exporting the files allows you to package the model with its required files into a single ZIP file, so you can easily send it to another user or save it in a revision control system.

To export your model with its required files:

1 Select **Analysis > 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.



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 "Generate Manifests" on page 13-105).

---

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 "Edit Manifests" on page 13-114. 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 "Update a Block Diagram" on page 1-25). 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 13-109.

For more information on what the tool analyzes, refer to the following sections:

- "Analysis Limitations" on page 13-121
- "Code Analysis" on page 13-121
- "Special Cases" on page 13-122

Analysis Limitations

The analysis might not find all files required by your model (for examples, see "Code Analysis" on page 13-121).

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. Some SimEvents blocks do not introduce a detectable dependence on SimEvents.

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 "Edit Manifests" on page 13-114).

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 13-126 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 Simulink Coder 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 "Edit Manifests" on page 13-114).

- 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
DSP System Toolbox	From Wave File (Obsolete) block (Microsoft Windows operating system only) From Multimedia File block (Windows only)
Computer Vision System Toolbox™	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 13-121).

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.

Use 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 13-126.
- **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 "Generate Manifests" on page 13-105. 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 13-126.

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. Some MathWorks files under toolbox/shared can report only requiring MATLAB instead of their associated toolbox.

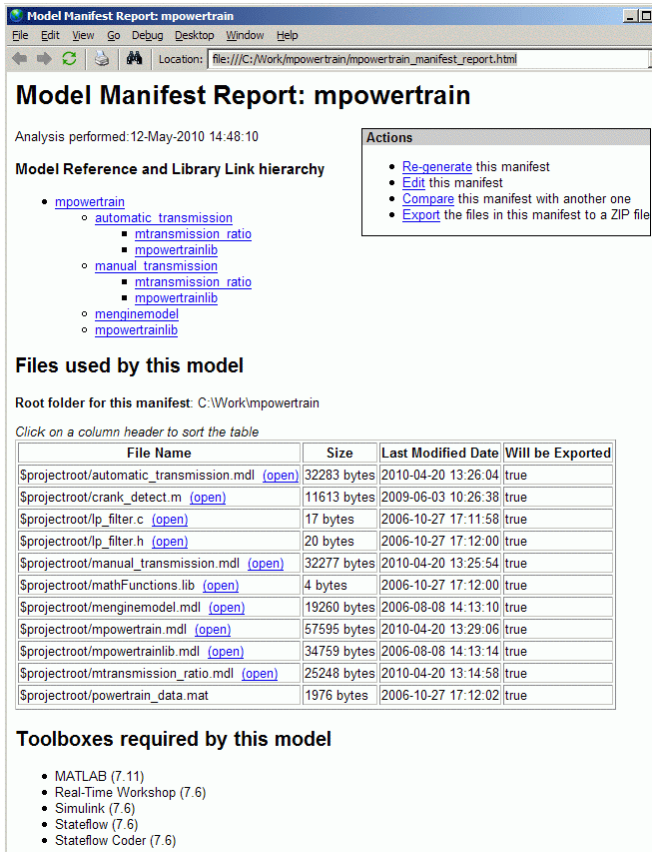
The results reported can be affected by your analysis scope settings and your installed products. For example:

- If you have code generation products and select the scope option "**Find files required for code generation**", then:
  - Simulink Coder software is always reported as required.
  - If you also have an `.ert` system target file selected then Embedded Coder software is always reported as required.
- If you clear the **Find library links** option, then the analysis cannot find a dependence on, for example, *`someBlockSet`*, 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
Model Reference and Library Link hierarchy
mpowertrain
automatic_transmission
mtransmission_ratio
mpowertrainlib
manual_transmission
mtransmission_ratio
mpowertrainlib
menginemodel
mpowertrainlib
Actions
Re-generate this manifest
Edit this manifest
Compare this manifest with another one
Export the files in this manifest to a ZIP file
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**

Simulating Dynamic Systems

14

Running Simulations

Simulation Basics

You can simulate a model at any time simply by clicking the **Run** button on the Model Editor displaying the model. See “Start a Simulation” on page 14-3.

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.

With 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 “Manage a Configuration Set” on page 10-12 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 “Pause or Stop a Simulation” on page 14-5), 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.

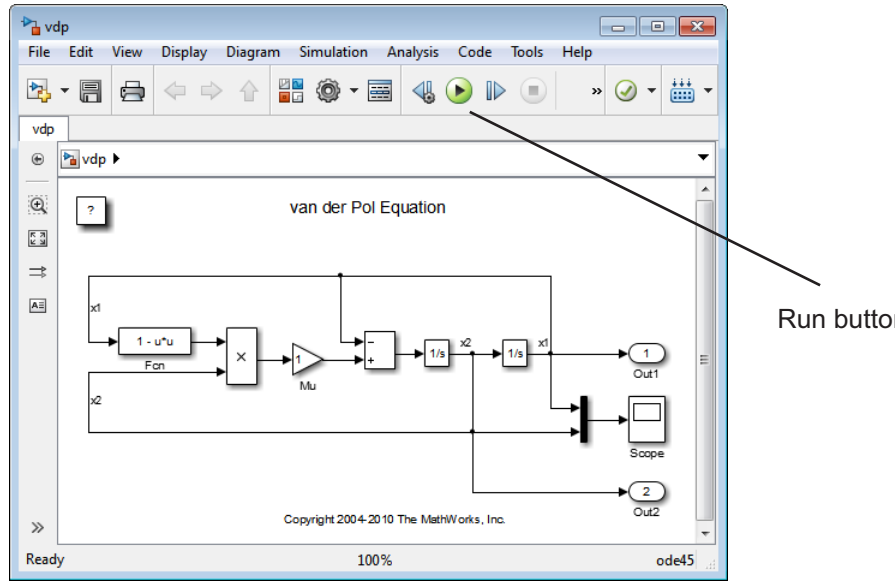
Control Execution of a Simulation

In this section...

Start a Simulation

This sections explains how to run a simulation interactively using this model. See "Run Simulation Using the sim Command" on page 15-3 and "Control Simulation using the set_param Command" on page 15-7 for information on running a simulation from a program, an S-function, or the MATLAB command line.

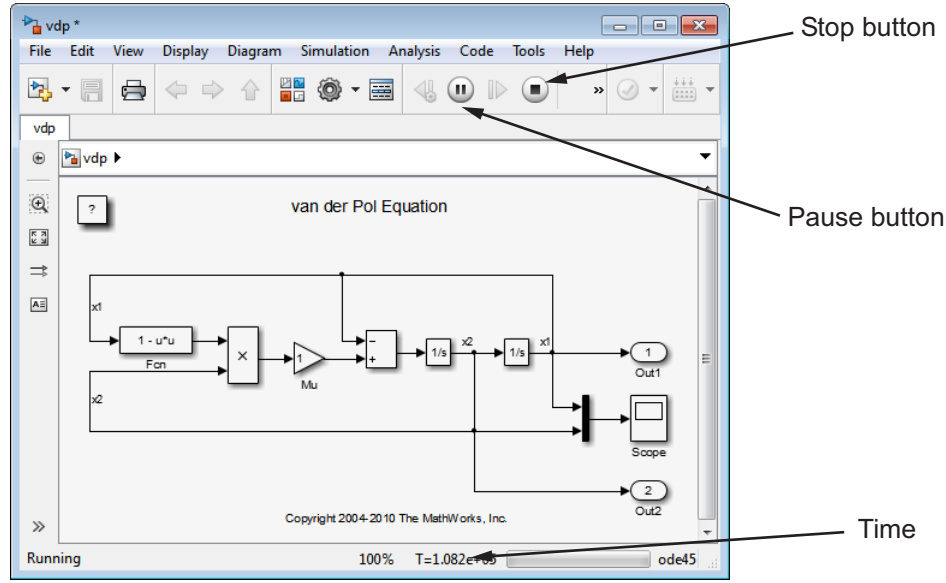
To start the execution of a model, from the **Simulation** menu of the Model Editor, select **Run** or click the **Run** button on the model toolbar.



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.

While the simulation is running, a progress bar at the bottom of the model window shows how far the simulation has progressed. A **Pause** command replaces the **Run** command on the **Simulation** menu. A **Pause** command appears on the menu and replaces the **Run** button on the model toolbar.



Your computer beeps to signal the completion of the simulation.

Pause or Stop 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 **Run** 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 **Run** 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.

Use Blocks to Stop or Pause a Simulation

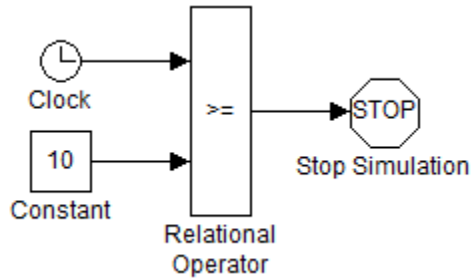
Using Stop Blocks

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

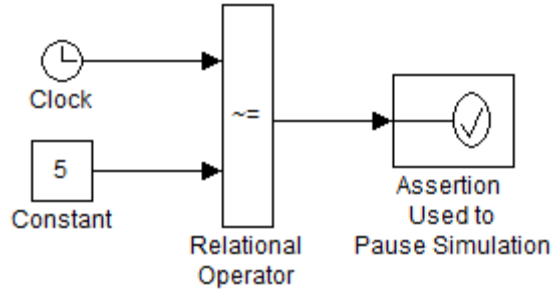
You can use an Assertion block to pause the simulation when the input signal to the block is zero. To create a pause block:

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 similarly 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 “Control Simulation using the set_param Command” on page 15-7 for more information on using the `set_param` command to control the execution of a Simulink model.

Specify 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.

Choose 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 14-10 provides background on the different types of solvers while "Choosing a Fixed-Step Solver" on page 14-13 and "Choosing a Variable-Step Solver" on page 14-17 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 14-14	Not Applicable
	Implicit	Not Applicable	"Implicit Fixed-Step Continuous Solvers" on page 14-16	Not Applicable

		Discrete	Continuous	Variable-Order
Variable-Step	Explicit	"Choosing a Variable-Step Solver" on page 14-17	"Explicit Continuous Variable-Step Solvers" on page 14-18	"Variable-Order Solvers" on page 14-13
	Implicit		"Implicit Continuous Variable-Step Solvers" on page 14-19	"Variable-Order Solvers" on page 14-13

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 14-12
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 "Improve Simulation Accuracy" on page 19-11.

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

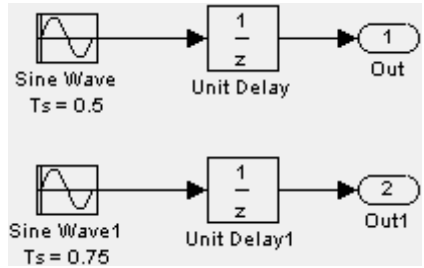
Both fixed-step and variable-step solvers compute the next simulation time as the sum of the current simulation time and a quantity known as the *step size*. With a fixed-step solver, the step size remains constant throughout the simulation. In contrast, with a variable-step solver, the step size can 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 14-24 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 14-20.

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 14-12 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 Error Tolerances for Variable-Step Solvers" on page 14-22.
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 14-10 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 an example 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 3-23) to handle continuous signals.

Specifying Error Tolerances for Variable-Step Solvers

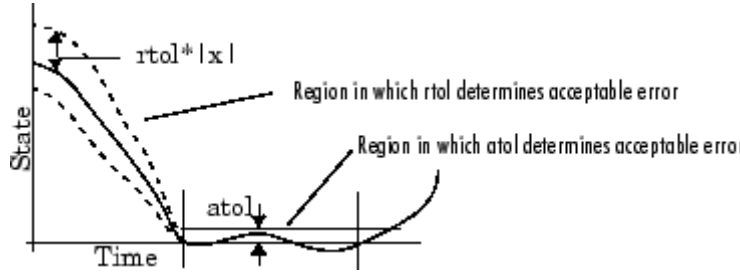
Local Error. The variable-step solvers use standard control techniques to monitor the local error at each time step. During each time step, the solvers compute the state values at the end of the step and determine the *local error*—the estimated error of these state values. They then compare the local 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 one* 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.



Absolute Tolerances. Your model has a global absolute tolerance that you can set on the Solver pane of the Configuration Parameters dialog box. This tolerance applies to all states in the model. You can specify `auto` or a real scalar. 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 resets to the maximum value that the state has assumed so 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` becomes 1e-3 also. If a state goes from 0 to 1000, then `abstol` changes 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.

Several blocks allow you to specify absolute tolerance values for solving the model states that they compute or that determine their output:

- Integrator
- Second-Order Integrator Limited
- Variable Transport Delay
- Transfer Fcn
- State-Space
- Zero-Pole

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 if, for example, the global setting does not provide sufficient error control for all of your model states because they vary widely in magnitude. The block absolute tolerance can be set to:

- `auto`
- –1 (same as `auto`)
- `real scalar`
- `real vector` (having a dimension equal to the number of corresponding continuous states in the block)

Tips. If you do choose to set the absolute tolerance, keep in mind that too low of a value causes the solver to take too many steps in the vicinity of near-zero state values. As a result, the simulation is slower.

On the other hand, if you choose too high of an absolute tolerance, your results can be inaccurate as one or more continuous states in your model approach zero.

Once the simulation is complete, you can verify the accuracy of your results by reducing the absolute tolerance and running the simulation again. If the results of these two simulations are satisfactorily close, then you can feel confident about their accuracy.

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:

$$\dot{x}_1 = f_1(x_1, x_3)$$
$$\dot{x}_2 = f_2(x_2)$$
$$\dot{x}_3 = f_3(x_2).$$

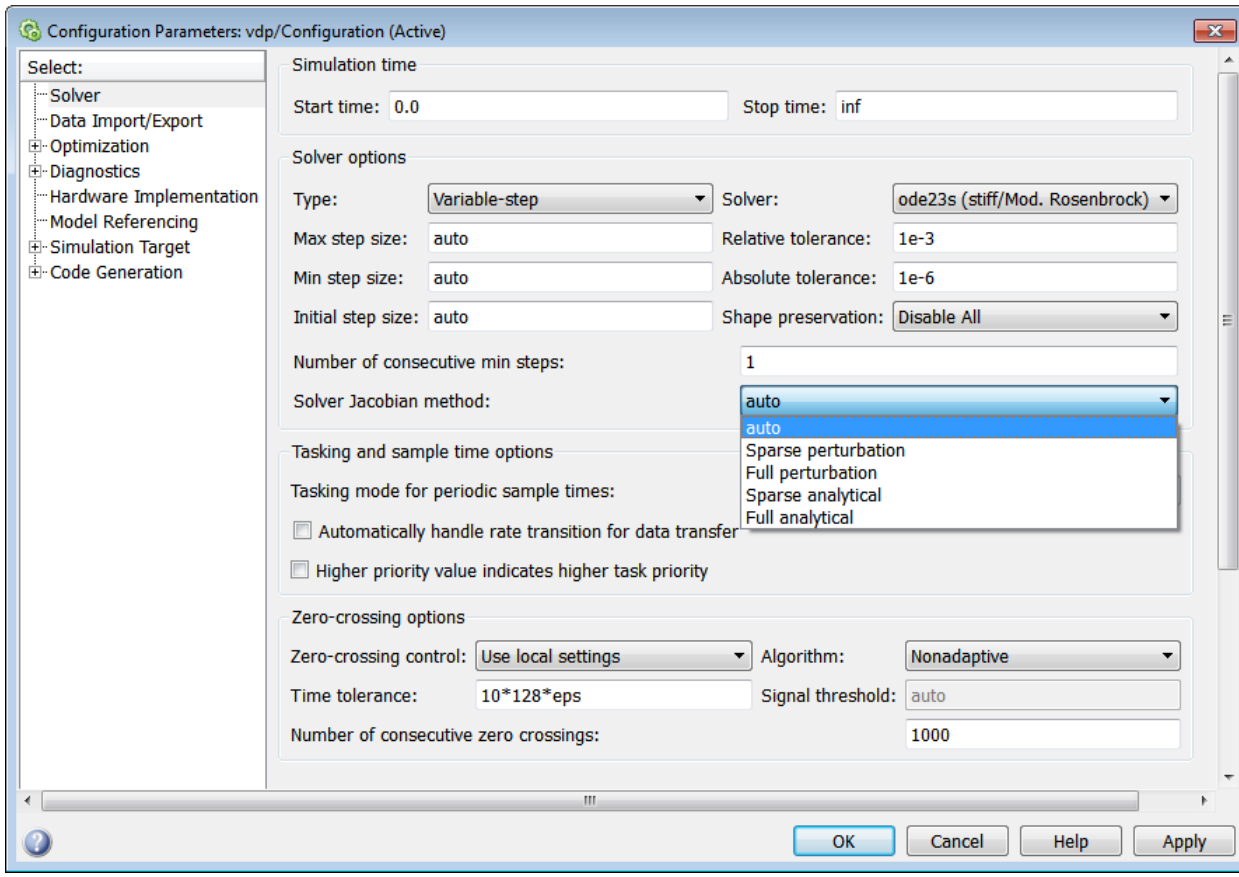
From this system, you can derive a sparsity pattern that reflects the structure of the equations. The pattern, a Boolean matrix, has a 1 for each x_i that appears explicitly on the right-hand side of an equation. You thereby attain:

$$J_{x,pattern} = \begin{pmatrix} 1 & 0 & 1 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \end{pmatrix}$$

As discussed in "Full and Sparse Perturbation Methods" on page 14-28 and "Full and Sparse Analytical Methods" on page 14-30 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.

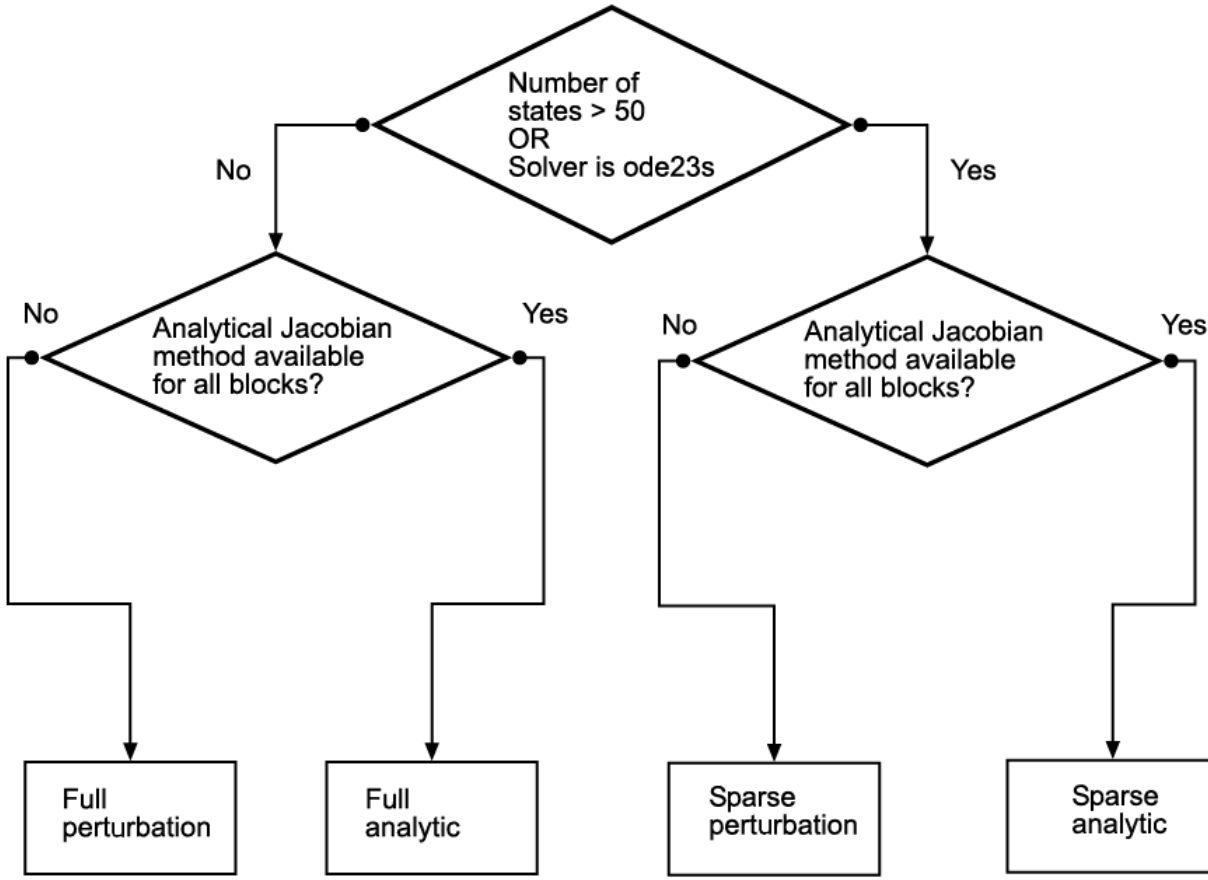
Limitations. The solver Jacobian methods have the following limitations associated with them.

- 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.



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.

Interact 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 (see “Block Tool Tips” on page 23-2)

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.

Save and Restore Simulation State as 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.

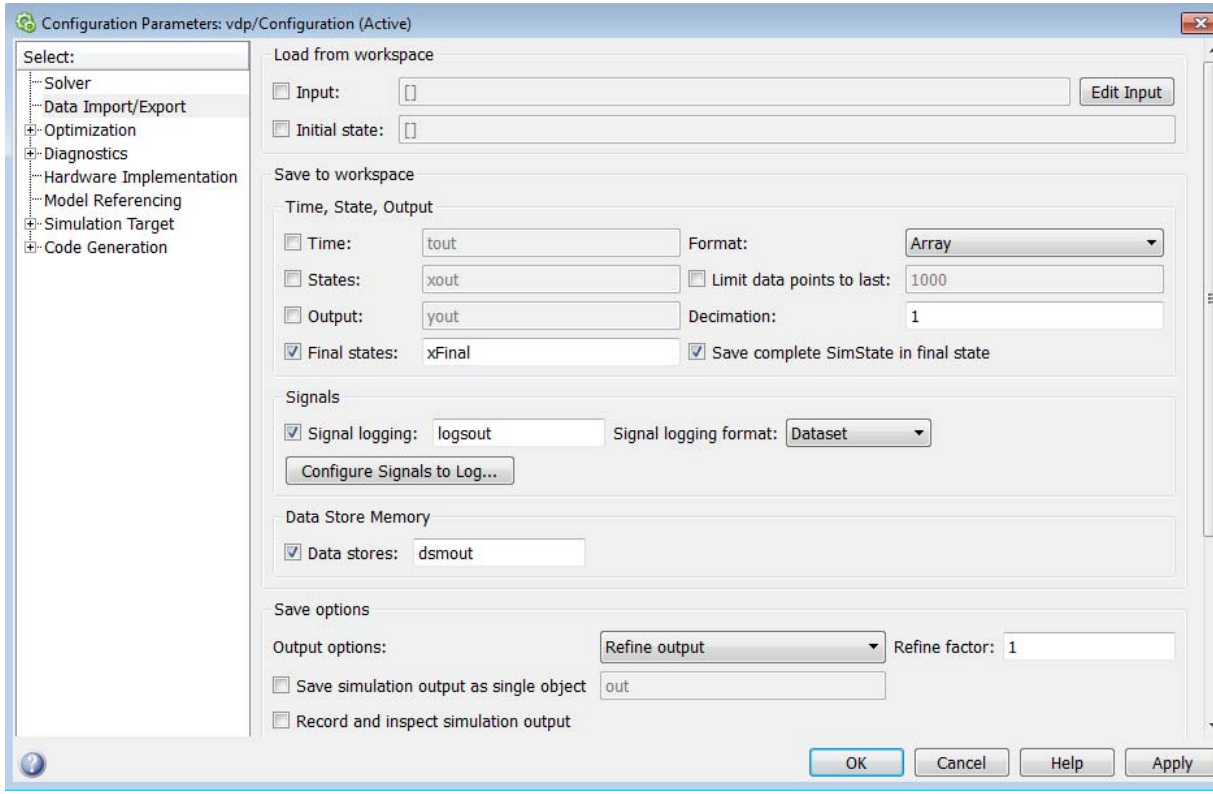
Note The **Final states** option of the **Data Import/Export** pane in Simulink saves only *logged* states—the continuous and discrete states of blocks—which are a subset of the complete simulation state of the model. Hence you cannot use the **Final states** to save and restore the complete simulation state as the initial state of a new simulation.

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 > Run**.



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')
```

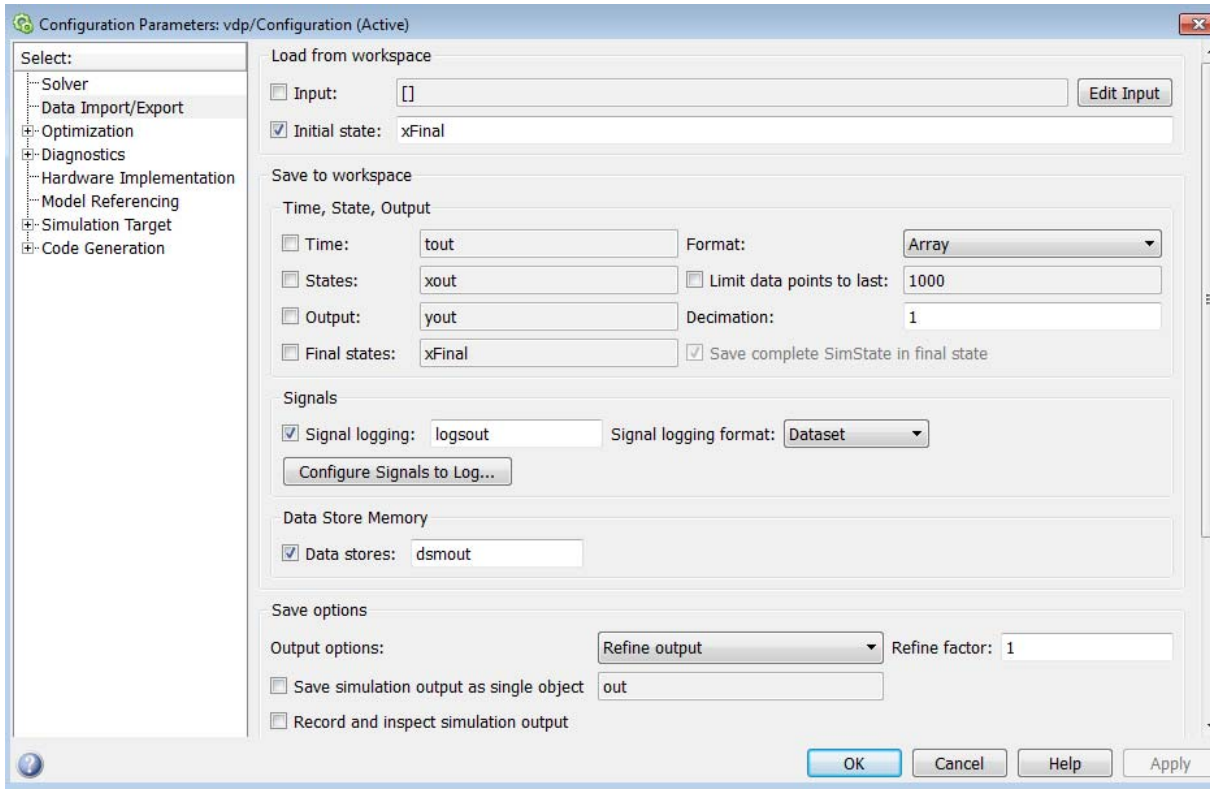
Restore the SimState

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

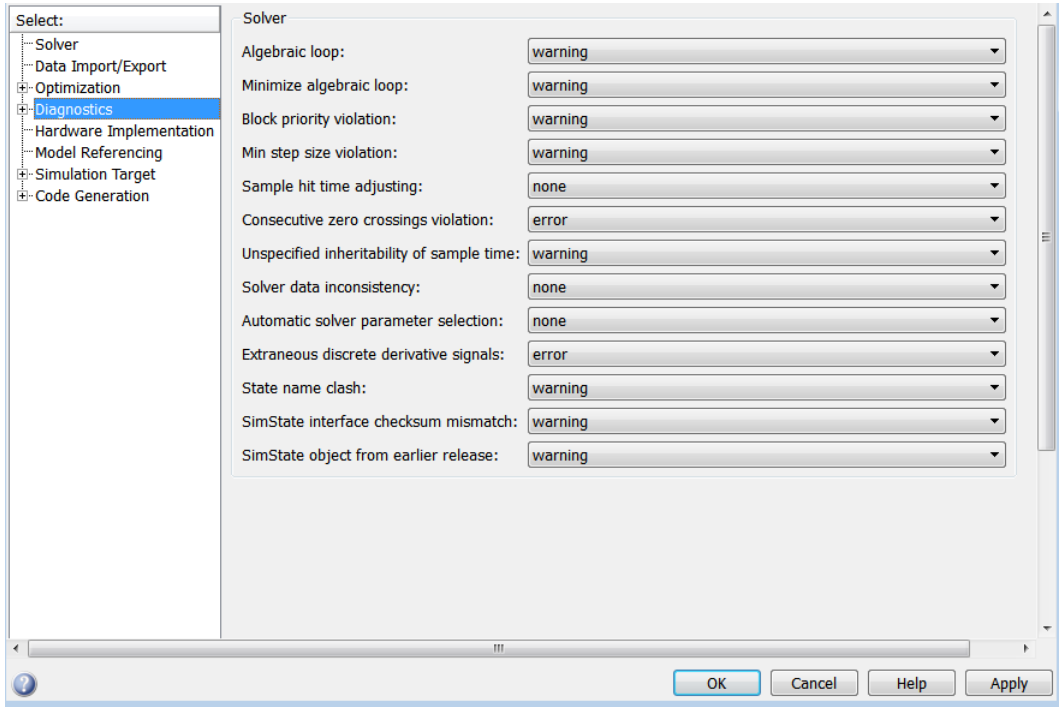
Use the `set_param` command to specify the initial condition as the `SimState`.

```
set_param(mdl, 'LoadInitialState', 'on', 'InitialState',...
[mdl 'SimState']);
simOut = sim(mdl, 'StopTime', tstop)
```

Restoring a SimState Saved in an Earlier Version of Simulink

You can now use SimState objects saved in earlier releases (R2010a or later) to restore the SimState of a model. You can see the version of Simulink used to save the SimState by examining the 'version' field of the SimState object. Simulink detects if the SimState object provided as the initial state was saved in the current release. By default, the Simulink software reports an error message if the SimState was not saved in the current release. You may configure the diagnostic to allow Simulink to report the message as a warning and try to restore as many of the values as possible. To enable this best-effort restoration, go to the Diagnostics pane of the Configuration Parameter dialog box and set the message for **SimState object from earlier release** to `warning`. You can also set the diagnostic programmatically using the `set_param` command.

```
set_param(mdl,  'SimStateOlderReleaseMsg', 'warning');
```



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.

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.

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`".

Diagnose Simulation Errors

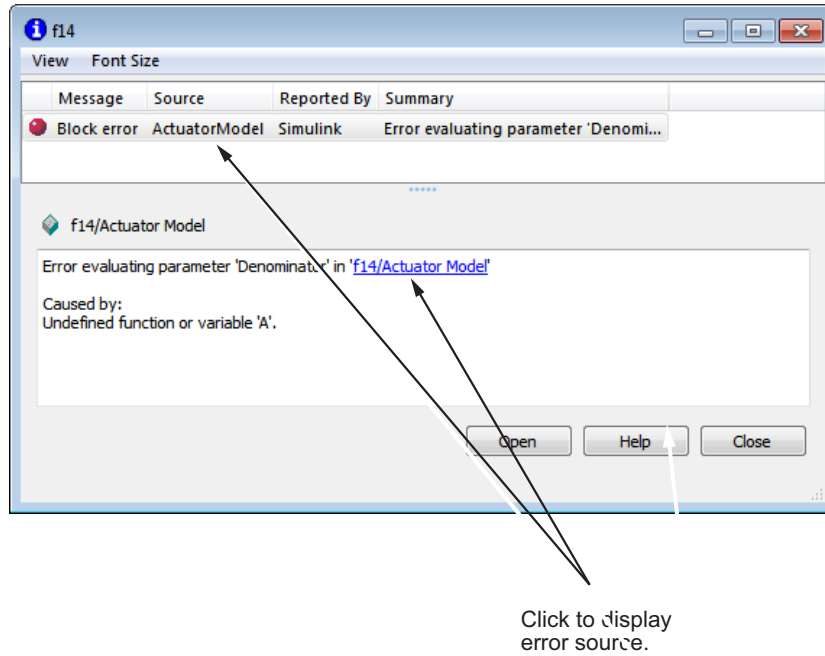
In this section...

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 Simulink Coder product).

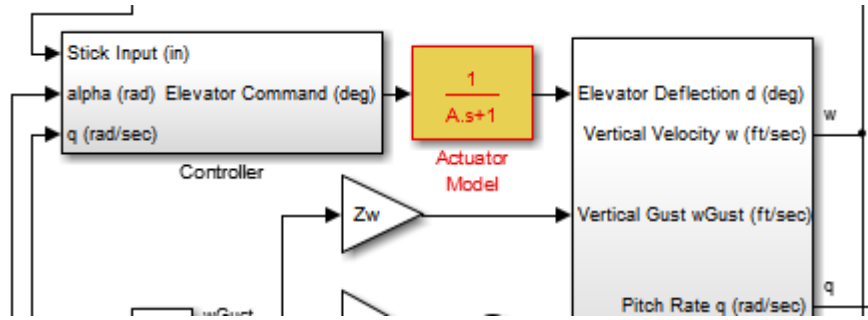
Summary. Error message, abbreviated to fit in the column

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.

Create 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 Function block executes.

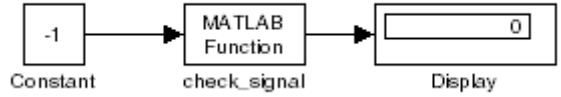
You can use the MATLAB error function in callbacks, S-functions or the MATLAB Function block to create custom error messages specific to your application. Capabilities available for messages include:

- 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.

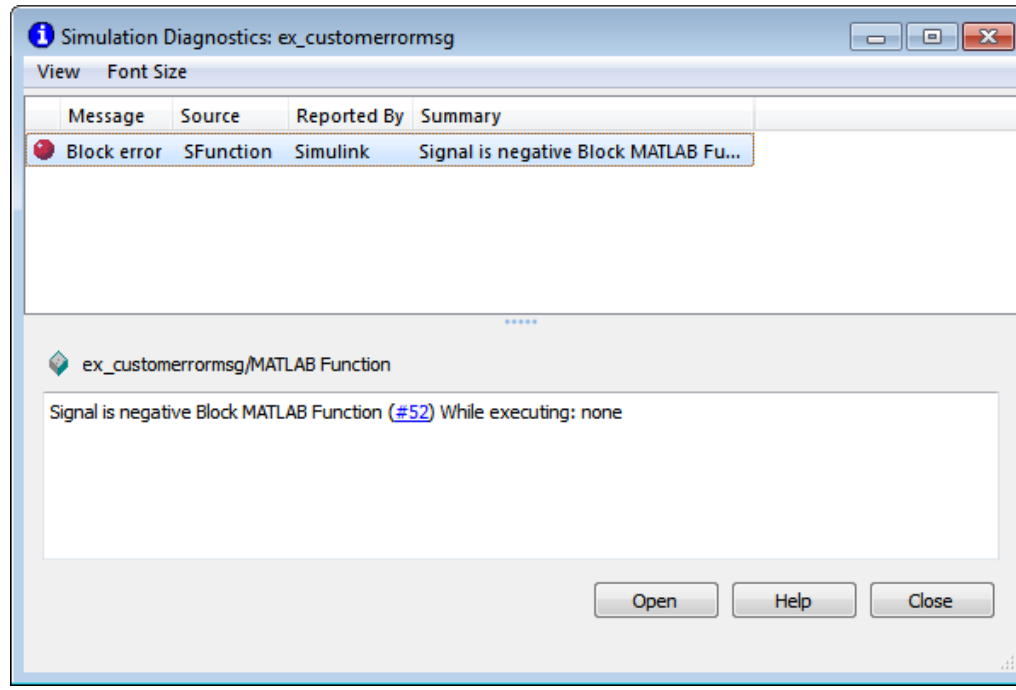
The following example shows how you can make the user-created function `check_signal` display the string `Signal is negative`.



The MATLAB Function block invokes the following function:

```
function y=check_signal(x)
  if x<0
    error('Signal is negative');
  else
    y=x;
  end
```

Executing this model causes a runtime error and starts the debugger when you click the **OK** button of the runtime error message. When you quit the debugger, an error message in the Simulation Diagnostics window.



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"')`

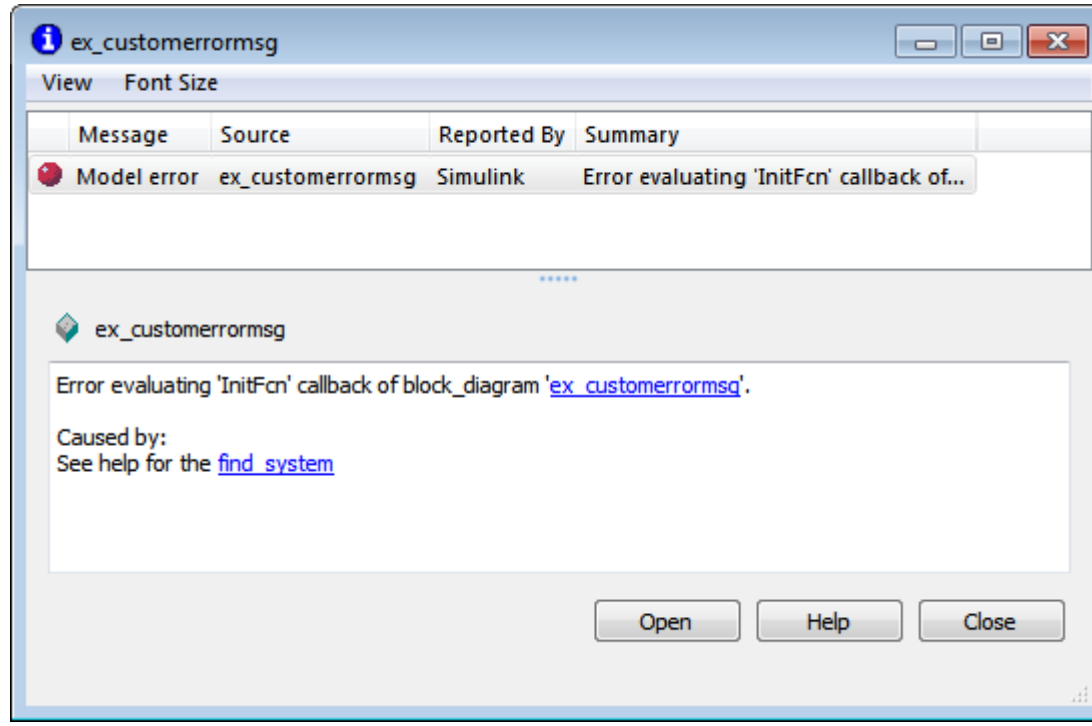
  displays a text hyperlink to the `c:/work` folder. Clicking the link opens a system command window (shell) and sets its working folder to `c:/work`.

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 window displays a hyperlink labeled `find_system`. Clicking the link opens the documentation for the `find_system` command in the MATLAB Help browser.



15

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.

Run Simulation 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 **Save simulation output 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.

Examples of Implementing the sim Command

Following are examples that show 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.

```
model = 'vdp';
load_system(model)
simMode = get_param(model, 'SimulationMode');
set_param(model, 'SimulationMode', 'rapid')
cs = getActiveConfigSet(model);
model_cs = cs.copy;
set_param(model_cs,'AbsTol','1e-5',...
         'SaveState','on','StateSaveName','xoutNew',...
         'SaveOutput','on','OutputSaveName','youtNew')
simOut = sim(model, model_cs);
set_param(model, '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 “Run Parallel Simulations” on page 15-8.

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. For supported expressions, see "Enable Data Import" on page 45-77.

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`.

Control Simulation 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'`.

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 Simulink Coder product).

Note If you use `matlab -nodisplay` to start a session, then you cannot use `set_param` to run your simulation session.

Run 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.

Run 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 "Choosing a Simulation Mode" on page 22-11 for details on selecting a simulation mode and "Design Your Model for Effective Acceleration" on page 22-16 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 more information on code regeneration and parameter handling in Rapid Accelerator mode, see "Parameter Handling in Rapid Accelerator Mode" on page 22-8.

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).

Note If you open models inside a parfor statement you should close them again using `bdclose all` to avoid leaving temporary files behind.

---

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 22-7.

As for the third condition, the following sample code shows how to disable the up-to-date check using the `sim` command.

```
matlabpool open
% Load the model and set parameters
model = 'vdp';
load_system(model)
% Build the Rapid Accelerator target
rtp = Simulink.BlockDiagram.buildRapidAcceleratorTarget(model);
% Run parallel simulations
parfor i=1:4
   simOut{i} = sim(model,'SimulationMode', 'rapid',...
               'RapidAcceleratorUpToDateCheck', 'off',...
               'SaveTime', 'on',...
               'StopTime', num2str(10*i));
end

matlabpool close
```

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 example of this method of running parallel simulations, refer to the Rapid Accelerator Simulations Using PARFOR.

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 "Model Workspaces" on page 4-67.

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
model = 'vdp';
paramName = 'StopTime';
paramValue = {'10', '20', '30', '40'};
parfor i=1:4
    simOut{i} = sim(model, ...
                    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(model, 'ExternalInput', 'extInp');
end
```

For further details, see the Rapid Accelerator Simulations Using PARFOR example.

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 block or MATLAB Function 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 HDL Verifier™ 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, MATLAB Function Block, or Model Block

In this example, either the model is configured to simulate in Accelerator mode or it contains a Stateflow, a MATLAB Function block, or a 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(model)
    % 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(model, 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(model, ...
       'ConcurrencyResolvingToFileSuffix', num2str(i),...
       'SimulationMode', 'rapid');
end
```

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 "Properties of the MException Class". 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 example 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

16

Visualizing and Comparing Simulation Results

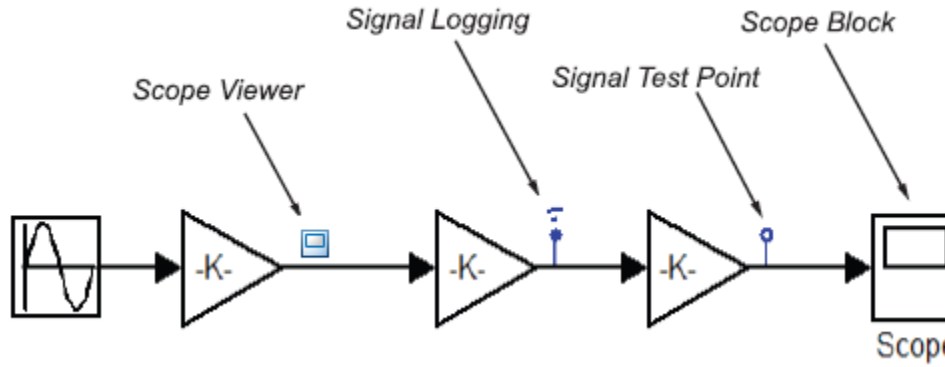
View Simulation Results

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 perform basic signal viewer tasks, see "Signal Viewer Tasks" on page 16-6 and "Scope Signal Viewer Tasks" on page 16-11.
- For detailed information on signal viewers, see "Signal and Scope Manager" on page 16-23.
- For information on signal logging, see "Export Signal Data Using Signal Logging" on page 45-19.

- For information on signal Test Points, see “Test Points” on page 47-58.
- For information on Scope Blocks, see Scope.

Scope Block and Scope Signal Viewer Differences

Use Scope blocks and scope signal viewers to display simulation results, but as shown in this table, they have different characteristics.

Characteristic	Scope Signal Viewer	Scope Block
Interface	Attach to signal using Signal Selector or context menu See “Signal Selector” on page 16-27 See “Scope Signal Viewer Context Menu” on page 16-15	Drag from Library Browser
Scope of Control	All viewers centrally managed from Signal and Scope Manager See “Signal and Scope Manager” on page 16-23.	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 “Creating a Multiple Axes Scope Signal Viewer” on page 16-11	Multiple
Data handling	Save data to a signal logging object	Save variable data to workspace as structures or arrays

Characteristic	Scope Signal Viewer	Scope Block
Data logging	Log data to model-wide data object See `Simulink.SimulationData.Dataset` and 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.	Only displays major time step values. The scope displays additional interpolated points between major time steps if specified by the refine parameter.

Why Use Signal Generators and Signal Viewers Instead of Source Blocks and Scope Blocks?

You should use signal generators and signal viewers instead of Source and Scope blocks when you want to:

- Navigate to and attach signal generators or signal viewers deep within a model hierarchy.
- Centrally manage all signal generators and signal viewers present in your model.

- Use the display features provided by signal viewers that are not available in Scope blocks.
- Reduce clutter in your block diagram. Because signal viewers attach directly to signals, it is not necessary for you to route them to a Scope block. This results in fewer signal routes in your block diagram.
- View data from referenced models. See “Test Points” on page 47-58 for more information.

Signal Viewer Tasks

In this section...

About Signal Viewers

- Signal viewers are not the same as Scope blocks. For an explanation of the differences, see "Scope Block and Scope Signal Viewer Differences" on page 16-3.
- Signal viewers do not show signal labels on the axis, display the simulation minor time step values, or work with Simulink Report Generator.
- Not all signal viewer features are supported when you simulate your model in Rapid Accelerator mode. See "Behavior of Scopes and Viewers with Rapid Accelerator Mode" on page 22-18.
- The **Help** button for a signal viewer is located on the parameters dialog box for a specific viewer type. For more information, see"Scope Signal Viewer Parameters Dialog Box" on page 16-16 .

Signal viewer

Attaching a Signal Viewer

If you want to,

- Quickly connect or disconnect a scope signal viewer, use the context menu.
- Review all of the signal viewers and the signals connected to them, use the Signal and Scope Manager.

Using the Context Menu

To attach a signal viewer with the signal content menu,

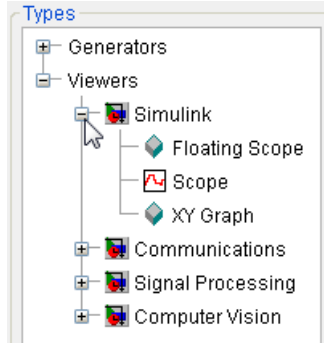
1. On your Simulink block diagram, right-click a signal, and then from the context menu, select **Create & Connect Viewer**.
2. From the list that appears, select the type of signal viewer you want to attach.

   If you attach a scope signal viewer, a viewer window opens. You must run the simulation after you attach the viewer for the information to be plotted.

Using the Signal and Scope Manager

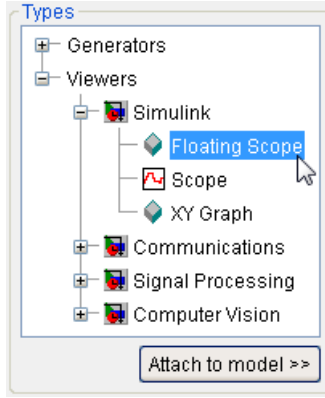
To attach a scope signal viewer using the Scope & Signal Manager,

1. On your Simulink block diagram, right-click a signal, and then from the context menu, select **Signal & Scope Manager**. The Signal & Scope Manager dialog box opens.
2. In the **Types** pane and under the Viewers node, expand a product node to show the viewers installed and available to you.

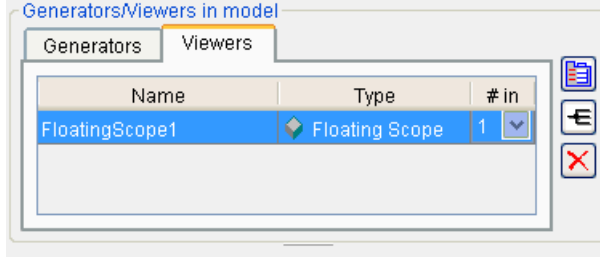


Note The Simulink Scope displayed in the Signal and Scope Manager Types pane is not the same as the Simulink Scope Block. For an explanation of the differences, see "Scope Block and Scope Signal Viewer Differences" on page 16-3.

3 Under an expanded product node, select a viewer, and then click the **Attach to model** button.



The viewer is added to a table in the **Viewers** tab in the Generators/Viewers in model pane. The table lists the viewers in your model.



Each row corresponds to a viewer. The columns specify each viewer 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, select a value from the pull-down list.

Adding Signals to a Signal Viewer

To add additional traces to an existing signal viewer,

1 In the Simulink Editor, right-click a signal.

2 From the signal context menu, point to **Create & Connect Viewer**, and then from the submenu, point to a product.

3 From the list, select the signal viewer you want to attach to the signal.

A viewer ion is added to the signal line.

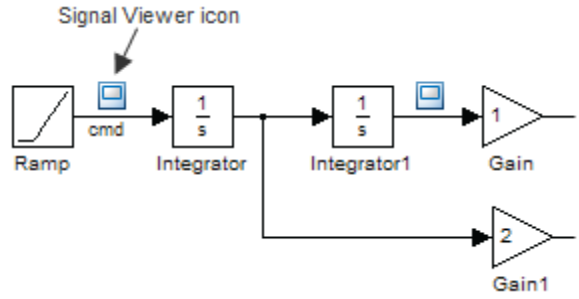
You can also add signals to a signal viewer with the Signal and Scope Manager. See "Signal and Scope Manager" on page 16-23.

Note You must run a simulation for the new signal trace to display in a viewer.

Note If you add or remove signals from a Signal Viewer, the Signal Viewer title and legends update only when you run a simulation, and then open the viewer.

Displaying a Signal Viewer

1 Right-click a signal viewer icon. From the context menu, point to **Open Viewer**, and then select a viewer from the list.



Depending on the type of signal viewer, the following happens:

- Scope and Floating Scope — A Viewer: Scope window opens with a graph of the signals attached to the viewer.

- XY Graph — A Sink Block Parameters dialog box opens. After running a simulation, a Viewer: XY Graph window opens with a graph of the X and Y signals attached to the viewer.

2 Customize the signal viewer to better visualize the simulation results.

Saving Data to MATLAB Workspace

To save the data displayed on the viewer to the MATLAB workspace, perform the following steps:

1 In the Viewer toolbar, click the parameters icon  .

2 Click the **History** tab.

3 Select **Save to model signal logging object (logsout)**.

4 In the **Logging name** field, enter a logging variable name.

5 Assign a name to the signal in the block diagram, for example, `x1`.

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 `x1` is the name of the signal.

Plotting the Viewer Data

You can plot the data interactively or programmatically.

- **Simulation Data Inspector —** plot the data as explained in "Inspect Signal Data" on page 17-11.
- **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.

Scope Signal Viewer Tasks

In this section...

Adding a Legend to a Scope Signal Viewer

1. In a Scope signal 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. To move a legend to another location on the graph, left-click and drag the legend box.

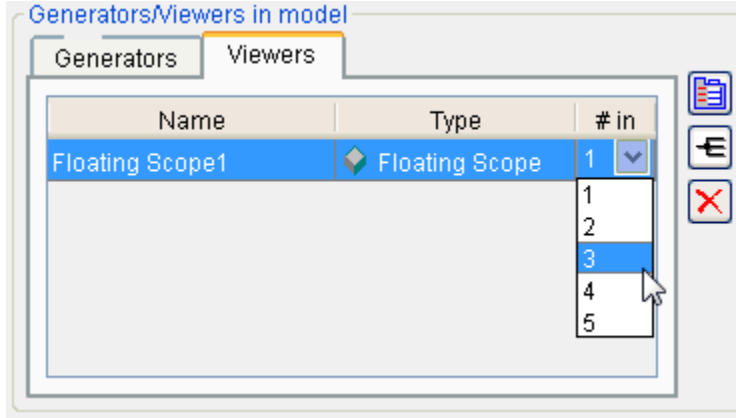
For information about the color and line styles in the Viewer window, see "Line Styles with Scope Signal Viewer" on page 16-19.

Creating a Multiple Axes Scope Signal Viewer

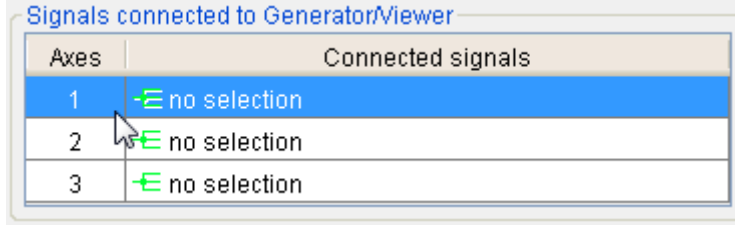
You can add multiple plots (called *axes*) to a scope signal viewer. Each axes can have different *y*-axis settings.

To create a viewer with more than one axes.

1. Open the Signal and Scope manager. Add a signal Scope or Floating Scope signal viewer to your model. See "Attaching a Signal Viewer" on page 16-6.
2. From the **# in** drop-down list, select the total number of axes for the graph.



3 In the **Signals connected to Generator/Viewer** section, select the first axis.

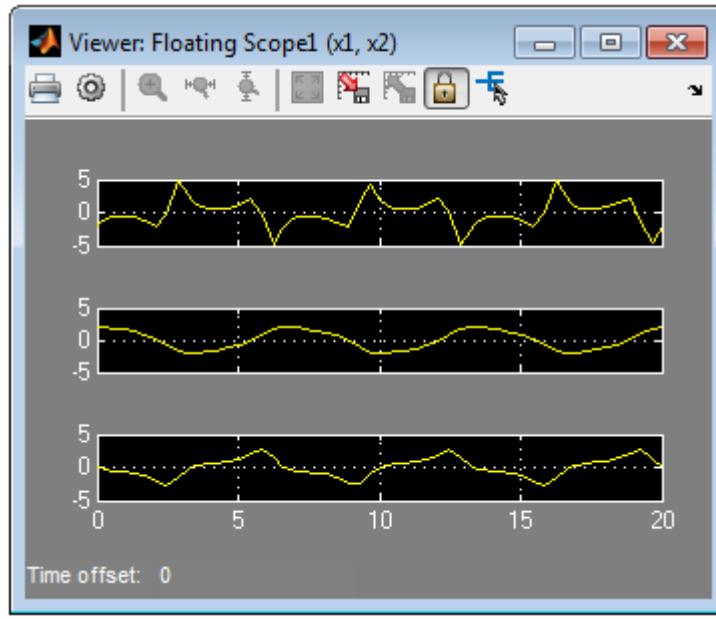


4 Click the **Signal Selector** button  . The Signal Selector dialog box opens.

5 Select the signal or signals to add to this axis, and then close the dialog.

6 Repeat steps 3 to 5 until you have added signals to all of the axes.

7 Click the parameters icon  to display the scope signal viewer, and then run the simulation.


Viewer: Floating Scope1 (x1, x2)
5
0
-5
5
0
-5
5
0
-5
0
5
10
15
20
Time offset: 0

Scope Signal Viewer Characteristics

In this section...

Scope Signal Viewer Toolbar

The signal viewer toolbar is attached to each scope signal 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 Signal Viewer Parameters Dialog Box" on page 16-16.
	Simultaneously zooms in on the *x* and *y* axes. The zoom feature is not active while the simulation is running.
	Use this button to zoom in on the *x* axis only. The zoom feature is not active while the simulation is running.
	Use this button to zoom in on the *y* axis only. The zoom feature is not active while the simulation is running.
	Automatically scales the axis to fully display all signals.
	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.

Icon	Function
	Activates the Signal Selector. For more information, see “Signal Selector” on page 16-27.
	Docks and undocks the Scope Viewer. When you dock the Scope Viewer, it is placed within the MATLAB Command Window and automatically resized.

Scope Signal Viewer Context Menu

The scope signal viewer context menu is a convenient way to make simple changes to a viewer without navigating to a Scope or Floating Scope parameters dialog box.

Within a Scope signal viewer window, right-click to display the context menu. It contains the following controls.

Control	Function
Legends	Adds a legend to your scope viewer.
Autoscale	Automatically scales the viewer axis.
Signal selection	Displays the Signal Selector dialog. For information, see “Signal Selector” on page 16-27
Axes properties	Displays the Axis Properties dialog. You can manually set the minimum and maximum range for the *y* axis here.

Control	Function
Scope parameters	Displays the Scope parameters dialog. For information, see "Scope Signal Viewer Parameters Dialog Box" on page 16-16.
Tick labels	Displays the Tick Labels dialog. From here you can turn on and off various tick options.

Scope Signal Viewer Parameters Dialog Box

To open a Scope or Floating Scope parameters dialog box,

- On the scope toolbar, click 

There are three tabs on the dialog box:

- **General** — set the axis characteristics and the sampling decimation value
- **History** — control the amount of stored and displayed data
- **Performance** — control the scope refresh rate.

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 Signals to a Signal Viewer" on page 16-8.

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 "Parameter Settings and Performance with Scope Signal Viewer" on page 16-20.

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 signal 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 "Export Signal Data Using Signal Logging" on page 45-19 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 Configuration Parameters** dialog box.

For new models, use the `Dataset` logging format. If you use the `Dataset` format for signal logging, then Simulink does not log the signals configured to be logged in the Signal Viewer. Explicitly mark the signal for signal logging by using the Signal Properties dialog box. To access the Signal Properties dialog box, right-click a signal and from the context menu, select **Properties**.

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 signal viewer is refreshed. Reducing the refresh rate can speed up the simulation in some cases.

Note For information about additional scope signal viewer parameters that can affect performance, see "Parameter Settings and Performance with Scope Signal Viewer" on page 16-20.

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.

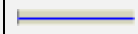
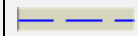
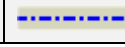
Drag the slider button to the right to increase the refresh period and hence decrease the refresh rate.

Freeze Button. Controls refresh.

Click the button to freeze (stop refreshing) or unfreeze the Scope Viewer.

Line Styles with Scope Signal Viewer

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	

Parameter Settings and Performance with Scope Signal Viewer

In some cases, when a Scope signal viewer needs to display a large number of data points, the simulation slows down. 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.
- Reduce the time range.
- Use decimation to reduce the number of data points.
- Increase the refresh period to decrease the refresh rate.
- Limit the number of data points that the viewer saves to the workspace.

Signal Generator Tasks

In this section...

Attaching a Signal Generator.

If you want to,

- Quickly connect or disconnect a Signal Generator, use the context menu.
- Review all of the Signal Generators and their signals, use the Signal and Scope Manager.

Using the Context Menu

To add additional traces to an existing signal viewer,

1. In the Simulink Editor, right-click the input to a block.
2. From the context menu, point to **Create & Connect Generator**, and then from the submenu, point to a product.
3. From the list, select the generator you want as input to the block.

   The name of the generator you choose appears in a box connected to the block input.
4. Double-click the name to edit the generator name.
5. Right-click the name and select **Generator Parameters** to display a dialog box where you can change the generator parameters.
6. Right-click the name and select **Properties** to display a dialog box where you can change the signal properties.

Using the Signal and Scope Manager

To attach a Signal Generator using the Signal and Scope Manager,

1. Right-click the input to a block, and then from the signal context menu select **Signal & Scope Manager**.

2. In the **Types** pane and under the Generators node, expand a product node to show the generator installed and available to you.

3. Under an expanded product node, select a generator, and then click the **Attach to model** button.

   The viewer is added to a table in the **Generators** tab in the Generators/Viewers in model pane. The table lists the generators in your model.

   Each row corresponds to a generator. The columns specify each generator name and type.

   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.

Removing a Generator

To remove the generator from the block diagram.

1. Right-click a generator.

2. From the context menu, select **Disconnect Generator**.

Signal and Scope Manager

In this section...

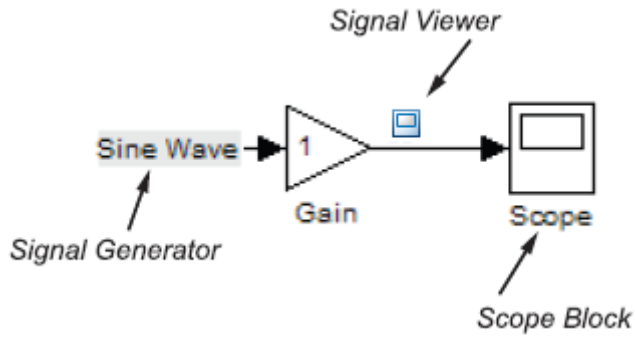
About the Signal & Scope Manager

The Signal & Scope Manager is a user interface to Signal Generator and Viewer objects. Using the Signal and Scope Manager you can manage from a central place all signal generators and viewers.

Note The Signal and Scope Manager requires that you have Java enabled when you start MATLAB. This is the default.

Signal Generator and Viewer Objects

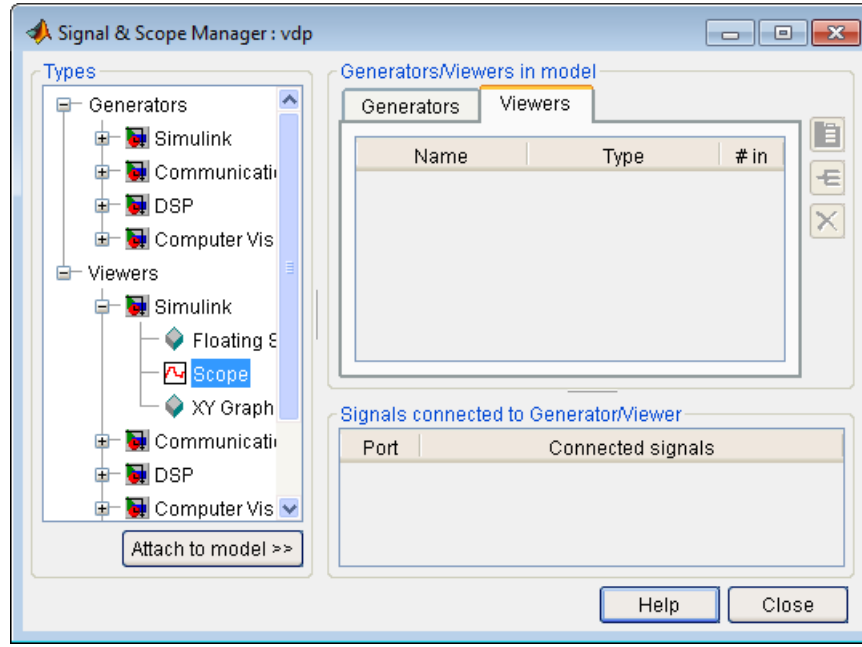
The small icons identifying a viewer or generator are called Viewer and Generator Objects. These objects are not the same as scope blocks or signal blocks. Generator and Viewer Objects are managed by the Signal and Scope Manager, and are placed on signals. Blocks are dragged from the Library browser and are not managed by the Signal and Scope manager.



Opening the Signal and Scope Manager

1 In the Simulink Editor window, select **Diagram > Signals & Ports > Signal & Scope Manager**.

The Signal & Scope Manger window opens.



Alternatively within your model, right click a signal line and from the context menu, select **Signal & Scope Manager**.

Changing Generator or Viewer Parameters

1. Open the Signal & Scope Manager window.
2. To the right side of the Generators/Viewers pane, click the parameters button  .

   The generator or viewer window opens.
3. From the toolbar, select the parameters button  . Review and change parameters.

Adding Signals to a Viewer

Use the Signal Selector to add signals to a Viewer.

1. To the right side of the Generators/Viewers pane, click the Signal Selector button  .

   The Signal Selector window opens. Use the Signal Selector to connect and disconnect generators and viewers.
2. From the signals pane, select the check boxes for the signals you want to display in the selected viewer.

Tip After adding the new signals, run a simulation to make them visible.

Removing a Generator or Viewer from a Simulink Model

1. In the Generators/Viewers pane, select either a listed generator for viewer.
2. On the right side, click the Delete button  .

The selected generator or viewer is removed from the table.

Viewing Test Point Data

You can use a Signal Viewer available from 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.

Note With some signal viewers (for example, XY Graph, To Video Display, Matrix Viewer, Spectrum Scope, and Vector Scope), you cannot use the Signal Selector to select signals with test points in referenced models.

For more information, see “Test Points” on page 47-58.

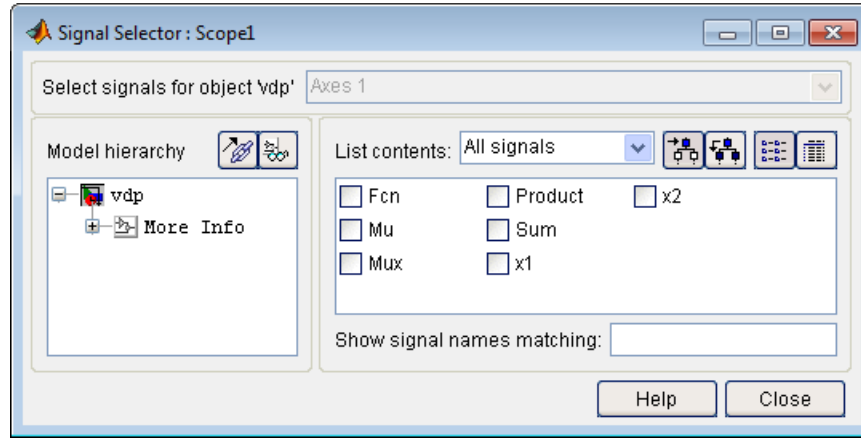
Signal Selector

In this section...

About the Signal Selector

The Signal Selector allows you to connect a generator or viewer object (see “Attaching a Signal Viewer” on page 16-6 and “Attaching a Signal Generator.” on page 16-21) or a Floating Scope block to other 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 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.



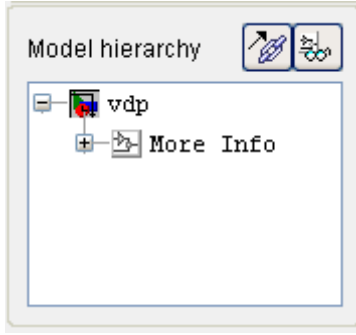
Select signals for object

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.

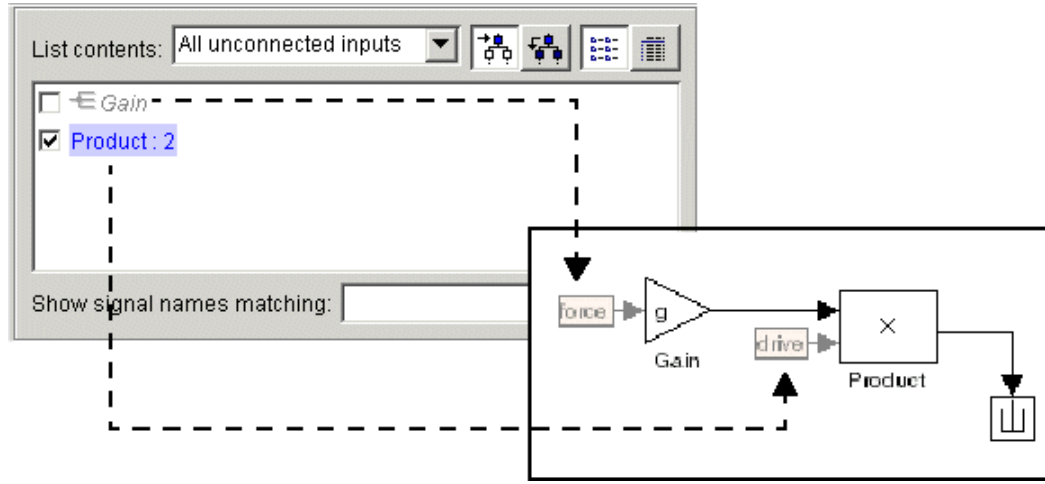


Selecting a subsystem causes the adjacent port list to display the ports available for connection in the selected subsystem. To display subsystems included as library links in your model, click the **Follow links** button at the top of the **Model hierarchy** control. To display subsystems contained 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.

17

Inspecting and Comparing Logged Signal Data

Inspect Signal Data with Simulation Data Inspector

The Simulation Data Inspector software 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 Simulink Coder, and fixed-step output with external data. "How the Simulation Data Inspector Tool Aligns Signals" on page 17-35 describes how signals are aligned between runs. "How the Simulation Data Inspector Tool Compares Time Series Data" on page 17-37 describes how aligned signal data are compared.

A typical workflow for inspecting and comparing signal data is:

1. Set up your model to log signal data, as in "Export Signal Data Using Signal Logging" on page 45-19.
2. Open the Simulation Data Inspector tool, as described in "Open the Simulation Data Inspector Tool" on page 17-39.
3. Simulate your model and record simulation data or import logged signal data, as described in "Record Simulation Data" on page 17-5 and "Import Logged Signal Data" on page 17-7.
4. Configure the Signal Browser table and specify how you want to graph the data, as described in "Customize the Simulation Data Inspector Interface" on page 17-38.
5. Inspect signals to quickly determine if the run satisfies requirements, as described in "Inspect Signal Data" on page 17-11.
6. If the run is unsatisfactory, delete it. Repeat steps 3 and 4 to collect the desired simulation runs for comparing data.

7. Optionally assign tolerances to signals and graphically inspect the applied tolerances.

8. Compare individual signals in the same run, or from different runs, as described in "Compare Signal Data" on page 17-23.

9. Compare all of the imported signal data from multiple runs, as described in "Compare All Logged Signal Data From Multiple Simulations" on page 17-28.

10. Determine which signals have discrepancies within the specified tolerances. Plot and analyze the discrepancies of any two signals.

11. Save the imported signal data and comparison results, as described in "Export Results in the Simulation Data Inspector Tool" on page 17-34.

The Simulation Data Inspector software provides a command-line interface. For more information, see "Record and Inspect Signal Data Programmatically" on page 17-55

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Requirements for Recording Data

The Simulation Data Inspector tool records the following data configured on the “Data Import/Export Pane” of the Configuration Parameter dialog box:

- **States** and **Output**, if **Format** is `Structure with time`, or if **Format** is `Array` or `Structure` and **Time** is logged.
- **Signal logging**
- **Data stores**

The Simulation Data Inspector tool supports the following data imported from MAT-files and the MATLAB base workspace:

- Simulink.Timeseries and MATLAB `timeseries` objects
- Simulink.SimulationData.Dataset or Simulink.ModelDataLogs objects
- Data in `Structure with time` format

The Simulation Data Inspector supports output from the following blocks:

- Scope (`Structure with time` and `Array` format)
- To File (`Timeseries` format)
- To Workspace (`Timeseries` or `Structure With Time` format)

Record Simulation Data

To set the Simulation Data Inspector to automatically import data after a simulation run:

1. Set up your model to log signal data, as in "Export Signal Data Using Signal Logging" on page 45-19.
2. Select **Simulation > Model Configuration Parameters** to open the Configuration Parameters dialog box.
3. On the **Data Import/Export** pane:
   - Select the **Signal logging** parameter.
   - Select the **Record and inspect simulation output** parameter.
4. On the Simulink Editor toolbar, click the **Record** button arrow.

   Select **Simulation Data Inspector** from the list. The Simulation Data Inspector opens.
5. On the Simulink Editor toolbar, the **Record** button is already pressed because in step 3 you selected the configuration parameter **Data Import/Export > Record and inspect simulation output**. You can click the **Record** button to toggle on and off recording data for a simulation.
6. 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 "Rename a Run" on page 17-44.
7. 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 new run.
8. When you are done importing data for your simulations, click the **Record** button. If the **Record** button is not selected, data from simulations are not imported into the tool and the configuration parameter **Data**

Import/Export > Record and inspect simulation output is not selected.

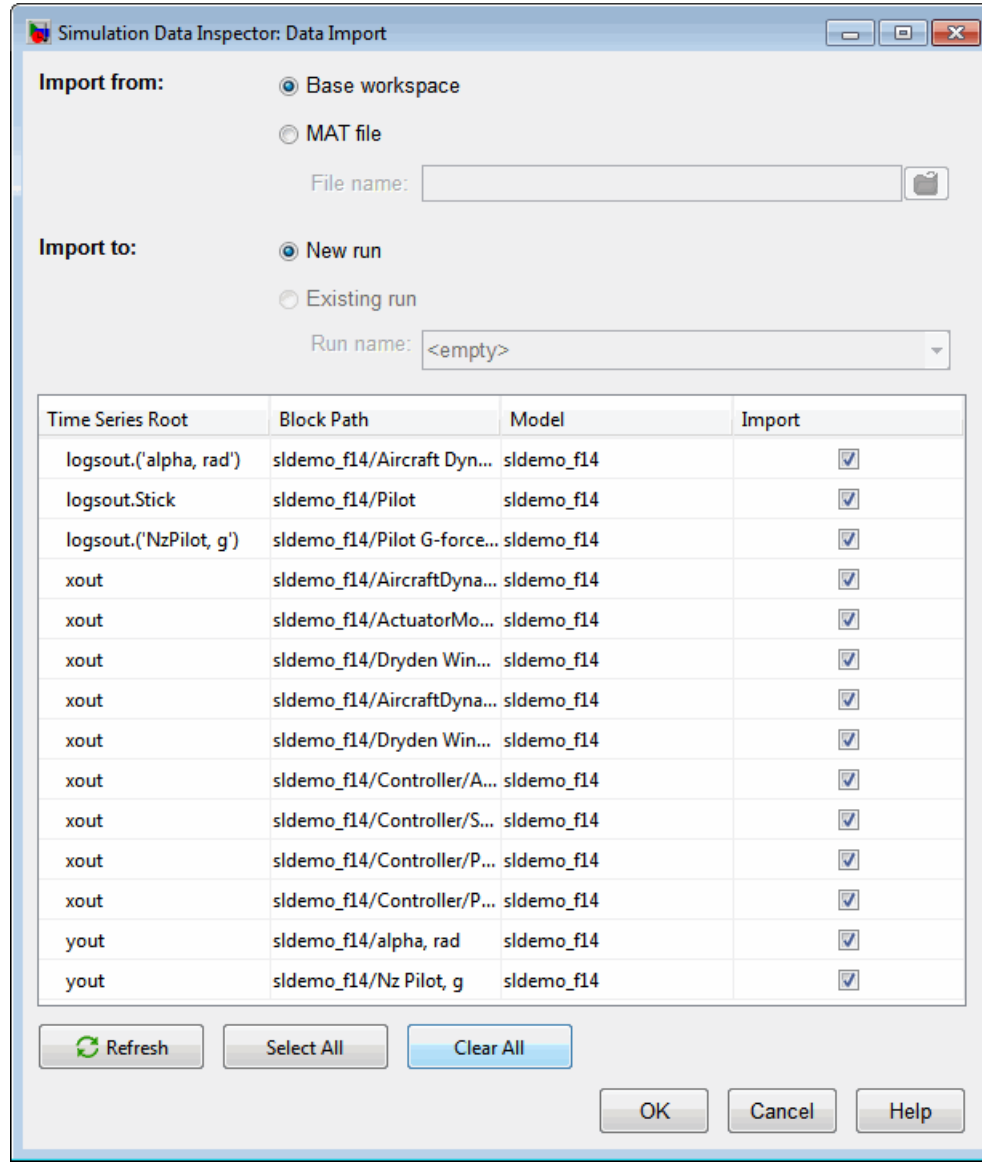
Import Logged Signal Data

Before importing data into the Simulation Data Inspector tool, you must have previously logged signal data to the base workspace or to a MAT-file. For information on how to log signal data, see “Export Signal Data Using Signal Logging” on page 45-19.

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. 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.

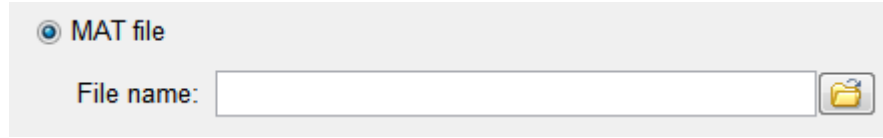
4 Click **OK**. The selected signals are displayed in the Signal Browser table.

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. Follow the steps to import a MAT-File.

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 locates 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 populates 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 Click **OK**.

Load Previously Recorded Data from a MAT-file

To load signal data from a MAT-file, which was created from the Simulation Data Inspector tool:

1. On the Simulation Data Inspector toolbar, 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 is displayed in the Simulation Data Inspector tool.

Inspect Signal Data

Overview

On the **Inspect Signals** tab you can inspect logged signal data. On the left pane you can open the Signal Browser table to view and configure signal and run properties (see "Customize the Simulation Data Inspector Interface" on page 17-38). On the right pane you can create different plot views. With a view of multiple plots, you can group signals to better view your data. For example, you can group the same signal from different simulation runs, group signals with a similar range of values, or normalize a subset of your signal data. The following examples use the `sldemo_f14` model.

View Signal Data

1. Configure a model to log signal data. This example uses the `sldemo_f14` model configured to log signals: `q, rad/sec`, `Stick`, and `NzPilot, g`. For more information, see "Export Signal Data Using Signal Logging" on page 45-19.

2. On the Simulink Editor, click the **Record** button arrow and select **Simulation Data Inspector** from the list.

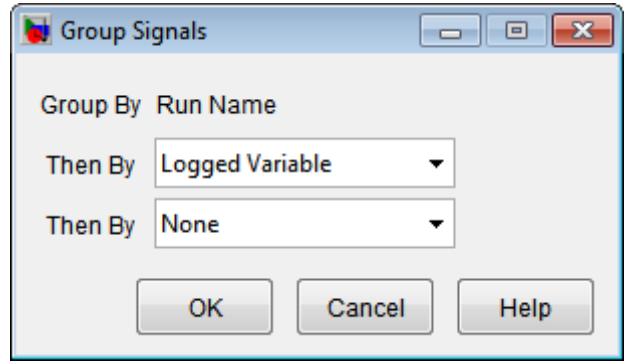
3. To record simulation data, click the **Record** button so that it is selected.

4. Simulate your model. The Simulation Data Inspector tool records and displays the simulation data. Instead of recording data from a simulation, you can import signal data from previous simulation runs, see "Import Logged Signal Data" on page 17-7.

5. If the **Inspect Signals** tab is not already selected, select it. By default, the **Inspect Signals** tab displays the Signal Browser table which contains 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 "Customize the Simulation Data Inspector Interface" on page 17-38.

6. Right-click the Signal Browser table title bar. Select `Columns` and uncheck **Block Name** and **Block Path**.

7. Right-click the Signal Browser table title bar. Select `Group Signals`. In the Group Signal dialog box, in the first drop-down box, select `Logged Variable`. Select `None` in the second drop-down box. Click OK.



8. Expand `logsout` to view the logged signals.

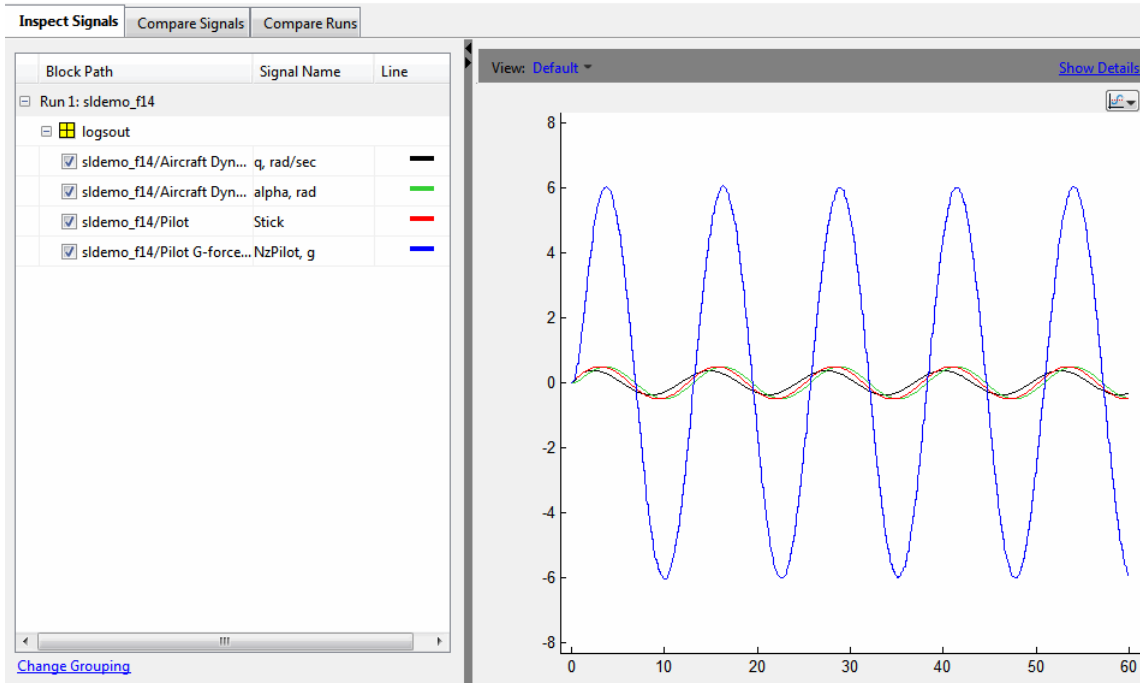
9. "Specify the Line Configuration" on page 17-45 for each signal.

10. To specify the synchronization method, right-click the Signal Browser table title bar. Select `Columns` and check **Synchronization Method**. The **Sync Method** column is displayed in the table. For each signal, click the field for the **Sync Method** column and select a method from the list. In this example, the synchronization method is `union`.

11 Repeat step 5 for the **Interpolation Method**.

12 Click the **Plot** column for a signal. On the right pane of the Simulation Data Inspector tool, the signal data is displayed in the graph.

13 To select multiple signals, hold down **Ctrl** and select each signal by clicking a row. In the **Plot** column, select a check box. All of the highlighted signals are now selected for plotting.



14 To create a report of the results, see “Create Simulation Data Inspector Report” on page 17-32.

Create a View of Multiple Plots

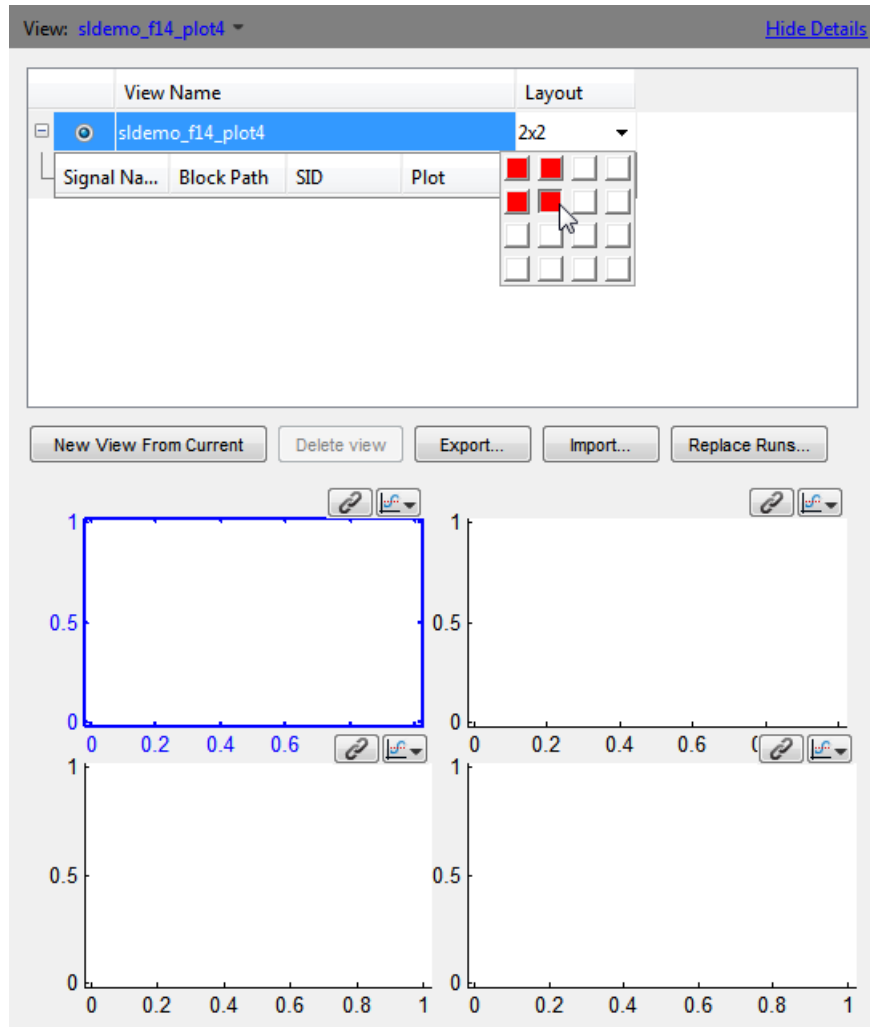
Before creating a view of multiple plots, the Simulation Data Inspector tool must contain signal data. You can obtain signal data by either recording simulation data or importing data into the Simulation Data Inspector tool.

For more information, see “Record Simulation Data” on page 17-5 or “Import Logged Signal Data” on page 17-7.

1. On the right pane, on the **View** toolbar, click **Show Details**.

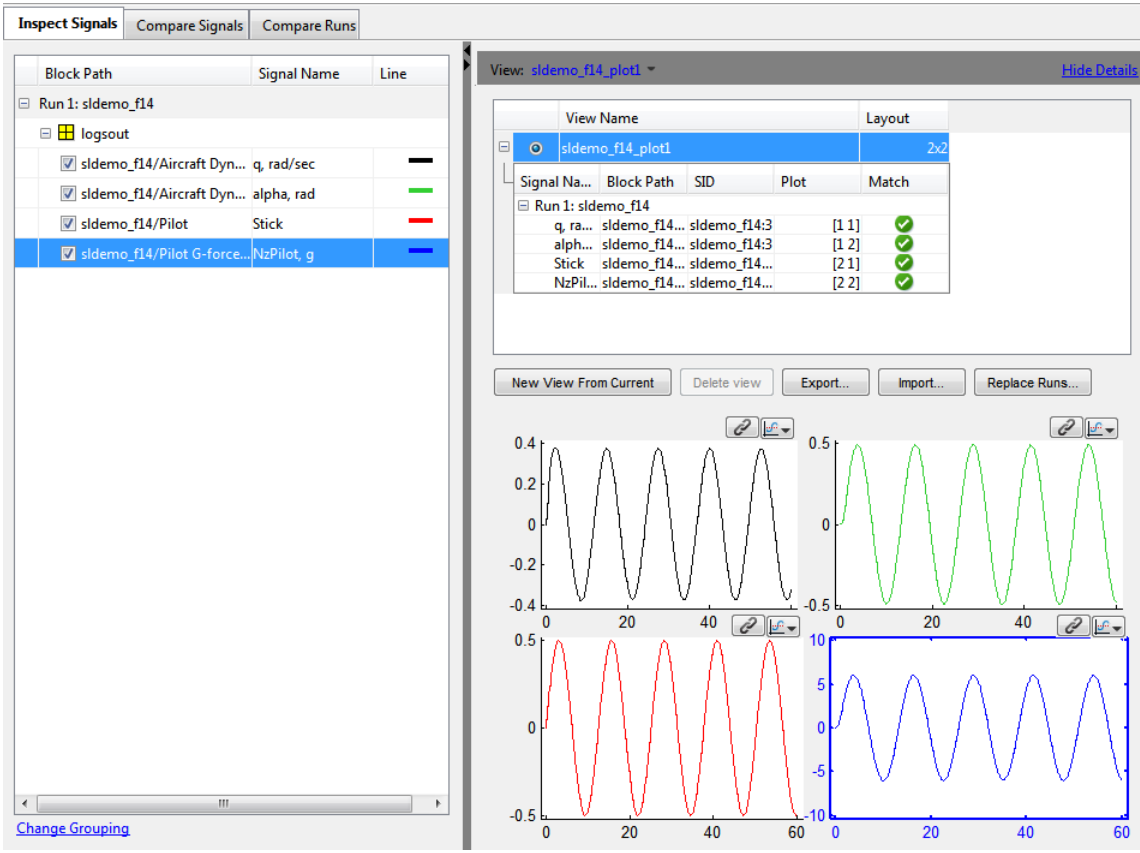
2. In the **View Name** column, click the field which displays **Default**. Type in a new name for the view. In this example, the name is `sldemo_f14_plot4`.

3. In the **Layout** column, click the field that displays `1x1`. A plot matrix opens. To create a view of 4 plots, select the `2x2` matrix.



4 To select a plot, click it. The selected plot is outlined in blue.

5 Once a plot is selected, on the left pane in the Signal Browser table, select a signal in the **Plot** column to add to the selected plot. In this example, a signal from `Run 1` is displayed in each plot in the `sldemo_f14_plot1` view.



For the selected plot `[2,2]`, the signal or signals are shaded in the **Inspect Signals** table to indicate which signals are in the selected plot.

Explore Signal Data in a Multiple Plot View

Linked Plots in a View

Plots within a view can be linked together to enable synchronized panning and zooming. When you create a view, by default, plots in a view are linked together. The following toolbar operations synchronize across linked plots:

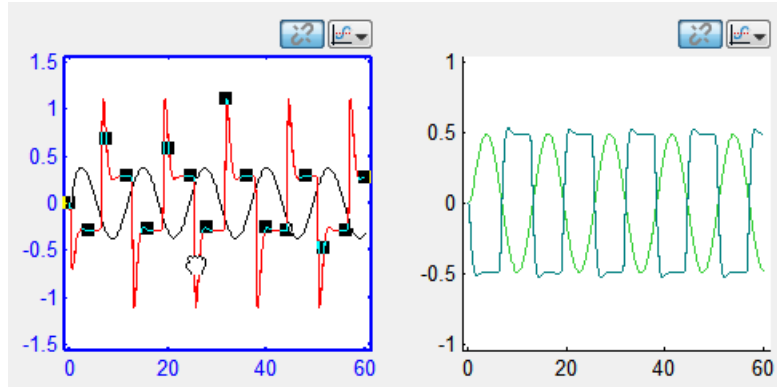
- Pan along the time axis: 

- Zoom on the time axis: 
- Zoom on the time and data value axis: 
- Zoom out: 

To determine if a plot in a view is linked, at the top of each plot, locate the link icon  . If a plot is unlinked, the broken link icon  is displayed and the plot pans and zooms independently.

Move Signals Between Plots in a View

To move a signal from one plot to another, click and hold a signal (markers appear).



Drag the signal to another plot, and the signal is now displayed in the other plot.

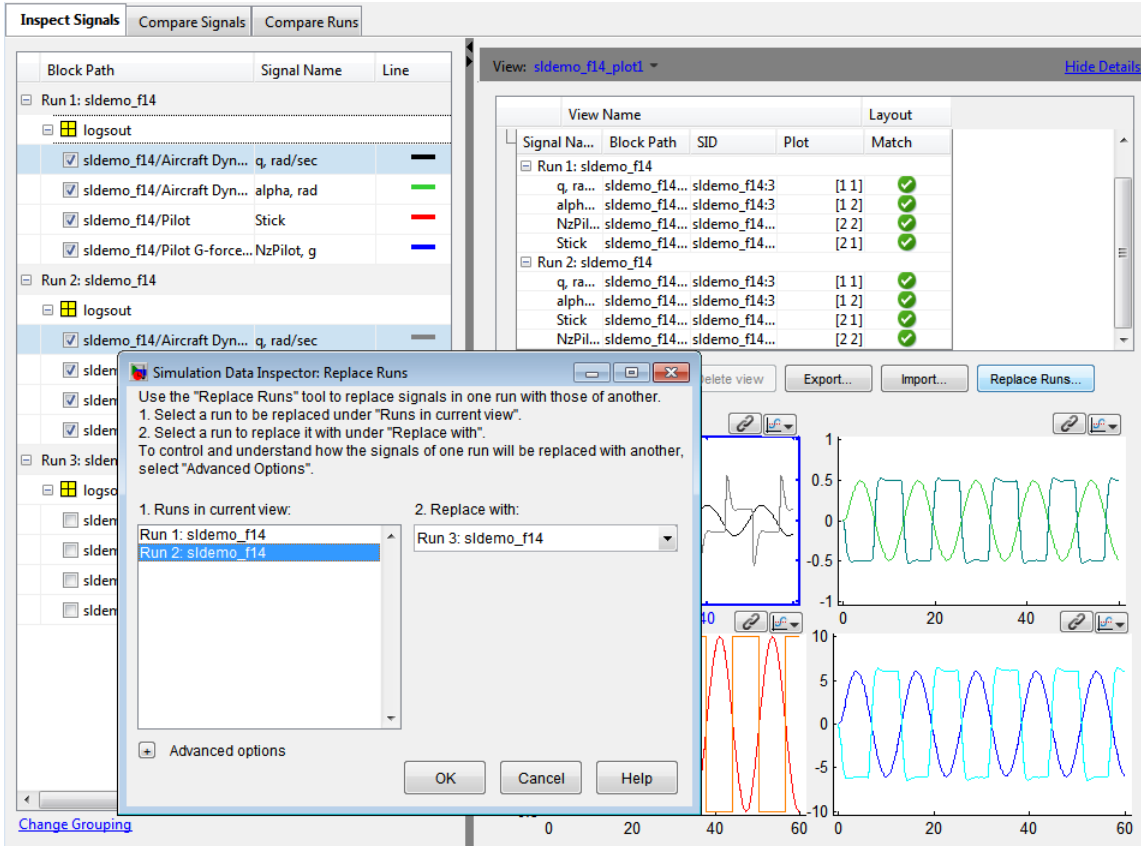
For more information on working with plots, see “Modify a Plot in the Simulation Data Inspector Tool” on page 17-49.

Replace a Run in a View

In this example, the Simulation Data Inspector tool contains three runs of data. To quickly swap out the data from one run with data from another run, do the following:

1. Select a view. In this example, the view is `sldemo_f14_plot1`.

2. Click **Replace runs...**, which opens the Replace runs dialog box.

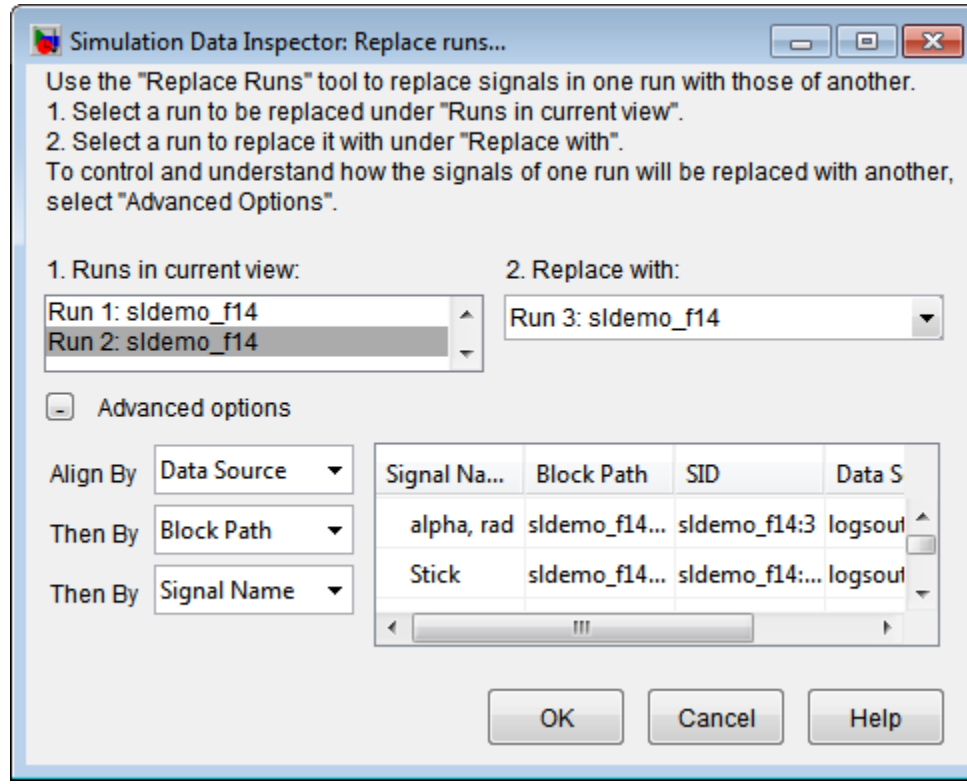


3. To replace the signal data in `Run 2` with the signal data from another run, in the **Runs in current view** list, select `Run 2: sldemo_f14`. Only the signals in the view are replaced

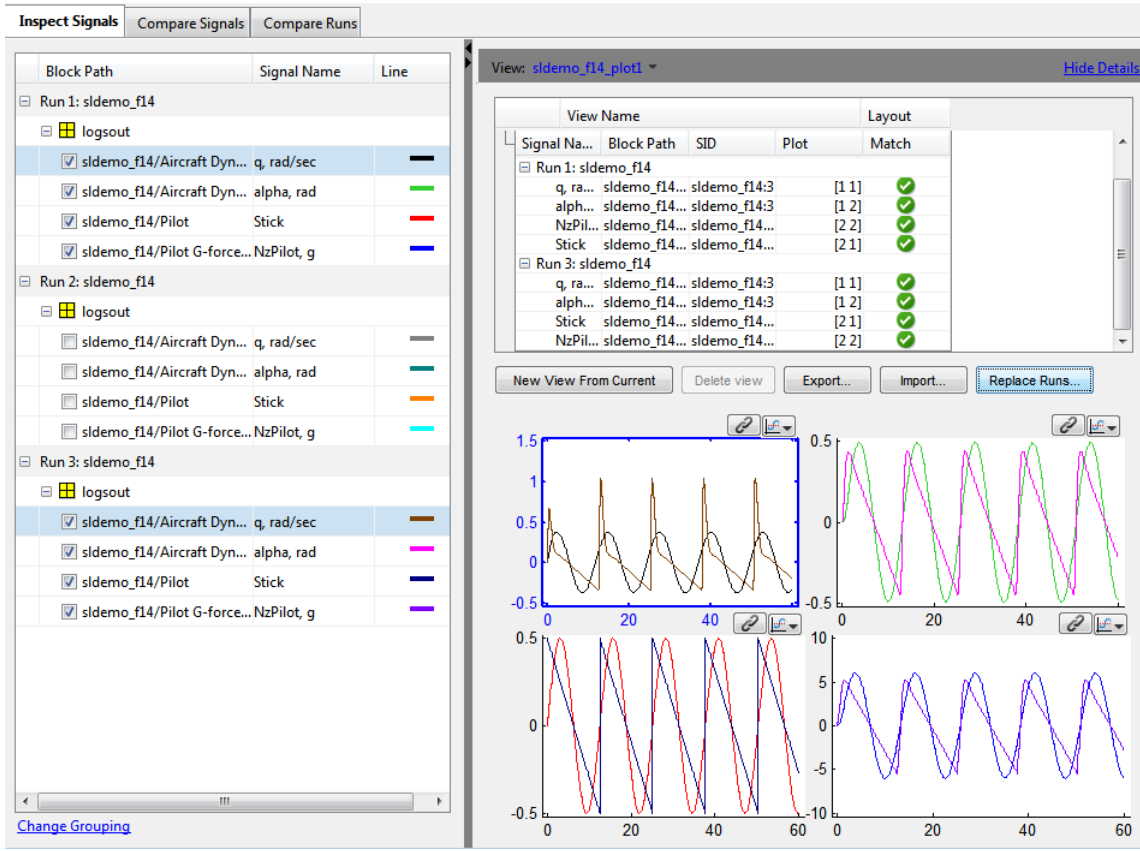
4. In the **Replace with** list, select `Run 3: sldemo_f14`.

5. To specify how the signal data in `Run 2` is replaced with `Run 3`, expand **Advanced options**. In this example, the Simulation Data Inspector first attempts to align the signals by `Data Source`, then by `Block Path`, and

lastly by `Signal Name`. For more information on aligning signals, see "How the Simulation Data Inspector Tool Aligns Signals" on page 17-35.



6 Click **OK**. The data from `Run 2` is replaced with data from `Run 3`.



The View Details table now includes `Run 3` instead of `Run 2`. `Run 3` lists signals from `Run 2`. The **Match** column displays a for a signal that aligned with a signal in `Run 3`. If a signal did not align, the **Match** column displays a .

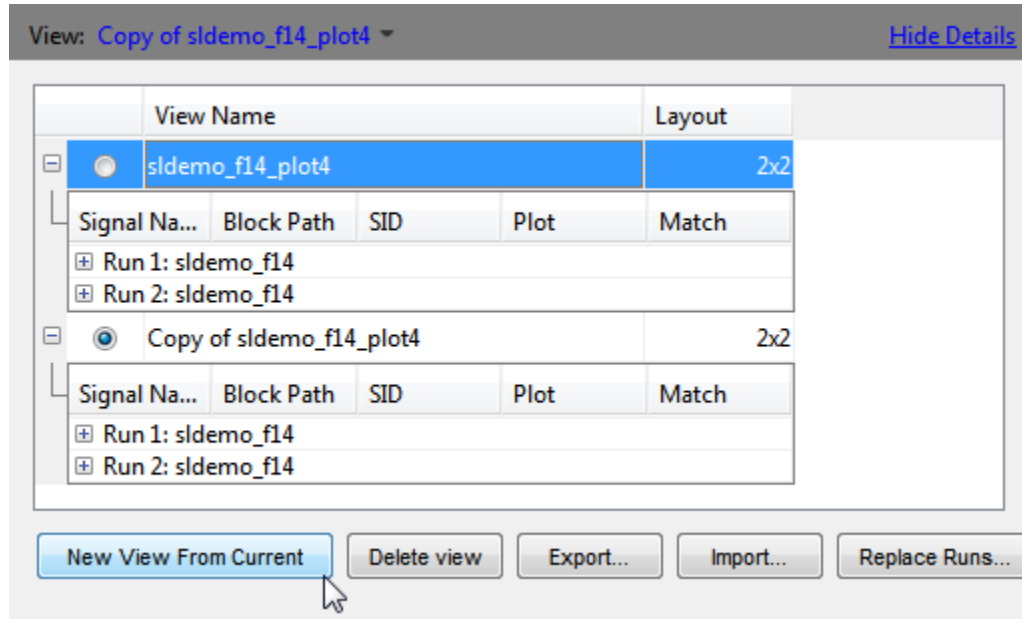
Copy a View in the Inspect Signals Tab

To copy a view:

1 On the right pane, in the View toolbar, click **Show Details** to open the View Details table.

2 Select the view to copy. Be sure to select the option button next to the **View Name** in the table.

3 Click the **New view from current** button. A new view is displayed in the View Details table



4 Select the new view, `Copy of sldemo_f14_plot4`, and rename it.

Delete a View in the Inspect Signals Tab

To delete a view:

1 On the right pane, in the View toolbar, click **Show Details** to open the View Details table.

2 In the View Details table, select the view to delete by selecting the corresponding option button.

3 Click the **Delete View** button.

Note The View Details table always includes one view.

Export a View in the Inspect Signals Tab

To export a view to a MAT-file:

1. On the right pane, in the View toolbar, click **Show Details** to open the View Details table.
2. Click the **Export** button and specify a file.
3. This saves the view, but not the data, into a MAT-file. To save the data and the view, see "Export Results in the Simulation Data Inspector Tool" on page 17-34.

Import a View in the Inspect Signals Tab

To reload a saved view from a MAT-file:

1. On the right pane, in the View toolbar, click **Show Details** to open the View Details table.
2. Click the **Import** button and specify a file.

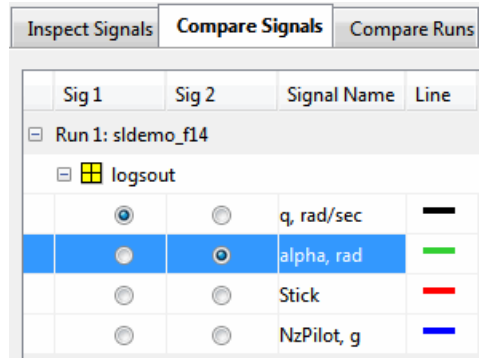
Note This only imports the configuration of the view, which is how the signal data is plotted among the multiple plots. The actual signal data is not imported.

3. To include signal data in the Simulation Data Inspector tool, you can record simulation data (see "Record Simulation Data" on page 17-5), or import data (see "Import Logged Signal Data" on page 17-7).

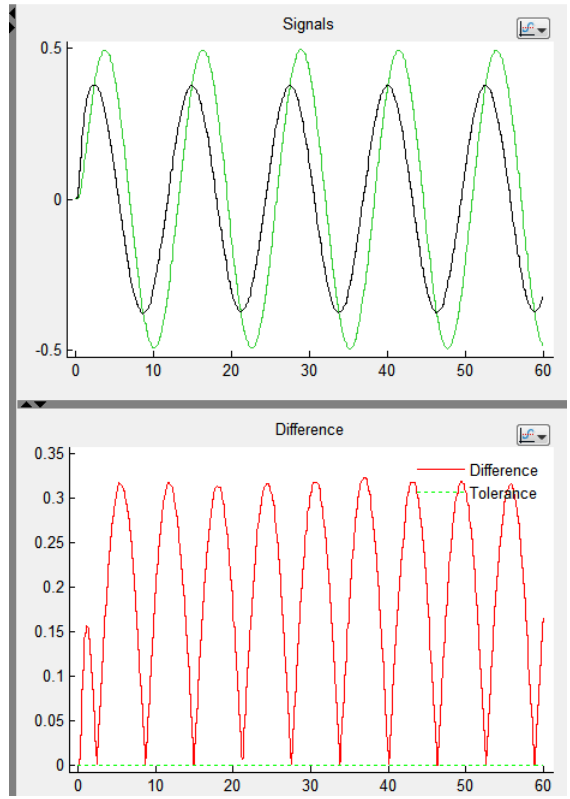
Compare Signal Data

In the Simulation Data Inspector tool, you can use the **Compare Signals** tab of the Signal Browser table for comparing two signals. To compare two signals:

1. Open the Simulation Data Inspector tool. See “Open the Simulation Data Inspector Tool” on page 17-39.
2. Record simulation data or import data into the Simulation Data Inspector tool. See “Record Simulation Data” on page 17-5 or “Import Logged Signal Data” on page 17-7.
3. If it is not already selected, select the **Compare Signals** tab. By default, Signal Browser table on the **Compare Signals** tab displays a row for each signal data, organized by simulation runs. For more information, see “Customize the Simulation Data Inspector Interface” on page 17-38.
4. “Specify the Line Configuration” on page 17-45 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 “Customize the Simulation Data Inspector Interface” on page 17-38.

7 To create a report of the results, see “Create Simulation Data Inspector Report” on page 17-32.

Comparison of One Signal From Multiple Simulations

In the Simulation Data Inspector tool, you can use the **Compare Signals** tab 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 "Open the Simulation Data Inspector Tool" on page 17-39.

2. Record simulation data or import data for two simulation runs. For more information, see "Record Simulation Data" on page 17-5 or "Import Logged Signal Data" on page 17-7.

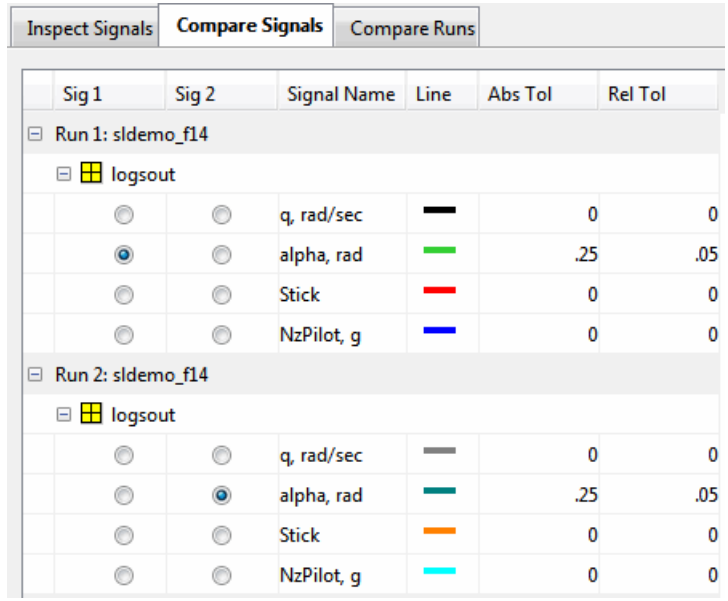
3. Select the **Compare Signals** tab. By default, the Signal Browser table on the **Compare Signals** tab displays a row for each signal data, organized by simulation runs. For more information on modifying the Signal Browser table, see "Customize the Simulation Data Inspector Interface" on page 17-38.

4. "Specify the Line Configuration" on page 17-45 for the signals that you are comparing.

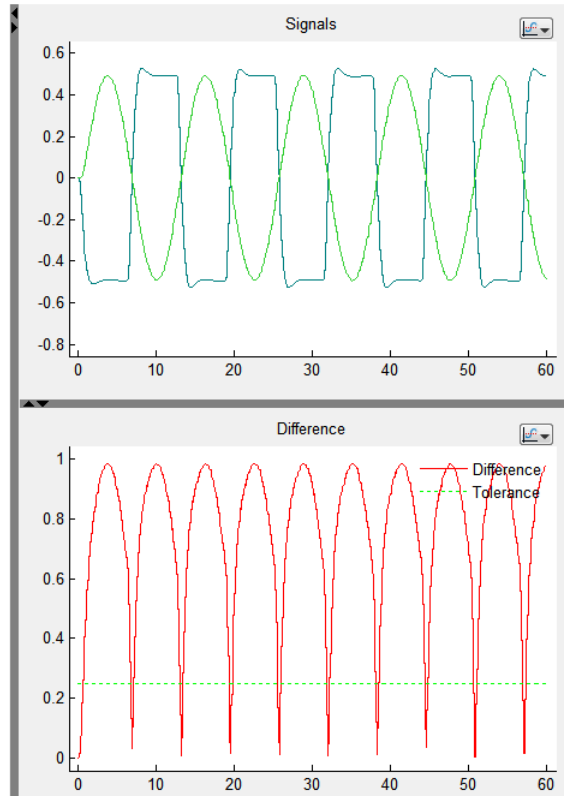
5. To change the relative tolerance and absolute tolerance, add the **Rel Tol** and **Abs Tol** columns to the Signal Browser table. Double-click the corresponding fields for a signal and type in a value.

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.



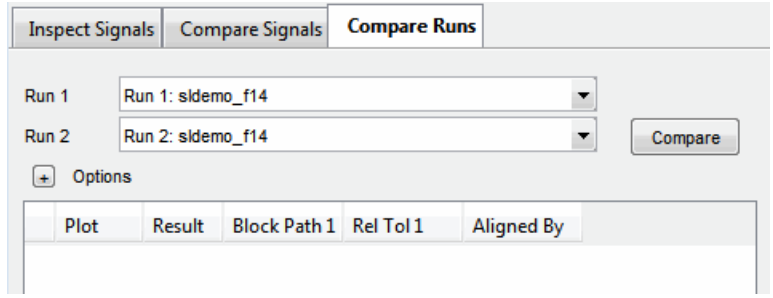
For information on manipulating the graphs, see “Customize the Simulation Data Inspector Interface” on page 17-38.

8 To create a report of the results, see “Create Simulation Data Inspector Report” on page 17-32.

Compare All Logged Signal Data From Multiple Simulations

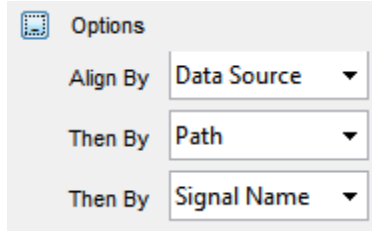
In the Simulation Data Inspector tool, you can use the **Compare Runs** tab to compare all signal data from two different simulation runs. To compare two runs:

1. Open the Simulation Data Inspector tool. See "Open the Simulation Data Inspector Tool" on page 17-39.
2. Record simulation data or import data from multiple simulation runs, for more information, see "Record Simulation Data" on page 17-5 or "Import Logged Signal Data" on page 17-7.
3. Select the **Compare Runs** tab.
4. From the **Run 1** and **Run 2** drop-down lists, select two different runs.



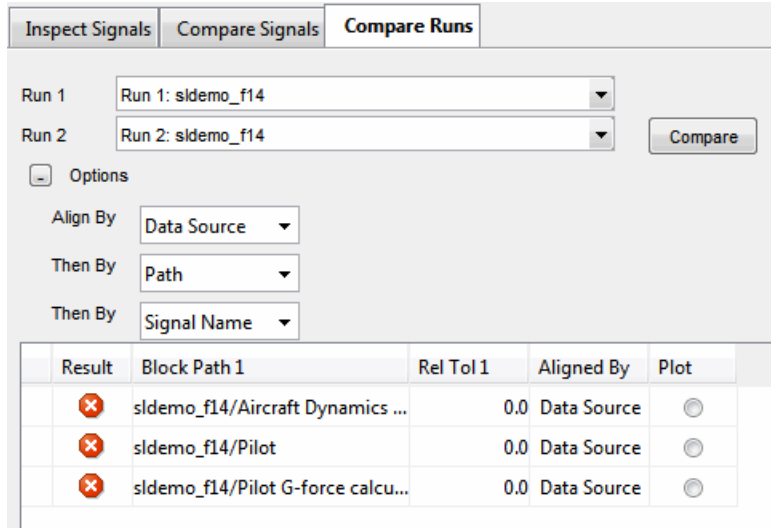
Note The number in a column name indicates the run number. For example, **Abs Tol 1** refers to the absolute tolerance values for signals of the run specified for **Run 1**. **Abs Tol 2** refers to the absolute tolerance values for signals of the run specified for **Run 2**.

5. Select the **Options** button to specify the signal alignment.



The Simulation Data Inspector aligns signals according to **Align By** and **Then By** parameters. For more information on signal alignment, see "How the Simulation Data Inspector Tool Aligns Signals" on page 17-35.

6 Click the **Compare** button. The Comparison Results table lists all signals from **Run 1** with a result. In this example, the comparison results of the aligned signals did not match.

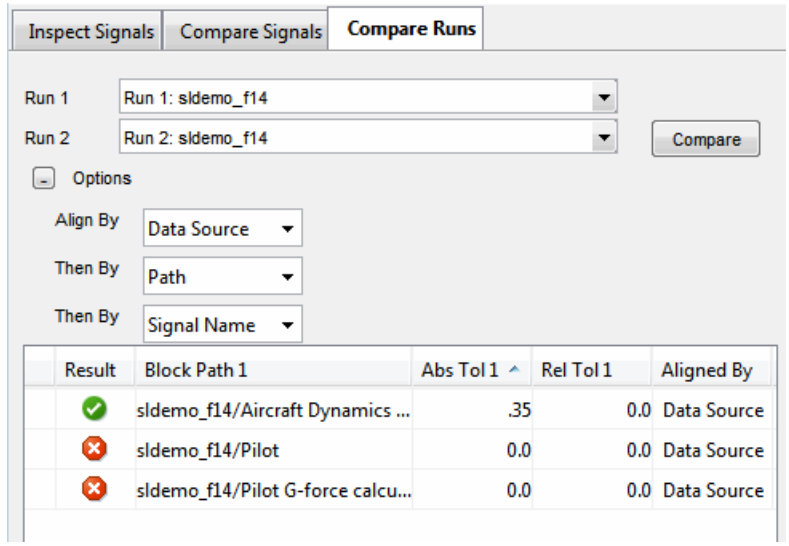


The Simulation Data Inspector only compares signals from **Run 1** that are aligned with a signal from **Run 2**. If a signal from **Run 1** did not align with a signal from **Run 2**, then the **Run 1** signal is listed in the Comparison Results table with a warning ⚠.

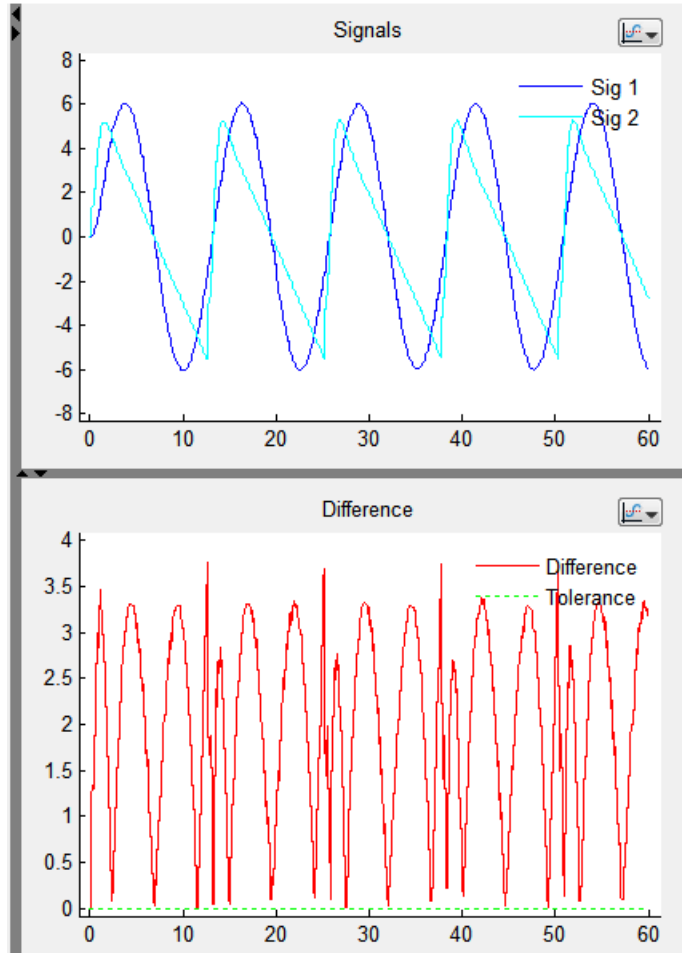
7 To modify the relative tolerance and absolute tolerance, add the **Abs Tol 1** column to the Signal Browser table. Double-click the corresponding fields for a signal and type in a value.

Note Tolerances specified in the other tab views do not carry over to the **Compare Runs** tab.

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 To plot a signal, in the plot column select the option button for `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.



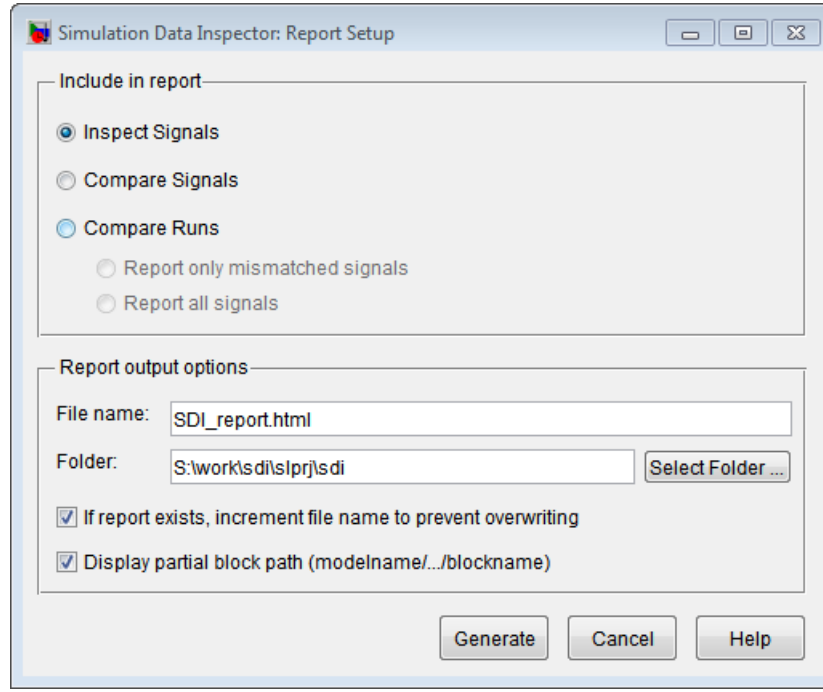
For information on manipulating the graph, see “Customize the Simulation Data Inspector Interface” on page 17-38.

10 To create a report of the results, see “Create Simulation Data Inspector Report” on page 17-32.

Create Simulation Data Inspector Report

To create a report of the current view and data in the Simulation Data Inspector:

1. In the Menu Bar, select **File > Generate Report**. The Report Setup dialog box opens.



2. In the **Include in report** section, specify which tab to include in the report. For the **Compare Runs** tab, you can select **Report only mismatched signals only** to shorten the report or select **Report all signals** which includes all logged signals in the designated runs.

3. Specify the **File name** and **Folder**, or use the default.

4. Optionally, select **If report exists, increment file name to prevent overwriting**, which appends and increments a number to the file name of the report to preserve earlier versions of the report file.

5. Optionally, select **Display partial block path (modelname/.../blockname)**, which shortens the block path string generated for the report.

6. Click **Generate**. The report opens automatically.

Export Results in the Simulation Data Inspector Tool

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 and views 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 and views are now saved in a MAT-file that you can load back into the Simulation Data Inspector.

How the Simulation Data Inspector Tool Aligns Signals

When the Simulation Data Inspector tool aligns signals across simulation runs, it attempts to match signals between runs by using metadata stored for each signal. You can specify the metadata used to align signals. The metadata options are: `Data Source`, `Path`, `SID`, and `Signal Name`. By default, the Simulation Data Inspector tool is configured to first align signals by `Data Source`, then by `Path`, and then by `Signal Name`.

To modify the signal alignment specifications see "Inspect Signals: Aligning Signals for Replacing a Run" on page 17-35 or "Compare Runs: Aligning Signals for Comparing Signal Data" on page 17-36.

Inspect Signals: Aligning Signals for Replacing a Run

To modify how signals are aligned on the **Inspect Signals** tab, do the following:

1. Click the **Inspect Signals** tab.
2. On the right pane, click **Show details**.
3. Click the **Replace runs...** button. The Replace Runs dialog opens.
4. Select **Advanced options**, which displays the **Align By** and **Then By** parameters.
5. Specify the **Align By** and **Then By** parameters from the drop-down lists.

When replacing a run, the Simulation Data Inspector tool attempts to align only the signals selected in the current view. Once those signals are aligned, in the view, the aligned signal data from the first run is replaced with signal data from another run. The View Details table displays the signals from the replaced run as follows:

Status	Result
	• Signal aligned • Signal data is replaced in the view
	Signal not aligned

Compare Runs: Aligning Signals for Comparing Signal Data

To modify how signals are aligned on the **Compare Runs** tab, do the following:

1. Click the **Compare Runs** tab.
2. Select the **Options** button, which displays the **Align By** and **Then By** parameters.
3. Specify the **Align By** and **Then By** parameters from the drop-down lists.
4. Click **Compare**, to align the signal data and compare the aligned signal data.

After signals are aligned from **Run 1** with signals from **Run 2**, the Simulation Data Inspector tool compares only the aligned signals. The Comparison Results table displays the results of all signals from **Run 1** as follows:

Status	Comparison Result
	• Signal aligned • Signal data from two runs matched within the tolerance
	• Signal aligned • Signal data from two runs did not match within the tolerance
	Signal from **Run 1** did not align with a signal from **Run 2**

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 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 17-37.

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:

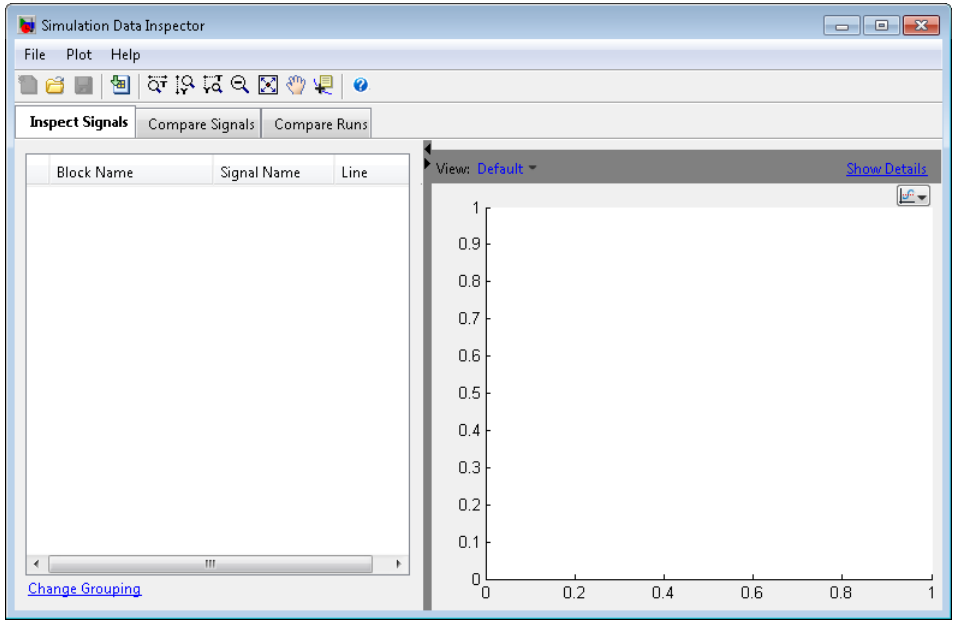
```
tolerance = max(absoluteTolerance, relativeTolerance*abs(baselineData));
```

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.

Customize the Simulation Data Inspector Interface

Overview

The Simulation Data Inspector tool provides the capability to inspect and compare time series data. There are several methods for launching the Simulation Data Inspector tool, see “Open the Simulation Data Inspector Tool” on page 17-39 to choose the method that best supports your workflow. The Simulation Data Inspector tool appears as follows,



The Simulation Data Inspector Window includes the following elements:

- Menu Bar
- “Toolbar” on page 17-51
- Three tabs: **Inspect Signals**, **Compare Signals**, and **Compare Runs**

The Signal Browser table appears on the three tabs: **Inspect Signals**, **Compare Signals**, and **Compare Runs**. You can customize the information displayed in the Signal Browser table by performing the following tasks:

- "Add/Delete a Column in the Signal Browser Table" on page 17-40
- "Modify Grouping in Signal Browser Table" on page 17-42
- "Rename a Run" on page 17-44
- "Select a Run or Signal Option in the Signal Browser Table" on page 17-46
- "Display Run Properties" on page 17-49

The Plot View displays in the right pane of the Simulation Data Inspector tool. To modify a plot, refer to the following:

- "Specify the Line Configuration" on page 17-45
- "Modify a Plot in the Simulation Data Inspector Tool" on page 17-49

Open 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
  ```

- **Simulink Editor**: Click the **Record** button arrow.

  Select **Simulation Data Inspector** from the list.

Why Is the Simulation Data Inspector Tool Empty?

There are several methods for populating the Simulation Data Inspector with data.

- If you are using the record button to simulate and record data, you must specify your model to export signals. For more information, see:
  - "Export Simulation Data" on page 45-4
  - "Export Signal Data Using Signal Logging" on page 45-19

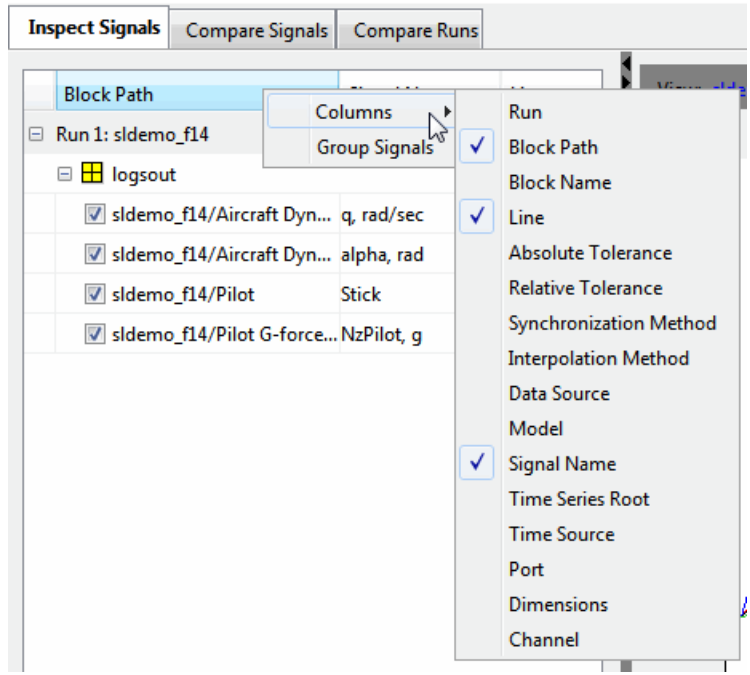
After your model is configured to export signal data, see “Record Simulation Data” on page 17-5.

- If you want to view previously logged signal data, see “Import Logged Signal Data” on page 17-7.

For a list of Simulink data export formats that are not supported in the Simulation Data Inspector, see “Limitations of the Simulation Data Inspector Tool” on page 17-54.

Add/Delete 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 Tabs

Column Option	Value
Run	Name of a simulation run
Block Path	Path to the source block for the signal
Block Name	Name of the source block
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)
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 Tab

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**
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

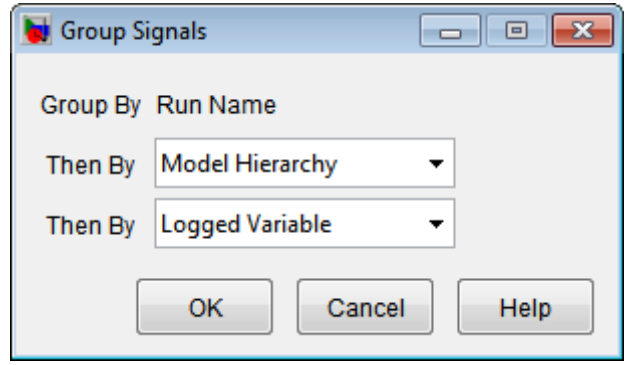
After selecting a column option, the new column is added to the table in the order that it appears in the options list.

Modify Grouping in Signal Browser Table

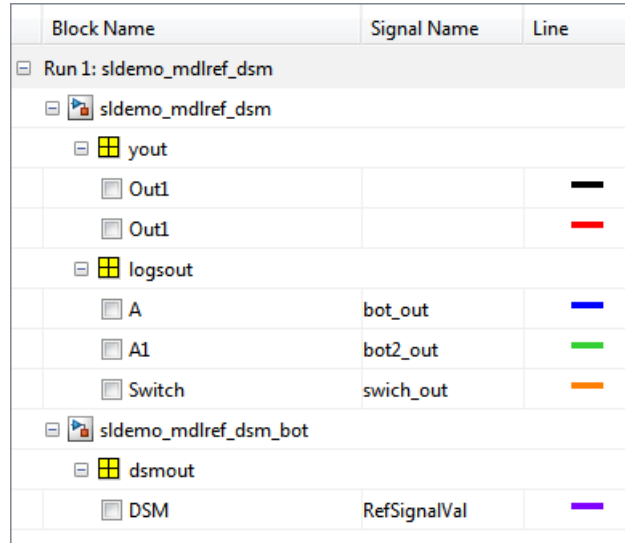
You can customize the organization of your logged data in the Signal Browser table. By default, data is first organized by run. You can then organize your data by model hierarchy, logged variable, or no hierarchy.

If your model contains referenced models to view, you can group your data by model hierarchy and then by the logged variables. To change the grouping in the Signal Browser table:

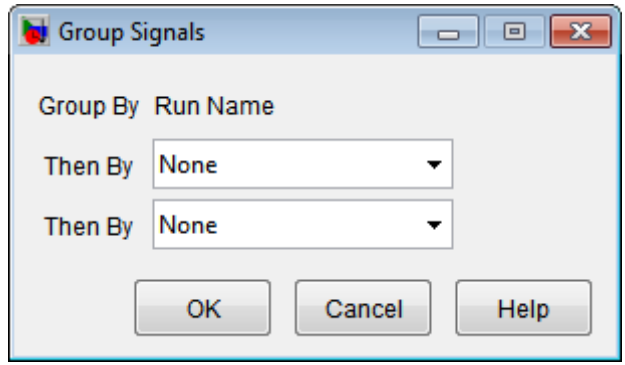
1. Right-click the Signal Browser table and select **Group Signals**.
2. In the Group Signals dialog box, in the first **Then By** list, select `Model Hierarchy`.
3. In the second **Then By** list, select `Logged Variable`.



4. Click **OK**. The Signal Browser table groups the signal data by model and then by the logged variables.



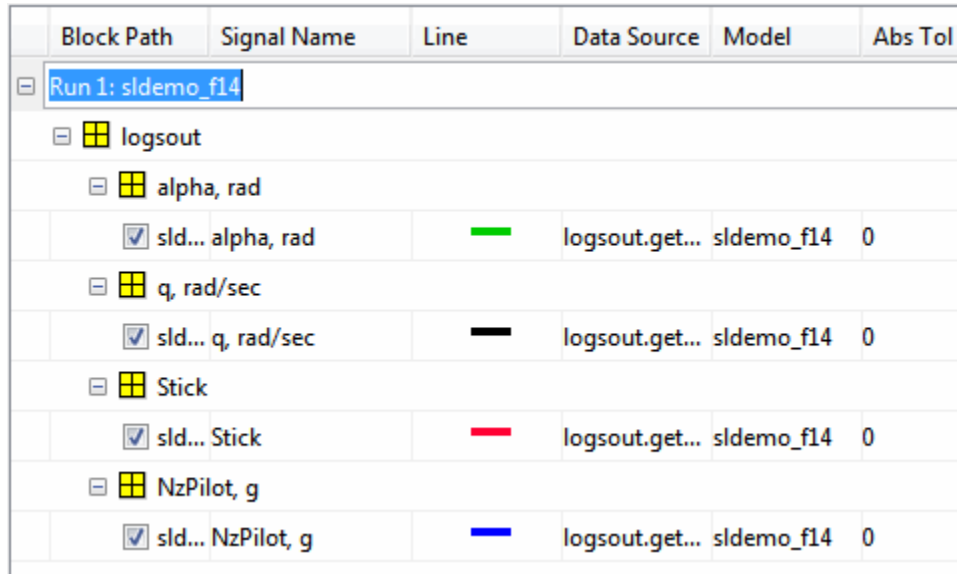
To remove the hierarchy and display a simple list of logged signals, you can select `None` in the Group Signals dialog box.



Rename a Run

To rename a run name:

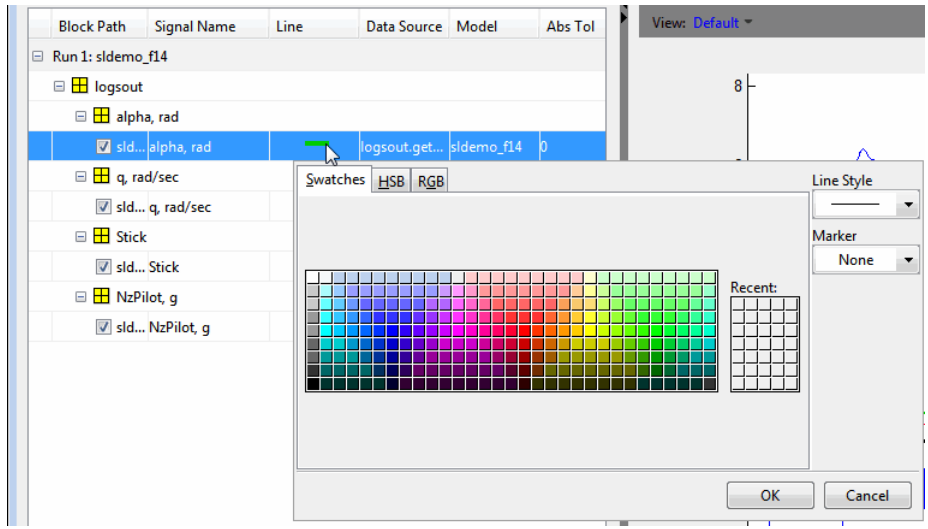
1. If the Signal Browser table is not grouped by run, right-click the table and in the menu select **Group By > Run**.
2. Double-click the Run row.



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.

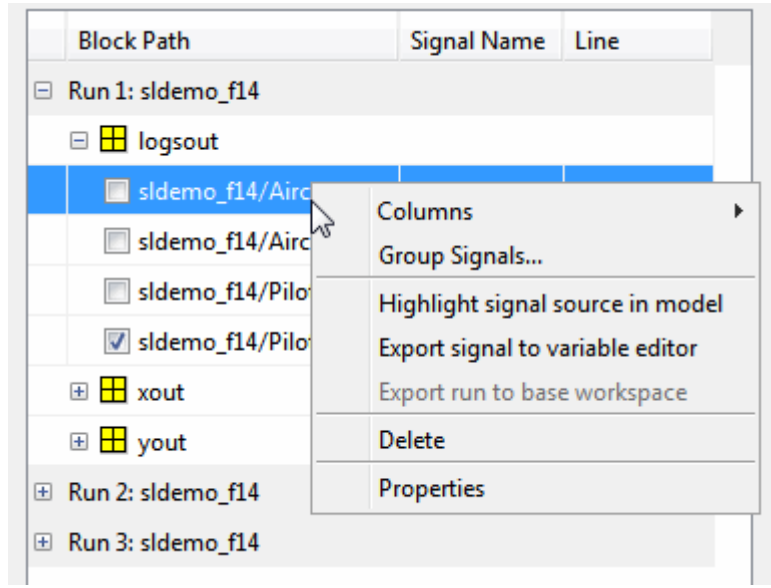


2 Specify the color, **Line Style**, and **Marker** for the signal.

3 Click **OK**.

Select a Run or Signal Option in the Signal Browser Table

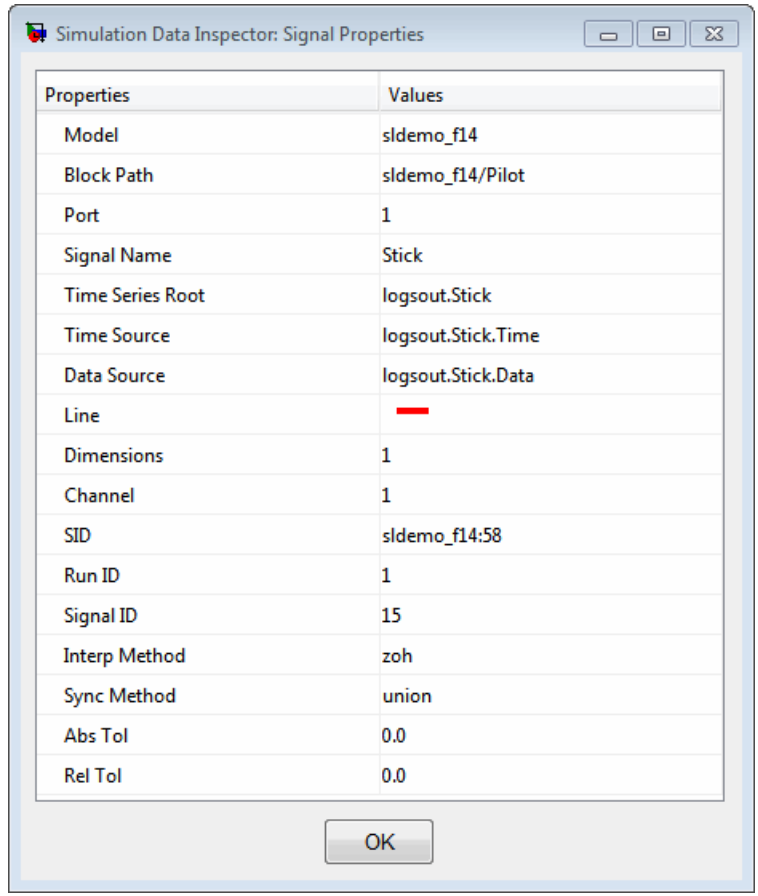
In the Signal Browser table, right-click a run or signal for a menu list of options.



To...	Select...
Display the list of Column options. See Column Options for the Inspect Signals and Compare Signals Tabs on page 17-41	**Columns**
Group signal data by the specified options: **Run**, **Block Path**, **Data Source**, **Model**, and **Signal Name** (this option does not appear in the **Compare Runs** tab)	**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**
Save signal data in the run to the base workspace	**Export run to base workspace**

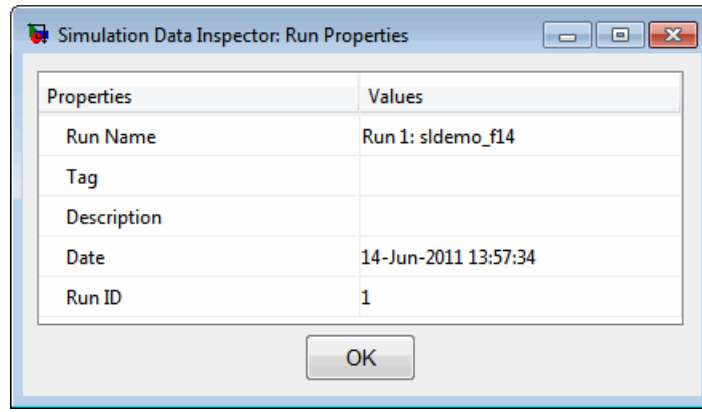
To...	Select...
Delete the highlighted signal in the Signal Browser table (this option does not appear in the **Compare Runs** tab)	**Delete**
Display the signal properties of the selected signal	**Properties**

The Signal Properties dialog box displays the following signal information.



Display Run Properties

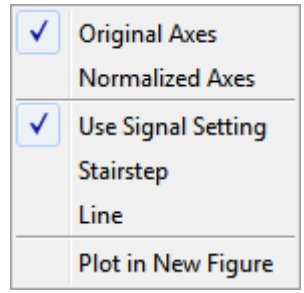
In the Signal Browser table, right-click a run name to view a list of options. To open the Run Properties dialog box, from the options list, select **Properties**.



Modify a Plot in the Simulation Data Inspector Tool

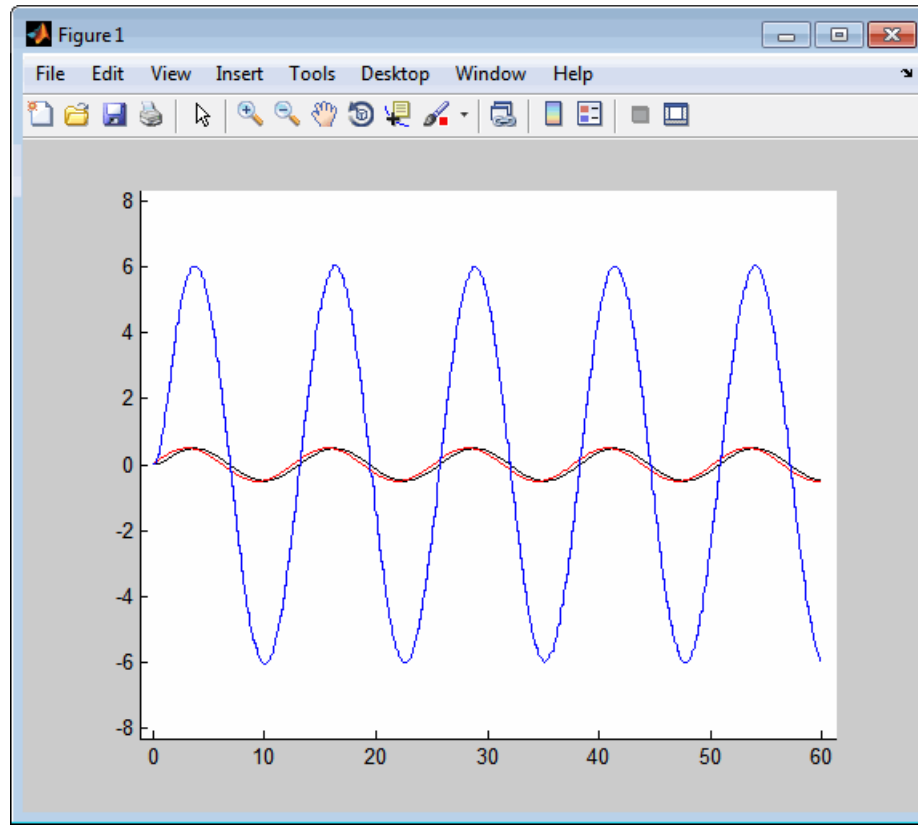
To modify a plot, you can:

- **Toolbar**: Select icons to zoom into data, move the plot, or add a data point to the plot. For more information on these icons, see the "Toolbar" on page 17-51 section.
- **Plot options**: Click  on the plot to select alternatives for plotting the data.



To...	Simulation Data Inspector...
Original Axes	Plots the data according to the maximum and minimum values of the data points. (default)
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.
Stairstep	Plots the data as a stairstep plot. (default)
Line	Interpolates the data points and produces a linear plot.
Plot in New Figure	Launches the graph in a MATLAB figure window.

- **New figure**: Click  on the plot and select **Plot 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 “Figures, Plots, and Graphs”.

To view an example, see “Create, Save, and Print a Figure”.

Toolbar

The toolbar 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** 
Save data in Simulation Data Inspector to a MAT-file.	**Save** 
Launches the Data Import tool.	**Import Data** 
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 from the graph. After selecting the icon, click the graph to incrementally zoom out.	**Zoom Out**
Fit the plot to the graph. After selecting the icon, click the graph to enlarge the plot to fill the graph.	**Fit to View** 

To...	Click...
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** 

Limitations of the Simulation Data Inspector Tool

The following Simulink data export formats are not supported if time is not logged:

- Structure
- Array

The following Simulink data types are not supported:

- Complex data, `int64` and `unit64`
- Enumerated data types

The Simulation Data Inspector tool supports up to 3–dimensional time series data.

Record and Inspect Signal Data Programmatically

Overview

Using the Simulation Data Inspector API, you can plot signal data, compare two signals, and compare two simulation runs of data. You can use the Simulink.sdi.createRun function to add simulation output data to the Simulation Data Inspector. Once the Simulation Data Inspector contains signal data, you can perform the following tasks:

To...	Use...
View signal data, open the Simulation Data Inspector tool	Simulink.sdi.view
Compare the data of two signals	Simulink.sdi.compareSignals
Compare the output of two simulation runs	Simulink.sdi.compareRuns

Run Management

Simulation Data Inspector software creates and manages a list of simulation runs. Each run is an instance of a Simulink.sdi.Run object. This object contains all of the simulation data and metadata for that simulation run.

To...	Use...
Get the number of runs currently in the Simulation Data Inspector	Simulink.sdi.getRunCount
Get the run ID from the list of simulation runs in the Simulation Data Inspector	Simulink.sdi.getRunIDByIndex
Determine if a run ID corresponds to a run currently in the Simulation Data Inspector	Simulink.sdi.isValidRunID
Add more data to a run currently in the Simulation Data Inspector	Simulink.sdi.addToRun

To...	Use...
Make a copy of a run currently in the Simulation Data Inspector	Simulink.sdi.copyRun
Delete a run from the Simulation Data Inspector	Simulink.sdi.deleteRun
Get simulation data for a run in the Simulation Data Inspector	Simulink.sdi.getRun
Manages output signal data and metadata of a simulation run	Simulink.sdi.Run class
Get the Simulink.sdi.Signal object corresponding to the given signal ID	Simulink.sdi.Run.getSignal method
Get the Simulink.sdi.Signal object corresponding to the index into the array signals in the run	Simulink.sdi.Run.getSignalByIndex method
Get the signal ID corresponding to the index into the array signals in the run	Simulink.sdi.Run.getSignalIDByIndex method
Determine if a signal ID corresponds to a signal currently in the run	Simulink.sdi.Run.isValidSignalID method

Signal Management

Each Simulink.sdi.Run object contains a Simulink.sdi.Signal object for each output signal data. This object contains all of the simulation data for the signal and its metadata.

To...	Use...
Get the simulation data and metadata for a signal from one simulation run.	Simulink.sdi.getSignal
Manages a signal's time series data and metadata for one simulation run.	Simulink.sdi.Signal class

Import/Export Data

To...	Use...
Save signal data currently in the Simulation Data Inspector	Simulink.sdi.save
Load previously saved Simulation Data Inspector session	Simulink.sdi.load
Clear all data from the Simulation Data Inspector	Simulink.sdi.clear

Comparison Results

To...	Use...
Manage the results of comparing two runs (Simulink.sdi.compareRuns creates the `Simulink.sdi.DiffRunResult` object)	Simulink.sdi.DiffRunResult class
Manage the results of comparing two signals (Simulink.sdi.compareSignals creates the `Simulink.sdi.DiffSignalResult` object)	Simulink.sdi.DiffSignalResult class

Create a Run in the Simulation Data Inspector

To populate the Simulation Data Inspector with runs of simulation data, you must first simulate your model and then call Simulink.sdi.createRun. When using the API, the Simulation Data Inspector does not automatically record simulation data. To create a run of simulation data, you can use the following code:

```
% Open the model 'sldemo_f14'
load_system('sldemo_f14');
```

```
% Configure model "sldemo_f14" for logging and simulate
simOut = sim('sldemo_f14', 'SaveOutput','on', ...
             'SaveFormat', 'StructureWithTime', ...
             'ReturnWorkspaceOutputs', 'on');
% Create a Simulation Data Inspector run
[runID,runIndex,signalIDs] = Simulink.sdi.createRun('My Run',...
     'namevalue',{'MyData'},{simOut});
```

Compare Signal Data

To compare the simulation data for two signals, you can use the following code:

```
% Configure model "f14" for logging and simulate
simOut = sim('sldemo_f14', 'SaveOutput','on', ...
             'SaveFormat', 'StructureWithTime', ...
             'ReturnWorkspaceOutputs','on');

% Create a Simulation Data Inspector run and get signal IDs
[~, ~, signalIDs] = Simulink.sdi.createRun('My Run', ...
      'namevalue', {'MyData'}, {simOut});

sig1 = signalIDs(1);
sig2 = signalIDs(2);

% Compare two signals, which returns the results in an instance of
% Simulink.sdi.diffSignalResult
diff = Simulink.sdi.compareSignals(sig1, sig2);

% Find if the signal data match
match = diff.match;

% Get the tolerance used in Simulink.sdi.compareSignals
tolerance = diff.tol;
```

Compare Runs of Simulation Data

To compare the signal data between two simulation runs, you can use the following code:

```
% Configure model "sldemo_f14" for logging and simulate
set_param('sldemo_f14/Pilot','WaveForm','square');
```

```
simOut = sim('sldemo_f14', 'SaveOutput','on', ...
                  'SaveFormat', 'StructureWithTime', ...
                  'ReturnWorkspaceOutputs', 'on');

% Create a Simulation Data Inspector run, Simulink.sdi.Run, from
% simOut in the base workspace
runID1 = Simulink.sdi.createRun('First Run','namevalue',{'simOut'},...
    {simOut});

% Simulate again
set_param('sldemo_f14/Pilot','WaveForm','sawtooth');
simOut = sim('sldemo_f14', 'SaveOutput','on', ...
             'SaveFormat', 'StructureWithTime', ...
             'ReturnWorkspaceOutputs', 'on');

% Create another Simulation Data Inspector run
runID2 = Simulink.sdi.createRun('Second Run','namevalue',{'simOut'},...
   {simOut});

% Compare two runs, the result is stored in a
% Simulink.sdi.DiffRunResult object
difference = Simulink.sdi.compareRuns(runID1, runID2);

% Number of comparisons in result
numComparisons = difference.count;

% Iterate through each result element
for i = 1:numComparisons
   % Get signal result at index i
   signalResult = difference.getResultByIndex(i);

   % Get signal IDs for each comparison result
   sig1 = signalResult.signalID1;
   sig2 = signalResult.signalID2;

   % Display if signals match or not
   displayStr = 'Signals with IDs %d and %d %s \n';
   if signalResult.match
      fprintf(displayStr, sig1, sig2, 'match');
   else
```

```
      fprintf(displayStr, sig1, sig2, 'do not match');
   end
end
```

Record Data During Parallel Simulations

To record and view the results from parallel simulations, use the following methods to get and set the location of the Simulation Data Inspector repository:

- `Simulink.sdi.getSource`
- `Simulink.sdi.setSource`
- `Simulink.sdi.refresh`

This example shows how to run multiple simulations in a `parfor` loop and record each run in the Simulation Data Inspector tool.

Open the Simulation Data Inspector.

```
Simulink.sdi.view;
```

Load the model.

```
mdl = 'sldemo_f14';
load_system(mdl);
```

Get the location of the simulation data repository.

```
src = Simulink.sdi.getSource();
```

Open MATLAB pool with 4 workers.

```
matlabpool(4);
```

Run the simulation in a `parfor` loop.

```
parfor i=1:4
   % Set the location of the simulation data repository of this
   % worker to be the same for aggregating the data
   Simulink.sdi.setSource(src);
   % Run the simulation
```

```
   simOut = sim(mdl,'SaveOutput','on',...
                'SaveFormat','StructureWithTime',...
                'ReturnWorkspaceOutputs','on');
   % Create a simulation run in the Simulink Data Inspector
   Simulink.sdi.createRun(['Run' num2str(i)],'namevalue',...
                          {'simout'},{simOut});
end
```

Close the MATLAB pool and all of the models.

```
matlabpool close;
bdclose all;
```

Refresh the Simulation Data Inspector

```
Simulink.sdi.refresh();
```

18

Analyzing Simulation Results

Viewing Output Trajectories

In this section...

Viewing and Exporting Simulation Data

You can use several approaches to view output trajectories. Some approaches display output trajectories during simulation. Other approaches export signal values to the MATLAB workspace during simulation for later retrieval and analysis.

The following sections describe several approaches for viewing output trajectories. For additional information about exporting simulation data, see "Export Simulation Data" on page 45-4.

Using the Scope Block

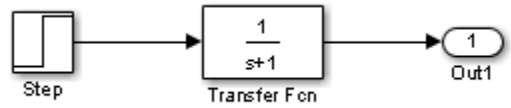
You can display output trajectories on a Scope block during simulation as illustrated by the following model.

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.



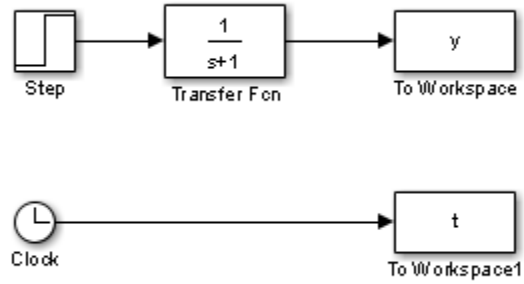
The block labeled Out is an Outport block from the Ports & Subsystems library. The output trajectory, `yout`, is returned by the integration solver. For more information, see "Data Import/Export Pane".

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:



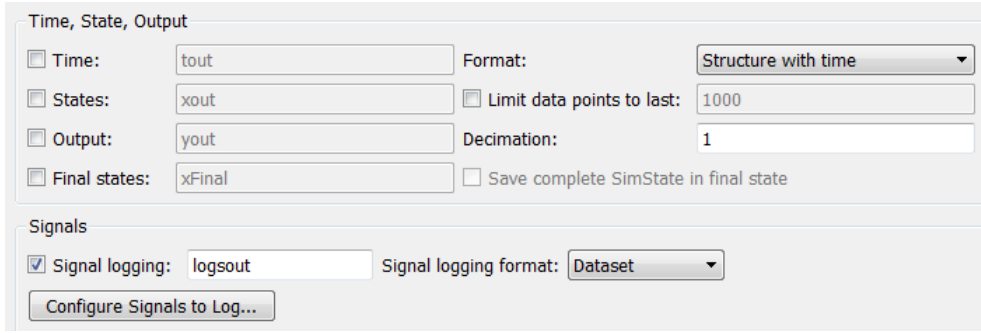
The variables `y` and `t` appear in the workspace when the simulation is complete. You store the time vector by feeding a Clock block into a To

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 parameters:

- **Time**: enable
- **States**: enable
- **Output**: enable
- **Signal logging**: enable
- **Format**: specify `Structure with time`

For more information on the Simulation Data Inspector tool, see "Inspect Signal Data with Simulation Data Inspector" on page 17-2.

Linearizing Models

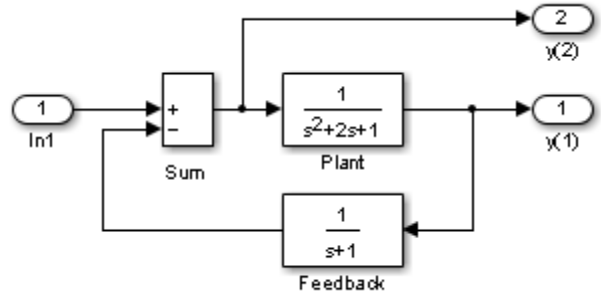
In this section...

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)
```

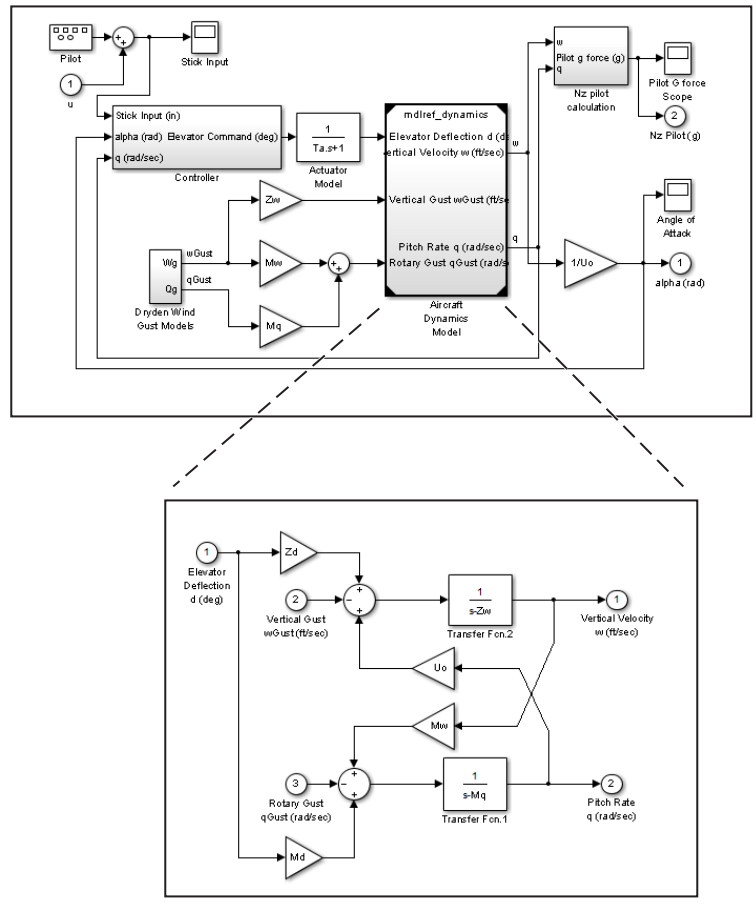
For discrete systems or mixed continuous and discrete systems, use the function `dlinmod` for linearization. This function has the same calling syntax as `linmod` except that the second right-hand argument must contain a sample time at which to perform the linearization.

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. For an explanation of the block-by-block linearization algorithm, see the Simulink Control Design™ documentation.

For example, consider the `f14` model `mdlref_f14`. The Aircraft Dynamics Model block refers to the model `mdlref_dynamics`.



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.

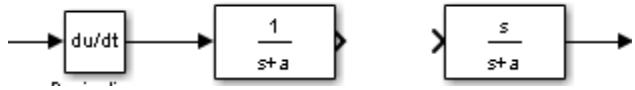
You access the Extras library by opening the Blocksets & Toolboxes icon:

- 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

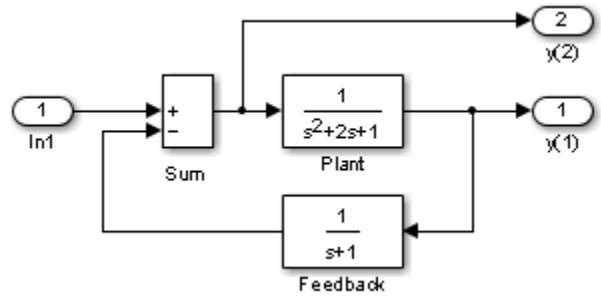
$$\frac{s}{s+a}.$$

In this example, the blocks on the left of this figure can be replaced by the block on the right.


du/dt
1
s+a
s
s+a

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 `ex_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`.

19

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.

Speed Up Simulation

Slow simulation speed can have many causes. Here are a few:

- Your model includes an Interpreted MATLAB Function block. When a model includes an Interpreted MATLAB Function block, the MATLAB interpreter is called at each time step, drastically slowing down the simulation. Use the built-in Fcn block or the 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”.
- 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 3-39.
- 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 “Parameter Settings and Performance with Scope Signal Viewer” on page 16-20.

Comparing Performance

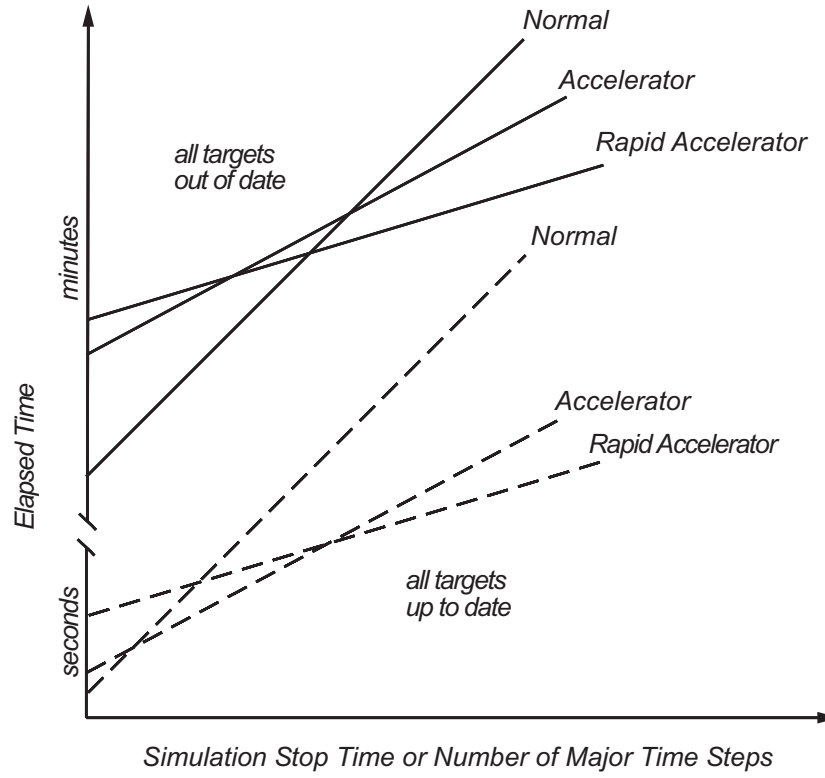
In this section...

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 MATLAB Function 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 “Select Blocks for Accelerator Mode” on page 22-16) might not run much faster than they would in Normal mode unless the simulation stop time is very large. Similarly, models with a large number of Stateflow Chart blocks or MATLAB Function blocks 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 Chart blocks or MATLAB Function 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.

Measure 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 > Mode** 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 > Mode** menu, and build an executable for the model by clicking the **Run** 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 22-7 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.

Improve 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 Simulink Coder software to create C code for the S-function). See "Control S-Function Execution" on page 22-17 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 "Insert S-Function 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 "Customize the Build Process" on page 22-22 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/`

Improve 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 5-29).
- A Derivative block found in an algebraic loop can result in a loss in solver accuracy.

20

Performance Advisor

Consult the Performance Advisor

In this section...

About the Performance Advisor

Whatever the level of complexity of the model, you might want to improve simulation performance. The Performance Advisor checks a model for conditions and configuration settings that can result in slower simulation of the system that the model represents. The Performance Advisor produces a report that lists the suboptimal conditions or settings that it finds, suggesting better model configuration settings where appropriate. The Performance Advisor provides mechanisms for automatically fixing warning or allowing you to fix them manually. For more information on individual Performance Advisor checks, see "Simulink Performance Advisor Checks".

For more guidelines, see Improving Simulation Performance in Simulink.

Prepare to Use Performance Advisor

Before you use the Performance Advisor:

- Make a backup copy of your original model.
- Check that the original model can simulate without error.
- Close all applications, including Web browsers. Only the MATLAB Command Window, the model you want to analyze, and the Performance Advisor tool should be running. The running of other applications can change the performance of model simulation and the ability of Performance Advisor to measure accurately.

Start the Performance Advisor

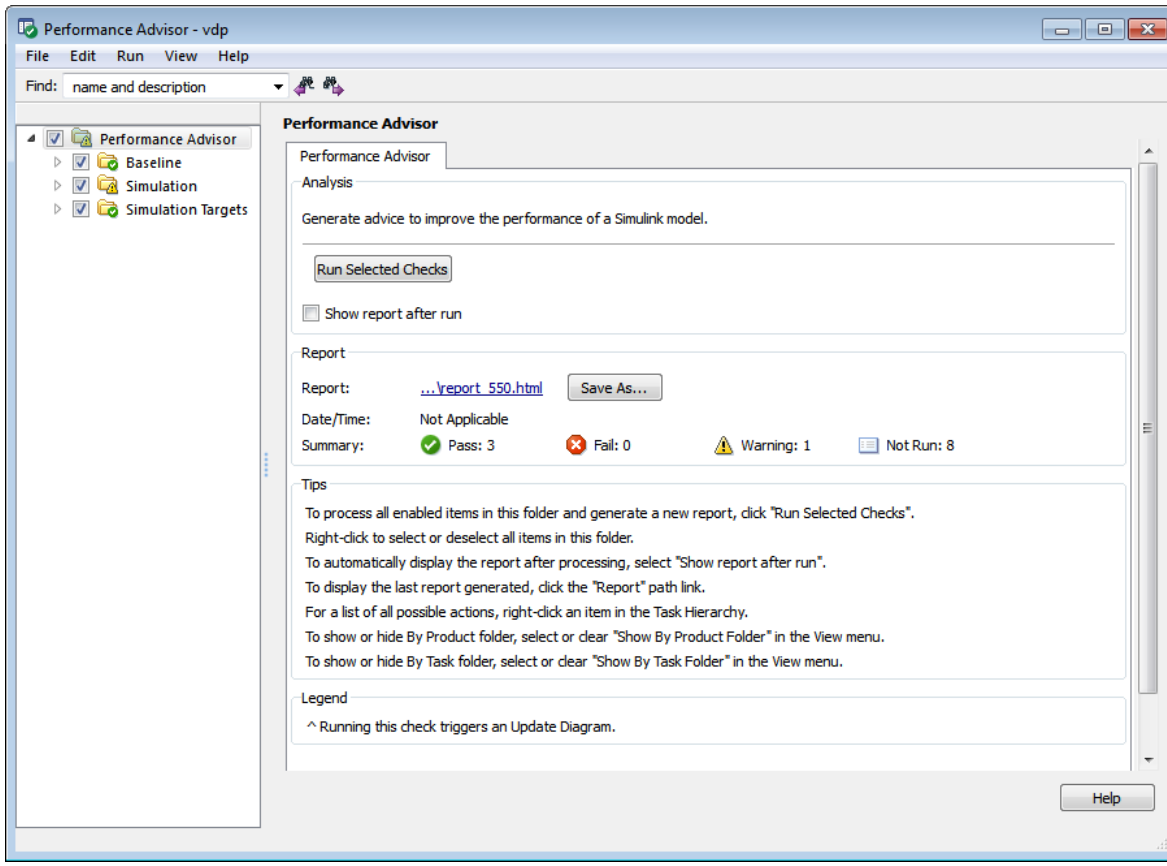
Start the Performance Advisor in one of the following ways:

- To start the Performance Advisor from the Simulink Editor menus, select **Analysis > Performance Tools > Performance Advisor**.
- To start the Performance Advisor from the Simulink Editor toolbar, on the Simulink Editor, on the  drop-down list, select `Performance Advisor`.
- To start the Performance Advisor from the MATLAB Command Window, type `performanceadvisor('model_name')`. For example:

  ```
  performanceadvisor('vdp')
  ```

Overview of the Performance Advisor Window

When you start the Performance Advisor, the Performance Advisor window displays two panes. The left pane lists the folders in the Performance Advisor. Expanding the folders displays the available checks. The right pane provides instructions on how to view and specify which checks you want to run. It also provides a legend describing the displayed symbols.



From the left pane, you can:

- Select by category and expand the folder to display checks related to specific tasks, such as creating a baseline for future checks or checks based on **Simulation** actions.
- Select some or all of the checks using the check boxes or context menus associated with the checks, then run an individual check or all selected checks in a folder.

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

After running checks, the Performance Advisor displays the results in the right pane. Additionally, the Performance Advisor generates an HTML report of the check results. You can optionally view this report in a separate browser window by clicking the **Show report after run** check box in the right pane before the check has run.

The right pane is contextual. It changes depending on your actions. From the right pane:

When you select a...	The right pane displays a Performance Advisor tab with...
Folder	Analysis pane, containing: • **Run Selected Checks** button — Click to run the selected checks in the folder or its subfolders. • **Show report after run** check box — Select to display an HTML report of the check results after the check has run. Tips and Legends sections, containing brief descriptions on using the checks.
Check	Analysis pane, containing: • Input Parameters section — Before running checks, specify how you want checks to run (for more information, see "Run Performance Advisor Checks" on page 20-8). • Result section — Display results after check run. Action pane, containing: • **Modify** button — Click this button to perform recommended actions. • Result section — Display results after performing recommended actions.

Performance Advisor Workflow

Your expected workflow when using Performance Advisor is:

1. When you determine that the performance of a model is slower than expected, use Performance Advisor to help identify and resolve bottlenecks.
2. Have Performance Advisor
   a. Create a baseline against it will compare measurements.
   b. Run the checks you selected.
   c. Make suggested changes.
   d. Run the checks again.
      - If performance is improved, you can stop.
      - If performance is worse than the baseline data, Performance Advisor reinstates the model to the settings it had before the check was run.

Create Baseline

Create a baseline before running checks in Performance Advisor. A baseline is a set of simulation measurements against which Performance Advisor measure check results.

To create the baseline, in the Performance Advisor:

1. Before creating the baseline, you need to verify and possibly set configuration parameters to enable data logging using the Structured with time format. To set configuration parameters, in the model, select **Simulation > Model Configuration Parameters**.
2. In the Configuration Parameters dialog box:
   - Set **Data Import/Export > Format** to `Structure with time`.
   - Set up signal logging. For an easy example, select the **Data Import/Export > States** or **Output** check box.
   - Click the **Configure Signals to Log** button to select the signals to log.

Note Select only the signals you are most interested in. Minimizing the number of signals you want to log can help performance. Selecting too many signals might cause the Performance Advisor to run for a longer time.

3 Click **OK**.

4 Run the model once and check that the simulation runtime is not too long.

5 If the Performance Advisor is not started, start it now.

6 In the left pane, select **Create Baseline**.

7 In the right pane, in the **Input Parameters** section:

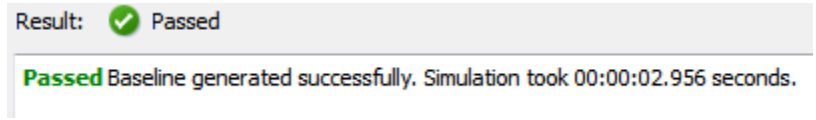
- In **Stop Time**, enter a stop time for the simulation for the baseline creation. By default, if the model stop time is less than 10, Performance Advisor uses that value as the stop time. Otherwise, it uses 10. You should avoid entering a large stop time because the simulation might be too large.
- Click the **Click to view baseline signals and set their tolerances** check box to see and change the baseline signal tolerance. Performance Advisor calculates a default tolerance for the model based on the solver setting.

  After the Performance Advisor runs the check, it starts the Simulation Data Inspector. With this tool, you can compare signals and adjust tolerance levels. For more information, see "Inspect Signal Data with Simulation Data Inspector" on page 17-2.

For more information on input parameters, see "Run Performance Advisor Checks" on page 20-8.

8 In the right pane, click **Run This Check**.

Upon successful creation of a baseline, a message like the following is displayed in the **Analysis Result** section:



Observe that Performance Advisor has filled the **Stop Time** parameter with the stop time of the model.

Note Alternatively, you can create the baseline when you run your selected Performance Advisor checks.

You can now run Performance Advisor checks (see "Run Performance Advisor Checks" on page 20-8).

Run Performance Advisor Checks

This topic assumes that you have created a baseline. If you have not yet done so, see "Create Baseline" on page 20-6.

1 Select checks to run:

- Click a folder, such as **Simulation** or **Simulation Targets**, to display checks related to specific tasks.
- In a folder, 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. By default, the first time you run, all checks are selected.

  Tip If you are unsure of which checks apply, you can select and run all checks, then clear the checks you are not interested in.

  - To select an individual check, in the right pane, select the check. The right pane updates with information particular to this check.
  - To run all selected checks in a folder, in the left pane, select the folder (for example, **Simulation**).

  - To select all selected checks for all the categories, in the left pane, select **Performance Advisor**. Performance Advisor creates the baseline, even if it has already been created, and runs the selected checks.

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

  The right pane changes depending on your selection in the left pane.

2 In the right pane, specify input parameters for checks to run.

Input Parameter	Description
Take action based on advice	`automatically` — Default. Allow Performance Advisor to make the change for you. `manually` — Make the recommended changes yourself or review the changes first. This option allows you to review the recommended change first. You then have the option of making the change yourself, or clicking a modify button that allows Performance Advisor to make changes for you.
Validate and revert changes if time of simulation increases	Select this check box to have Performance Advisor rerun the simulation and verify that the change made based on the advice improves simulation time. If the change does not improve simulation time, Performance Advisor reverts the changes. Clear this check box if you do not want Performance Advisor to run the simulation and verify the results.

Input Parameter	Description
Validate and revert changes if degree of accuracy is greater than tolerance	Select this check box to have Performance Advisor rerun the simulation and verify that after the change, the model results are still within tolerance. If the result is outside tolerance, Performance Advisor reverts the changes. **Note** If you select only this check box, Performance Advisor compares just the signal to see that it is within tolerance. Clear this check box if you do not want Performance Advisor to rerun the simulation and verify that the results are within tolerance.
Quick estimation of model build time	Click this check box to allow Performance Advisor to use the number of blocks of a referenced model to estimate model build time. Performance Advisor performs this quick estimate as follows: **1** Search the model for referenced models that do not refer to other referenced models. **2** Calculate the average number of blocks in each of the referenced models that do not refer to other referenced models. **3** Of the list of referenced models that do not refer to others, select a referenced model whose number of blocks is closest to the calculated average. **4** Build this model to obtain the build time. **5** Based on the number of blocks and the build time for this referenced model, estimate the build time for all other referenced models. **6** Based on these build times, estimate the parallel build time for the top model.

3 To run a check, in the right pane, click the **Run This Check** button. Alternatively, in the menu bar, select **Run > Run Selected Checks**.

After running checks, the Performance Advisor displays the results in the right pane. Additionally, the Performance Advisor generates an HTML report of the current check results in a file with a name like *model_name*\report_#.html

You can optionally view this report in a separate browser window by clicking the **Report** link in the right pane of the folder node.

Note When you open the Performance Advisor for a model that you have previously checked, the Performance 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 Performance Advisor window.

After you run your checks, you can:

- "View and Save Performance Advisor Reports" on page 20-11
- "Understand Performance Advisor Analysis Results" on page 20-14

View and Save Performance Advisor Reports

When the Performance Advisor runs checks, it generates an HTML report of check results.

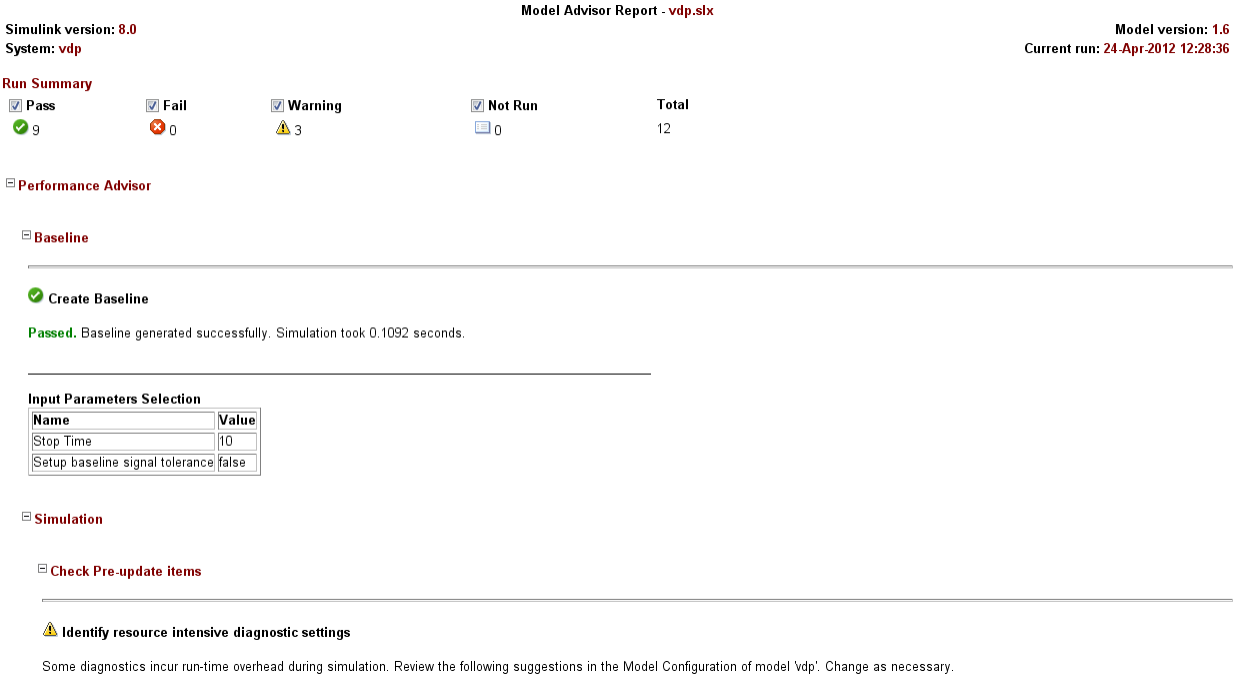
View Performance Advisor Reports

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 Performance Advisor reports, use the Performance Advisor window for interactive fixing. Performance Advisor reports are best for viewing a summary of checks.

As you run checks, the Performance 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.

Some checks have input parameters specified in the right pane of the Performance Advisor. For example, **Identify resource intensive diagnostic settings** has several input parameters. When you run checks with input parameters, the Performance Advisor displays the values of the input parameters in the HTML report:

Identify resource intensive diagnostic settings

Passed

Input Parameters Selection

Name	Value
Take action based on advice	automatically
Validate and revert changes if time of simulation increases	false
Validate and revert changes if degree of accuracy is greater than tolerance	false
Adjust tolerance	N/A

Save Performance Advisor Reports

You can archive a Performance Advisor report by saving it to a new location. To save a report:

1. In the Performance 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 Performance 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 Performance Advisor saves the report and its image graphics to the new location. Performance Advisor does not save its action results to a report.

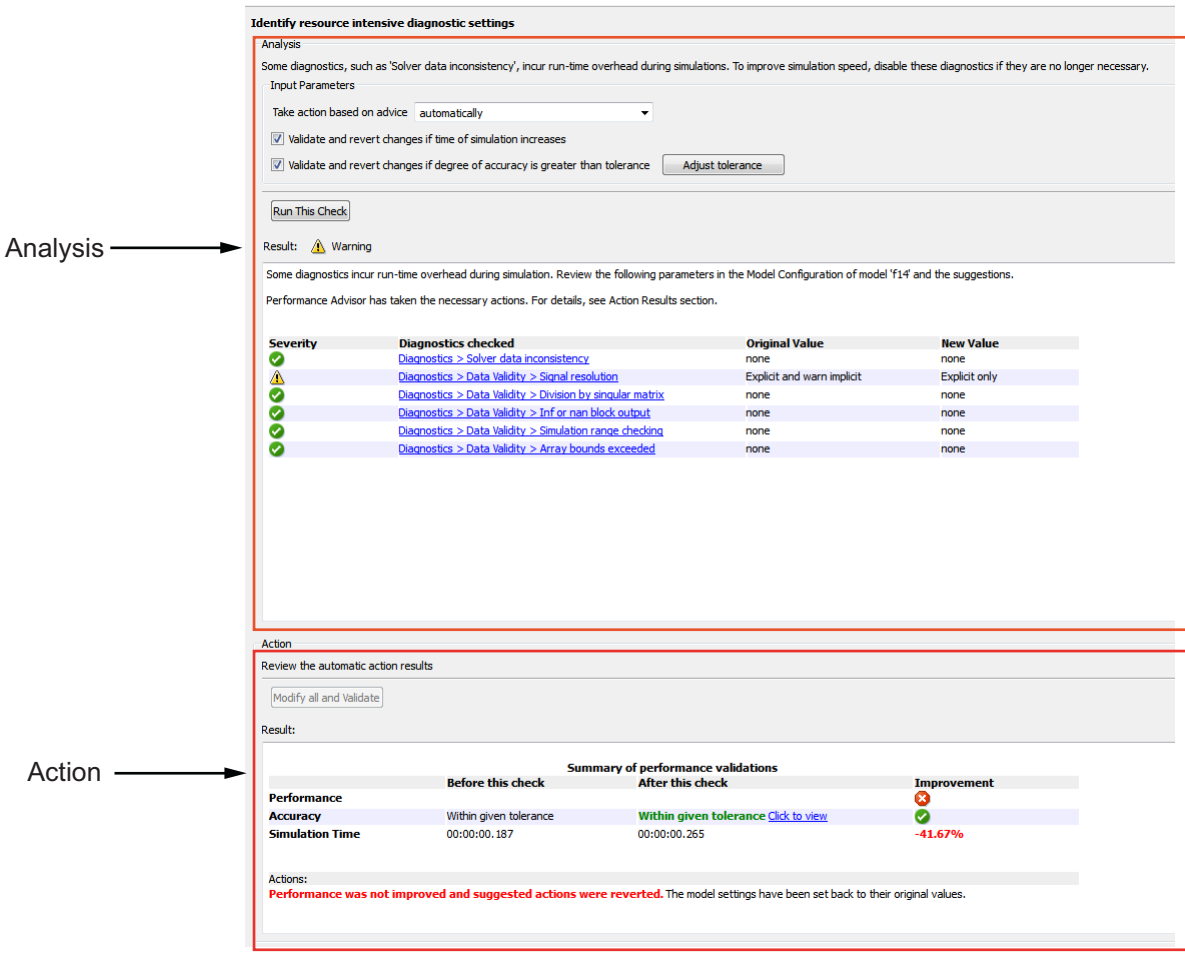
Note If you rerun the Performance Advisor, the report is updated in the working folder, not in the save location.

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 with a structure like the following

`slprj/modeladvisor/com_2emathworks_2eSimulink_2ePerformanceAdvisor_2ePerformanceAdvisor_/`*`model_name`*`/report_`*`xxx`*`.html`

Understand Performance Advisor Analysis Results

After the Performance Advisor runs checks, it updates the right pane of the GUI to reflect the results, for example:



To view the results of a check, in the left pane, select the check that you ran. The right pane updates with the results of the check. This pane has the following sections:

Section	Description
Analysis	Input section contains the input parameters that control the actions. Result section contains a description of the check and the advice action to change the model.
Action	Result section lists the status of the check, action taken or recommended, and a summary of the checks in a table. • If you set the **Take action based on advice parameter** to `automatically`, Performance Advisor has made the change for you. You can click the links on the table to evaluate the changes. • If you **Take action based on advice parameter** to `manually`. Performance Advisor has not made the change for you. To make the changes yourself, click the links and make the recommended changes. **Tip** The modify button action changes depending on the **Input Parameter** settings. It can only make recommended changes (**Modify all**), or it can make recommended changes and verify (**Modify all and validate**). • Action section lists a summary of the actions that Performance Advisor took based on recommendations listed in the Result section of the Analysis section. If the tool also performed validation actions, this section lists the results in a summary table. If performance has not improved, Performance Advisor reinstates the model to the settings it had before the check was run.

When you are done, see “Fix a Warning” on page 20-16.

Fix a Warning

The top of the Analysis Result section displays text that describes actions that Performance Advisor suggests. Based on your settings in the Input Parameters section.

- If you set the **Take action based on advice** parameter to `automatically`, Performance Advisor has made the recommended changes for you.
- If you set the **Take action based on advice** parameter to `manually`, you can perform the change yourself, or have Performance Advisor make the change for you by clicking the **Modify** button.

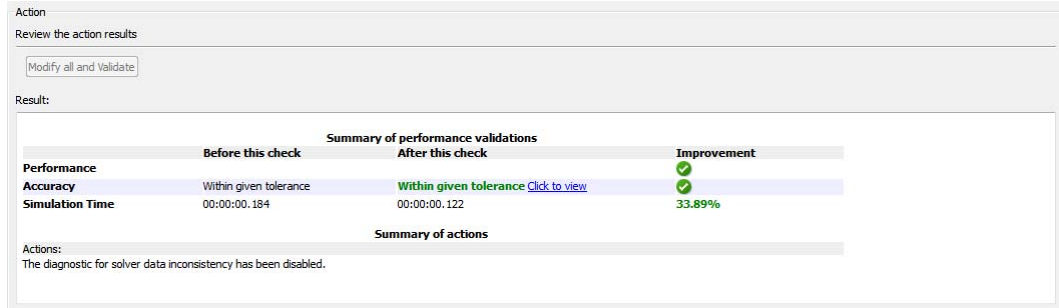
The bottom part of the Analysis Result section contains a table that lists the results of the checks.

Severity	Description
	The model setting is optimal.
	The model setting is suboptimal. You can choose to fix the reported issue, or move on to the next check. For best performance, make the recommended change. For more information on why a specific check does not pass, see the check documentation.

For a description of the actions that Performance Advisor takes, see “Review the Actions Taken” on page 20-16.

Review the Actions Taken

The Action Result section contains a summary of the actions that Performance Advisor took based on **Input Parameters** setting. If the tool also performed validation actions, this section lists the results in a summary table.



Severity	Description
	The actions succeeded. The table lists the percentage of improvement.
	The actions failed. For example, if Performance Advisor cannot make a recommended change, it flags this as failed. It also flags a check as failed if performance was not improved and reinstates the model to the settings it had before the check was run.

Save Your Model

Performance Advisor does not automatically save your model after it makes changes. When you are satisfied with the changes to your model from Performance Advisor, save the model.

Performance Advisor Limitations

When you use the Performance Advisor to check systems, the following limitations apply:

- If you rename a system, you must restart the Performance Advisor to check that system.
- Use Performance Advisor on top models. Performance Advisor does not traverse referenced models or library links.
- Remember to save your model after Performance Advisor makes changes to the model. Performance Advisor does not save the model.

For limitations that apply to specific checks, see the Limitations section within the documentation of each check.

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.

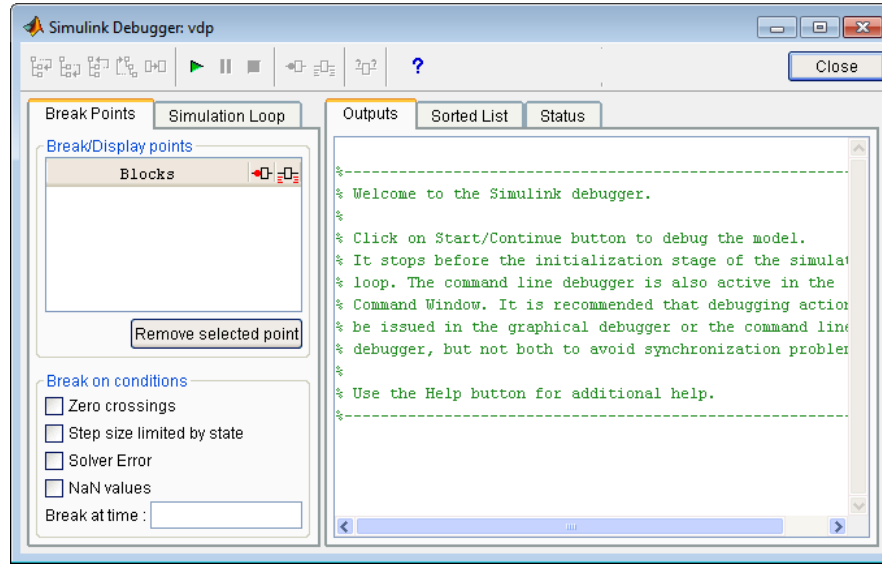
The debugger has both a graphical and a command-line user interface. The graphical interface allows you to access the most commonly used features of the debugger. The command-line interface gives you access to all of the capabilities in the debugger. If you can use either to perform a task, the documentation shows you first how to use the graphical interface, then the command-line interface.

Debugger Graphical User Interface

In this section...

Displaying the Graphical Interface

Select **Debug Model** from a model window **Simulation > Debug** menu to display the debugger graphical interface.



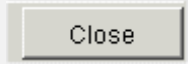
Note The debugger graphical user interface does not display state or solver information. The command line interface does provide this information. See "Display System States" on page 21-31 and "Display Solver Information" on page 21-32.

Toolbar

The debugger toolbar appears at the top of the debugger window.

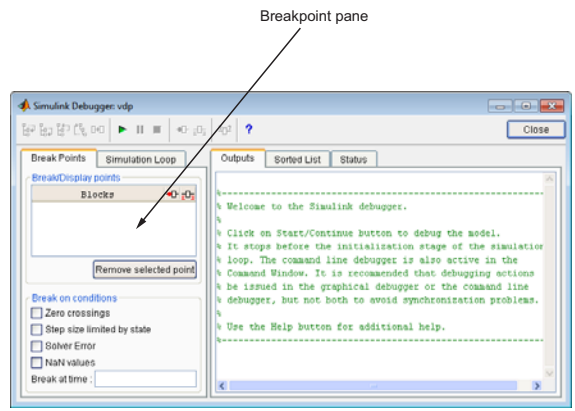
From left to right, the toolbar contains the following command buttons:

Button	Purpose
	Step into the next method (see "Stepping Commands" on page 21-19 for more information on this command, and the following stepping commands).
	Step over the next method.
	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.

Button	Purpose
	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`).
	Display help for the debugger.
	Close the debugger.

Breakpoints Pane

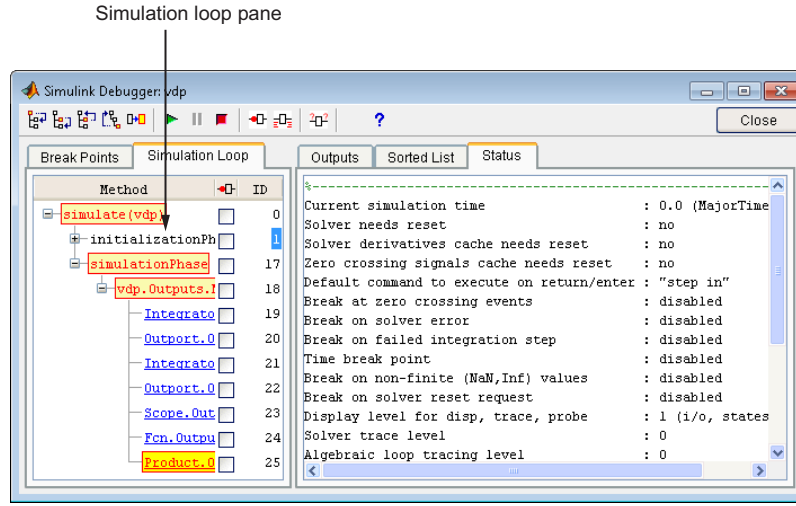
To display the **Breakpoints** pane, select the **Break Points** tab on the debugger window.



The **Breakpoints** pane allows you to specify block methods or conditions at which to stop a simulation. See “Set Breakpoints” on page 21-22 for more information.

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

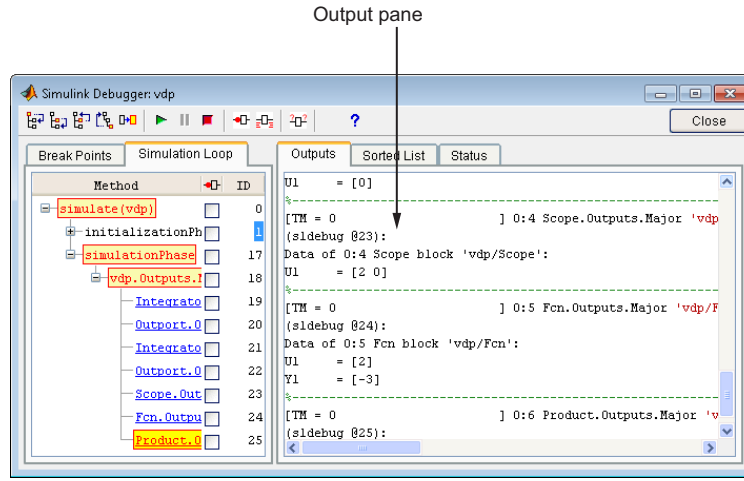
The breakpoints column consists of check boxes. Selecting a check box sets a breakpoint at the method whose name appears to the left of the check box. See “Setting Breakpoints from the Simulation Loop Pane” on page 21-24 for more information.

ID Column

The ID column lists the IDs of the methods listed in the **Methods** column. See “Method ID” on page 21-10 for more information.

Outputs Pane

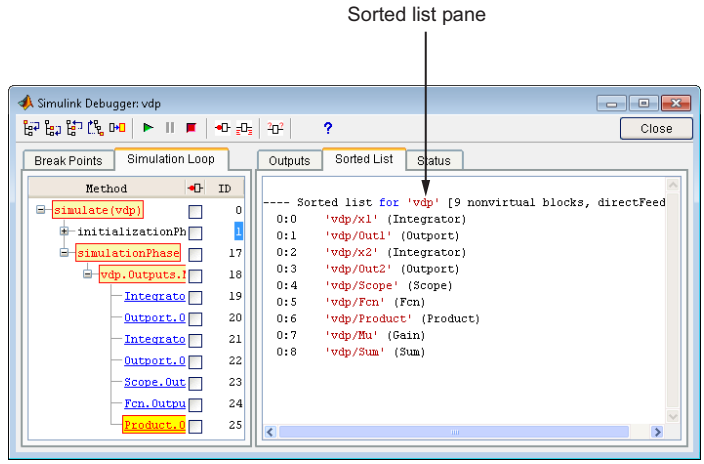
To display the **Outputs** pane, select the **Outputs** tab on the debugger window.



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 21-18). 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 21-10).

Sorted List Pane

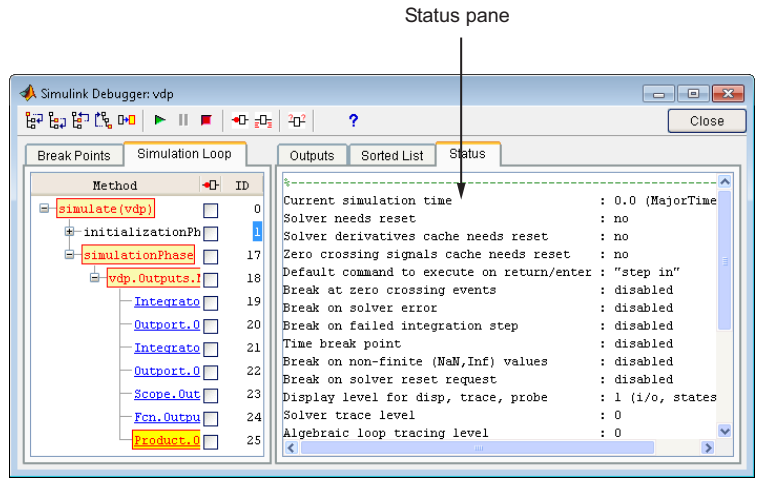
To display the **Sorted List** pane, select the **Sorted List** tab on the debugger window.



The **Sorted List** pane displays the sorted lists for the model being debugged. See “Display Model’s Sorted Lists” on page 21-33 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.

Debugger 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 `sldebug` to access 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.

Debugger 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.

Start 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 **Simulation > Debug > Debug Model** > .

The debugger graphical user interface opens. See "Debugger Graphical User Interface" on page 21-3.

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"Start a Simulation" on page 21-15.

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

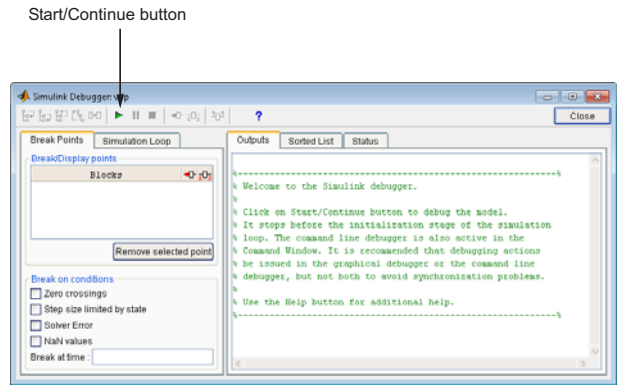
  ```
  sldebug 'vdp'
  ```

In both cases, the example 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.

Start a Simulation

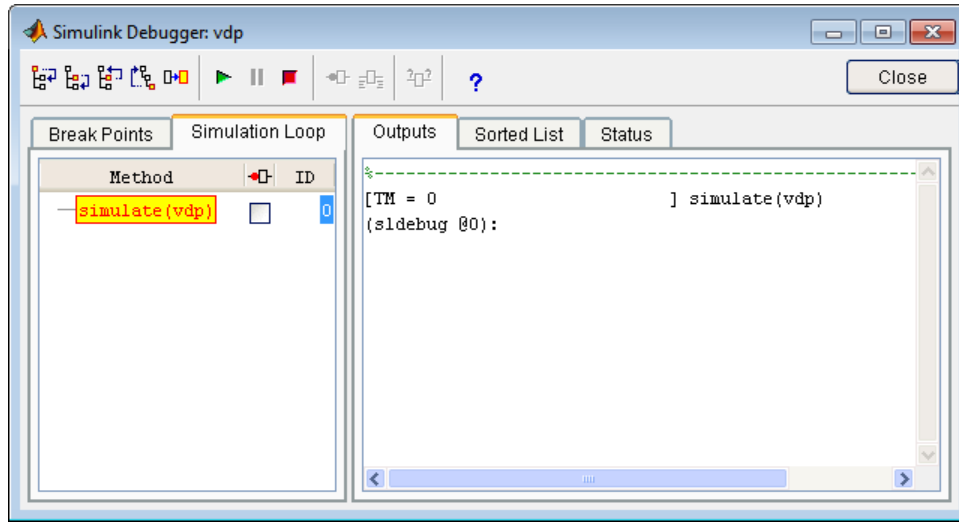
To start the simulation, click the **Start/Continue** button on the debugger toolbar.



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. 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.

The debugger displays the name of the method in the Simulation Loop pane, as shown in the following figure:



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.

Run a Simulation Step by Step

In this section...

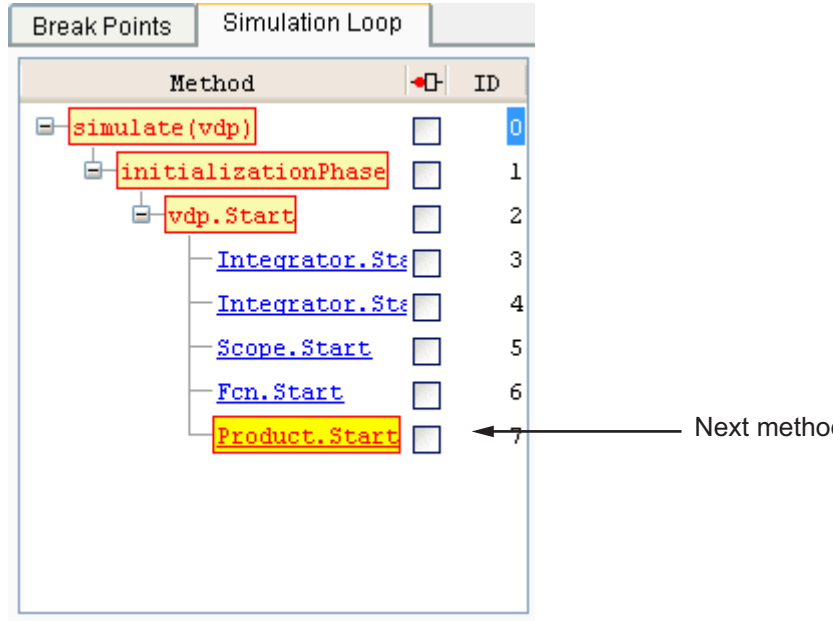
Introduction

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 21-19). 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.

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 `n`th output.

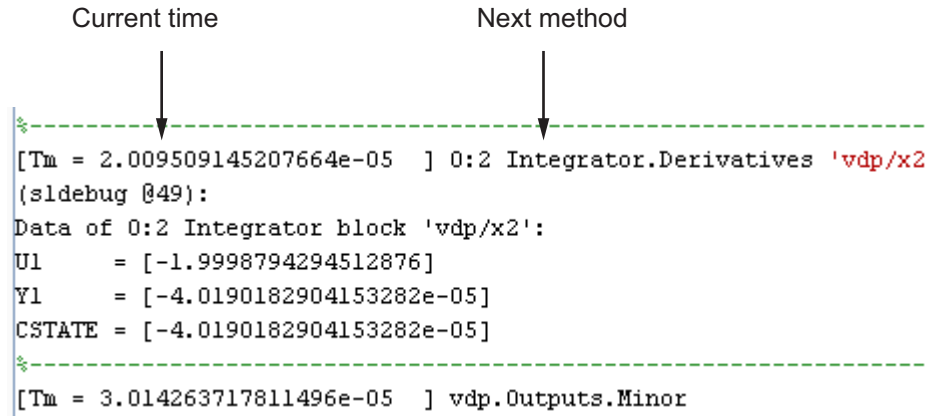
- `CSTATE = v`

  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.



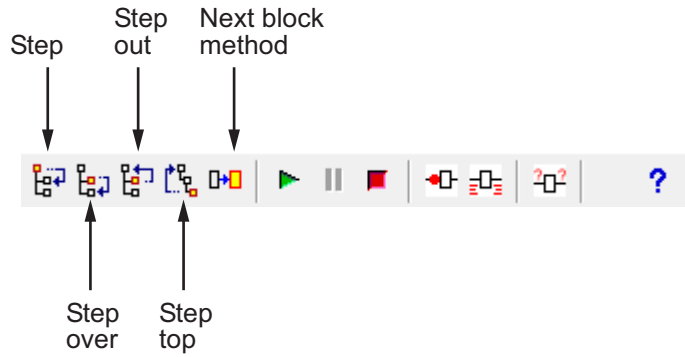
Stepping Commands

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
`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)

This command...	Advances the simulation...
`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 "Set Breakpoints" on page 21-22) or to the end of the simulation, whichever comes first.

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.

Set 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.

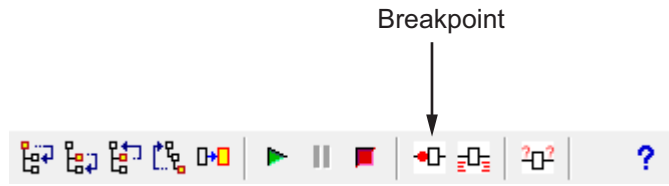
Setting Unconditional Breakpoints

You can set unconditional breakpoints from the:

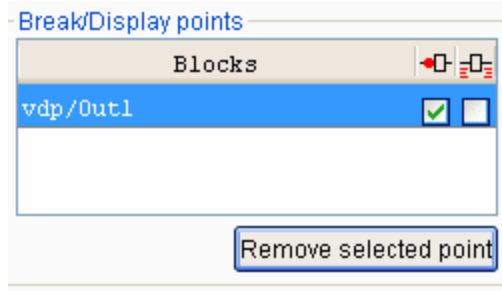
- Debugger toolbar
- **Simulation Loop** pane
- MATLAB product Command Window (command-line mode only)

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.

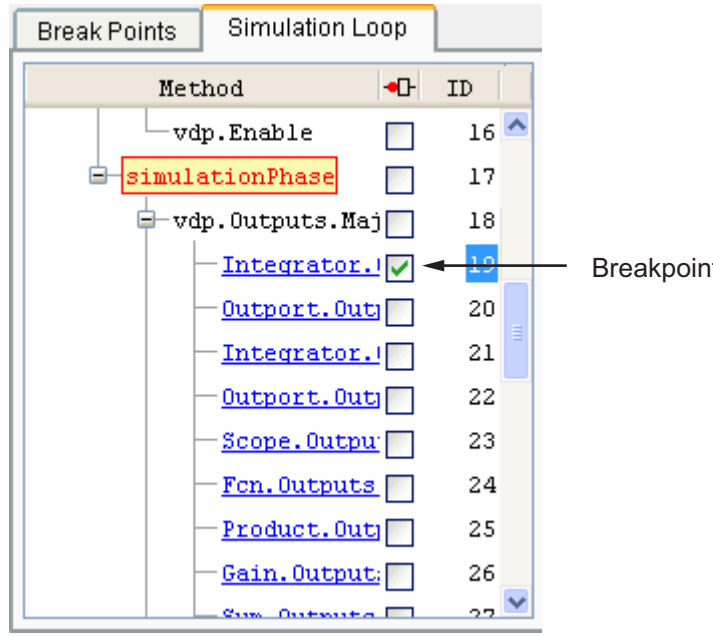
You can temporarily disable the breakpoints on a block by deselecting the check box in the breakpoints column of the panel. To clear the breakpoints on a block and remove its entry from the panel,

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 21-35).

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.



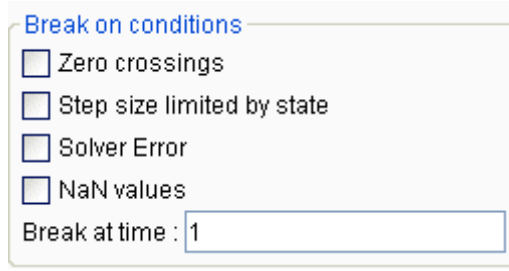
To clear the breakpoint, deselect the check box.

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 = 2.034340153847549      ] vdp.Outputs.Minor
(sldebug @37):
```

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 21-10).

For example, setting a zero-crossing break at the start of execution of the `zeroxing` example 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

```
Interrupting model execution before running mdlOutputs at the left post of
(major time step just before) zero crossing event detected at the following location:
  6[-0]  0:5:2  Saturate  'zeroxing/Saturation'
%--------------------------------------------------------------%
[TzL= 0.3435011087932808     ] zeroxing.Outputs.Major
(sldebug @16): >>
```

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

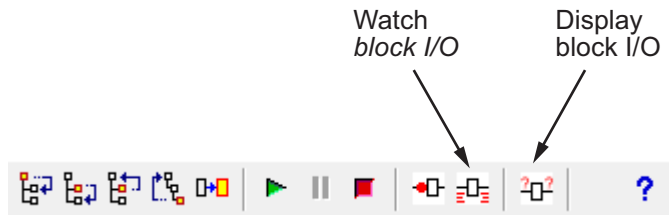
Selecting the debugger **Solver Errors** option or entering the `ebreak` command causes the simulation to stop if the solver detects a recoverable error in the model. If you do not set or disable this breakpoint, the solver recovers from the error and proceeds with the simulation without notifying you.

Display Information About the Simulation

In this section...

Display 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. 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 by entering its block index 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`, 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.

Display Algebraic Loop Information

The `atrace` command causes the debugger to display information about a model's algebraic loops (see "Algebraic Loops" on page 3-39) 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

Display System States

The `states` debug command lists the current values of the system states in the MATLAB Command Window. For example, the following sequence of commands shows the states of the bouncing ball example (`sldemo_bounce`) after its first, second, and third time steps. However, before entering the debugger, open the Configuration Parameters dialog box, clear the **Block reduction** check box on the Optimization pane, and clear the **Signal storage reuse** check box on the Optimization > Signals and Parameters pane.

```
 sldebug sldemo_bounce
%------------------------------------------------------------------%
[TM = 0                      ] simulate(sldemo_bounce)
(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                      ] solverPhase
(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)
```

Display 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.

Display Information About the Model

In this section...

Display Model's 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' [9 nonvirtual blocks, directFeed=0]
  0:0    'vdp/x1' (Integrator)
  0:1    'vdp/Out1' (Outport)
  0:2    'vdp/x2' (Integrator)
  0:3    'vdp/Out2' (Outport)
  0:4    'vdp/Scope' (Scope)
  0:5    'vdp/Fcn' (Fcn)
  0:6    'vdp/Product' (Product)
  0:7    'vdp/Mu' (Gain)
  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 21-36 for more information.

Display 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 Model's Nonvirtual Systems

The systems command displays a list of the nonvirtual systems in the model that you are debugging. For example, the sldemo_clutch) model contains the following systems:

```
open_system('sldemo_clutch')
set_param(gcs, 'OptimizeBlockIOStorage','off')
sldebug sldemo_clutch
(sldebug @0): %--------------------------------------------------------------%
[TM = 0                      ] simulate(sldemo_clutch)
(sldebug @0): >> systems
 0   'sldemo_clutch'
 1   'sldemo_clutch/Locked'
 2   'sldemo_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`) example model.

```
sldebug vdp
%------------------------------------------------------------------%
[TM = 0                        ] simulate(vdp)
sldebug @0): >> slist

---- Sorted list for 'vdp' [9 nonvirtual blocks, directFeed=0]
  0:0    'vdp/x1' (Integrator)
  0:1    'vdp/Out1' (Outport)
  0:2    'vdp/x2' (Integrator)
  0:3    'vdp/Out2' (Outport)
  0:4    'vdp/Scope' (Scope)
  0:5    'vdp/Fcn' (Fcn)
  0:6    'vdp/Product' (Product)
  0:7    'vdp/Mu' (Gain)
  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): >> zclist
  0  0:4:0    F  HitCross  'sldemo_clutch/Friction Mode Logic/Lockup
Detection/Velocities Match'
  1  0:4:1    F
  2  0:10:0    F  Abs  'sldemo_clutch/Friction Mode Logic/Lockup
Detection/Required Friction for Lockup/Abs'
  3  0:12:0    F  RelationalOperator  'sldemo_clutch/Friction Mode
Logic/Lockup Detection/Required Friction for Lockup/Relational Operator'
  4  0:19:0    F  Abs  'sldemo_clutch/Friction Mode Logic/Break Apart
Detection/Abs'
  5  0:20:0    F  RelationalOperator  'sldemo_clutch/Friction Mode
Logic/Break Apart Detection/Relational Operator'
  6  2:3:0    F  Signum  'sldemo_clutch/Unlocked/slip direction'
```

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 21-33) 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                        ] simulate(vdp)
(sldebug @0): >> status
```

```
%------------------------------------------------------------------%
Current simulation time                    : 0.0 (MajorTimeStep)
Solver needs reset                         : no
Solver derivatives cache needs reset       : no
Zero crossing signals cache needs reset    : no
Default command to execute on return/enter : ""
Break at zero crossing events              : disabled
Break on solver error                      : disabled
Break on failed integration step           : disabled
Time break point                           : disabled
Break on non-finite (NaN,Inf) values       : disabled
Break on solver reset request              : disabled
Display level for disp, trace, probe       : 1 (i/o, states)
Solver trace level                         : 0
Algebraic loop tracing level               : 0
Animation Mode                             : off
Window reuse                               : not supported
Execution Mode                             : Normal
Display level for etrace                   : 0 (disabled)
Break points                               : none installed
Display points                             : none installed
Trace points                               : none installed
```

22

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, 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 "Run Accelerator Mode with the Simulink Debugger" on page 22-29 and "Capture Performance Data" on page 22-31.

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 19-5.

How Acceleration Modes Work

In this section...

Overview

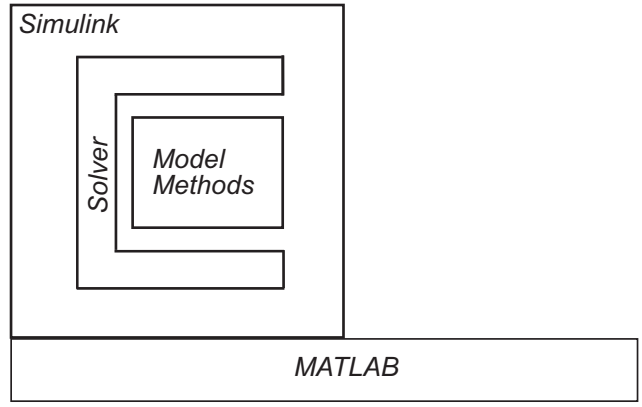
The Accelerator and Rapid Accelerator modes use portions of the Simulink Coder product to create an executable. These modes replace the interpreted code normally used in Simulink simulations, shortening model run time.

Although the acceleration modes use some Simulink Coder code generation technology, you do not need the Simulink Coder 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 Simulink Coder 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.



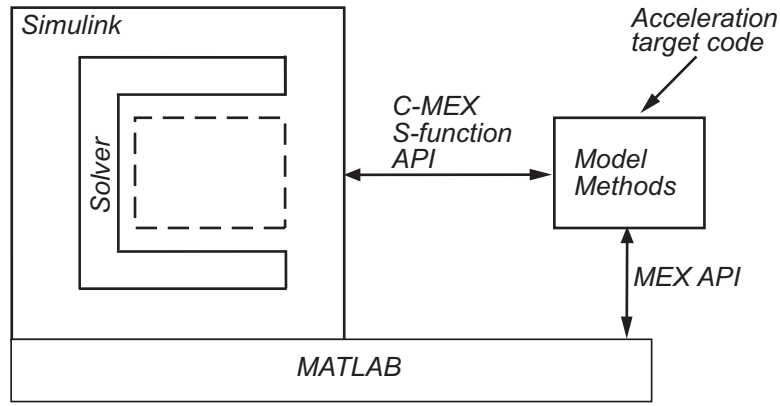
One Process

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.

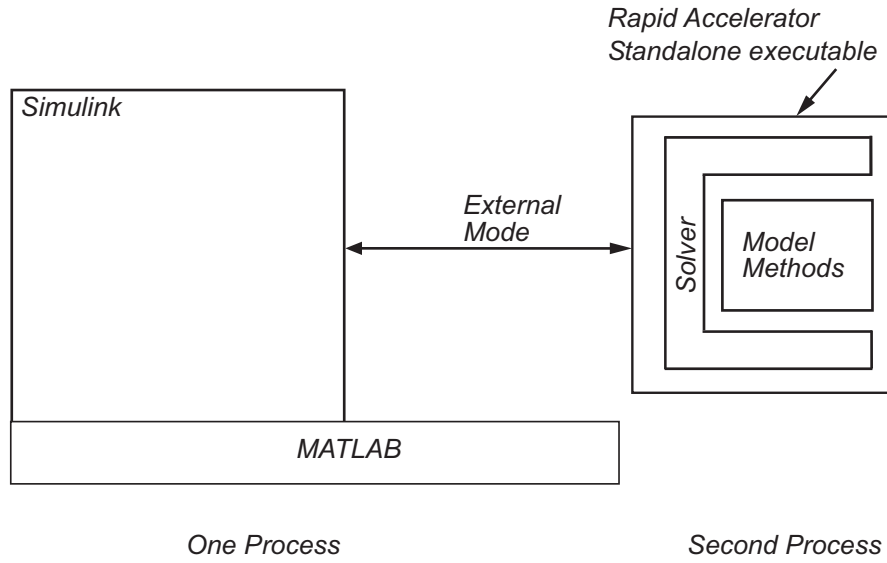
Simulink checks that the acceleration target code is up to date before reusing it. As explained in "Code Regeneration in Accelerated Models" on page 22-7, the target code regenerates if it is not up to date.

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 "Host/Target Communication") 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 Rapid Accelerator mode
- Changing solver parameters such as stop time or `rel tol` when using 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 example model `slAccelDemoWhyRebuild`.

Parameter Handling in Rapid Accelerator Mode

In model rebuilds, Rapid Accelerator Mode handles block diagram and run-time parameters differently than other parameters. You can change some block diagram parameters 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
MinStep	SaveFinalState

Block Diagram Parameters That Do Not Require Rapid Accelerator Rebuild	
NumberNwtonIterations	SaveFormat
OutputTimes	SaveOutput
Refine	SaveState
RelTol	SaveTime
SolverName	SignalLogging
StartTime	SignalLoggingName
StopTime	StateSaveName
ZCDetectionTol	TimeSaveName

For run-time parameters that you change graphically via the block diagram or programmatically with the `set_param` command, you will need to recompile the model. Recompilation might cause parts of the model to rebuild. Alternatively, you can programmatically change tunable run-time parameters without rebuilding parts of the model:

1. Collect the run-time parameters in a run-time parameter structure while building a rapid accelerator target executable using the `Simulink.BlockDiagram.buildRapidAcceleratorTarget` function.
2. To change the parameters, use the `Simulink.BlockDiagram.modifyTunableParameters` function.
3. To specify the modified parameters to the `sim` command, use the `RapidAcceleratorParameterSets` and `RapidAcceleratorUpToDateCheck` parameters.

For more information, see “sim in parfor with Rapid Accelerator Mode” on page 15-9.

All other parameter changes might necessitate a rebuild of the model.

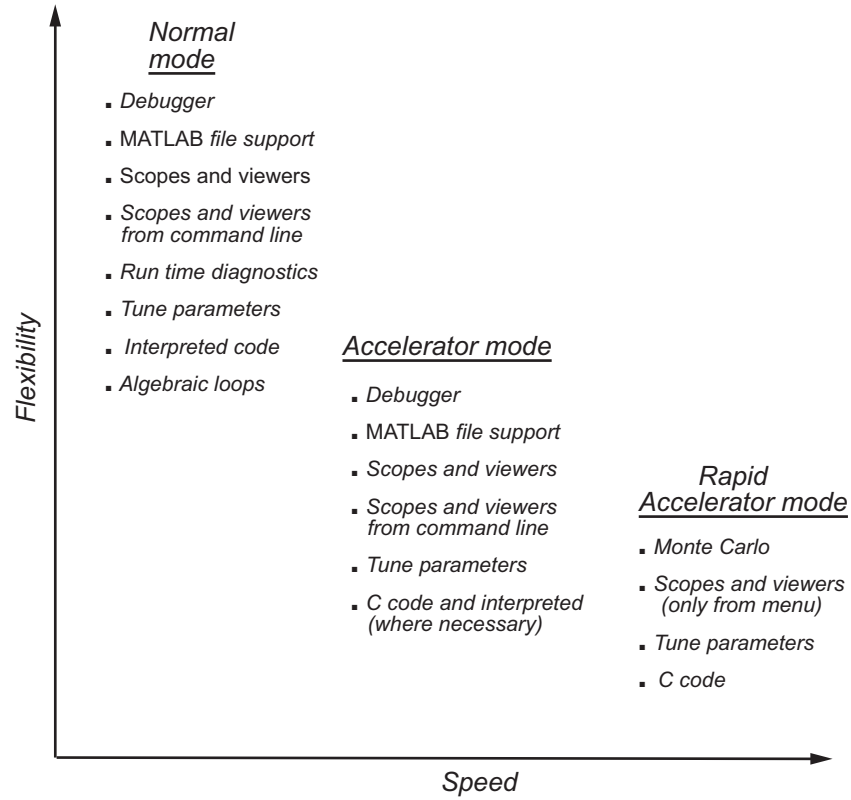
Parameter Changes:	Passed Directly to `sim` command	Passed Graphically via Block Diagram or via `set_param` command
Run-time	Rebuild *not* required	Rebuild might be required
Block diagram (solver and logging parameters)	Rebuild *not* required	Rebuild *not* required
Other	Rebuild might be required	Rebuild might be required

Choosing a Simulation Mode

In this section...

Simulation Mode 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. In addition, Rapid Accelerator mode does not support 3-D signals. If your model has 3-D signals, use Normal or Accelerator mode instead. 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(model); % 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.

Tip To gain additional flexibility, consider using model referencing to componentize your model. If the top-level model uses Normal mode, then you can simulate a referenced model in a different simulation mode than you use for other portions of a model. During the model development process, you can choose different simulation modes for different portions of a model. For details, see "Referenced Model Simulation Modes" on page 6-21.

Comparing Modes

The following table compares the characteristics of Normal mode, Accelerator mode, and Rapid Accelerator mode.

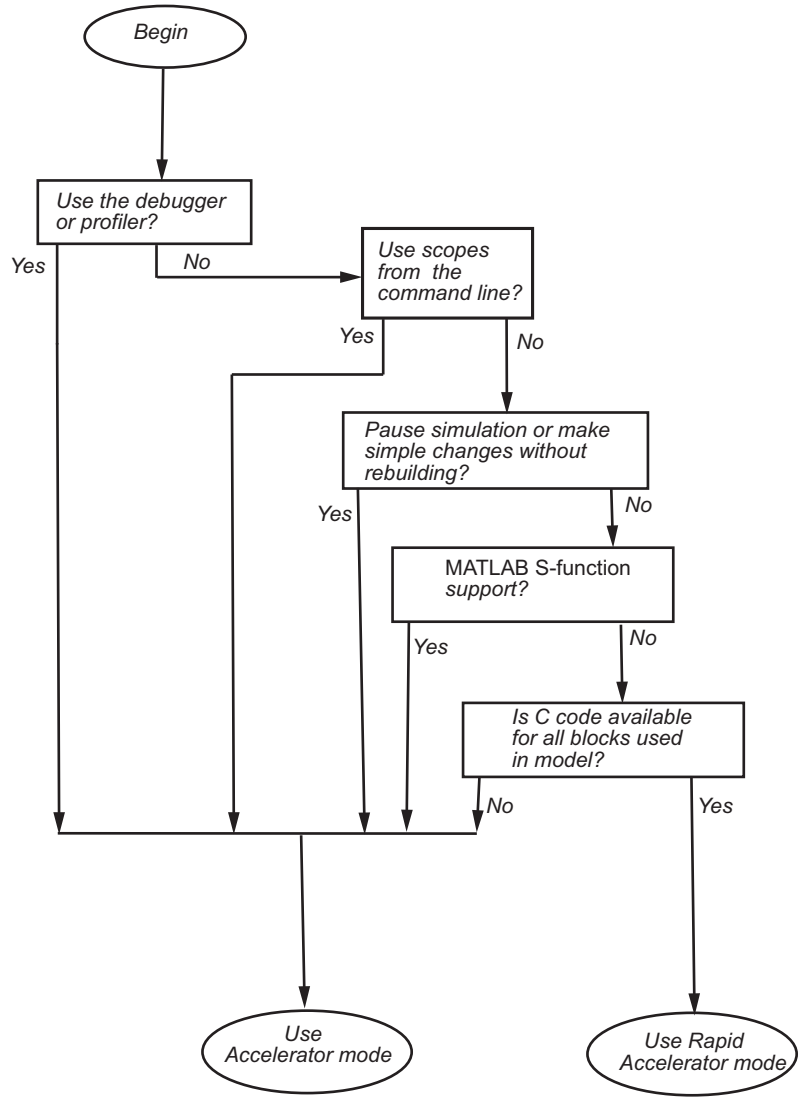
If you want to...	Then use this mode...		
	Normal	Accelerator	Rapid Accelerator
Performance			
Run your model in a separate address space			✓
Efficiently run batch and Monte Carlo simulations			✓
Model Adjustment			
Change model parameters such as solver type, stop time without rebuilding	✓	✓	
Change block tunable parameters such as gain	✓	✓	✓
Model Requirement			
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 "Behavior of Scopes and Viewers with Rapid Accelerator Mode" on page 22-18
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 19-5 to understand how effective the accelerator modes will be in improving the performance of your model.


Begin
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 Accelerator mode
Use Rapid Accelerator mode

Design Your Model for Effective Acceleration

In this section...

Select 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
- From File
- From Workspace
- Inport (root level only)
- Interpreted MATLAB Function
- MATLAB Function
- 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.

Select 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:

- Interpreted MATLAB Function
- 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.

Control 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.

Behavior of Scopes and Viewers with Rapid Accelerator Mode

Running the simulation from the command line or the menu determines the 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
Stateflow Chart blocks	Same support for chart animation as Normal mode	Not supported

Rapid Accelerator mode does not support multirate signal viewers such as the DSP System Toolbox spectrum scope or the Communications System Toolbox™ 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. "Run Acceleration Mode from the User Interface" on page 22-23 shows how to run Rapid Accelerator mode from the menu. "Interact with the Acceleration Modes Programmatically" on page 22-26 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
- 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 Simulink Coder 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 Simulink Coder product are listed in "Configure 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

Perform Acceleration

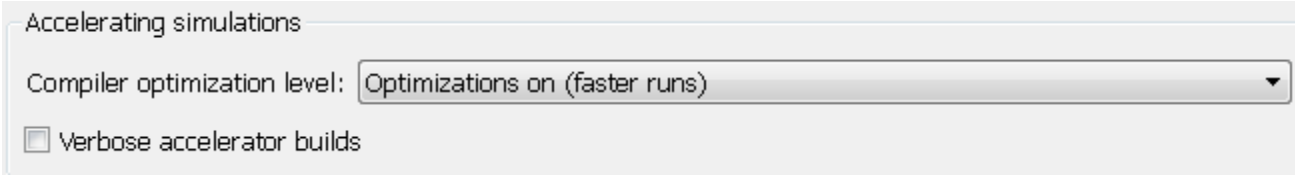
In this section...

Customize the Build Process

Compiler optimizations are off by default. This results in faster build times, but slower simulation times. You can optimize the build process toward a faster simulation.

1. From the **Simulation** menu, select **Model Configuration Parameters**.
2. In the left pane of the Configuration Parameters dialog box, select **Optimization**, and then from the **Compiler optimization level** drop-down list, select `Optimizations on (faster runs)`.

   Code generation takes longer with this option, but the model simulation runs faster.
3. Select **Verbose accelerator builds** to display progress information using code generation, and to see the compiler options in use.



Changing the Name of the Generated File Location

By default, the Accelerator mode places the generated code in a subfolder of the working folder called `slprj/accel/`*modelname* (for example, `slprj/accel/f14`), and places a compiled MEX-file in the current working folder. To change the name of the folder into which the Accelerator Mode writes generated code:

1. In the Simulink editor window, select **File > Simulink Preferences**.

   The Simulink Preferences window appears.

2. In the Simulink Preferences window, navigate to the **Simulation cache folder** parameter.

3. Enter the absolute or relative path to your subfolder and click **Apply**.

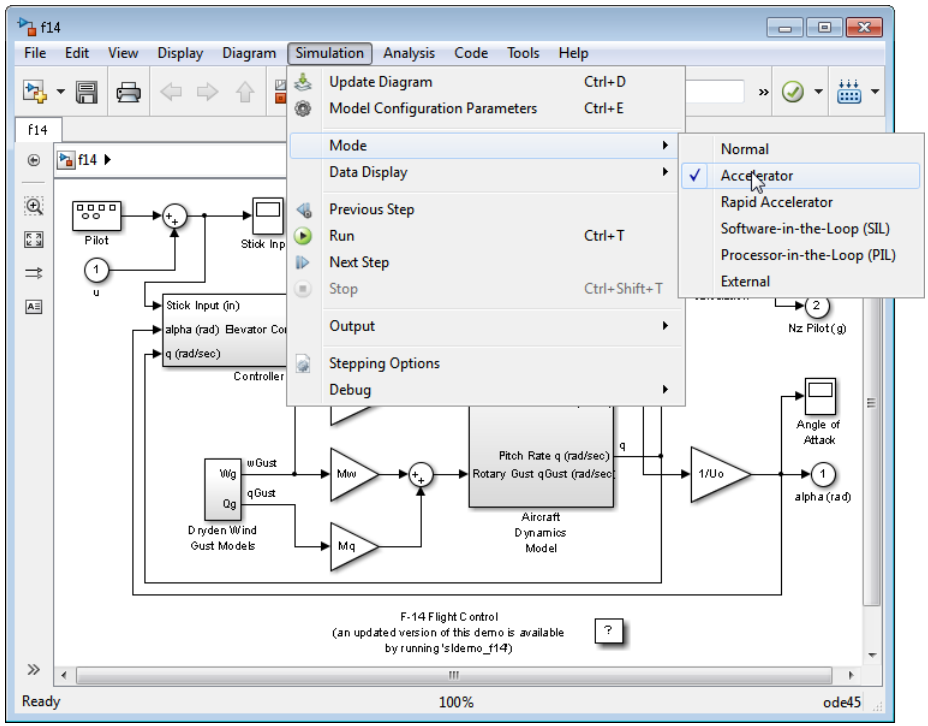
Run Acceleration Mode from the User Interface

To accelerate a model, first open it, and then from the **Simulation > Mode** 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 > Mode** menu, select **Accelerator**.

   Alternatively, you can select `Accelerator` from the model editor's toolbar.



2 From the **Simulation** menu, select **Run**.

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 22-7.

The Accelerator mode places the generated code in a subfolder of the working folder called `slprj/accel/`*modelname* (for example, `slprj/accel/f14`), and places a compiled MEX-file in the current working folder. If you want to change this path, see “Changing the Name of the Generated File Location” on page 22-22.

The Rapid Accelerator mode places the generated code in a subfolder of the working folder called `slprj/raccel/`*modelname* (for example, `slprj/raccel/f14`).

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.

Interact 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.

Build 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
```

Control 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');
```

Simulate 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 22-7 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.

Customize 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 "Customize the Build Process" on page 22-22 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')
```

Run 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, see "Run Accelerator Mode with the Simulink Debugger" on page 22-29.

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 > Mode** 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`

Capture 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.

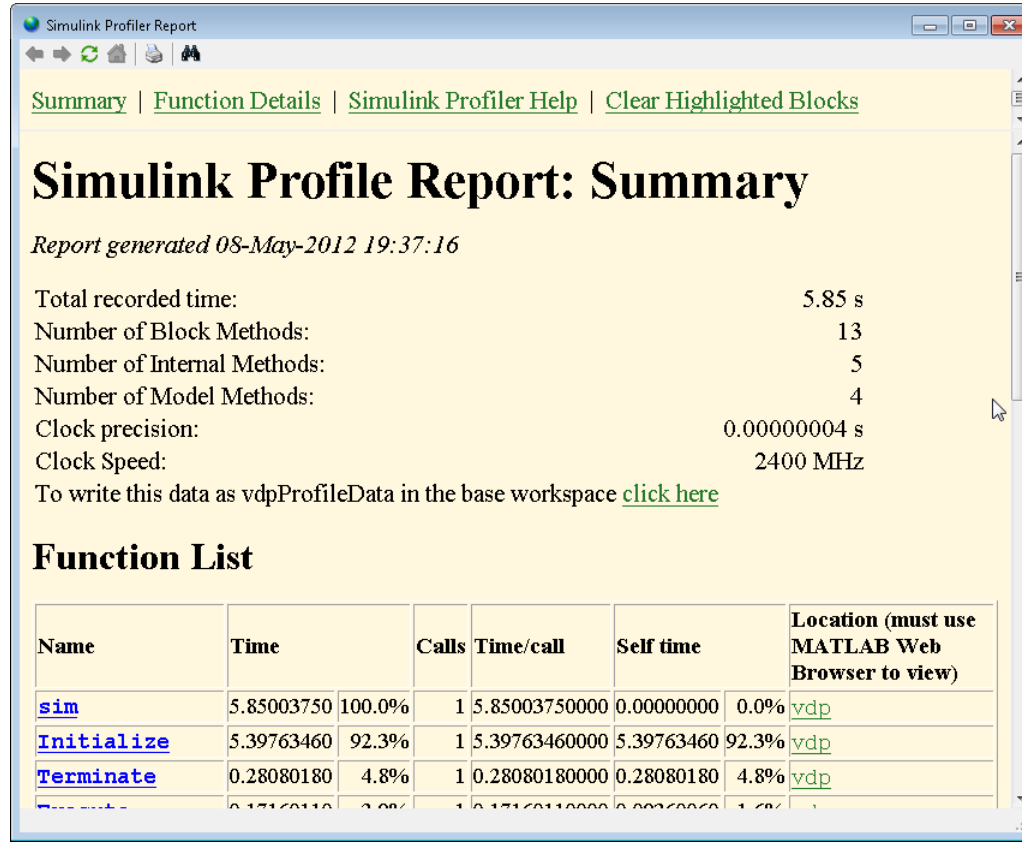
Function	Purpose	Level
`sim`	Simulate the model. This top-level function invokes the other functions required to simulate the model. The time spent in this function is the total time required to simulate the model.	System
`ModelInitialize`	Set up the model for simulation.	System
`ModelExecute`	Execute 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 **Show Profiler Report** from the **Analysis > Performance 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
Summary | Function Details | Simulink Profiler Help | Clear Highlighted Blocks
Simulink Profile Report: Summary
Report generated 08-May-2012 19:37:16
Total recorded time: 5.85 s
Number of Block Methods: 13
Number of Internal Methods: 5
Number of Model 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 | 5.85003750 | 100.0% | 1 | 5.85003750000 | 0.00000000 | 0.0% | vdp
Initialize | 5.39763460 | 92.3% | 1 | 5.39763460000 | 5.39763460 | 92.3% | vdp
Terminate | 0.28080180 | 4.8% | 1 | 0.28080180000 | 0.28080180 | 4.8% | 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 "Normal Mode" on page 6-21 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

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 "About Block Parameters" on page 24-2 and "Set Block Parameters" on page 24-4 for information about setting and changing block parameters.

Block Tool Tips

Information about a block is displayed in a tool tip when you hover the mouse pointer over the block in the diagram view. To disable this feature, or control what information the tool tip displays, select **Display > Blocks > Tool Tip Options** in the Simulink Editor.

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".
Terminator	Always virtual.
Trigger	Virtual when the output port is *not* present.

Add 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.

Add 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 "Populate a Model" on page 4-4 for more information.

Copy Blocks from a Model

To copy a block from a model in the Simulink Editor:

1. Select the block that you want to copy from a model.
2. Choose **Edit > Copy**.
3. In the model window in which you want to place the copied block, choose **Edit > Paste**.

You can copy a block:

- Within the same model window
- Between multiple systems open in one Simulink Editor instance
- Between systems open in multiple Simulink Editor instances

When you copy a block, the parameters use default values.

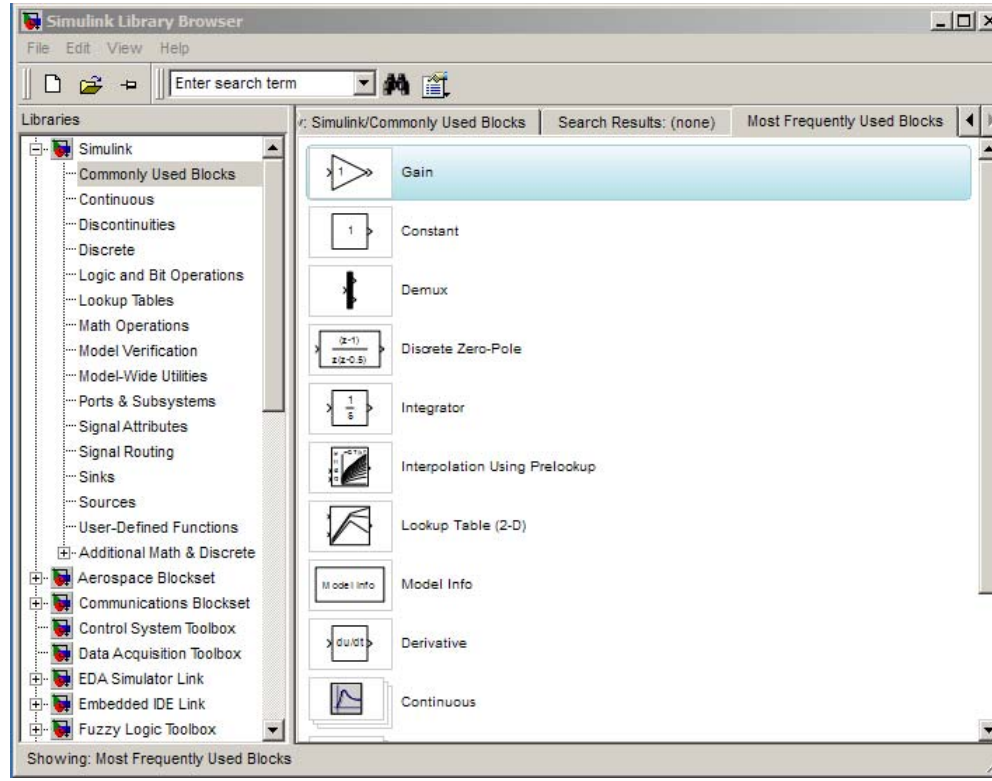
For details, see "Copy Blocks Between Windows" on page 23-10.

Add 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 from the Library Browser:

- Drag the block into your model.
- Right-click the block, and from the context menu select **Add to <model_name>**.

Select Most Frequently Used Blocks from the Model Editor

In the Simulink 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

  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.

Add 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.

Edit Blocks

In this section...

Copy Blocks in a Model

To copy a blocks in a model:

1. In the Simulink Editor, select the block.
2. Press right mouse button.
3. Drag the block to a new location and release the mouse button.

You can also do this by using the **Ctrl** key:

1. In the Simulink Editor, press and hold the **Ctrl** key.
2. Select the block with the left mouse button.
3. Drag the block to a new location and release the mouse button.

Copies of blocks have the same parameter values as the original blocks. Sequence numbers are added to the new block names.

Note Simulink 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`, `Gain18`...`Gain31`.

Copy Blocks Between Windows

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 "Browse Block Libraries" on page 4-4 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 Simulink Editor:

1. Select the block you want to copy.
2. Select **Edit > Copy**.
3. Make the target model window the active window.
4. Choose **Edit > Paste**.

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 "Manipulate Block Names" on page 23-26.

When you copy a block, the new block inherits all the original block's parameter values.

For more ways to add blocks, see "Add Blocks" on page 23-4.

add blocks

Move Blocks

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. For information about how to select more than one block, see "Select Multiple Objects" on page 4-6.
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.

You cannot move a block between:

- Multiple systems open in one Simulink Editor instance
- Systems open in multiple Simulink Editor instances

  If you drag a block between Simulink Editor instances, the block is copied to the target Simulink Editor model window.

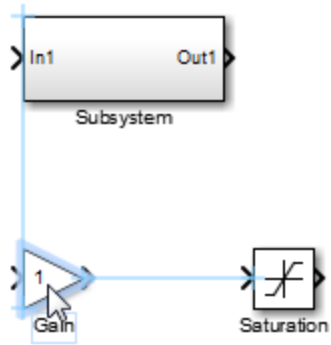
Align Blocks

You can manually align blocks. You can also use commands that align a group of blocks automatically (see “Align, Distribute, and Resize Groups of Blocks” on page 4-22 for details).

Smart Guides. You can enable smart guides to help you align blocks and lines. When you move a block, smart guides appear to indicate when the block ports, center, or edges are aligned with the ports, centers, and edges of other blocks in the same diagram.

To display smart guides, in the Simulink Editor, select **View > Smart Guides**. The setting applies to all open instances of the Simulink Editor.

For example, the following figure shows a snapshot of a Gain block that you drag from one position in a diagram to another. The blue smart guides indicate that if you drop the Gain block at this position, its left edge is aligned with the left edge of the Subsystem block and its output port is aligned with the input port of the Saturation 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 center aligns with the Subsystem block center and the Gain block output port aligns with the Saturation block input port.

However, because ports take precedence over centers, Simulink draws a guide only for the ports.

Position 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 20 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.

Delete Blocks

To delete one or more blocks, select the blocks to be deleted and press the **Delete** or **Backspace** key.

As an alternative, you can select **Edit > ClearClear** or **Edit > Cut**.

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.

To replace a deleted block, use the **Edit > Undo** command.

Comment Out Blocks

Comment out blocks in your model if you want to exclude them during simulation. To exclude a block, right-click the selected block and select **Comment out**.

Commenting out blocks may be useful for several tasks, such as:

- Incrementally testing parts of a model under development
- Debugging a model without having to delete and restore blocks between simulation runs
- Testing and verifying the effects of certain model blocks on simulation results
- Improving simulation performance

Set Block Properties

For each block in a model, you can set general block properties, such as:

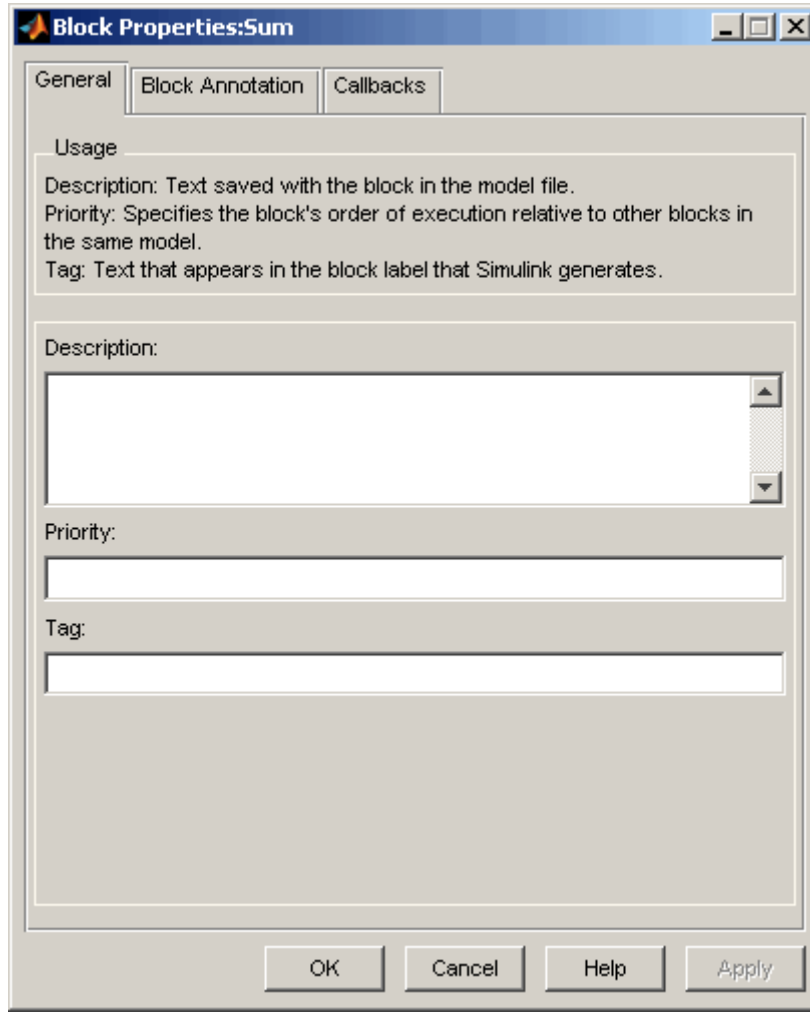
- A description of the block
- The block's order of execution
- A block annotation
- Block callback functions

Block Properties Dialog Box

To set these block properties, open the Block Properties dialog box.

1. In the Simulink Editor, select the block.
2. Select **Diagram > Properties**.

The Block Properties dialog box opens, with the **General** tab open. For example:



General Block Properties

Description

Enter a brief description of the purpose of the block or any other descriptive information.

Priority

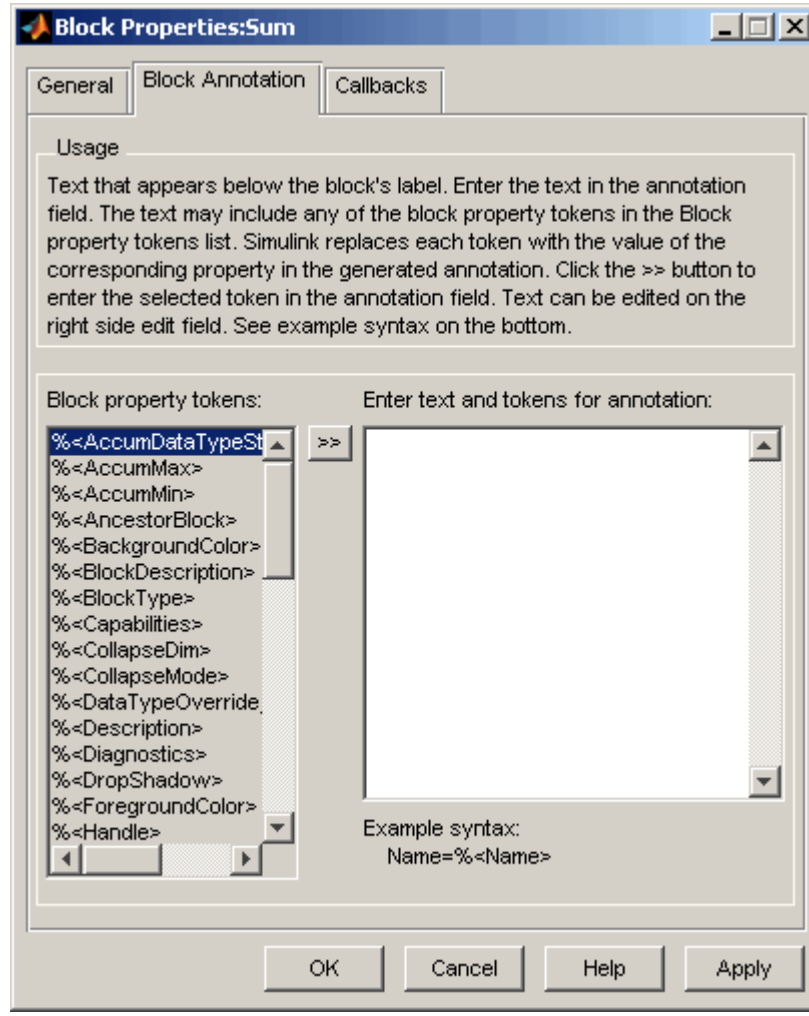
Specify the execution priority of this block relative to other blocks in the model. For more information, see “Assign Block Priorities” on page 23-47.

Tag

You can use a tag to create your own block-specific label for a block. Specify text that Simulink assigns to the block’s Tag parameter and saves with the block in the model.

Block Annotation Properties

Use the **Block Annotation** tab 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, Simulink 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>
```

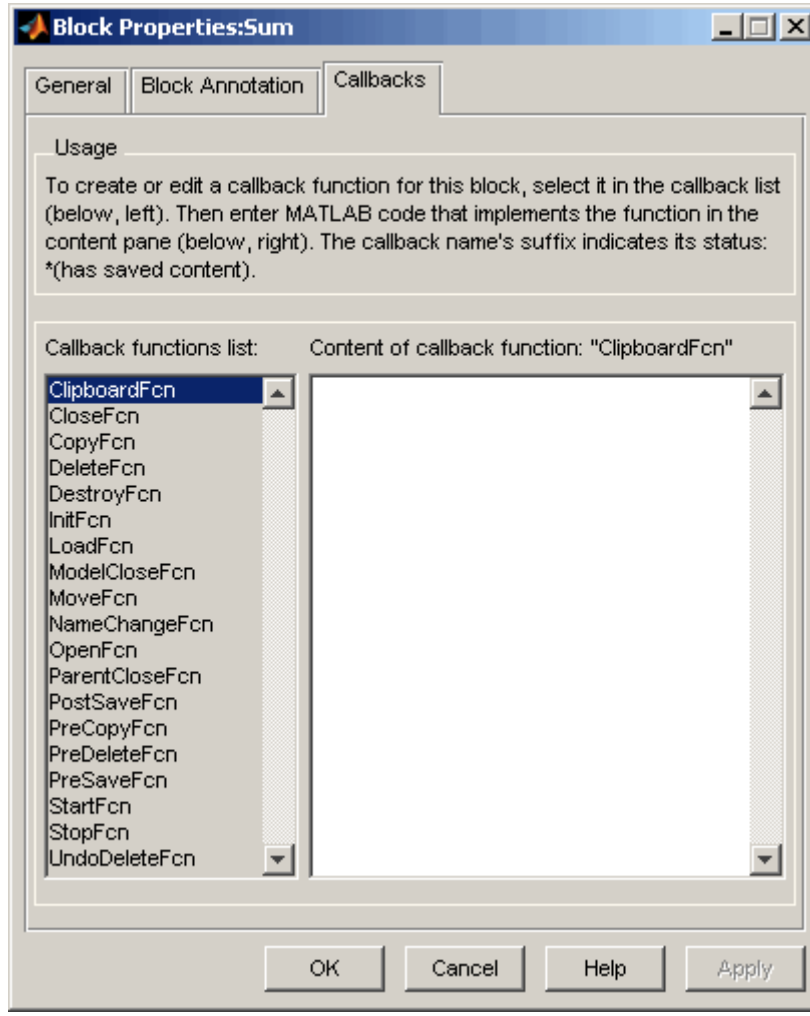
In the Simulink Editor model window, the annotation appears as follows:

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 "Common Block Parameters" and "Block-Specific Parameters"). 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 "Create Block Annotations Programmatically" on page 23-21.

Block Callbacks

Use the **Callbacks** tab to specify implementations for a block's callbacks (see "Callback Functions" on page 4-54).



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.

Create Block Annotations Programmatically

You can use a block's `AttributesFormatString` parameter to display selected block parameters beneath the block as an "attributes format string," which is a string that specifies values of the block's attributes (parameters). "Common Block Parameters" and "Block-Specific Parameters" describe 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, enter the following at the MATLAB command prompt:

```
set_param(gcb, 'AttributesFormatString','pri=%<priority>\ngain=%<Gai
```

The Gain block displays the following block annotation:

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.

Change the Appearance of a Block

In this section...

Change a Block 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 by flipping it 180 degrees around its horizontal or vertical axis.

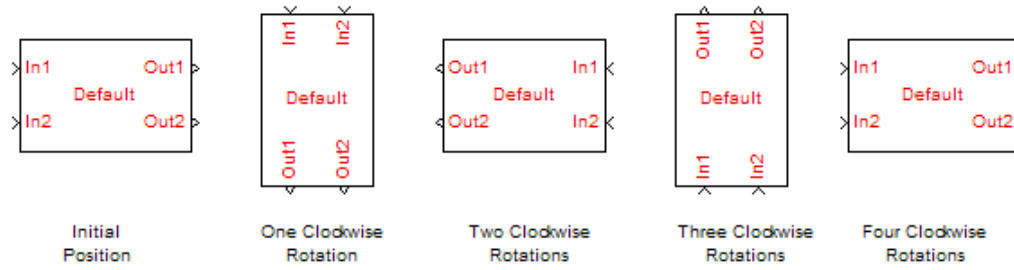
How to Rotate a Block

You can rotate a block 90 degrees by selecting one of these commands from the **Diagram** menu:

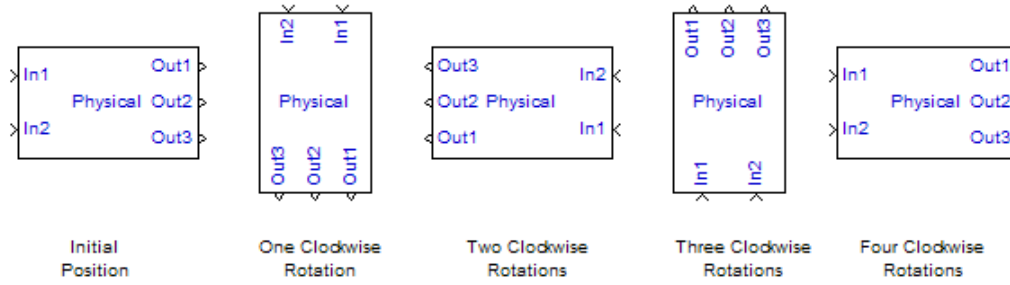
- **Rotate & Flip > Clockwise** (or **Ctrl+R**)
- **Rotate & Flip > Counterclockwise**

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 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 & FlipClockwise** command on a block with the default rotation policy.



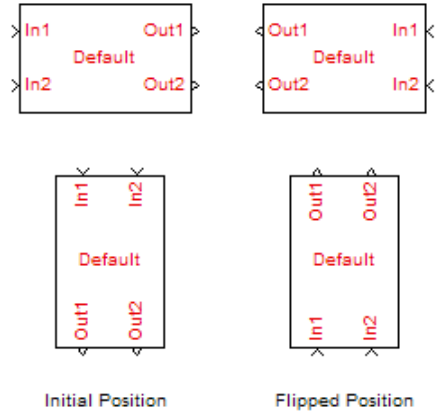
A masked block can optionally specify that its ports not be reordered after a clockwise rotation (see "Port Rotation"). Such a block is said to have a *physical port rotation* type. This policy facilitates layout of diagrams in mechanical and hydraulic systems modeling and other applications where diagrams 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.

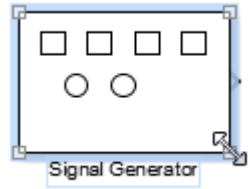
A block with the default rotation type has one flip command: **Diagram > Rotate & Flip > Flip Block** (**Ctr+I**). This command effectively moves the block's input and output ports to the side of the block opposite to the side on which they are initially located, i.e., from the left to the right side or from the top to the bottom side.



Resize 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.



Tip Use the model editor's resize blocks commands to make one block the same size as another (see "Align, Distribute, and Resize Groups of Blocks" on page 4-22).

Displaying Parameters Beneath a Block

You can cause Simulink to display one or more of a block's parameters beneath the block. Specify the parameters to be displayed by using one of the following approaches:

- Enter an attributes format string in the **Attributes format string** field of the block's **Properties** dialog box (see "Set Block Properties" on page 23-15)
- Set the value of the block's `AttributesFormatString` property to the format string, using `set_param`

Drop Shadows

By default, blocks appear with a drop shadow.

To increase the depth of a block drop shadow:

1. Select the block.
2. Select **Diagram > Format > Block Shadow**.

For example, in this model, the `Constant1` block has the **Block Shadow** option enabled, and the `Constant2` block uses the default drop shadow.

To remove the default drop shadows for all blocks, select **File > Simulink Preferences > Editor Defaults > Use classic diagram theme**.

Manipulate 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 (/) 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.

Change Block Names

You can edit a block name in one of these ways:

- To replace the block name, click the block name, select the entire name, and 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.

Note If you change the name of a library block, all links to that block become unresolved.

Change Font of Block Name

To modify the font used in a block name by selecting the block, then choosing the **Font Style** menu item from the **Diagram > Format** menu.

1. Select the block name.
2. Select **Diagram > Format > Font Style**.

   The Select Font dialog box opens.
3. Select a font and specify other font characteristics, such as the font size.

Note Changing the block name font also changes the font of any text that appears inside the block.

This procedure also changes the font of any text that appears inside the block.

Change the Location of a Block Name

To change the location of the name of a selected block, use one of these approaches:

- Drag the block name to the opposite side of the block.
- Choose **Diagram > Rotate & Flip > Flip Block Name**. 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 23-22.

Hide a Block Name

By default the Simulink Editor displays the names of blocks (except for a few blocks, such as the Bus Creator block). To hide the name of a selected block, clear the **Diagram > Format > Show Block Name** menu option.

Specify Block Color

See "Specify Block Diagram Colors" on page 4-8 for information on how to set the color of a block.

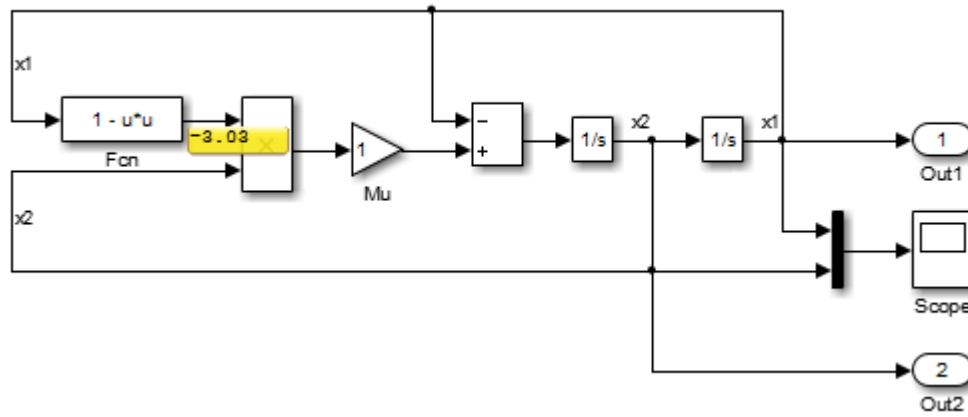
Display Port Values

In this section...

Port Value Data Tips

Signals can be data signals or non-data signals. For many blocks with data signals, Simulink can display port values (block output) 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 `3.03`.

Displaying port value data tips can be helpful during interactive debugging of a model. The data tips do not persist when you save a model, so do not rely on data tips as a form of built-in documentation for the model.



In some cases, data signals are not accessible for display. In those cases, a label such as `wait` might be displayed for optimized signals, or `action` might be displayed for an action subsystem.

Note The port value 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 23-33.

Display Value for a Port

To display a data tip that shows the value of a port:

1. In the Simulink Editor model window, select a port.
2. Specify when the port value appears.
   - To display the port value when you click on a port, select **Display > Data Display in Simulation > Show Value Label of Selected Port**. The data tip remains until you remove it.
   - To display the port value when you hover the cursor over the port, select **Display > Data Display in Simulation > Show Value Labels When Hovering**. When you move the cursor away from the port, the data tip disappears.
   - To toggle between displaying and hiding the port value, select **Display > Data Display in Simulation > Toggle Value Labels When Clicked**.

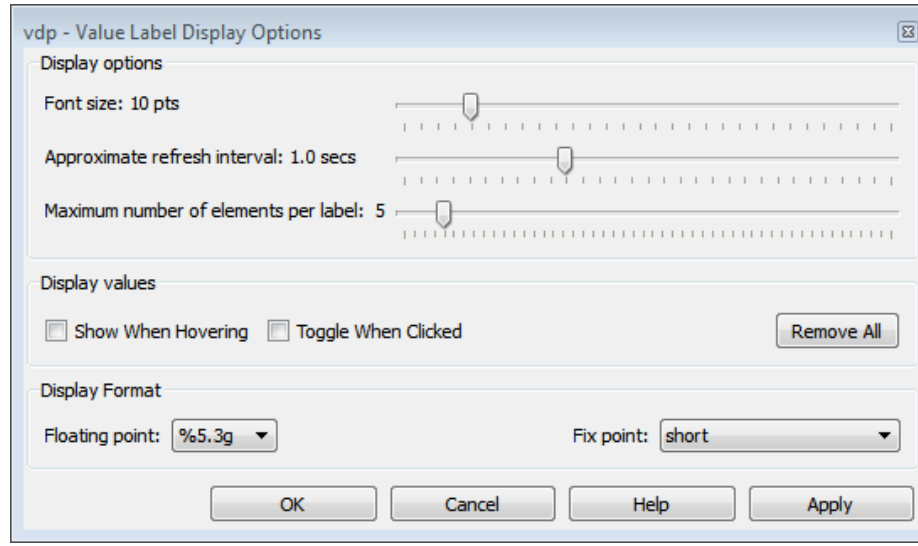
     Reselecting that block turns off the display. If you select a block with this port value display method, then change the display method to **Show When Hovering**, the port value for that block continues to display.

To remove the all displayed port value data tips, select **Display > Data Display in Simulation > Remove All Value Labels**.

Control the Port Value Display

To specify port value display formatting and how frequently the display updates:

1. In the Simulink Editor model window, select a port.
2. Select **Display > Data Display in Simulation > Options**. The Value Label Display Options dialog box opens.



3. In the Value Label Display Options dialog box, select the appropriate option.

Port Value Data Tip Display Characteristic	What You Specify
When to display the port value	Choose **Show When Hovering**, **Toggle When Clicked**, or **Remove All**. For details, see "Display Value for a Port" on page 23-30.
Text size	To increase the size of the output display text, move the **Font size** slider to the right.

Port Value Data Tip Display Characteristic	What You Specify
Floating point data format	Choose a floating point format from the **Floating point** list.
Fixed-point data format	Choose a fixed-point format from the **Fix point** 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 **Approximate refresh interval: 1.0** slider to the right.
Number of elements in port value display	To change the number of elements to display in the port value display, move the **Maximum number of elements per label: 3** slider to the left or right. This setting affects the number of elements displayed for vector or matrix signals with signal widths greater than 1. This setting does not affect scalar signals.

Displayed Value When No Data Is Available

Simulink displays an empty box when you toggle or hover on a block, indicating that no port value is available. You see the empty box if you did not run the simulation.

Also, if you toggle or hover on a block that Simulink optimizes out of a simulation (such as a virtual subsystem block), the model displays a `wait` string before displaying the port value during simulation.

To prevent the optimization delay of the port value display, designate the signal as a test point. This enables the port value display to update immediately.

Port Value Display Limitations

Performance

Enabling the hovering option, or toggling at least one block, slows down the simulation.

Accelerated Modes

Port values display as follows.

Accelerated Mode	Port Values...
Accelerator	Display as in Normal mode. See "Port Value Data Tips" on page 23-29.
Rapid Accelerator	Do not display. The limitation exists whether the model itself specifies accelerated simulation or the model is subordinate to a model that specifies accelerated simulation. For more information, see "Rapid Simulations".

Signal Storage Reuse

Invoking the port value displays the text `optimized` when the software cannot determine the signal value, if you:

- Select **Show When Hovering** or **Toggle When Clicked**.
- Enable the **Configuration Parameters > Optimization > Signals and Parameters > Signal storage reuse** parameter.

Disabling signal storage reuse increases the amount of memory used during simulation.

Signal Data Types

Simulink displays the port value 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, Simulink does not display data for signals with some complex data types, such as bus

signals. In addition, the software shows the floating and fixed-point formats for only non-complex signal value displays.

Control 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 3-16
- "Conditional Execution Behavior" on page 7-32

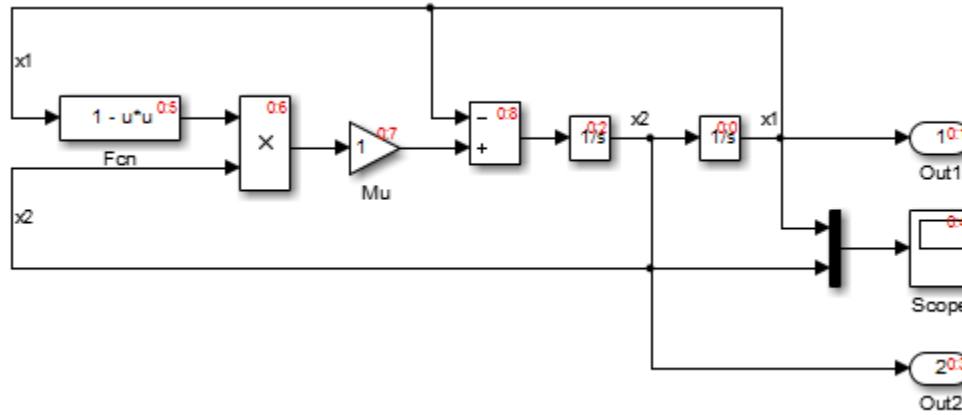
Display the Sorted Order

To display the sorted order of the `vdp` model:

1 Open the van der Pol equation 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 **Simulation > Update diagram**.

Sorted Order Notation

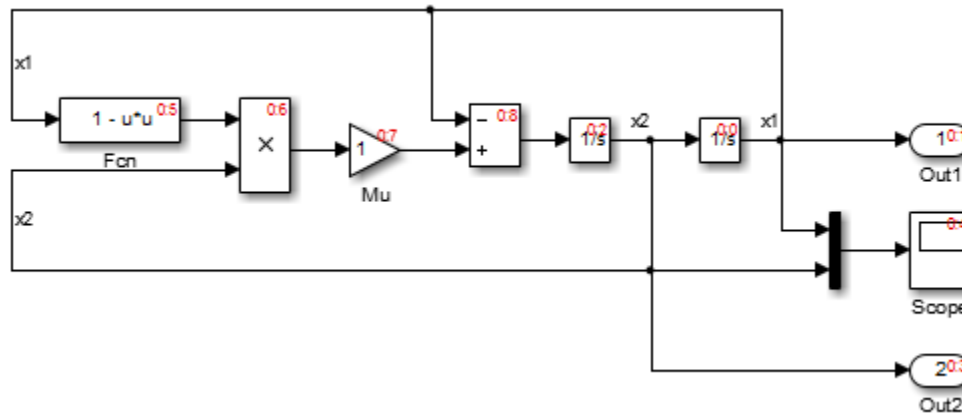
The sorted order notation varies depending on the type of block. The following table summarizes the different formats of sorted order notation. Each format is described in detail in the sections that follows the table.

Block Type	Sorted Order Notation	Description
"Nonvirtual Blocks" on page 23-38	`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 23-39	`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 23-41	Not applicable	Virtual blocks do not execute.
"Function-Call Subsystems" on page 23-42	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 23-44	*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 23-45	*s*:B	• *s* is a system index of the model or subsystem. • B indicates a bus-capable block.

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.

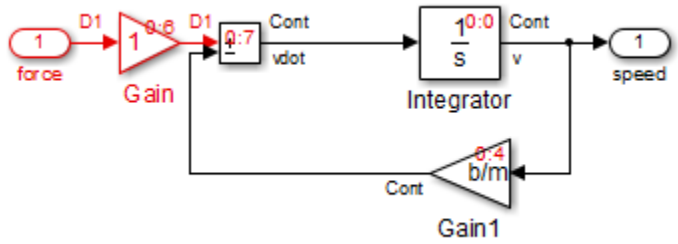


Nonvirtual Subsystems

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.

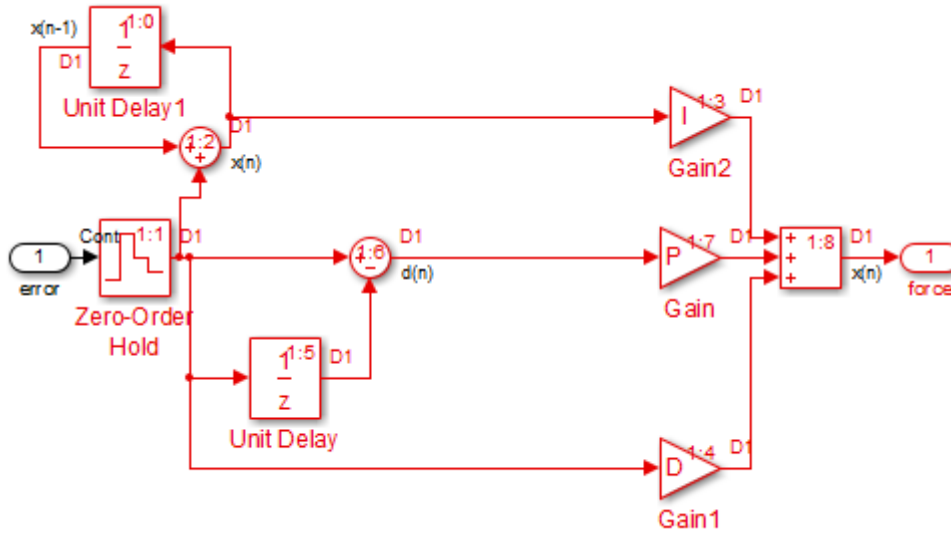


The Discrete Cruise Controller subsystem has a sorted order of `0:5{1}`:

- `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.
- `5` indicates that the atomic subsystem is the sixth 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 `8`.

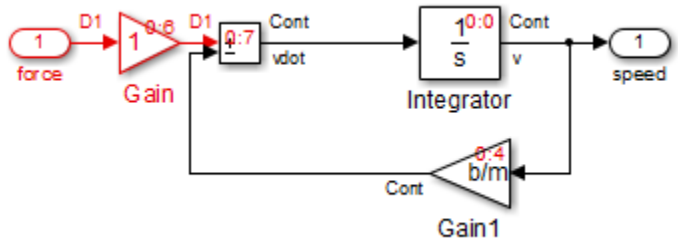


Virtual Blocks and Subsystems

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 23-39, 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.

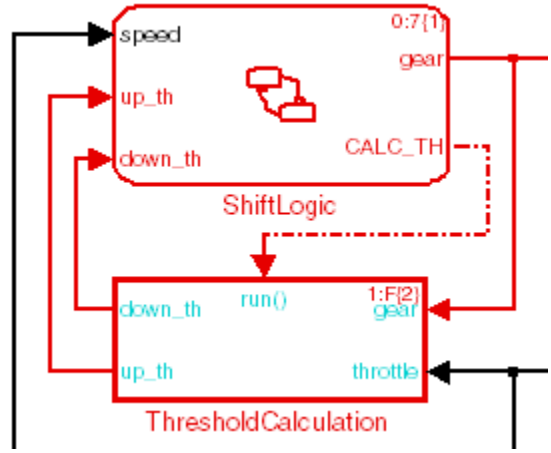


Function-Call Subsystems

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, 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.

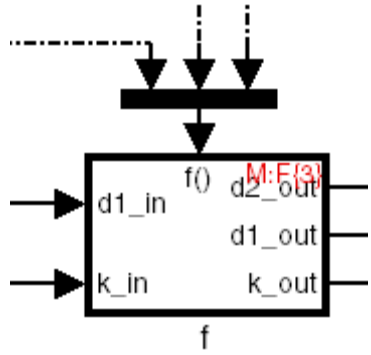


Multiple Initiators. For a function-call subsystem that connects to more than one initiator, the sorted order notation depends on the execution context of the initiators:

- 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` model. The f subsystem has three initiators, two from the Stateflow chart, Chart1, and one from the Stateflow chart, Chart.

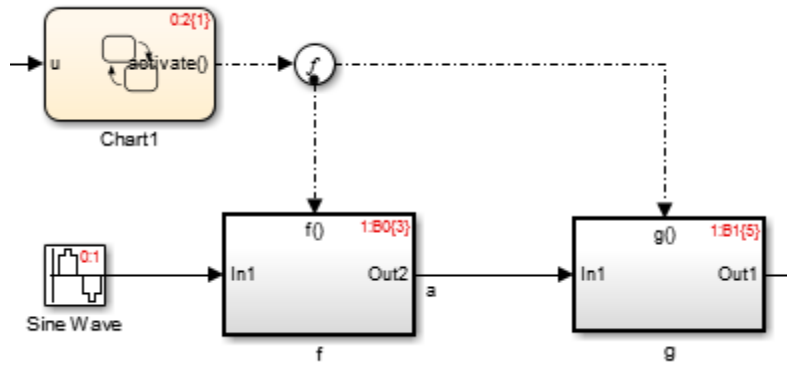
Because Chart1 has a system index of `2` and Chart has a system index of `1`, the initiators execute at different levels in the model hierarchy. The Function-Call Subsystem f has a sorted order notation of `M:F{3}`.



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.

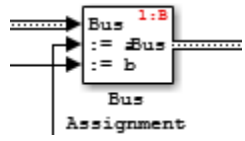
For example, open the `sl_subsys_fncall11` model and display the sorted order. The sorted order indicates that the subsystem f (`B0`) executes before the subsystem g (`B1`).



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` 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 48-19.

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.

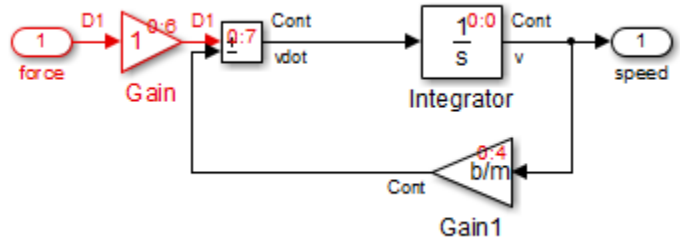
- Blocks that do not have direct-feedthrough inputs can appear anywhere in the sorted order as long as they precede any direct-feedthrough blocks that they drive.

  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.

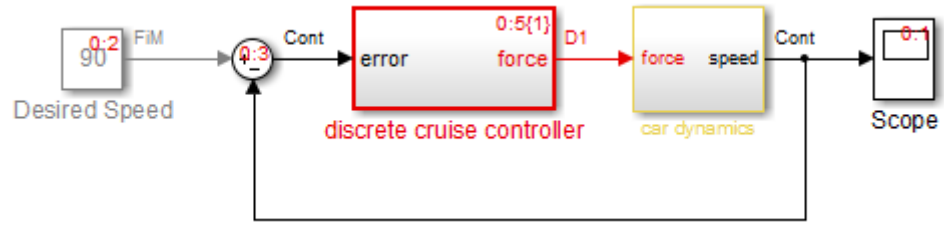
Applying these rules results in the sorted order. Blocks without direct-feedthrough ports appear at the beginning of the list in no particular order. These blocks are followed by blocks with direct-feedthrough ports arranged such that they can supply valid inputs to the blocks which they drive.

The following model, from "Nonvirtual Subsystems" on page 23-39, 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:

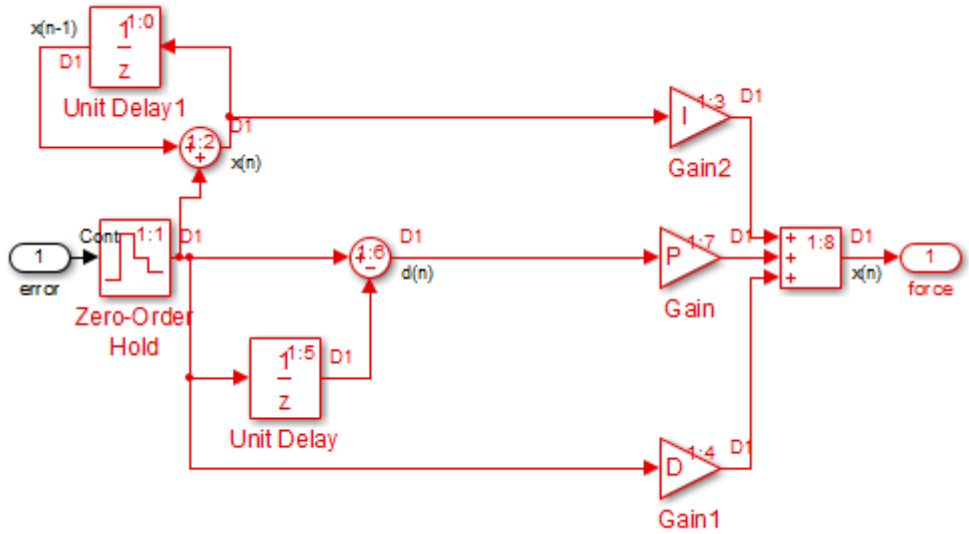
- Integrator block in the Car Dynamics virtual subsystem



- 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.



Assign 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 23-48
- “Assigning Block Priorities Interactively” on page 23-48

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 **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 23-51 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:

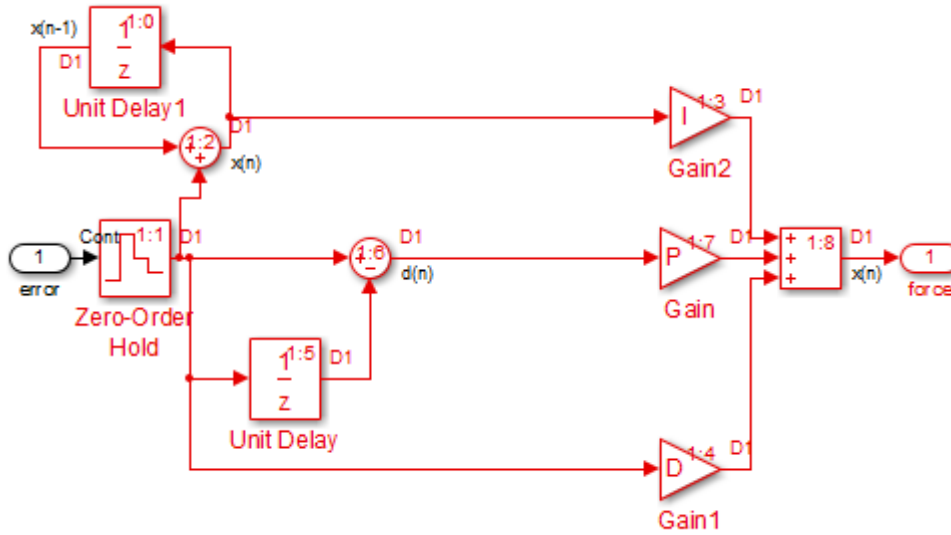
Priorities Are Relative

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 23-39.

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

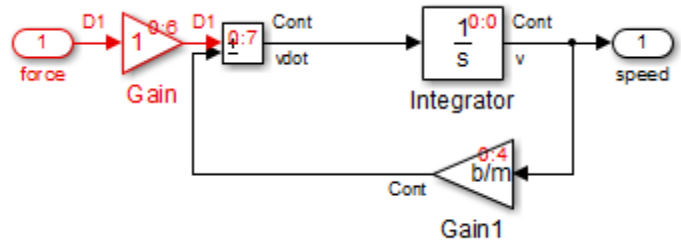
necessarily correspond to the priority values. Simulink arranges the blocks so that their priorities are honored relative to each other.

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` 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 execute before the Memory block. However, the Coefficient of Restitution block depends on the output of the Memory block, so the priorities you just set violate the data dependencies.

3. In the model window, enable sorted order by selecting **Format > Block displays > Sorted Order**.

4. Select **Simulation > 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=[2]) 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.

Access 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 "Write Level-2 MATLAB S-Functions" 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 "Data Objects" on page 43-37) 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.

Access 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 23-2) 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.

Listen 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 documentation 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

You can use run-time objects to obtain the value of a block output and display in the MATLAB Command Window by entering the following commands.

```
rto = get_param(gcb,'RuntimeObject')
rto.OutputPort(1).Data
```

However, the displayed data may not be the true block 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 from the MATLAB Command Window, 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, open the Configuration Parameters dialog box, and then clear the **Signal storage reuse** check box on the **Optimization > Signals and Parameters** pane (see “Signal storage reuse”).

Configure a Block for Code Generation

Use the **State Attributes** pane of a Block Parameters dialog box to specify Simulink Coder code generation options for blocks with discrete states. See "States" in the Simulink Coder documentation.

24

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 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 "Symbol Resolution" on page 4-76. Do not confuse Simulink block parameters with Simulink parameter objects. See "Block Parameters" on page 3-9 and `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. Tunable parameter changes take effect at the start of the next time step after simulation resumes.

You can use the **Inline parameters** check box on the **Optimization > Signals and Parameters** pane of the Configuration Parameters dialog box to specify that all parameters in your model are nontunable except for those that you specify. This action can speed up execution of large models and enable generation of faster code from your model. See "Optimization Pane: Signals and Parameters" 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 "Structure Parameters" on page 24-16 for more information.

Set 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 Simulink Editor's **Diagram > 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 "Change the Appearance of a Block" on page 23-22 for more information).

- **Block Properties** dialog box

  Specifies various attributes that are common to all blocks (see "Set Block Properties" on page 23-15 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 "Display a Block Parameter Dialog Box" on page 24-4 for information on displaying a block's parameter dialog box.

- 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 "Model Explorer Overview" on page 9-2 for more information.

Display a Block 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 Simulink Editor's **Diagram** menu or from the block's context (right-click) menu.

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 Simulink Editor's **Diagram** menu or the block's context menu to display a Subsystem or Model block's parameter dialog box.

Specify 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.

Use 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 "Symbol Resolution" on page 4-76 and "Numeric Values with Symbols" on page 4-78.

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 "Tunable Parameters" on page 24-13.

Note If you have a Simulink Coder license, and 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 "Parameters" in the Simulink Coder documentation.

Resolve 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 "Symbol Resolution" on page 4-76 and "Numeric Values with Symbols" on page 4-78 for more information.

Use 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 "Symbol Resolution" on page 4-76 and "Numeric Values with Symbols" on page 4-78for 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 24-15 and "Parameterize Model References" on page 6-52 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.

Determine 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").

Obtain Parameter Information

You can use `get_param` to find the system and block parameter values for your model. See "Model Parameters" and "Common Block Parameters" for 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')
```

Check 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**
1-D Lookup Table	**Table data**
2-D Lookup Table	**Table data**
n-D Lookup Table	**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**

Specify 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 finite, scalar, real number with `double` data type. The default values for the minimum and maximum are `[]` (unspecified). 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 47-38).

Note You cannot specify the minimum or maximum value as `NaN`, `inf`, or `inf`.

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))`

Perform 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.
- In the Simulink Editor, when you start a simulation or select **Simulation > Update Diagram**, 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 "Specify Ranges for Parameters" on page 24-10) 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

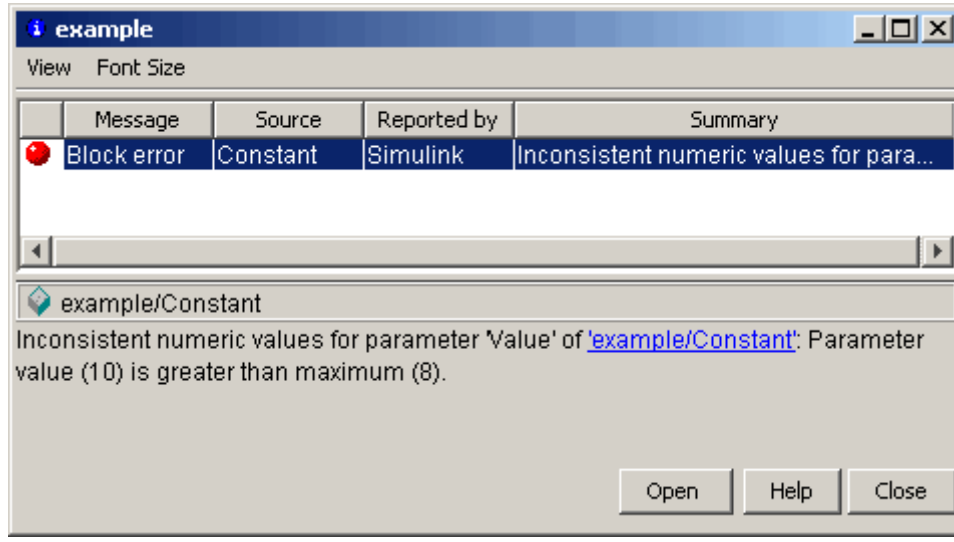
- **Constant value** parameter specifies the variable `const`, which you have yet to define in a workspace.
- **Output minimum** and **Output maximum** parameters are set to `2` and `8`, respectively.

- **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 "Update a Block Diagram" on page 1-25). Simulink displays the following error message:



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 "Inline Parameters" on page 24-14 for more information.

Tune a Block Parameter

You can use a block's dialog box or the Model Explorer to modify the tunable parameters of any block. 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 "Update a Block Diagram" on page 1-25).

Inline 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 selected, 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** is selected.

Note Simulink ignores tunable parameter specifications in the Model Parameter Configuration dialog box if the model is a referenced model or contains any Model blocks. Do not use this dialog box to override the inline parameters optimization for selected parameters to permit them to be tuned. Instead, see "Parameterize Model References" on page 6-52 for alternate techniques. If you define tunable parameters using `Simulink.Parameter` objects, you can tune the top model and reference model parameters.

Specify 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 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.

If you have a Simulink Coder license, 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. For more information, see "Tunable Workspace Parameter Data Type Considerations".

Note The documentation for the Simulink Coder 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 "Use Parameter Objects to Specify Parameter Values" on page 24-7), you can also use the object to specify the parameter as noninlined. To do this, set the parameter object's `CoderInfo.StorageClass` property to any value but `'Auto'` (the default).

```
K=Simulink.Parameter;
K.CoderInfo.StorageClass = 'SimulinkGlobal';
```

If you set the `CoderInfo.StorageClass` property to any value other than `Auto`, you should not include the parameter in the tunable parameters table in the **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.

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`.

Define 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 "Tunable Structure Parameters" on page 24-19.

MATLAB structures, 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.

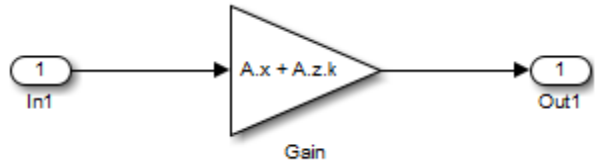
Referencing Structure Parameters

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 3-11, "Masking", and "Using Model Arguments" on page 6-53 more information about passing and using arguments.

Tunable Structure Parameters

Declare a structure parameter to be tunable using one of the following techniques.

- Clear **Model Configuration Parameters > Optimization > Signals and Parameters > Inline parameters**. See "Inline parameters" for more information.
- Set **Inline parameters**, and 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`. In the following example, the structure parameter `myStruct` is associated with a `Simulink.Parameter` object.

```
myStruct = Simulink.Parameter;
myStruct.Value = [1 2 3];
myStruct.CoderInfo.StorageClass = 'ExportedGlobal';
```

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 "Inline Parameters" on page 24-14 and "Tunable Parameters" on page 24-13. 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.

25

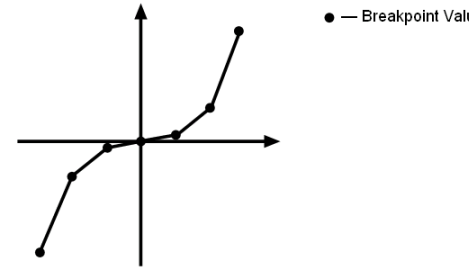
Working with Lookup Tables

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

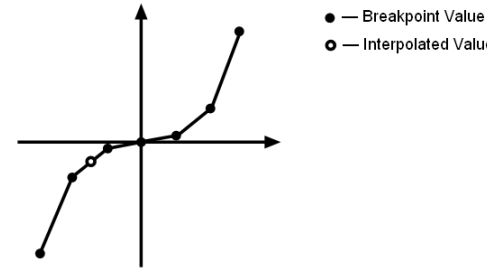


An input of -2 enables the table to look up and retrieve the corresponding output value (-8). Likewise, the lookup table outputs 27 in response to an input of 3.

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

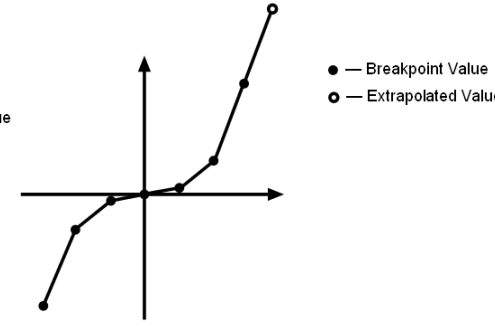
x	-3	-2	-1.5	-1	0	1	2	3
y	-27	-8	-4.5	-1	0	1	8	27



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



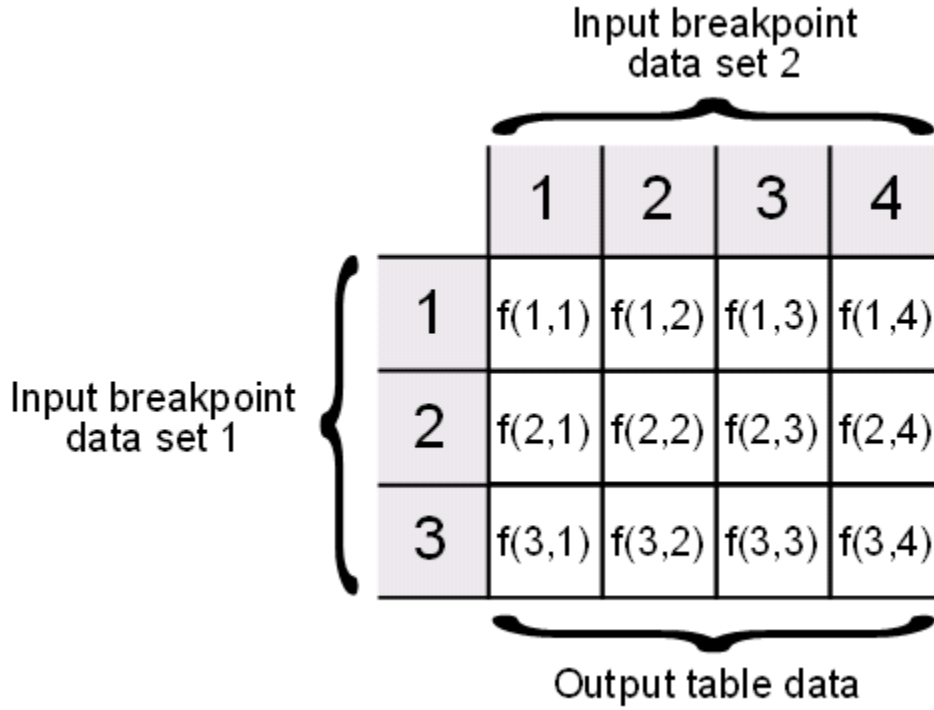
Since table lookups and simple estimations can be faster than mathematical function evaluations, using lookup table blocks might result in speed gains when simulating a model. Consider using lookup tables in lieu of mathematical function evaluations when:

- 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

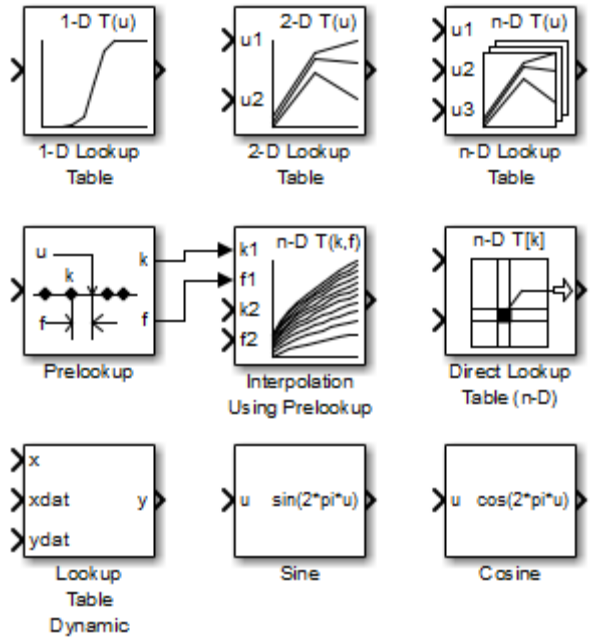
The following figure illustrates the anatomy of a two-dimensional lookup table. Vectors or *breakpoint data sets* and an array, referred to as *table data*, constitute the lookup table.



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
1-D Lookup Table	Approximate a one-dimensional function.
2-D Lookup Table	Approximate a two-dimensional function.
n-D Lookup Table	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 1-D Lookup Table or Lookup Table Dynamic block. If you are approximating a two-dimensional function, consider the 2-D Lookup Table block. Blocks such as the n-D Lookup Table 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), 1-D Lookup Table, 2-D Lookup Table, and n-D Lookup Table 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 you should use. 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 Dynamic block performs linear interpolation and extrapolation, while the n-D Lookup Table 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 1-D Lookup Table, 2-D Lookup Table, n-D Lookup Table, 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. Some lookup table blocks also provide a search algorithm that works best for breakpoint data sets composed of evenly spaced breakpoints. 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 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	1-D Lookup Table	2-D Lookup Table	Lookup Table Dynamic	n-D Lookup Table	Direct Lookup Table (n-D)	Prelookup	Interp. Using Prelookup
Interpolation Methods							
Flat	•	•	•	•	•	•	•
Linear	•	•	•	•		•	•
Cubic spline	•	•		•			
Extrapolation Methods							
Clip	•	•	•	•	•	•	•
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	•	•		•	•	•	•

Enter Breakpoints and Table Data

In this section...

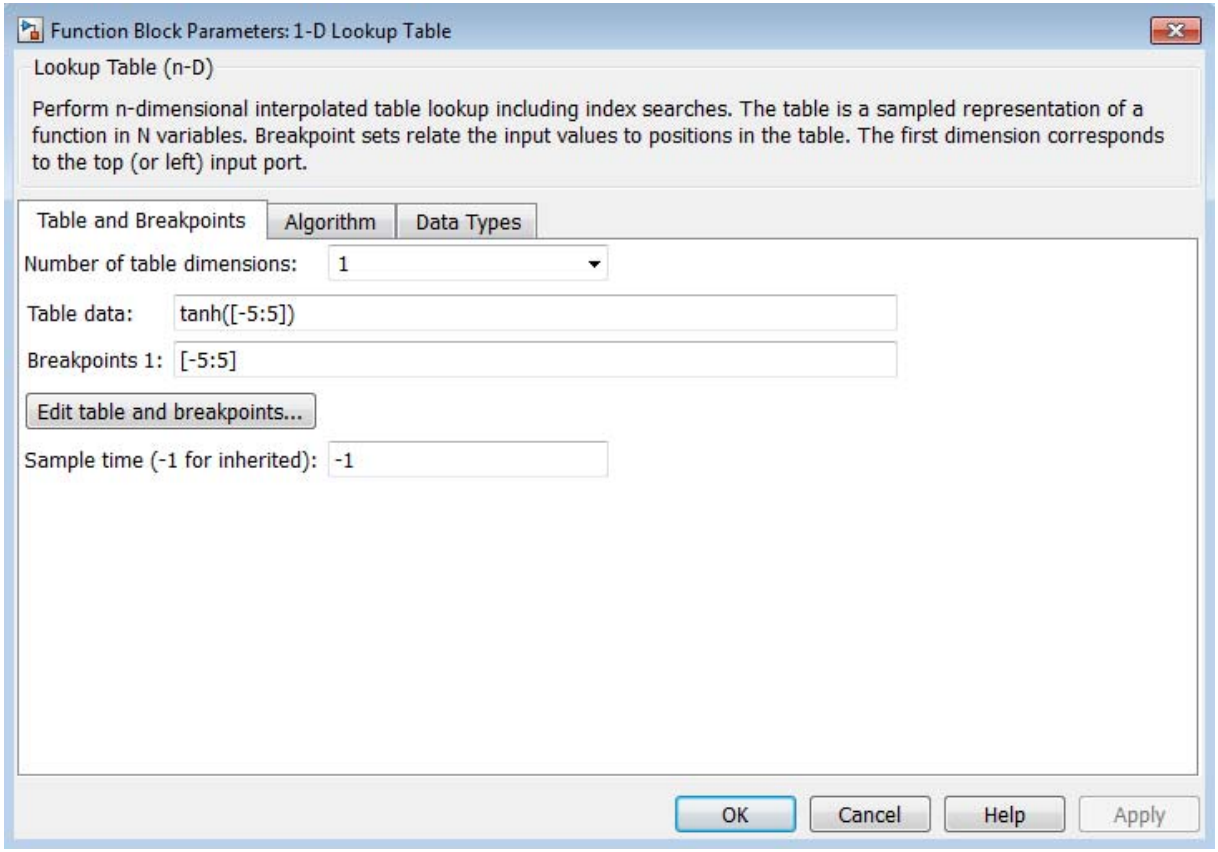
Entering Data in a Block Parameter Dialog Box

Use the following procedure to populate a 1-D Lookup Table 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 1-D Lookup Table block from the Lookup Tables block library to a Simulink model.

2. In the model window, double-click the 1-D Lookup Table block.

The block parameter dialog box appears.

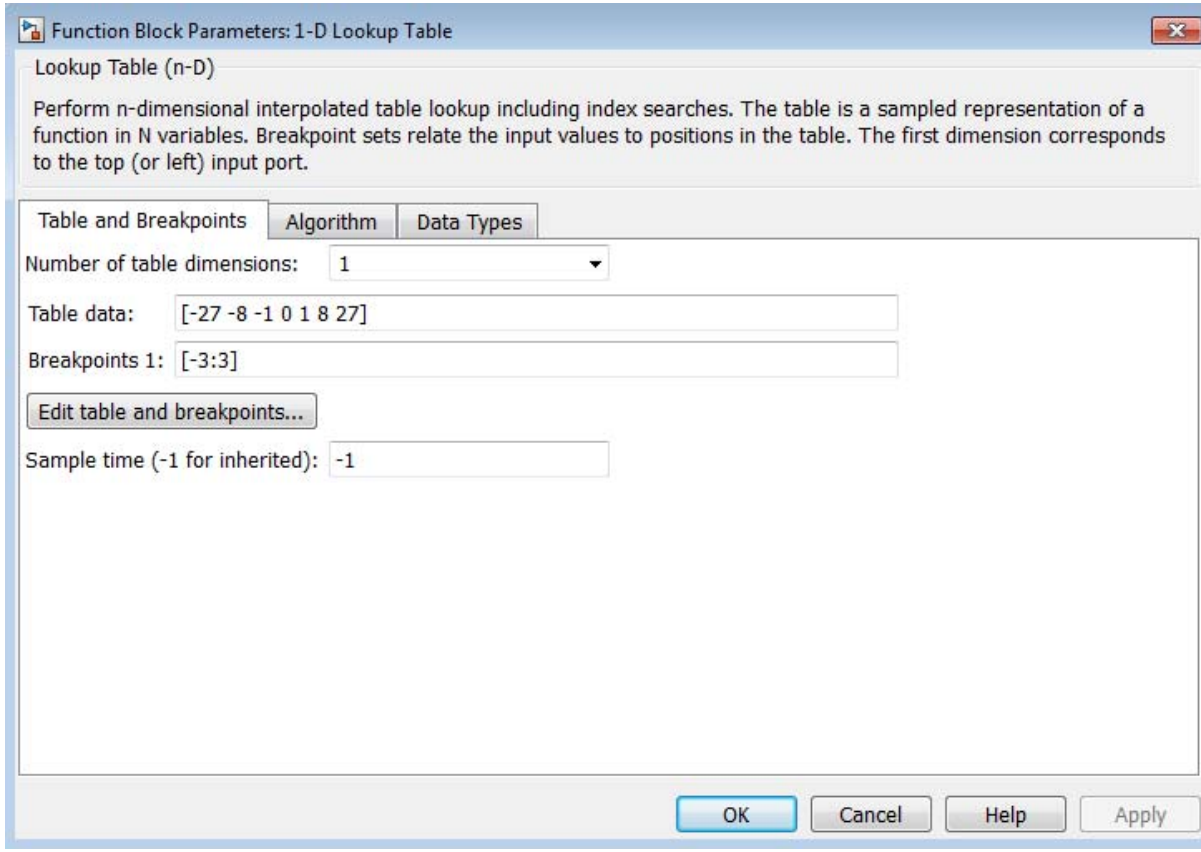


The dialog box displays the default values for the block.

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 data** field, enter `[-27 -8 -1 0 1 8 27]`.
- In the **Breakpoints 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.

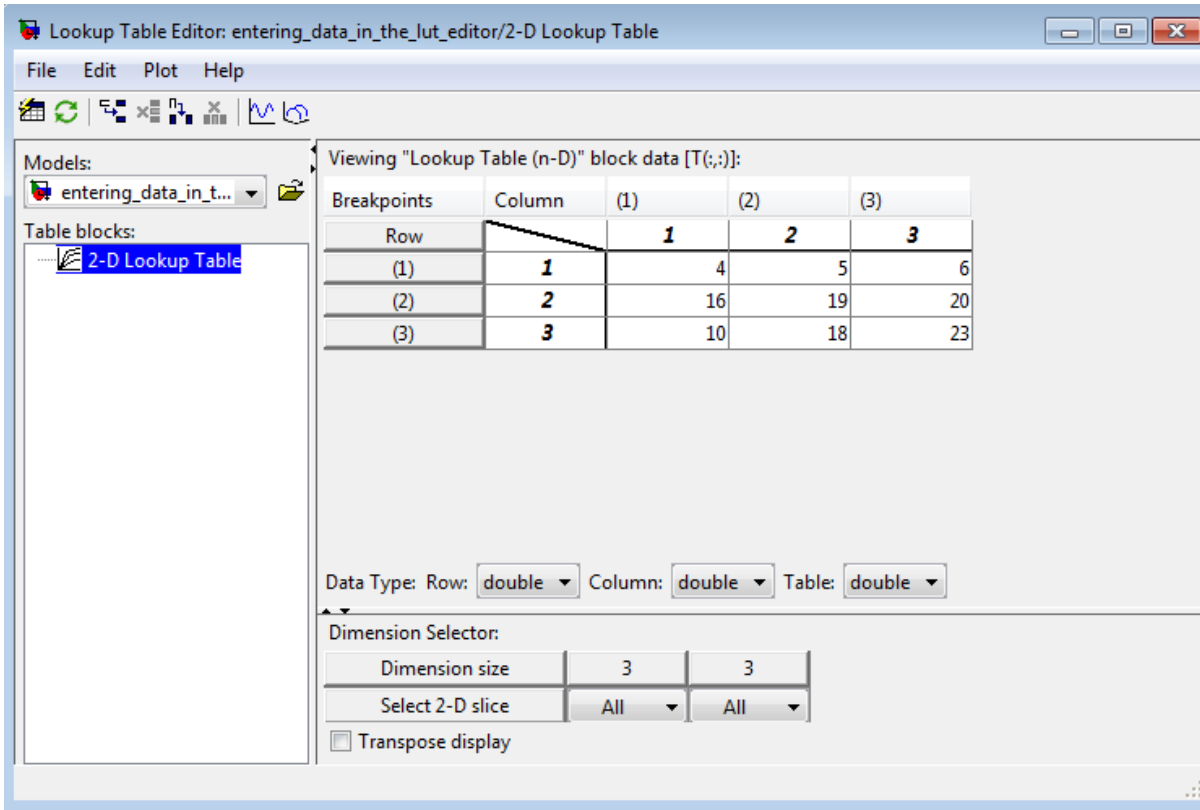
Entering Data in the Lookup Table Editor

Use the following procedure to populate a 2-D Lookup Table 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 2-D Lookup Table 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 **Edit** menu or by clicking **Edit table and breakpoints** on the dialog box of the 2-D Lookup Table block.

The Lookup Table Editor appears.

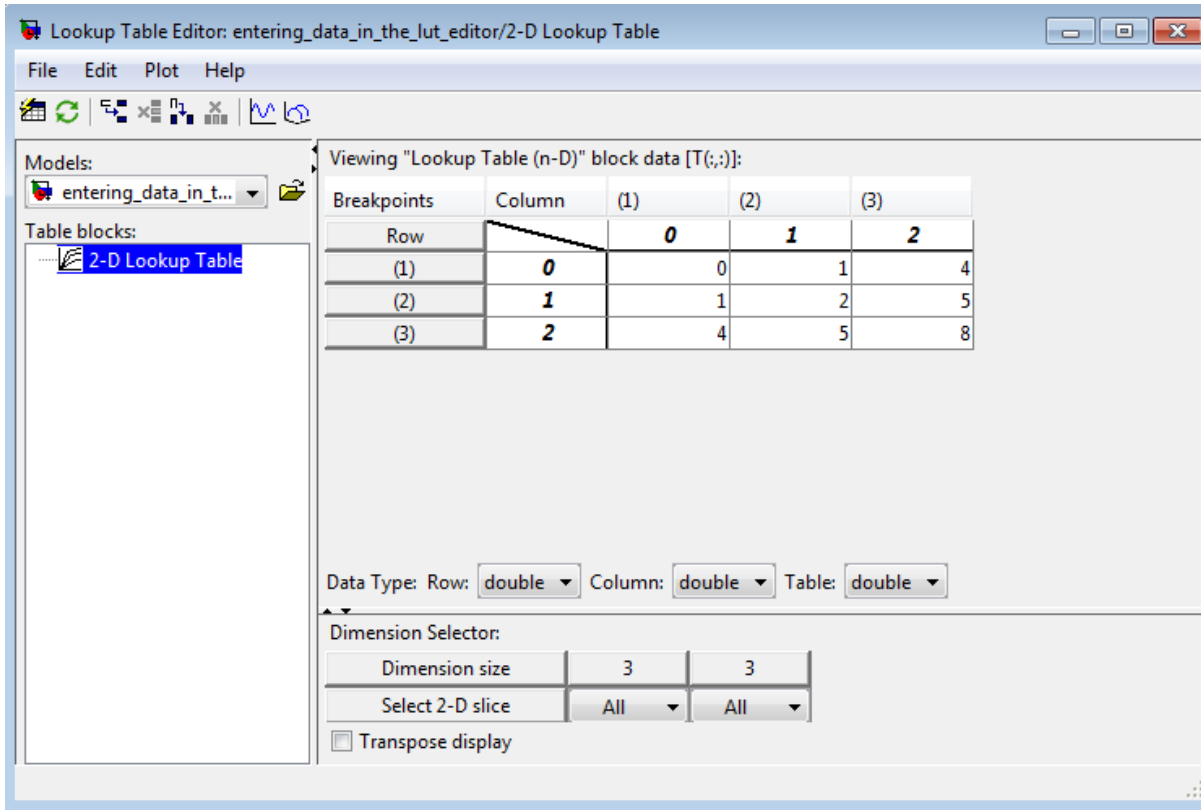


It displays the default data for the 2-D Lookup Table block.

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 like this:



4 In the Lookup Table Editor, select **File > Update Block Data** to update the data in the 2-D Lookup Table 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:
   - One Constant block to define the input range, from the Sources library
   - One Math Function block to square the input range, from the Math Operations library
   - One Gain block to multiply the signal by 3, also from the Math Operations library

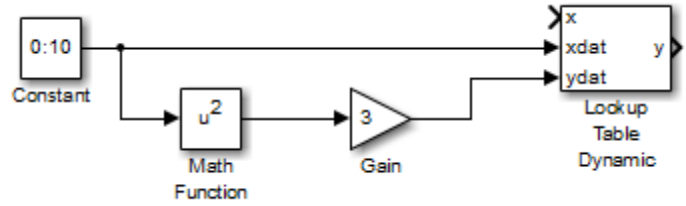
3. Assign the following parameter values to the Constant, Math Function, and Gain blocks using their dialog boxes:

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 something like this:



Characteristics of Lookup Table Data

In this section...

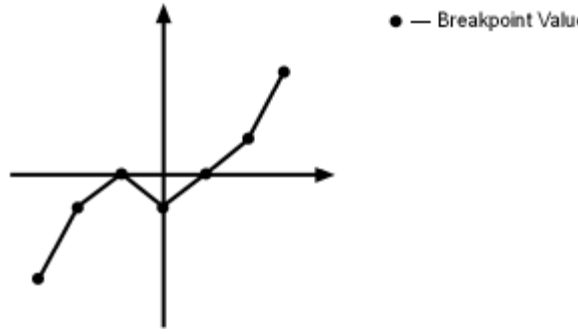
Sizes of Breakpoint Data Sets and Table Data

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]
```

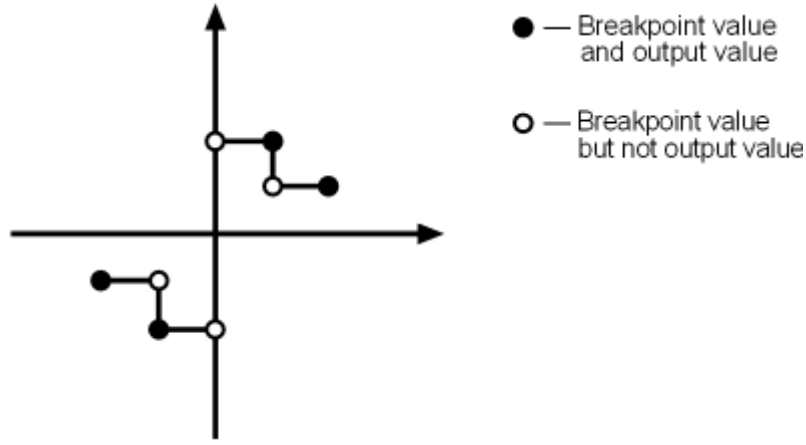
in which each successive element is greater than its preceding element, making `B` strictly monotonically increasing.

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.

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]
```



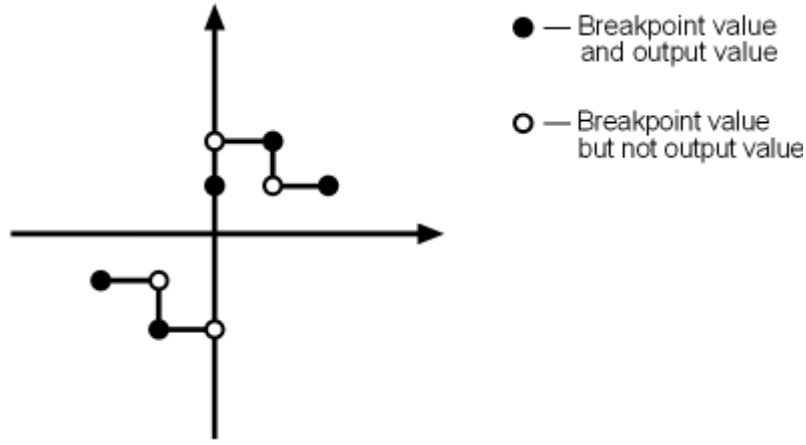
This example has discontinuities at $x = -1$, 0, and +1.

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.

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]`. For a list of lookup table blocks that support evenly spaced breakpoints, see "Summary of Lookup Table Block Features" on page 25-10.

Among other advantages, evenly spaced breakpoints can make the generated code division-free and reduce memory usage. For more information, see:

- `fixpt_evenspace_cleanup` in the Simulink documentation
- "Effects of Spacing on Speed, Error, and Memory Usage" in the Simulink Fixed Point documentation
- "Identify questionable fixed-point operations" in the Simulink Coder documentation

---

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.

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:

- `Flat` — Disables interpolation and uses the rounding operation titled `Use Input Below`. For more information, see "Rounding Methods" on page 25-25.
- `Linear` — Fits a line between the adjacent breakpoints, and returns the point on that line corresponding to the input.
- `Cubic spline` — Fits a cubic spline to the adjacent breakpoints, and returns the point on that spline corresponding to the input.

Note The Lookup Table Dynamic block does not let you select an interpolation method. The `Interpolation-Extrapolation` option in the **Lookup Method** field of the 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:

- `Clip` — Disables extrapolation and returns the table data corresponding to the end of the breakpoint data set range.
- `Linear` — 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` — 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 The Lookup Table Dynamic block does not let you select an extrapolation method. The `Interpolation-Extrapolation` option in the **Lookup Method** field of the block parameter dialog box performs linear extrapolation.

In addition to these methods, some lookup table blocks, such as the n-D Lookup Table 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 **Diagnostic for out-of-range input** list on the block parameter dialog box.

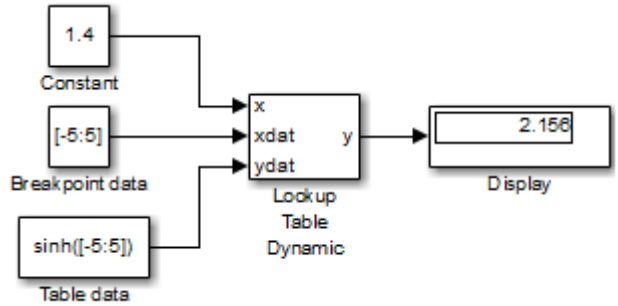
Rounding Methods

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. For example, the Lookup Table Dynamic block lets 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)`.

Edit Existing LookupTables

In this section...

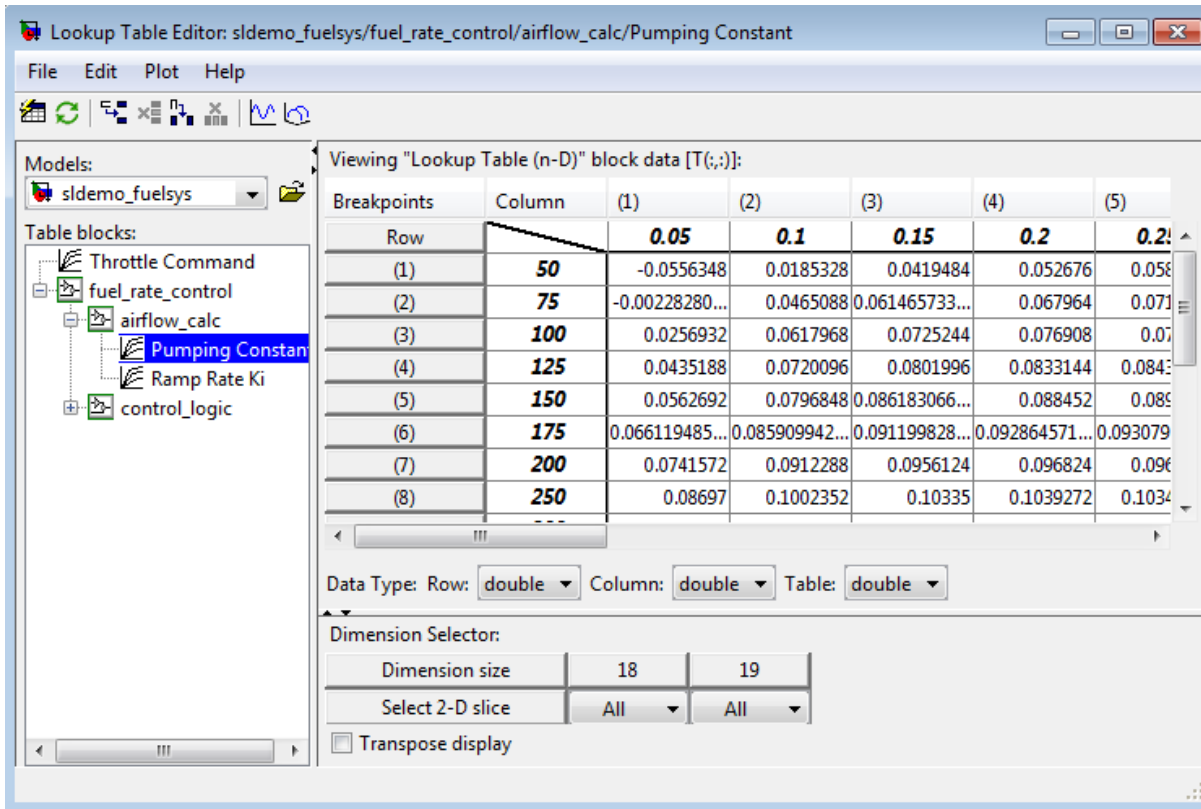
When to Use the Lookup Table Editor

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 25-61). 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.

Tip 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 **Edit** menu. The editor appears.



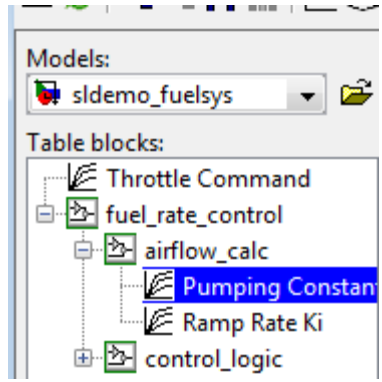
The editor contains two panes and a toolbar.

- Use the left pane to browse and select lookup table blocks in any open model (see “Browsing Lookup Table Blocks” on page 25-29).
- Use the right pane to edit the lookup table of the selected block (see “Editing Table Values” on page 25-30).
- 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.



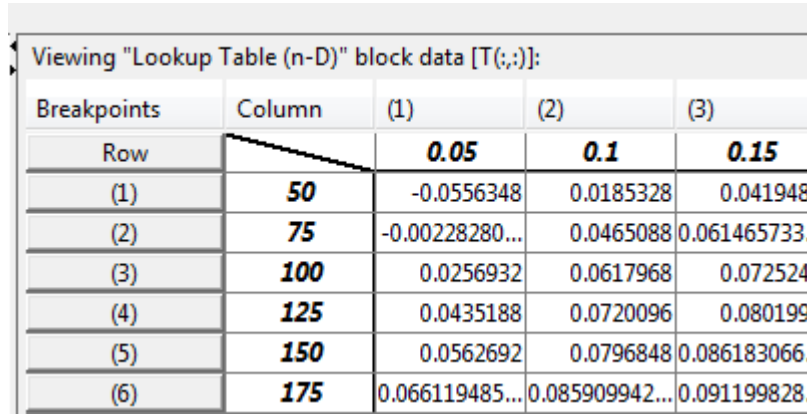
The tree view initially lists all lookup table blocks that reside at the model root level. It also displays any subsystems that contain lookup table blocks. Clicking the expand button (+) to the left of the subsystem name expands the tree to show lookup table blocks in that subsystem. The expanded view 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 25-30).

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	-0.0556348	0.0185328	0.0419484
(2)	75	-0.00228280...	0.0465088	0.061465733..
(3)	100	0.0256932	0.0617968	0.0725244
(4)	125	0.0435188	0.0720096	0.0801996
(5)	150	0.0562692	0.0796848	0.086183066..
(6)	175	0.066119485...	0.085909942...	0.091199828..

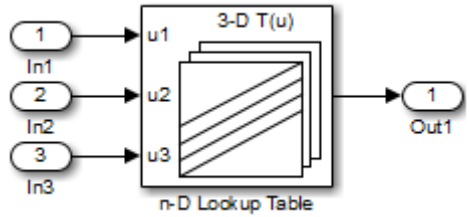
The table view displays the entire table if it is one- or two-dimensional or a two-dimensional slice of the table if the table has more than two dimensions (see "Displaying N-Dimensional Tables in the Editor" on page 25-56). To change any value that appears, double-click the value. The Lookup Table Editor 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.

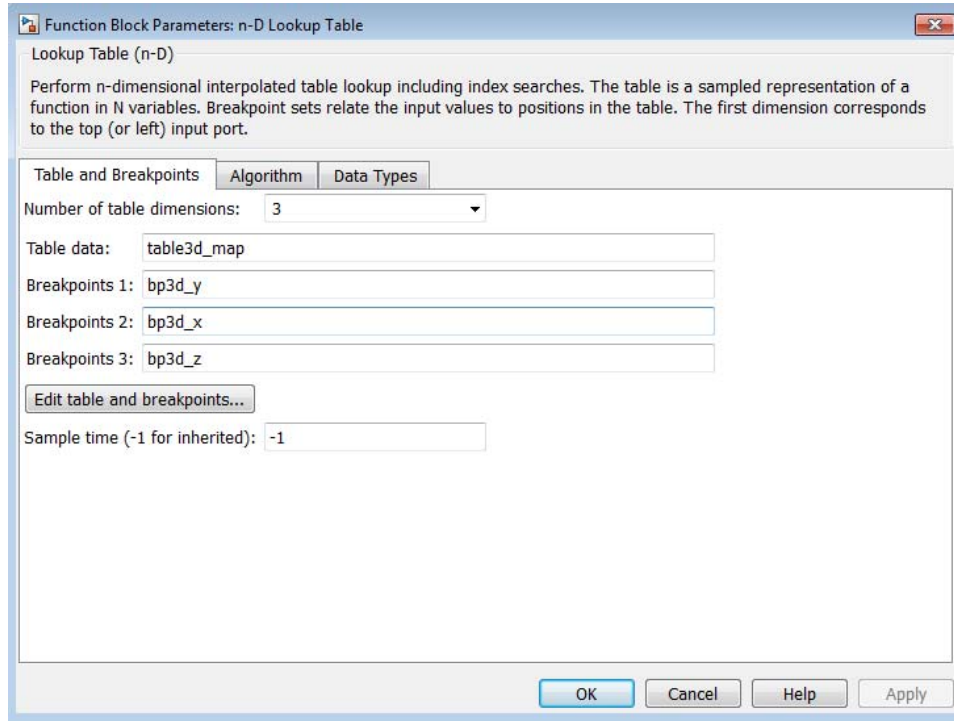
The Lookup Table Editor records your changes by maintaining a copy of the table. To update the copy that the lookup table block maintains, select **File > Update Block Data** in the Lookup Table Editor. To restore the Lookup Table Editor's copy to the values stored in the block, select **File > Reload Block Data**.

Working with Table Data of Standard Format

Suppose that you specify a 3-D lookup table in your n-D Lookup Table block.



You use workspace variables to define the breakpoint and table data:



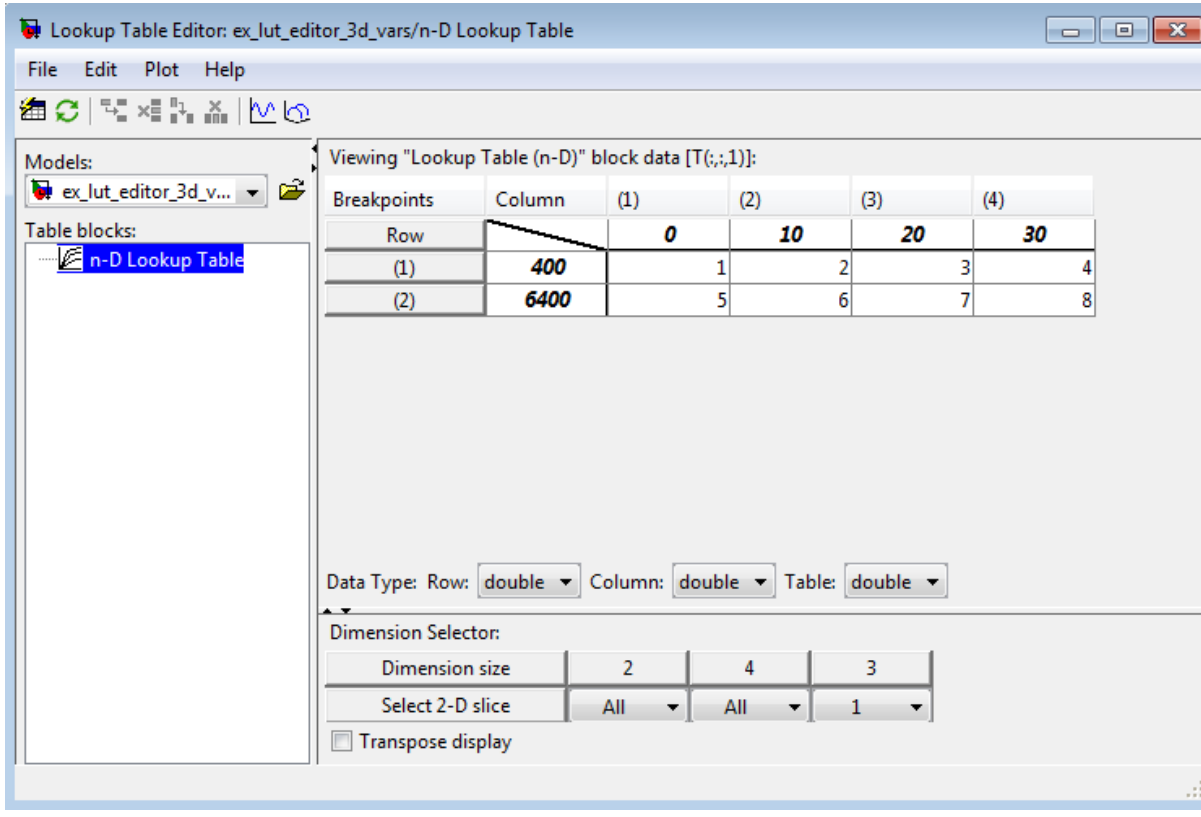
The table data uses the default Simulink format:

```
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
```

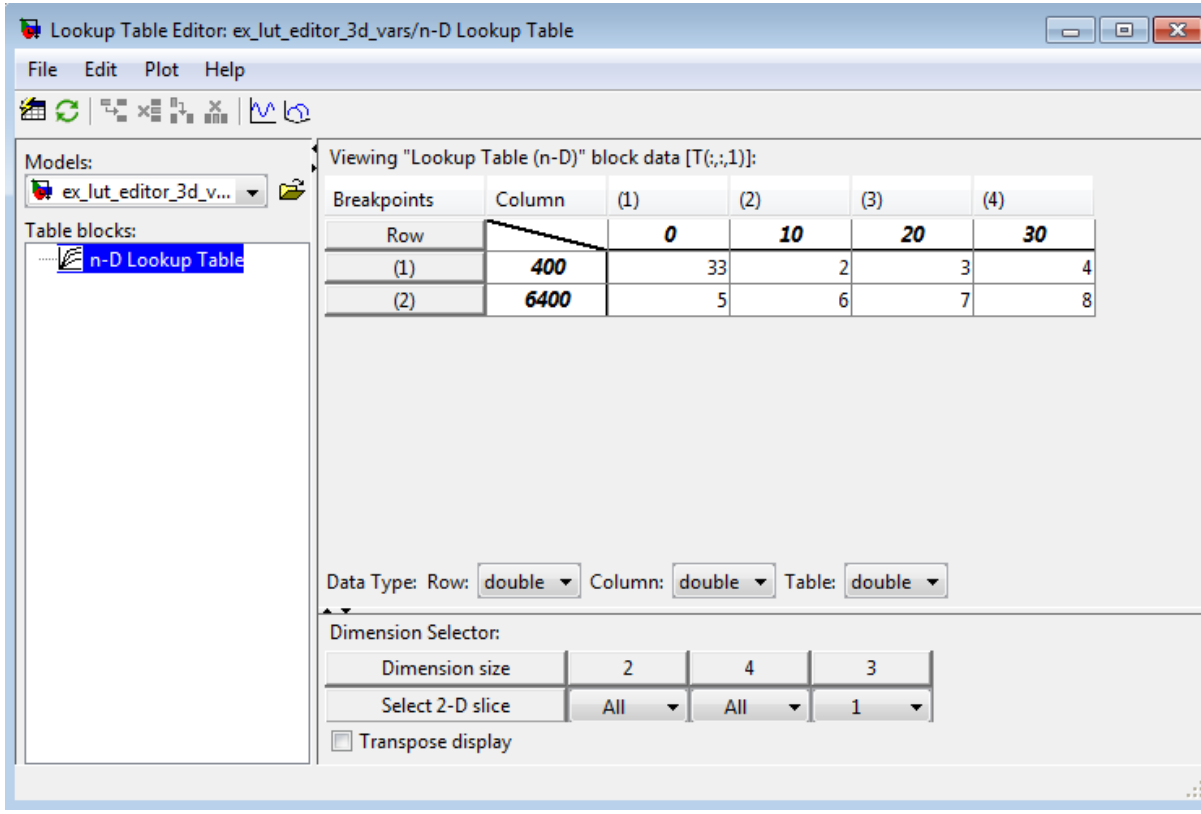
The breakpoint sets have the following values:

```
bp3d_y =

   400  6400

bp3d_x =

     0    10    20    30

bp3d_z =

     0    10    20
```

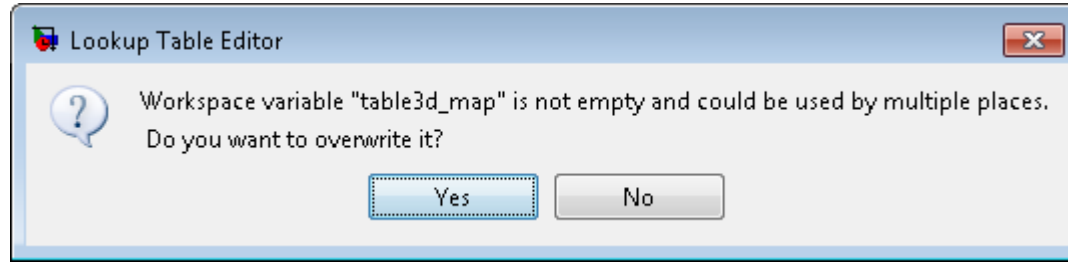
When you click **Edit table and breakpoints** to open the Lookup Table Editor, you see:



Suppose that you change a value in the Lookup Table Editor as follows:

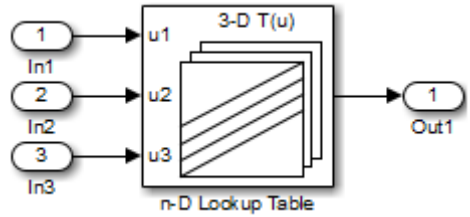


When you select **File > Update Block Data**, you can propagate the change to `table3d_map`, the workspace variable that contains the table data for the n-D Lookup Table block. To propagate the change, click **Yes** in the pop-up window that asks if you want to overwrite the workspace variable:

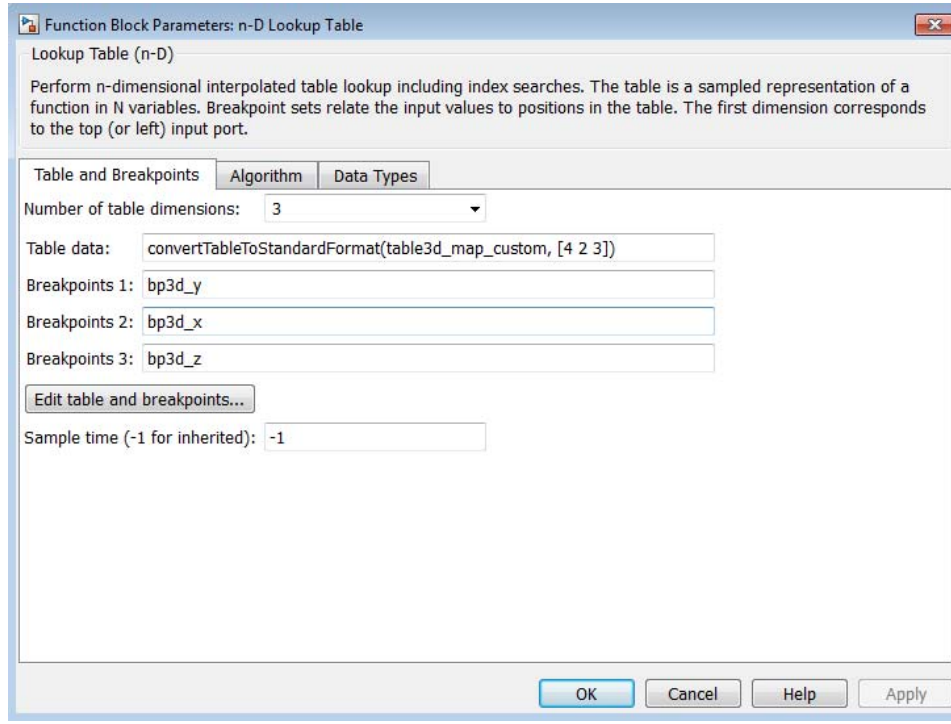


Working with Table Data of Nonstandard Format

Suppose that you specify a 3-D lookup table in your n-D Lookup Table 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:

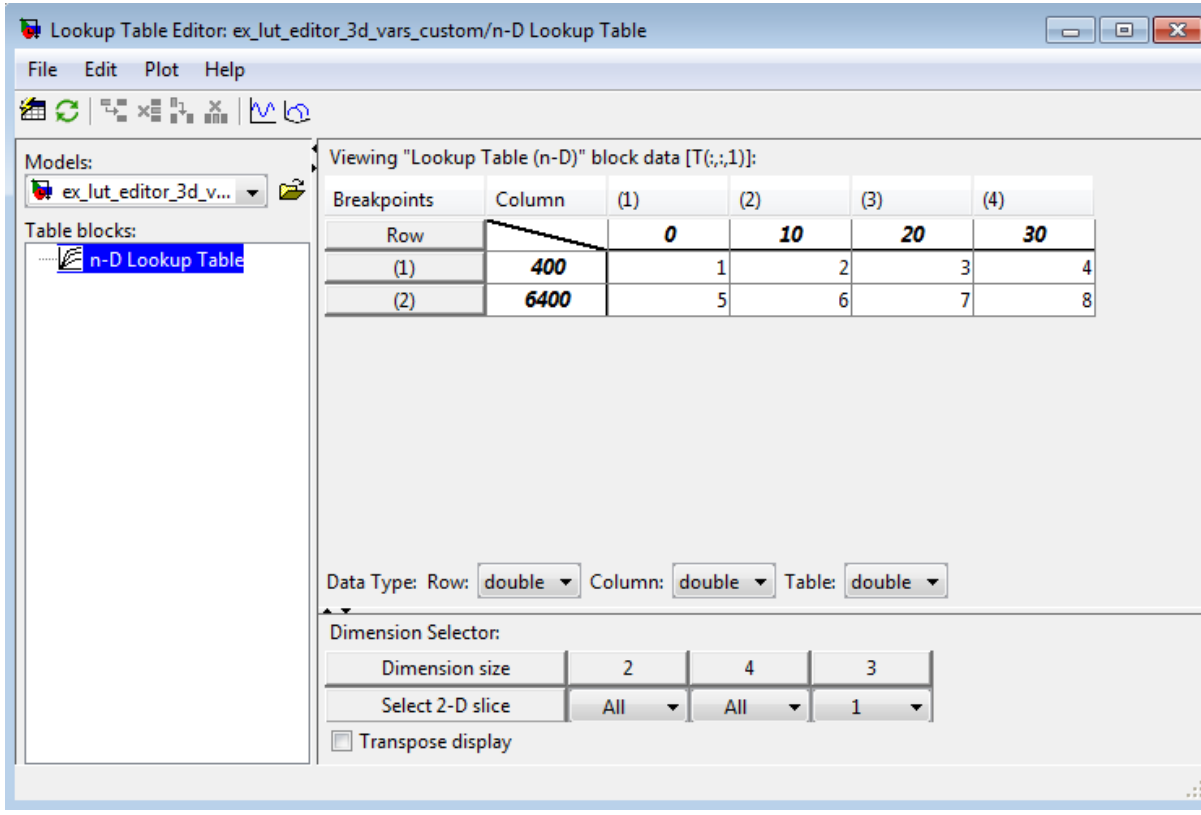
```
table3d_map_custom =

     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 data** field converts the table data from a nonstandard format to the default Simulink format.

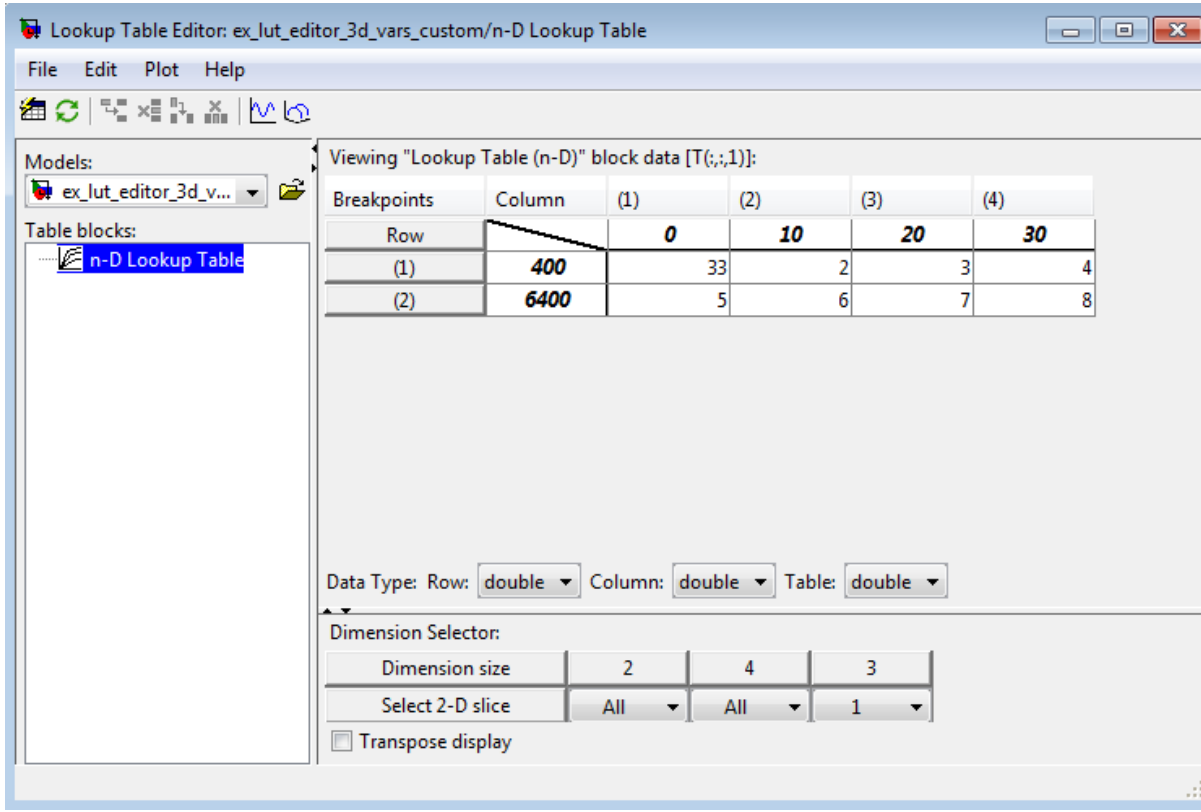
The breakpoint sets have the following values:

```
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 n-D Lookup Table 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 25-45.

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 25-41
2	Select the appropriate responses when prompted in the Lookup Table Editor.	"How to Respond to Prompts in the Lookup Table Editor" on page 25-45

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 n-D Lookup Table 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 n-D Lookup Table 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
```

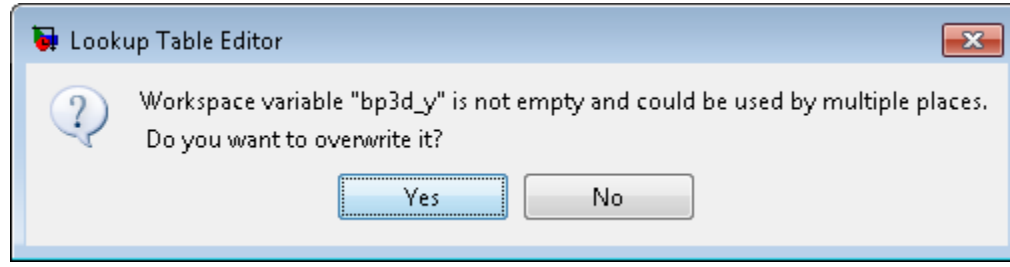
5 Put `sl_customization.m` on the MATLAB search path.

6 At the MATLAB prompt, enter the following command to refresh all Simulink customizations.

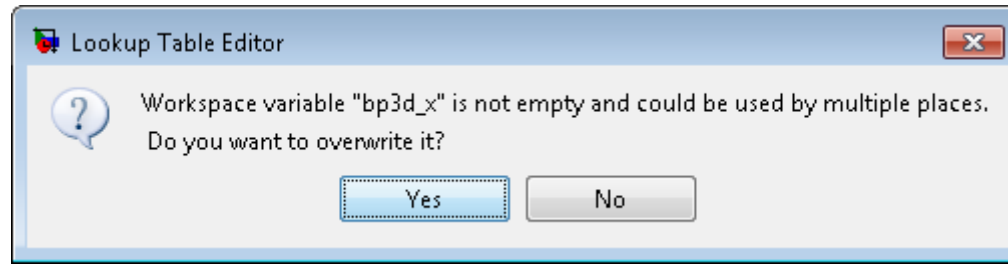
```
sl_refresh_customizations
```

7 In the Lookup Table Editor, select **File > Update Block Data**. Several pop-up windows appear:

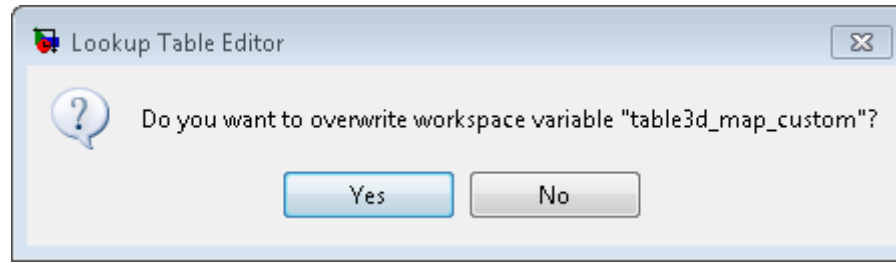
a Click **Yes** to overwrite the workspace variable `bp3d_y`.



b Click **Yes** to overwrite the workspace variable `bp3d_x`.



c Click **Yes** to overwrite the workspace variable `table3d_map_custom`.

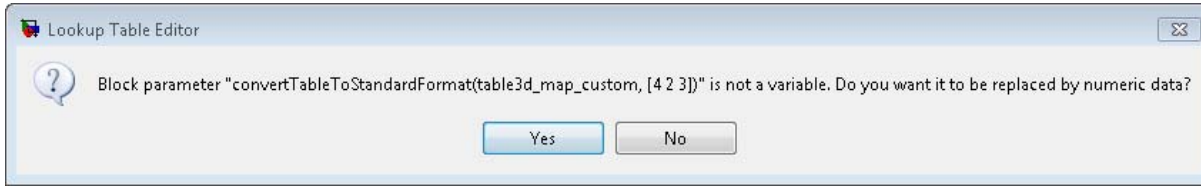


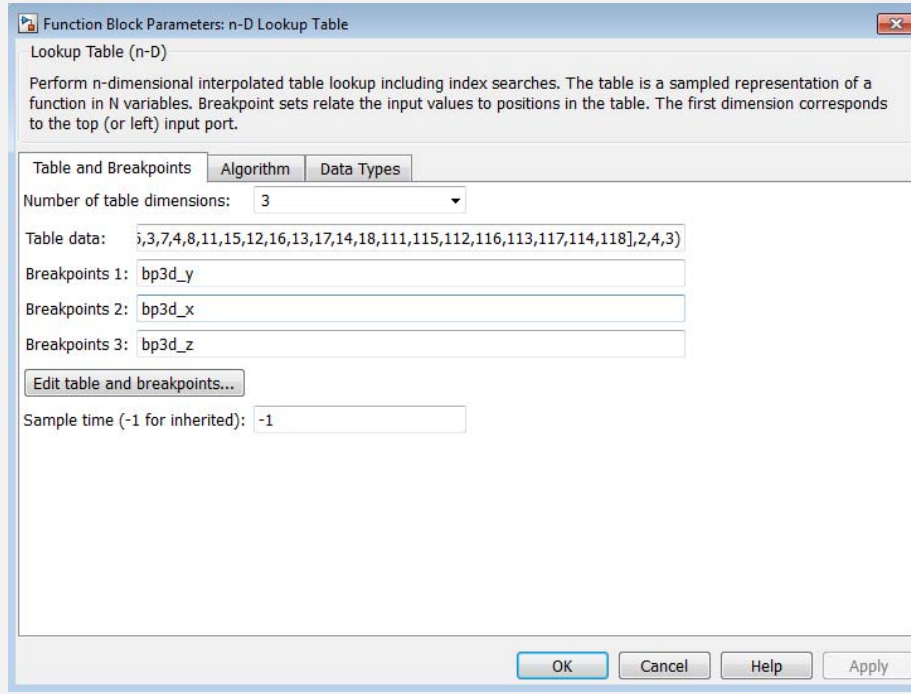
8 If you check the value of `table3d_map_custom` in the base workspace, you now see:

```
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 data** field with numeric data. 
No	Your Lookup Table Editor changes for the table data do not appear in the block dialog box.

Importing Data from an Excel Spreadsheet

If you have table data in a Microsoft Excel spreadsheet, you can import the data into the Lookup Table Editor.

How to Import Data from the Spreadsheet

To import data into the Lookup Table Editor:

1. Save the Excel file in a folder on the MATLAB path.
2. Open the model that contains a lookup table block.
3. Save the model with a different name.
4. Open the Model Properties dialog box, for example, by selecting **File > Model Properties**.
5. Click the **Callbacks** tab and enter code for the model post-load function.

   For a 2-D lookup table, the commands look something like this:

   ```
   %%% BEGIN NEW CODE %%%
   % Import the data from Excel for a lookup table
   data = xlsread('name_of_spreadsheet','sheet_name');
   % Row indices for lookup table
   breakpoints1 = data(2:end,1)';
   % Column indices for lookup table
   breakpoints2 = data(1,2:end);
   % Output values for lookup table
   table_data = data(2:end,2:end);
   %%% END NEW CODE %%%
   ```

   For more information about using `xlsread`, see the MATLAB documentation.

6. Save the model again.

Example of Importing Data from an Excel Spreadsheet

Suppose that you have table data in an Excel spreadsheet named `airflow_tables.xls` and you want to import the data into the Lookup Table Editor.

1. Save `airflow_tables.xls` in a folder on the MATLAB path. Enter the following command at the MATLAB prompt and replace *`destination`* with a location that is on the search path:

   ```
   copyfile((docpath(fullfile(docroot,'toolbox','simulink','examples','airflow_tables.xls'))),...
   'destination','f')
   ```

   For example, `C:\MyFiles\airflow_tables.xls` might be a valid value for *`destination`*.

2. Open the `sldemo_fuelsys` model, which contains a lookup table block named Pumping Constant.

3. Save the model with a different name, such as `my_fuelsys`.

4. Open the Model Properties dialog box, for example, by selecting **File > Model Properties**.

5. Click the **Callbacks** tab and add the following commands under the existing code for the post-load function:

   ```
   %%% BEGIN NEW CODE %%%
   % Import the data from Excel for a lookup table
   data = xlsread('airflow_tables', 'Pumping Constant');
   % Row indices for Pumping Constant data
   SpeedVect = data(2:end,1)';
   % Column indices for Pumping Constant data
   PressVect = data(1,2:end);
   % Output values for Pumping Constant data
   PumpCon = data(2:end,2:end);
   %%% END NEW CODE %%%
   ```

6. Save the model again.

Whenever you open `my_fuelsys`, Simulink imports the table data for the Pumping Constant block from the Excel spreadsheet.

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)

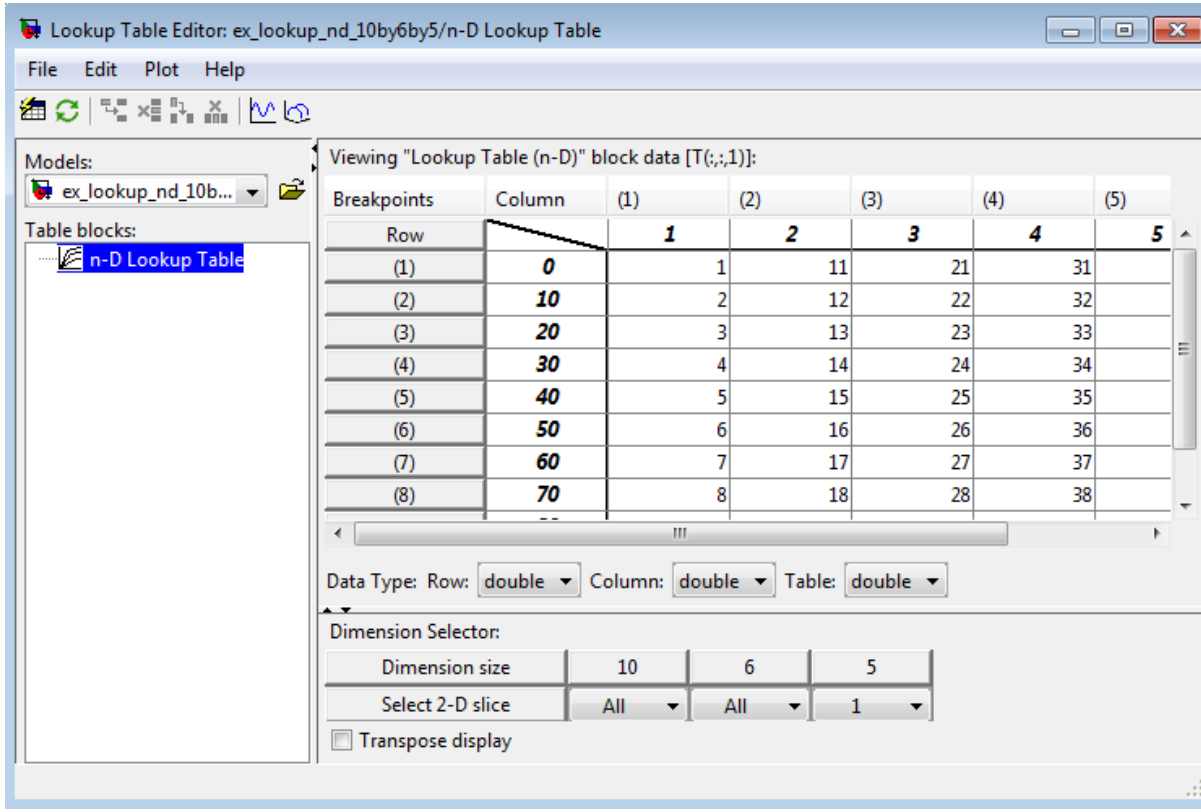
In those cases, follow these instructions to add or remove columns of a table in the Lookup Table Editor.

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 lookup 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.

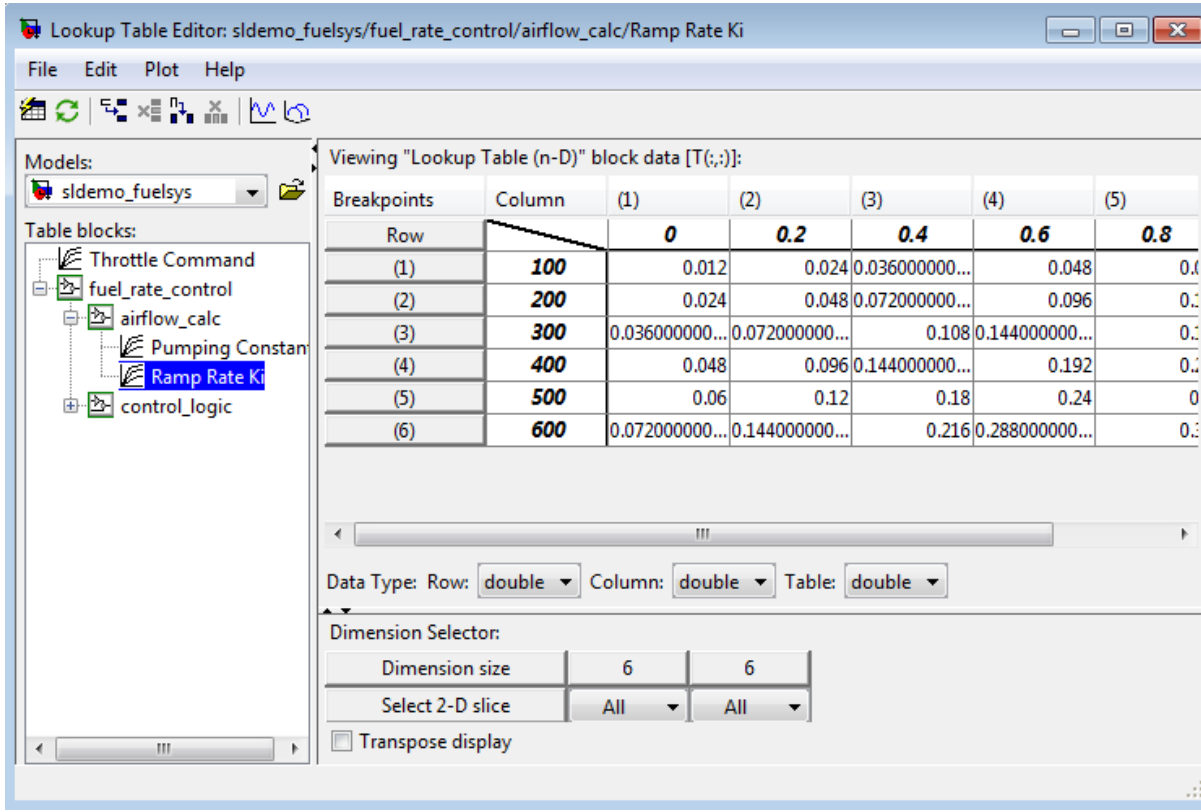
For example, the following selector displays slice (:,:,1) of a 3-D lookup table.

To transpose the table display, select the **Transpose display** check box.

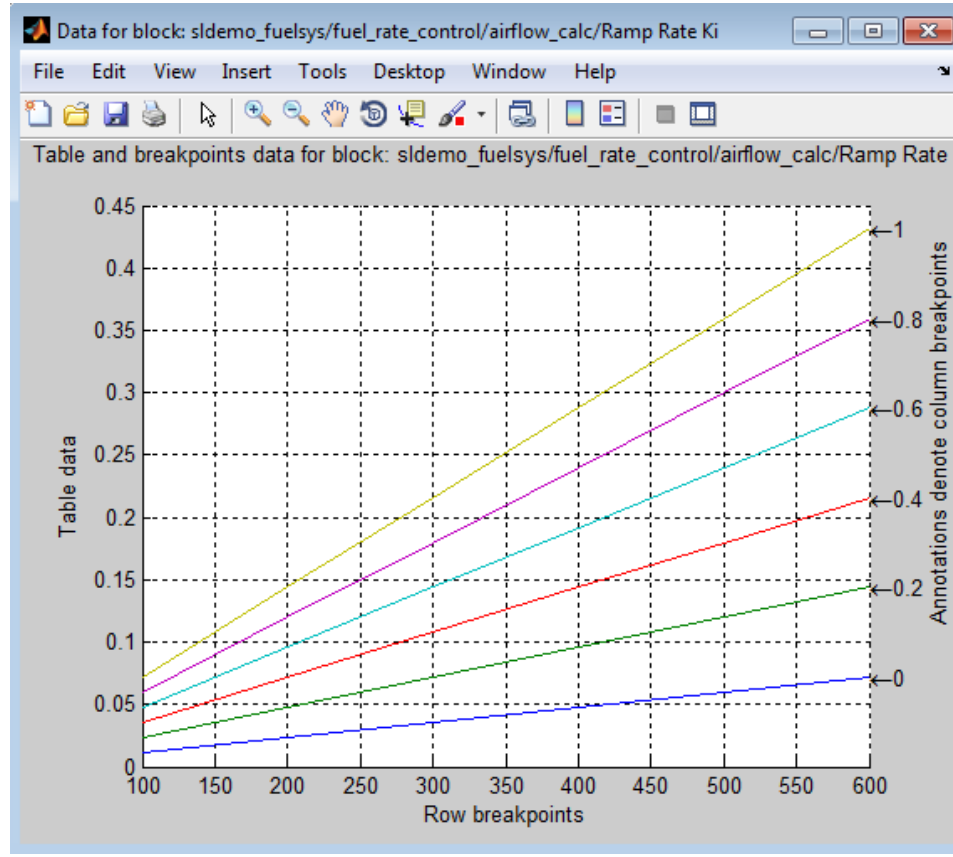
Plotting Lookup Tables

To display a linear or mesh plot of the table or table slice in the Lookup Table Editor, select **Plot > Linear** or **Plot > Mesh**.

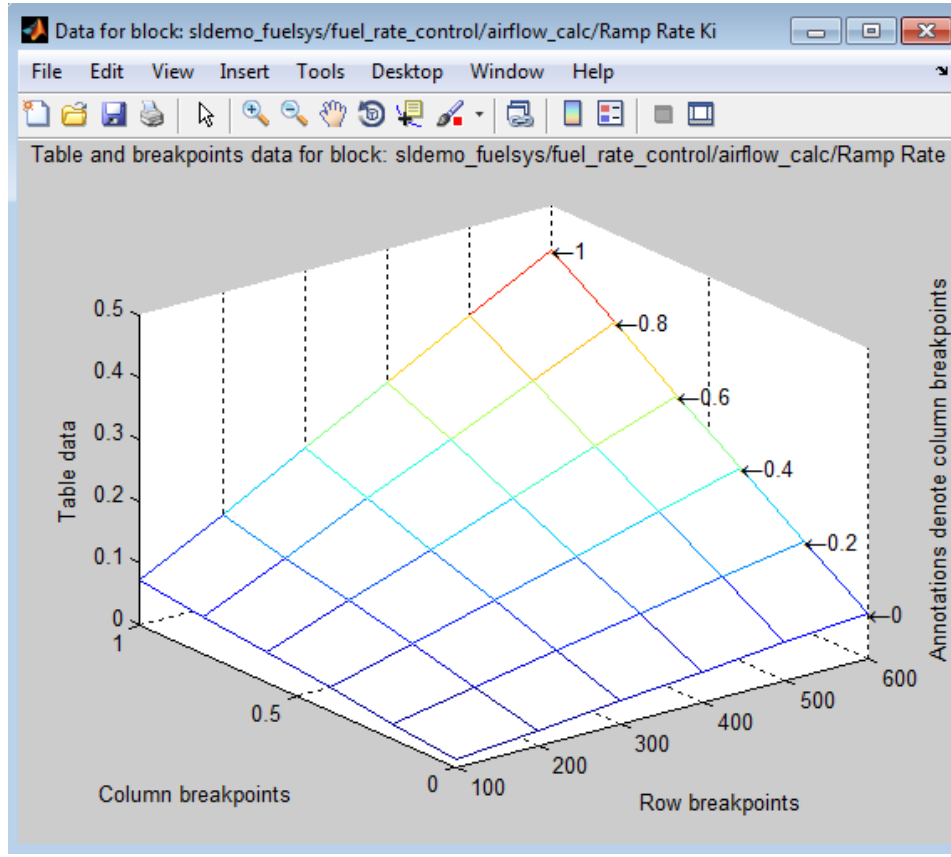
Suppose that you have the following lookup table open:



A linear plot of the table looks something like this:



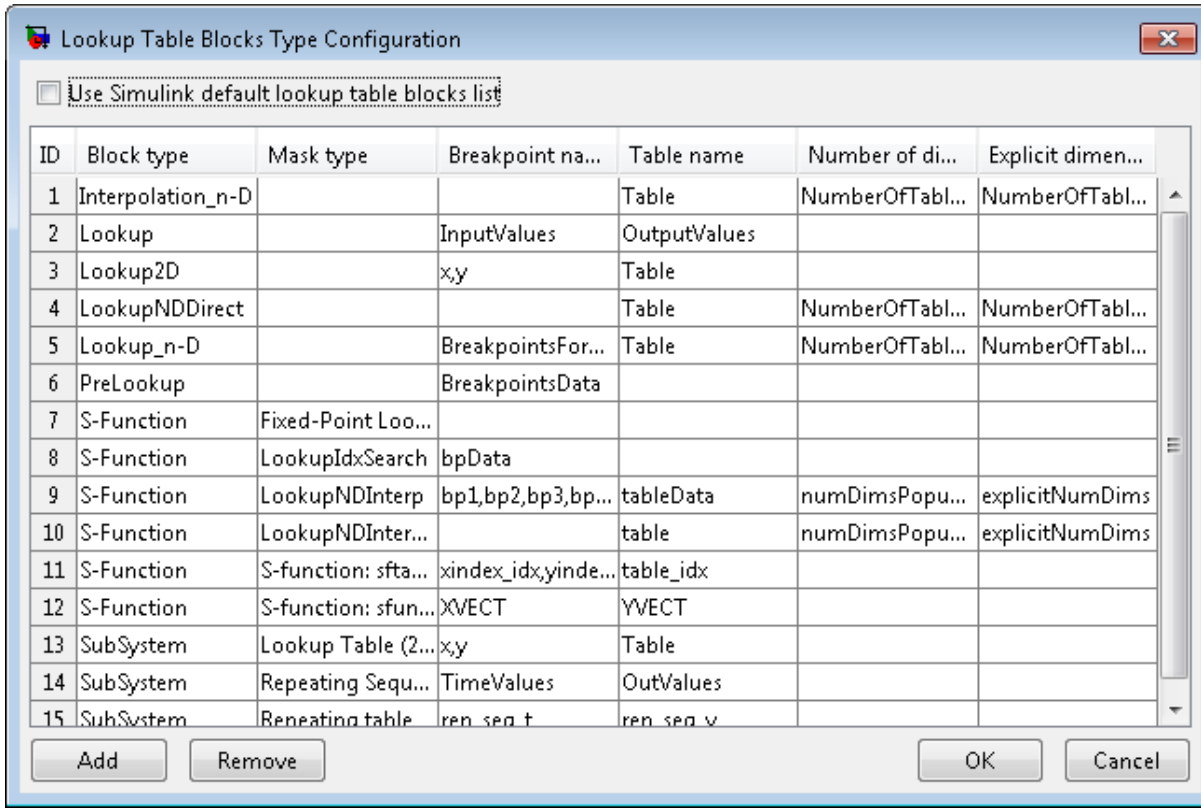
A mesh plot of the table looks something like this:



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**.

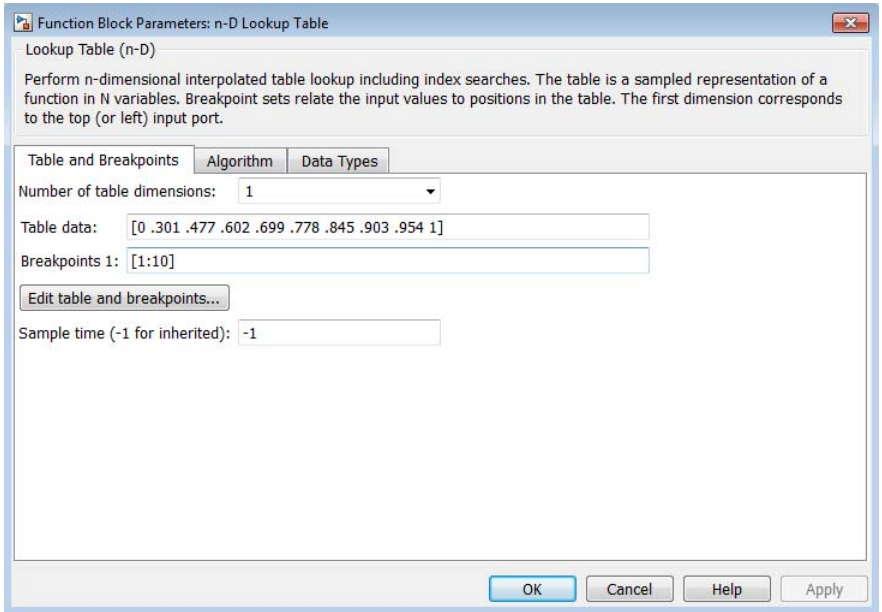
To remove all custom lookup table block types, select the **Use Simulink default lookup table blocks list** check box at the top of the dialog box.

Create 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.

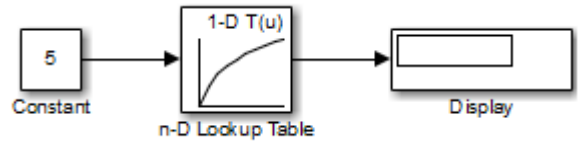
1. Copy the following blocks to a Simulink model:
   - One Constant block to input the signal, from the Sources library
   - One n-D Lookup Table block to approximate the common logarithm, from the Lookup Tables library
   - One Display block to display the output, from the Sinks library
2. Assign the table data and breakpoint data set to the n-D Lookup Table block:
   a. In the **Number of table dimensions** field, enter `1`.
   b. In the **Table data** field, enter `[0 .301 .477 .602 .699 .778 .845 .903 .954 1]`.
   c. In the **Breakpoints 1** field, enter `[1:10]`.
   d. Click **Apply**.

The dialog box looks something like this:



3 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.

4 Connect the blocks as follows.



5 Start simulation.

The following behavior applies to the n-D Lookup Table block.

Value of the Constant Block	Action by the n-D Lookup Table 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

For the n-D Lookup Table block, the default settings for **Interpolation method** and **Extrapolation method** are both `Linear`.

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 in the generated code	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.

Optimize Generated Code for Lookup Table Blocks

In this section...

Remove Code That Checks for Out-of-Range Inputs

By default, generated code for the following lookup table blocks include conditional statements that check for out-of-range breakpoint or index inputs:

- 1-D Lookup Table
- 2-D Lookup Table
- n-D Lookup Table
- Prelookup
- Interpolation Using Prelookup

To generate code that is more efficient, you can remove the conditional statements that protect against out-of-range input values.

Block	Check Box to Select
1-D Lookup Table	**Remove protection against out-of-range input in generated code**
2-D Lookup Table	
n-D Lookup Table	
Prelookup	
Interpolation Using Prelookup	**Remove protection against out-of-range index in generated code**

Selecting the check box on the block dialog box improves code efficiency because there are fewer statements to execute. However, if you are generating code for safety-critical applications, you should not remove the range-checking code.

To verify the usage of the check box, run the following Model Advisor checks and perform the recommended actions.

Model Advisor Check	When to Run the Check
By Product > Embedded Coder > Identify lookup table blocks that generate expensive out-of-range checking code	For code efficiency
By Product > Simulink Verification and Validation > Modeling Standards > DO-178C/DO-331 Checks > Check usage of lookup table blocks	For safety-critical applications

For more information about the Model Advisor, see “Consult the Model Advisor” on page 4-81 in the Simulink documentation.

Optimize Breakpoint Spacing in Lookup Tables

When breakpoints in a lookup table are tunable, the spacing does not affect efficiency or memory usage of the generated code. When breakpoints are *not* tunable, the type of spacing can affect the following factors.

Factor	Even Power of 2 Spaced Data	Evenly Spaced Data	Unevenly Spaced Data
Execution speed	The execution speed is the fastest. The position search and interpolation are the same as for evenly-spaced data. However, to increase speed a bit more for fixed-point types, a bit shift replaces the position search, and a bit mask replaces the interpolation.	The execution speed is faster than that for unevenly-spaced data because the position search is faster and the interpolation uses a simple division.	The execution speed is the slowest of the different spacings because the position search is slower, and the interpolation requires more operations.
Error	The error can be larger than that for unevenly-spaced data because approximating a function with nonuniform curvature requires more points to achieve the same accuracy.	The error can be larger than that for unevenly-spaced data because approximating a function with nonuniform curvature requires more points to achieve the same accuracy.	The error can be smaller because approximating a function with nonuniform curvature requires fewer points to achieve the same accuracy.
ROM usage	Uses less command ROM, but more data ROM.	Uses less command ROM, but more data ROM.	Uses more command ROM, but less data ROM.
RAM usage	Not significant.	Not significant.	Not significant.

Follow these guidelines:

- For fixed-point data types, use breakpoints with even, power-of-2 spacing.
- For non-fixed-point data types, use breakpoints with even spacing.

To identify opportunities for improving code efficiency in lookup table blocks, run the following Model Advisor checks and perform the recommended actions:

- **By Product > Embedded Coder > Identify questionable fixed-point operations**
- **By Product > Embedded Coder > Identify blocks that generate expensive saturation and rounding code**

For more information about the Model Advisor, see “Consult the Model Advisor” on page 4-81 in the Simulink documentation.

Update Lookup Table Blocks to New Versions

In this section...

Comparison of Blocks with Current Versions

In R2011a, the following lookup table blocks were replaced with newer versions in the Simulink library:

Block	Changes	Enhancements
Lookup Table	• Block renamed as 1-D Lookup Table • Icon changed	• Default integer rounding mode changed from `Floor` to `Simplest` • Support for the following features: - Specification of parameter data types different from input or output signal types - Reduced memory use and faster code execution for nontunable breakpoints with even spacing - Cubic-spline interpolation and extrapolation - Table data with complex values - Fixed-point data types with word lengths up to 128 bits - Specification of data types for fraction and intermediate results - Specification of index search method - Specification of diagnostic for out-of-range inputs

Block	Changes	Enhancements
Lookup Table (2-D)	• Block renamed as 2-D Lookup Table • Icon changed	• Default integer rounding mode changed from `Floor` to `Simplest` • Support for the following features: - Specification of parameter data types different from input or output signal types - Reduced memory use and faster code execution for nontunable breakpoints with even spacing - Cubic-spline interpolation and extrapolation - Table data with complex values - Fixed-point data types with word lengths up to 128 bits - Specification of data types for fraction and intermediate results - Specification of index search method - Specification of diagnostic for out-of-range inputs • Check box for **Require all inputs to have the same data type** now selected by default
Lookup Table (n-D)	• Block renamed as n-D Lookup Table • Icon changed	• Default integer rounding mode changed from `Floor` to `Simplest`

Compatibility of Models with Older Versions of Lookup Table Blocks

When you load existing models that contain the Lookup Table, Lookup Table (2-D), and Lookup Table (n-D) blocks, those versions of the blocks appear. The current versions of the lookup table blocks appear only when you drag the blocks from the Simulink Library Browser into new models.

If you use the `add_block` function to add the Lookup Table, Lookup Table (2-D), or Lookup Table (n-D) blocks to a model, those versions of the blocks appear. If you want to add the *current* versions of the blocks to your model, change the source block path for `add_block`:

Block	Old Block Path	New Block Path
Lookup Table	`simulink/Lookup Tables/Lookup Table`	`simulink/Lookup Tables/1-D Lookup Table`
Lookup Table (2-D)	`simulink/Lookup Tables/Lookup Table (2-D)`	`simulink/Lookup Tables/2-D Lookup Table`
Lookup Table (n-D)	`simulink/Lookup Tables/Lookup Table (n-D)`	`simulink/Lookup Tables/n-D Lookup Table`

How to Update Your Model

To update your model to use current versions of the lookup table blocks, follow these steps:

Step	Action	Reason
1	Run this Model Advisor check: **By Product > Simulink > Check model, local libraries, and referenced models for known upgrade issues requiring compile time information**.	Identify blocks that do not have compatible settings with the 1-D Lookup Table and 2-D Lookup Table blocks.
2	For each block that does not have compatible settings: • Decide how to address each warning. • Adjust block parameters as needed.	Modify each Lookup Table or Lookup Table (2-D) block to ensure compatibility with the current versions.
3	Repeat steps 1 and 2 until you are satisfied with the results of the Model Advisor check.	Ensure that block replacement works for the entire model.
4	Run the `slupdate` function on your model.	Perform block replacement with the 1-D Lookup Table and 2-D Lookup Table blocks.

After block replacement, the block names that appear in the model remain the same. However, the block icons match the ones for the 1-D Lookup Table and 2-D Lookup Table blocks. For more information about the Model Advisor, see "Consult the Model Advisor" on page 4-81 in the Simulink documentation.

What to Expect from the Model Advisor Check

The Model Advisor check groups all Lookup Table and Lookup Table (2-D) blocks into three categories:

- Blocks that have compatible settings with the 1-D Lookup Table and 2-D Lookup Table blocks
- Blocks that have incompatible settings with the 1-D Lookup Table and 2-D Lookup Table blocks
- Blocks that have repeated breakpoints

Blocks with Compatible Settings

When a block has compatible parameter settings, automatic block replacement can occur without backward incompatibilities.

Lookup Method in the Lookup Table or Lookup Table (2-D) Block	Parameter Settings After Automatic Block Replacement	
	Interpolation	Extrapolation
`Interpolation-Extrapolation`	`Linear`	`Linear`
`Interpolation-Use End Values`	`Linear`	`Clip`
`Use Input Below`	`Flat`	Not applicable

Depending on breakpoint spacing, one of two index search methods can apply.

Breakpoint Spacing in the Lookup Table or Lookup Table (2-D) Block	Index Search Method After Automatic Block Replacement
Not evenly spaced	`Binary search`
Evenly spaced and tunable	A prompt appears, asking you to select `Binary search` or `Evenly spaced points`.
Evenly spaced and not tunable	

Blocks with Incompatible Settings

When a block has incompatible parameter settings, the Model Advisor shows a warning and a recommended action, if applicable.

- If you perform the recommended action, you can avoid incompatibility during block replacement.
- If you use automatic block replacement without performing the recommended action, you might see numerical differences in your results.

Incompatibility Warning	Recommended Action	What Happens for Automatic Block Replacement
The **Lookup Method** is `Use Input Nearest` or `Use Input Above`. The replacement block does not support these lookup methods.	Change the lookup method to one of the following options: • `Interpolation - Extrapolation` • `Interpolation - Use End Values` • `Use Input Below`	The **Lookup Method** changes to `Interpolation - Use End Values`. In the replacement block, this setting corresponds to: • **Interpolation** set to `Linear` • **Extrapolation** set to `Clip` You also see a message that explains possible numerical differences.
The **Lookup Method** is `Interpolation - Extrapolation`, but the input and output are not the same floating-point type. The replacement block supports linear extrapolation only when all inputs and outputs are the same floating-point type.	Change the extrapolation method or the port data types of the block.	
The block uses small fixed-point word lengths, so that interpolation uses only one rounding operation. The replacement block uses two rounding operations for interpolation.	None	You see a message that explains possible numerical differences.

Blocks with Repeated Breakpoints

When a block has repeated breakpoints, the Model Advisor recommends that you change the breakpoint data and rerun the check. You cannot perform automatic block replacement for blocks with repeated breakpoints.

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

Block Masks

In this section...

What Are Masks?

Masks are custom interfaces you can apply to Simulink blocks. A mask hides the user interface of the block, and instead displays a custom dialog to control specific parameters of the masked block.

When you mask a block, you change only the interface to the block, not its underlying characteristics. 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.

Note You cannot save a mask separately from the block that it masks. You can also not create an isolated mask definition and apply it to more than one block.

The mask icon and Mask Parameters dialog box are analogous to the block icon and block Parameters dialog, respectively.

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.

When to Use Masks?

Masks are useful for customizing block interfaces, encapsulating logic, and providing restricted access to data.

Masks are comparable to subsystems, in that they both simplify the graphical appearance of a model. However, subsystems do not offer an interface for users to interact with underlying block parameters.

Consider masking a Simulink block when you want to

- display a meaningful dynamic icon that reflects values within a block
- define customized parameters whose names reflect the purpose of a block
- provide a dialog box that lets users access only select parameters of the underlying blocks
- provide users customized documentation that is specific to the masked block

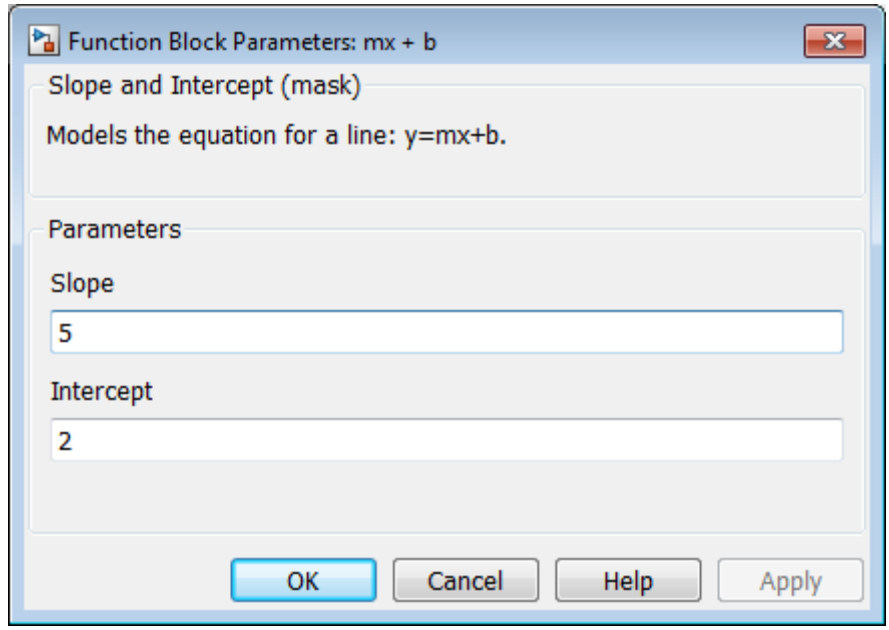
How Mask Parameters Work

A masked block is a custom interface to underlying blocks that are governed by block parameters. Mask parameters are the links to these underlying block parameters.

Mask parameters are defined in the mask workspace, while block parameters may be defined in the model or base workspace.

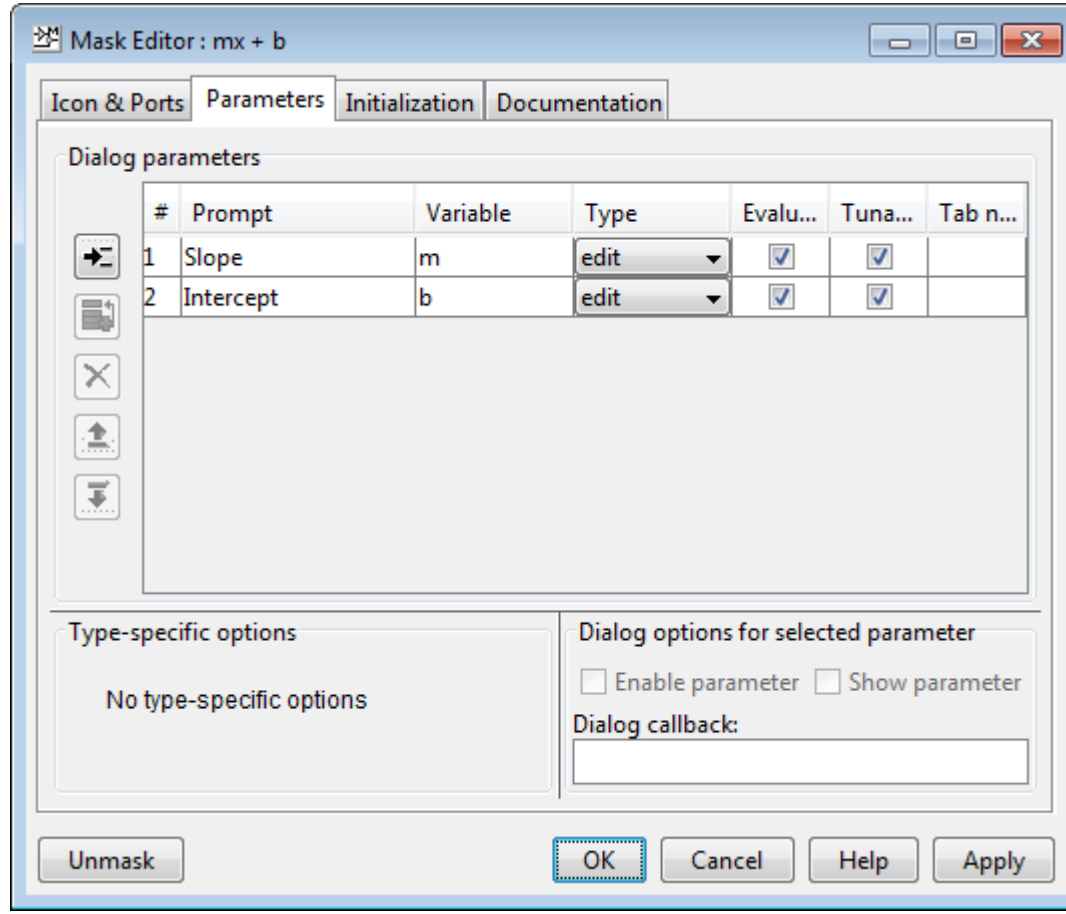
You can provide access to one or more underlying block parameters by defining the corresponding number of mask parameters. Mask parameters appear in the **Mask Parameters** dialog box as editable fields. Simulink applies the value of a mask parameter to the value of the corresponding block parameter during simulation.

Consider the **Mask Parameters** dialog box of model masking_example.



This dialog contains fields for mask parameters **Slope** and **Intercept**, both defined in the Mask Editor.

Slope corresponds to mask workspace variable *m*, and **Intercept**, to mask workspace variable *b*. Moreover, variable names *m* and *b* correspond to the **Gain** and **Constant value** parameters of the underlying blocks.



In the **Mask Parameters** dialog box, when you set **Slope** and **Intercept** to `5` and `2`, respectively, Simulink assigns these values to mask workspace variables *m* and *b*.

Before simulation begins, Simulink searches up the workspace hierarchy, looking in the mask workspace first, for values to resolve the **Gain** parameter

m and **Constant value** parameter *b*. Since variables *m* and *b* are defined in the mask workspace, Simulink applies their values to the block parameters.

Without a mask for the same subsystem, no mask workspace would exist. In that case, Simulink would continue searching up the workspace hierarchy for definitions of *m* and *b*.

Mask Code Execution

In this section...

Mask Code Placement

You can use MATLAB code to initialize a mask as well as to draw mask icons. Since the location of code affects model performance, place your code to reflect the functionality you need.

Purpose	Placement in Mask Editor	Programmatic Specification
Initialize the mask	**Initialization** pane	`MaskInitialization` parameter
Draw mask icon	**Icon & Ports** pane	`MaskDisplay` parameter
Callback code for mask parameters	**Parameters** pane	`MaskCallbacks` parameter

Drawing Command Execution

Place MATLAB code for drawing mask icons in the **Icon Drawing Commands** section of the **Icon & Ports** pane. Simulink executes these commands sequentially to redraw the mask icon in the following cases:

- The drawing commands are dependent on mask parameters and the values of these mask parameters change.
- The block's appearance is altered due to rotation or other changes.

Note If you place MATLAB code for drawing mask icons in the **Initialization** pane, model performance is affected, because Simulink redraws the icon each time the masked block is evaluated in the model.

Initialization Command Execution

When you open a model, Simulink locates visible masked blocks that reside at the top level of the model or in an open subsystem. Simulink only executes the initialization commands for these visible masked blocks if they meet either of the following conditions:

- The masked block has icon drawing commands.

  Note Simulink does not initialize masked blocks that do not have icon drawing commands, even if they have initialization commands.

- The masked subsystem belongs to a library and has the **Allow library block to modify its contents** parameter enabled.

Simulink initializes masked blocks that are not initially visible when you open the subsystem or model that contains these blocks.

When you load a model into memory without displaying it graphically, no initialization commands initially run for any masked blocks. See "Load 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 that have drawing commands 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 drawing depends 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.

Callback Code Execution

Simulink executes the callback commands in the following cases:

- You open the Mask Parameters dialog box. Callback commands execute sequentially, starting with the top mask dialog box parameter.
- You 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.

- You modify the parameter value, either in the Mask Parameters dialog box or using `set_param`, and then apply the change by clicking **Apply** or **OK**. Mask initialization commands execute after callback commands (See "Initialization Pane").
- You hover over a 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 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 **Simulation > Update diagram** in the Simulink Editor).

Mask Terminology

Term	Description
Mask icon	The masked block icon generated using drawing commands. This icon may be static or change dynamically with underlying block parameter
Mask parameters	Parameters defined in the Mask Editor that link to underlying block parameters. Setting a mask parameter sets the corresponding block parameter.
Mask initialization code	MATLAB code that initializes a masked block or reflects current parameter values.
Mask callback code	MATLAB code that runs when the value of a mask parameter changes. Use callback code to modify a mask dialog box to reflect current parameter values.
Mask documentation	Description and usage information for a masked block defined in the Mask Editor.
Mask dialog	A dialog box that contains fields for setting mask parameter values and provides mask documentation.
Mask workspace	Masks that define mask parameters or contain initialization code have a mask workspace. This workspace stores mask parameters and temporary values used by the mask.

Mask a Block

This example shows how to create a block mask and define its parameters.

Create mask

1. Open the model `subsystem_example`. Alternately, execute the following command in MATLAB:

   ```
   open_system([docroot '/toolbox/simulink/ug/examples/masking/subsystem_exa
   ```

   This model contains a Subsystem block that models the equation for a line: `y = mx + b`.

2. Double-click the subsystem block to open it.

   Notice that this subsystem contains the following blocks that are controlled by parameters.

   - Gain block, named *Slope*, with parameter `m`
   - Constant block, named *Intercept*, with parameter `b`

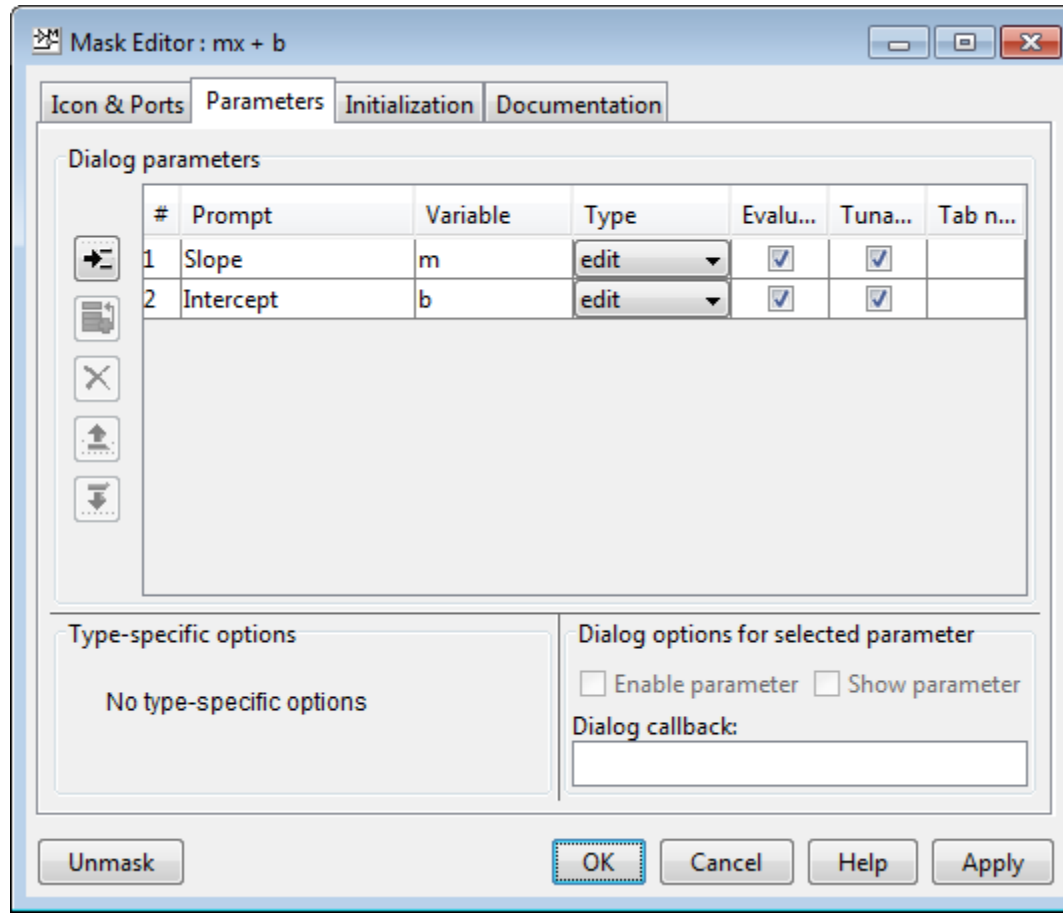
3. Return to the top-level model, right-click the subsystem block, and select **Mask > Create Mask**.

   The Mask Editor appears.

Define mask parameters

Define parameters to control the underlying blocks.

1. In the Mask Editor, click the **Parameters** tab.
2. In the **Dialog parameters** pane, click the **Add parameter** icon.
3. In the row that appears, specify the parameters as follows.



4 Click **Apply**.

Set mask parameter values

Provide values to the parameters.

1 Double-click the mask to view the mask parameter dialog.

2 Set **Slope** and **Intercept** as 5 and 2, respectively.

To control the underlying blocks, change these parameters.

3 Click **OK**.

Draw Mask Icon

This example shows how to use drawing commands to create a mask icon. You can create icons that update when you change the mask parameters, thereby reflecting the purpose of the block.

Draw static icon

A static mask icon remains unchanged, independent of the value of the mask parameters.

1. Right-click the masked block that requires the icon and select **Mask > Edit Mask**.

   The Mask Editor appears.

2. In the **Icons & Ports** tab, enter the following command in the **Icon Drawing commands** pane:

   ```
   % Use specified image as mask icon
   image(imread('engine.jpg'))
   ```

   The image file must be on the MATLAB path.

Note For more examples of drawing command syntax, explore the **Command** drop-down list in the **Examples of drawing commands** pane.

Draw dynamic icon

A dynamic icon changes with the values of the mask parameters. Use it to represent the purpose of the masked block.

1. Right-click the masked block that requires the icon and select **Mask > Edit Mask**.

   The Mask Editor appears.

2. In the **Icons & Ports** tab, enter the following command in 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)
```

3 Under **Options**, set **Icon Units** to `Pixels`.

The drop-down lists under **Options** allow you to specify icon frame visibility, icon transparency, drawing context, icon rotation, and port rotation.

4 Click **Apply**.

Note If Simulink cannot evaluate all commands in the **Icon Drawing commands** pane to generate an icon, three question marks (`? ? ?`) appear on the mask.

See model `masking_example` to view the icon generated.

Additional examples

See model `slexMaskDisplayAndInitializationExample` for more examples of icon drawing commands. This model shows how to draw:

- a static mask
- a dynamic shape mask
- a dynamic text mask
- an image mask

Create Mask Documentation

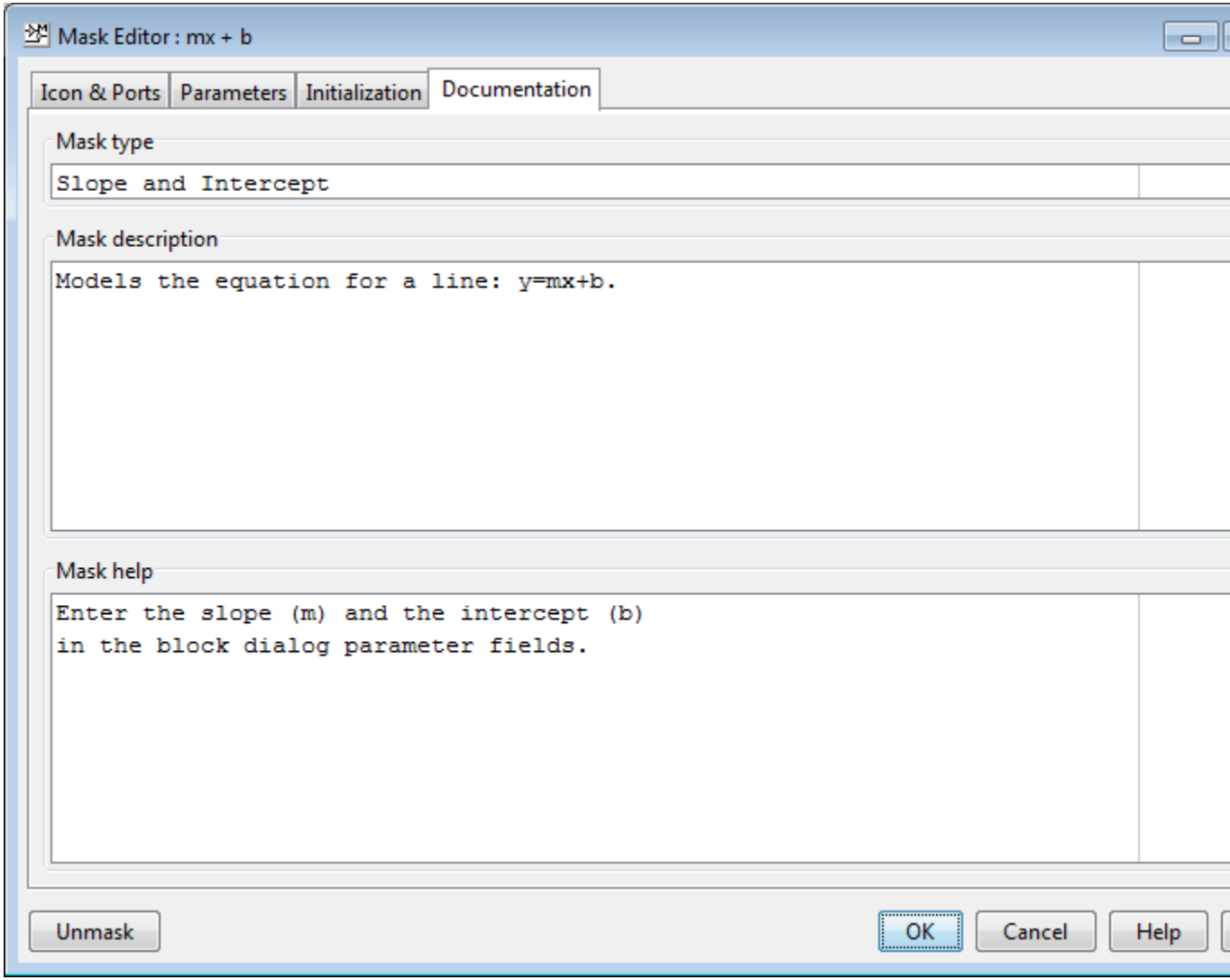
This example shows how to create mask documentation for display in the Mask Parameters dialog box.

1. Right-click the masked block to document and select **Mask > Edit Mask**.

   The Mask Editor appears.

2. In the **Documentation** tab, enter the following information:

   - **Mask type**: The name of the mask. This name appears at the top of the Mask Parameters dialog box. Newlines are not permitted.
   - **Mask description**: A summary of what the mask does. This description appears below the mask name, and it contain newlines as well as spaces.
   - **Mask help**: Additional mask information that appears when you click **Help** in the Mask Parameters dialog box. You can use plain text, HTML and graphics, URLs, and `web` or `eval` commands.


Mask Editor : mx + b
Icon & Ports
Parameters
Initialization
Documentation
Mask type
Slope and Intercept
Mask description
Models the equation for a line: y=mx+b.
Mask help
Enter the slope (m) and the intercept (b)
in the block dialog parameter fields.
Unmask
OK
Cancel
Help

Initialize Mask

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 26-8). 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.

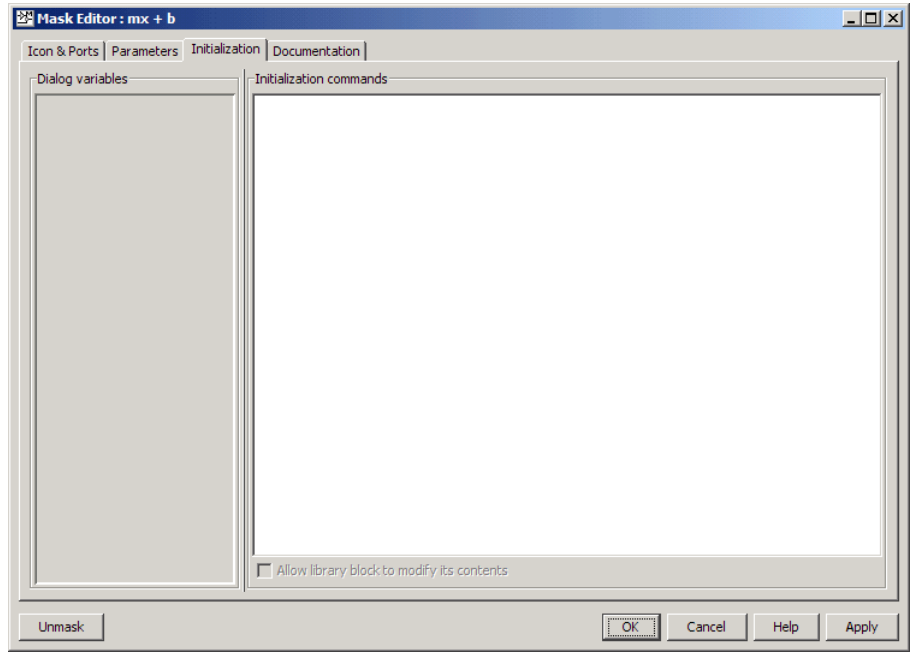
When you reference the block within, or copy the block into, a model, the Mask Parameters dialog box displays the specified default values. You cannot use mask initialization code to change mask parameter default values in a library block or any other block.

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 26-21and "How Do I Debug Masks That Use MATLAB Code?" on page 26-67.

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 "Create Dynamic Mask Dialog Boxes" on page 26-56.
- 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.

Best Practices for Masking

These examples show best practices for masking Simulink blocks. There are also some examples that show practices to avoid.

In this section...

Use These Best Practices

- Set mask parameters
- Group parameters under tabs
- Promote mask parameters
- Sequence mask callbacks
- Define mask display and initialization
- Create dynamic mask dialog boxes
- Use self-modifying library masks
- Use handle graphics in masking

Avoid These Practices

- Unsafe mask callbacks
- Unsafe nested mask callbacks

Considerations for Masking Model Blocks

In this section...

Referenced Model Name

You can use a mask parameter to specify the name of a model referenced by

- a masked Model block, or
- a Model block in a masked subsystem

In these cases, the mask parameter should receive the name of the reference model literally, without being evaluated, because Simulink updates model reference targets before mask parameters.

Use one of the following approaches to obtain the literal name of the referenced model:

- **Restricted model names:** In the **Parameters** pane of the Mask Editor, select the parameter that stores the referenced model name. Set its **Type** to `popup` and clear the check box for **Evaluate**.

  With this approach, users can only select a model name from a drop-down list in the Mask Parameters dialog box. Further, since the **Evaluate** option is cleared, the name is provided literally and not numerically evaluated.

- **Unrestricted model names:** In the **Parameters** pane of the Mask Editor, select the parameter that stores the referenced model name. Set its **Type** to `edit` and clear the check box for **Evaluate**.

  With this approach, users can type the model name in the Mask Parameters dialog box. However, since the **Evaluate** option is cleared, the name is provided literally and not numerically evaluated.

See "Control Types" for more information about **Pop-Up** and **Edit** controls.

Variable Workspace

When you mask a Model block that references another model, the referenced model cannot access the mask workspace of the Model block.

Therefore, variables used by the referenced model must resolve either to workspaces defined by the referenced model or to the 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 "Create Block Libraries" on page 28-20.

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, open the library that contains the block. 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. Additional information relating to masked library blocks appears in "Create Block Libraries" on page 28-20.

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.

Promote Underlying Block Parameters to Mask

This example shows to promote the parameters of underlying blocks to the mask. See model `slexMaskParameterPromotionExample` for more examples of parameter promotion.

1. Right-click a block or subsystem in your model and select **Mask > Create Mask**.

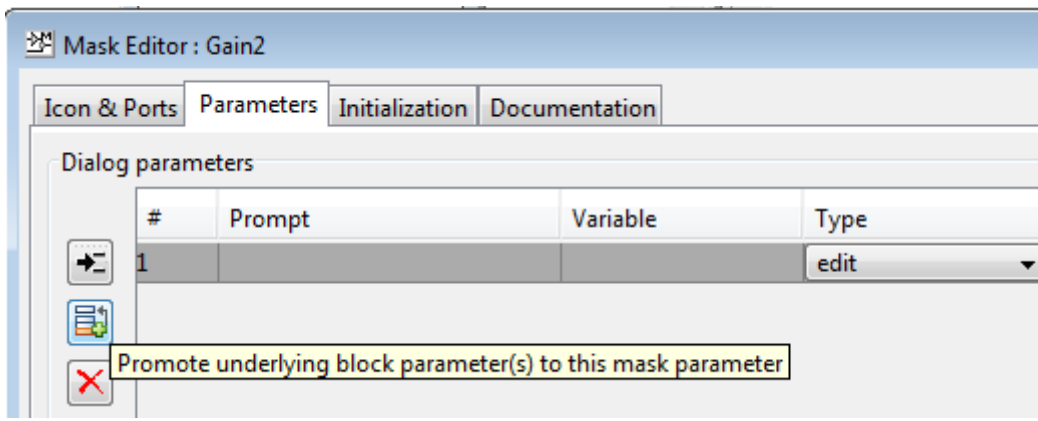
   The Mask Editor appears.

2. Select the **Parameters** pane.

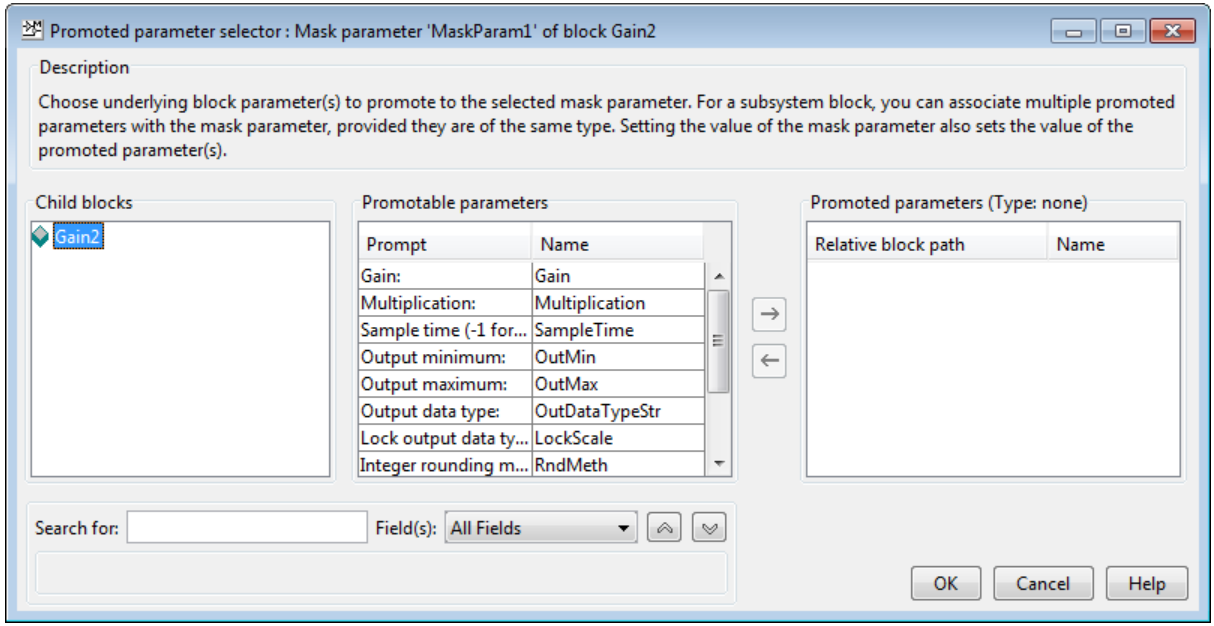
3. Choose one or more parameters for promotion.

   a. Create a new mask parameter. Click **Add Parameter**.

   b. Click the **Promote** button. 



The **Promoted parameter selector** dialog box opens.



c Choose underlying block parameters to promote to the currently selected mask parameter.

- Select a parameter in the **Promotable parameters** table and click the right arrow button to add to the **Promoted parameters** list.

  Tip View the tooltips on promotable parameters to see key fields such as **Type**.

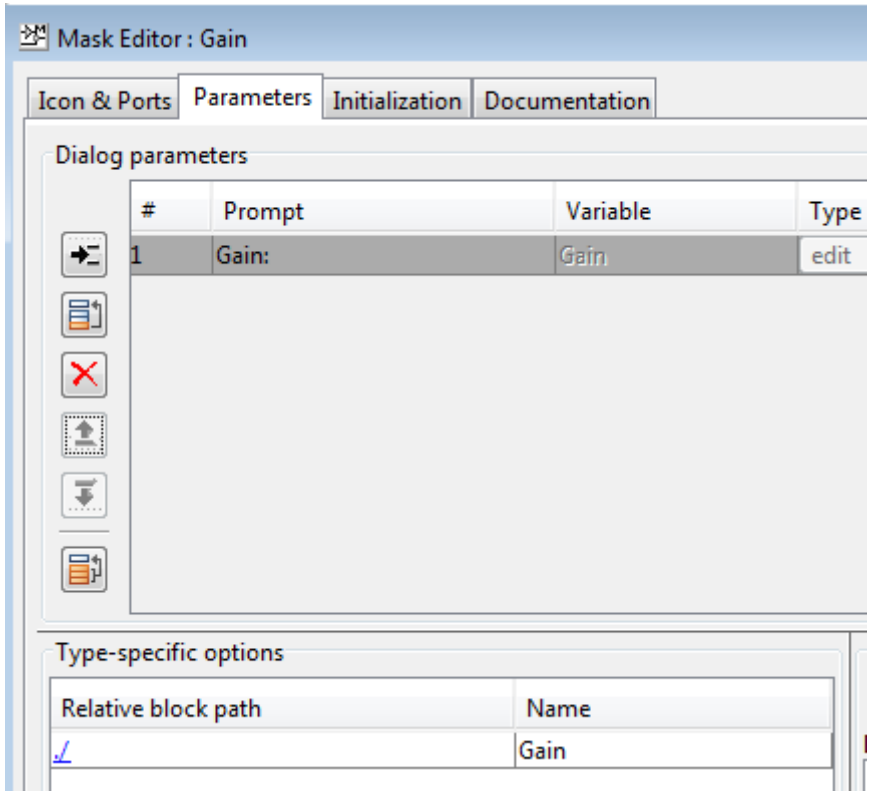
- When masking a subsystem, you can use the **Child blocks** list or the **Search** box to find underlying block parameters to promote.
- (Optional) When masking a subsystem, you can associate multiple promoted parameters with the currently selected mask parameter, provided they are of the same type.

  For example, you can promote multiple Gain parameters in a subsystem to a single prompt on your mask.

d Click **OK** to return to the Mask Editor.

4 Observe that the **Type** field is now disabled because you have promoted a parameter to this mask parameter. Type is always disabled. Variable is also disabled if you are directly masking a built-in block and not a subsystem.

   The **Relative block path** table shows you the location of the underlying original block (where `.` means `self`). Click the link under **Relative block path** to open the underlying block.



5 Edit the prompt names for the mask, if desired. You cannot edit the variable names of built-in block parameters. See “Rules for Promoting Parameters” on page 26-36.

6 Repeat step 3 to add mask parameters and add or edit additional promoted parameters.

Tip If you want to promote many parameters from a built-in block, click **Promote All**  .

The **Promote All** button is only available for block masks, not subsystem masks.

All the parameters appear in the Mask Editor. To remove any unwanted parameters, use the **Delete Parameter** button.

7 Click **OK** to finish editing the mask.

Now whenever you set a mask parameter, you also set the value of the underlying promoted parameters.

Create Custom Interface for Simulink Blocks

This example shows how to mask the Gain block and promote only the Gain parameter to the mask, while hiding the other options and adding custom parameters.

1. Right-click a Gain block in your model and select **Mask > Create Mask**.

   The Mask Editor appears.

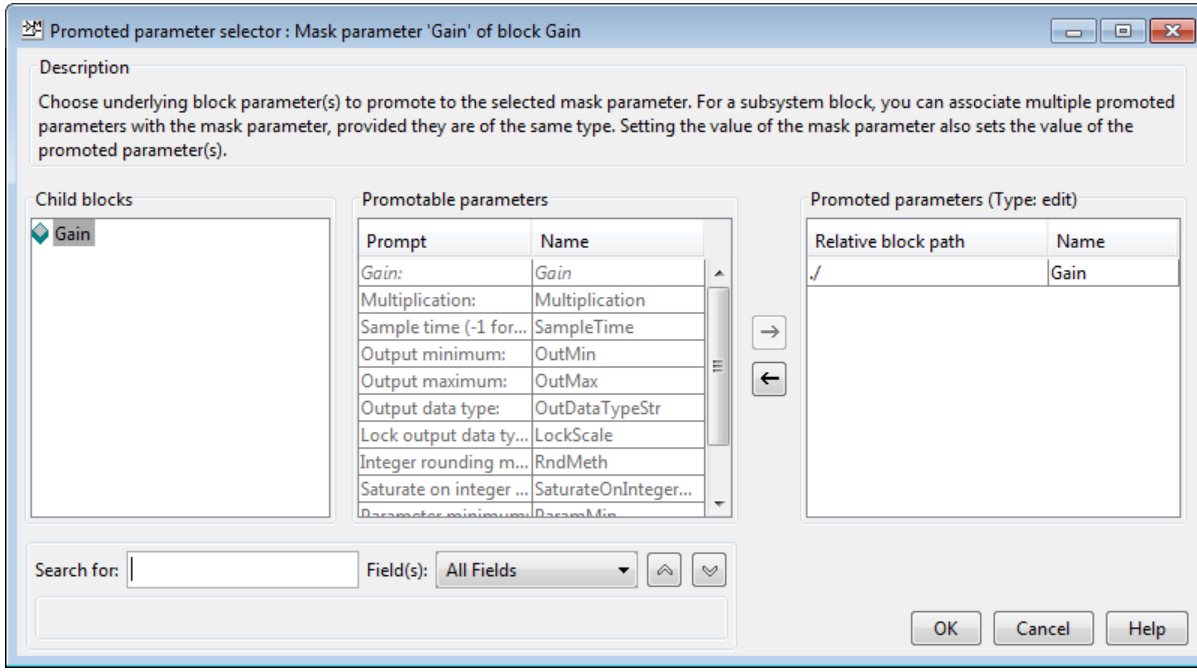
2. Select the **Parameters** pane.

3. Create a new mask parameter. Click **Add Parameter**.

4. Click the **Promote** button.  .

   The **Promoted parameter selector** dialog box opens.

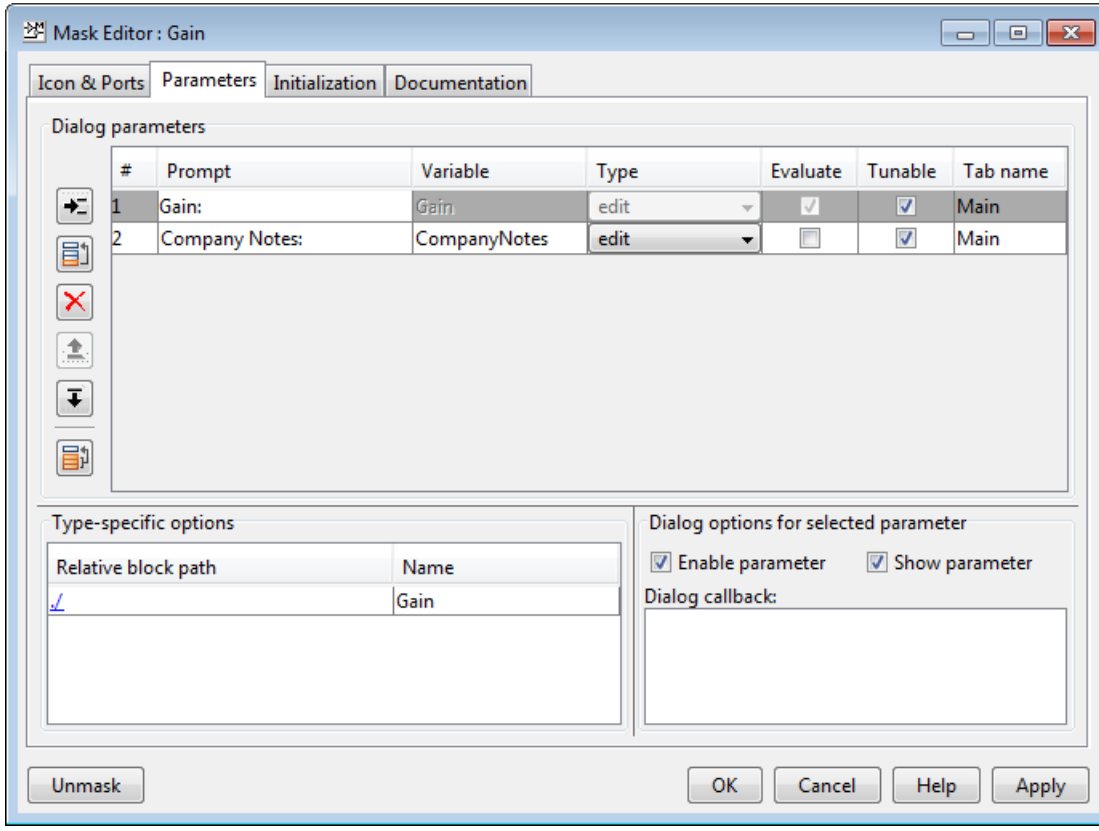
5. Select the Gain parameter in the **Promotable parameters** table and click the right-arrow button to add to the **Promoted parameters** list.



6 Click **OK** to return to the Mask Editor.

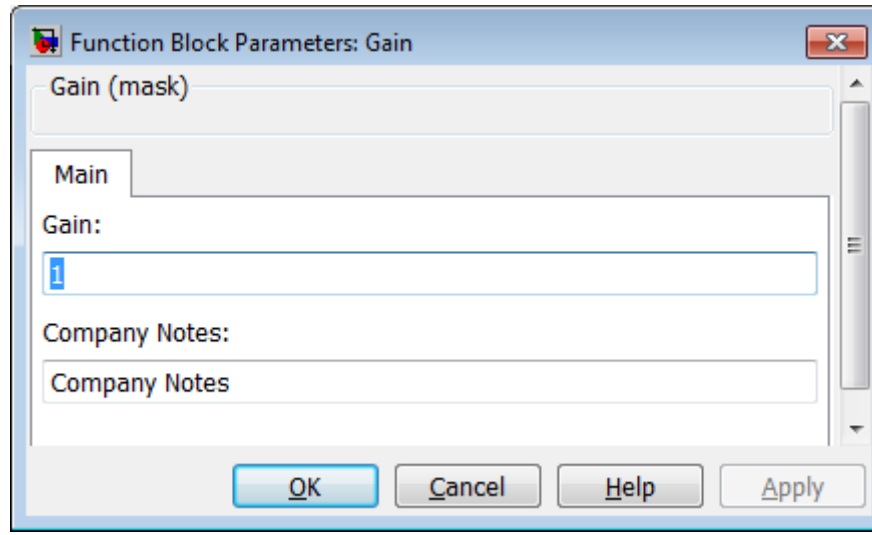
7 Observe that fields such as **Variable** and **Type** are now disabled because you have promoted a built-in parameter to this mask parameter, and the **Relative block path** table shows you the location of the underlying original block (where `./` means `self`). Click the link in the **Relative block path** table to open the underlying Gain block.

8 (Optional) Add custom mask parameters by clicking **Add Parameter**. For example, you can add an edit box to capture company notes.

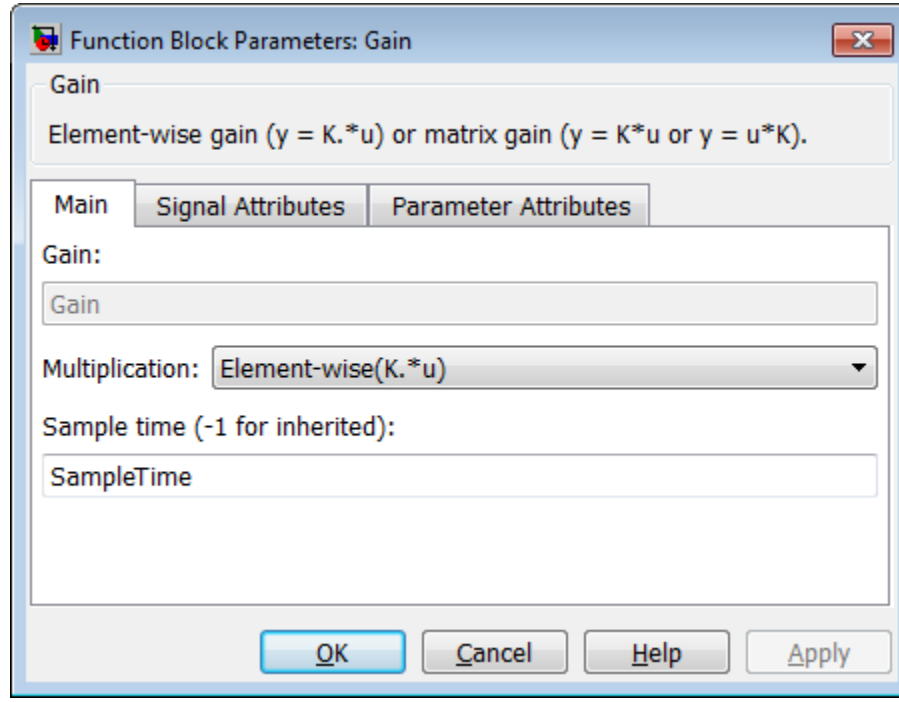


9 Click **OK** to finish creating the mask.

10 Double-click the Gain block. The new mask opens, showing only the promoted Gain parameter and custom parameter.



11 Look under the mask to see the underlying Gain block dialog box. You can see that the Gain parameter is now disabled because you have promoted it to the mask.


Function Block Parameters: Gain
Gain
Element-wise gain (y = K.*u) or matrix gain (y = K*u or y = u*K).
Main
Signal Attributes
Parameter Attributes
Gain:
Gain
Multiplication:
Element-wise(K.*u)
Sample time (-1 for inherited):
SampleTime
OK
Cancel
Help
Apply

Rules for Promoting Parameters

In this section...

General Rules

- You cannot mask blocks that already have masks. For example, some Simulink blocks like the Ramp and Chirp Signal in the Sources library cannot be masked.
- Some parameters with certain attributes cannot be promoted, and if you try, an error message appears.
- After you promote a parameter to the mask, the following rule apply.
  - The parameter is disabled on the block dialog box. If you try to directly edit promoted parameters, either in the dialog or at the command line, an error message appears.
  - You cannot promote the same parameter again to a different mask parameter.
  - The mask parameter inherits the `Evaluate` property from the parameter promoted to it, and you cannot change it. Any mismatch between the `Evaluate` property of the mask parameter and the promoted parameter results in an error message.

Promotion from directly masked block

- The mask parameter must have the same variable name as that of the parameter promoted to it. You cannot change the promoted mask parameter variable names because they are strictly inherited from the underlying built-in block parameter.

- The mask tries to retain the dynamic dialog behavior, if any, of the promoted parameter. You can specify your own dynamic dialog behavior of the mask parameter. If you do, the mask first executes the dynamic dialog callback of the promoted parameter, followed by the user-specified dynamic dialog callback of the mask parameter.
- You cannot promote multiple parameters to a single mask parameter.

Promotion from child blocks within subsystems

- You can associate multiple parameters provided they are of the same type. If the parameter is of type `popup` or `DataType` then the options must also be the same for them to be promoted together. The `Evaluate` property among the parameters to be promoted together must be similar.

Tip View the tooltips on promotable parameters to see key fields such as `Type` and `Evaluate`.

- If a child block is masked, you cannot promote the underlying block dialog parameters.
- For child blocks, you cannot view or promote parameters from inside a masked block.
- For child blocks, you cannot view or promote parameters from inside a linked block.

Links created from masked blocks

- The underneath block dialog opens completely disabled for the links of masked blocks. You can edit values only from the mask dialog.
- If the mask author decides not to promote a parameter, its value in the linked blocks is tied to the library value for that parameter as specified in the library.

Mask Blocks and Promote Parameters

In this section...

Mask Built-In Blocks Directly and Within Subsystems

You can directly mask built-in blocks with the Mask Editor to provide custom icons and dialog boxes. In the Mask Editor, you can choose to *promote* any underlying parameter of any block to the mask. For subsystems, you can choose to promote parameters from any child blocks. For a subsystem block, you can associate a single mask parameter with multiple promoted parameters if they are of the same type. Changing the value of the mask parameter also sets the value of the associated promoted parameters.

You can use masking in the following use cases:

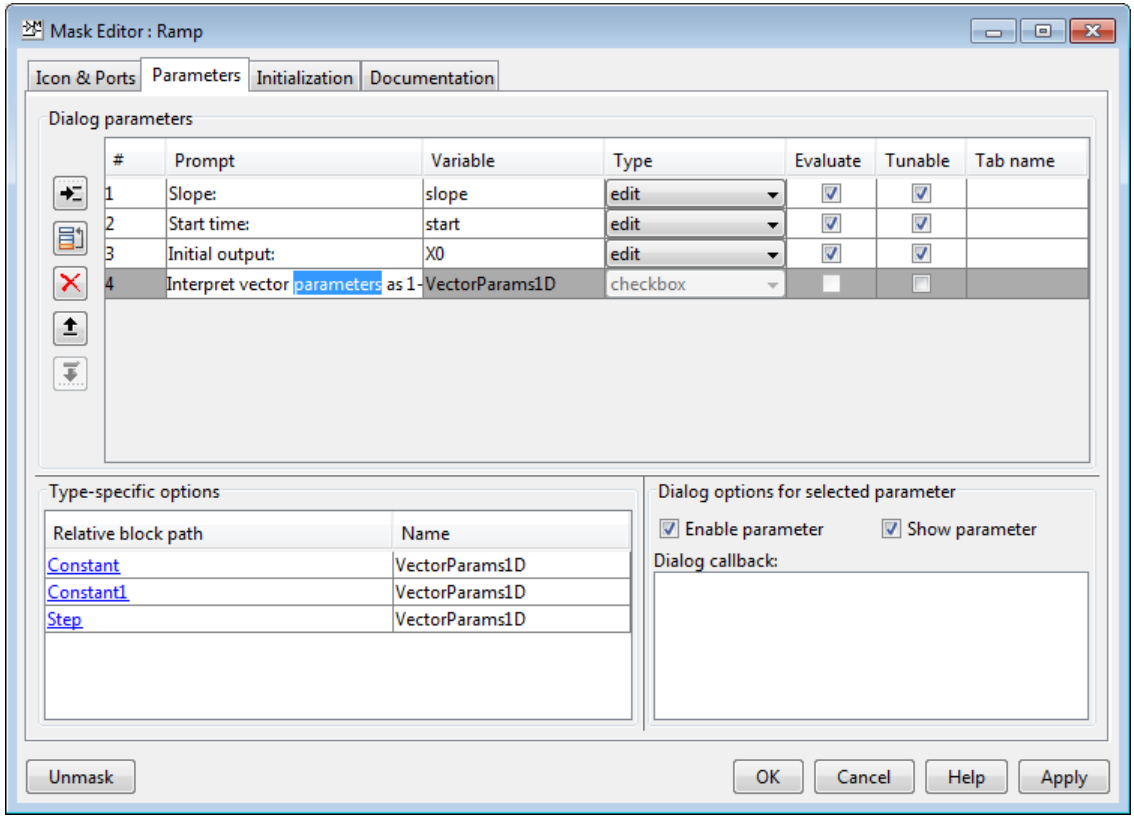
- You can directly mask a built-in block to simplify the interface and add custom parameters.
- You can promote multiple parameters from child blocks to a single mask parameter for a subsystem block.
- You can promote all parameters for a directly masked built-in block, and then choose a subset of the parameters to keep in the mask.

Create Custom Interface for Multiple Parameters in Subsystem

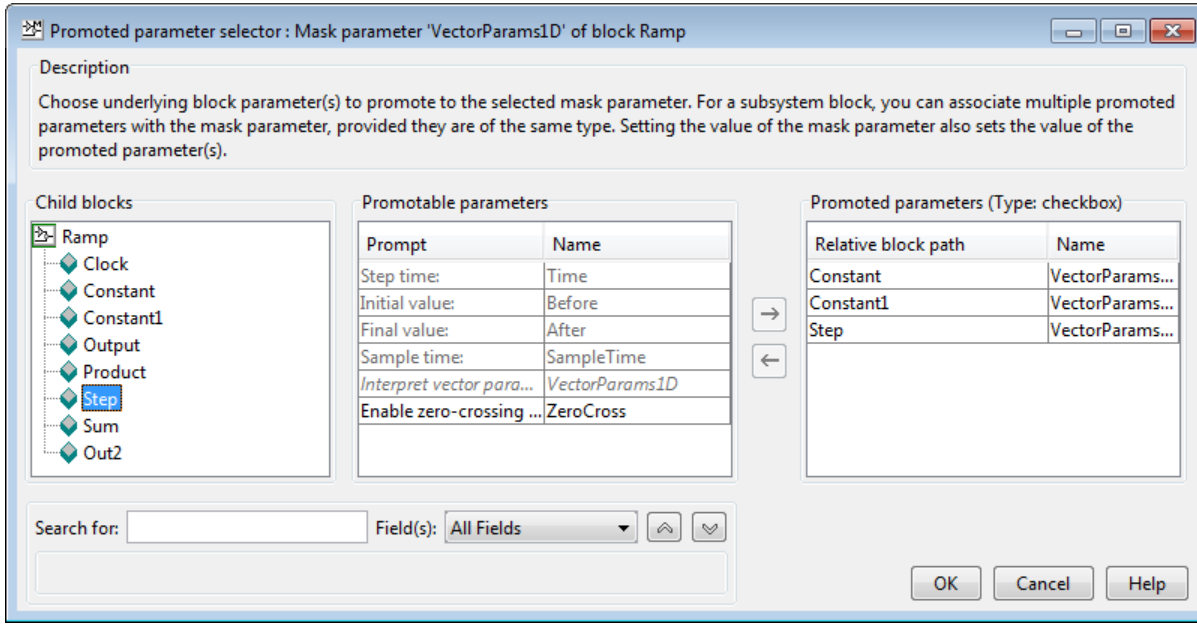
You can promote multiple parameters from child blocks to a single mask parameter for a subsystem block. This enables you to use a simplified single setting in the mask to set multiple child block parameters (of the same type) in the subsystem.

The following example demonstrates this capability. It recreates the functions of the Ramp block by using other blocks in a subsystem, and then masking the subsystem to create a simplified custom interface.

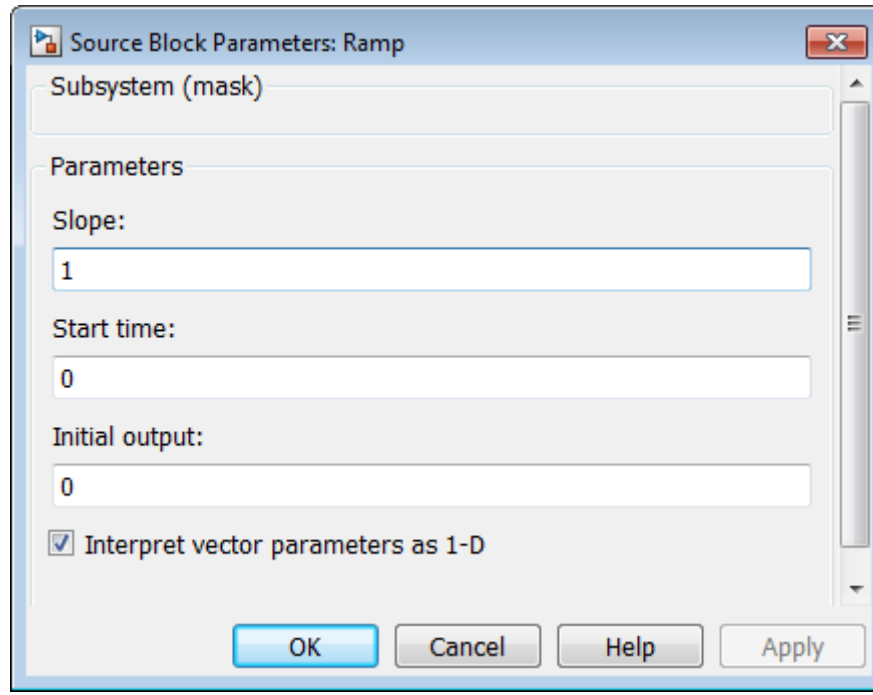
The Mask Editor contains a selection of promoted parameters from underlying blocks within the subsystem. The selected parameter has three underlying parameters of the same type promoted to the same mask parameter.



The Promoted parameter selector dialog shown next demonstrates how to specify this setup. Three parameters of the same type, from different child blocks, are added to the **Promoted parameters** list to promote to the currently selected mask parameter.



The mask shows the four parameters specified in the Mask Editor.



When you select the **Interpret vector parameters as 1-D** check box on the mask, you also set the underlying promoted parameters in the three child blocks.

Operate on Existing Masks

In this section...

Change 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. Select **Mask > Edit Mask**.

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.

View Mask Parameters

To display a masked block's Mask Parameters dialog box, double-click the block. Alternatively, right-click the block and select **Mask > Mask Parameters**.

To display the Block Parameters dialog box that double-clicking would display if no mask existed, right-click the masked block and select **Block Parameters (BlockType)**.

Look Under Block Mask

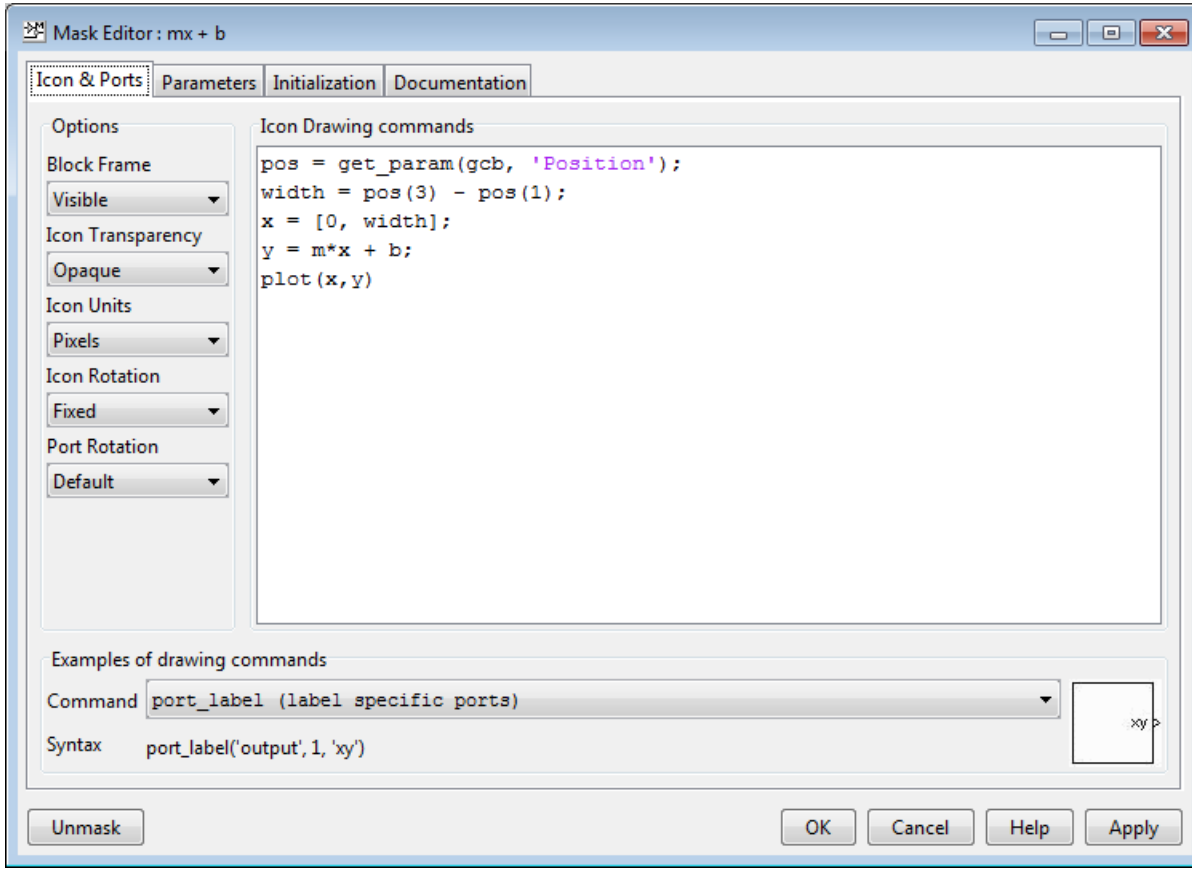
To see the block diagram under a masked Subsystem block, built-in block, or the model referenced by a masked Model block, right-click the block and select **Mask > Look Under Mask**.

Remove and Cache Mask

To remove a mask from a block and cache it for possible restoration later:

1. Right-click the block.
2. Select **Mask > Edit Mask**.

   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 “Restore Cached Mask” on page 26-45, or delete it, as described in “Permanently Delete Mask” on page 26-45. The removed cached mask has no further effect unless you restore it.

Restore Cached Mask

As long as a model remains open, you can restore a mask that you removed as described in “Remove and Cache Mask” on page 26-43.

1. Right-click the block.
2. Select **Mask > Create Mask**.

   The Mask Editor reopens, showing the cached masked definition.
3. Modify the definition if needed, using the techniques in “Mask a Block” on page 26-12
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.

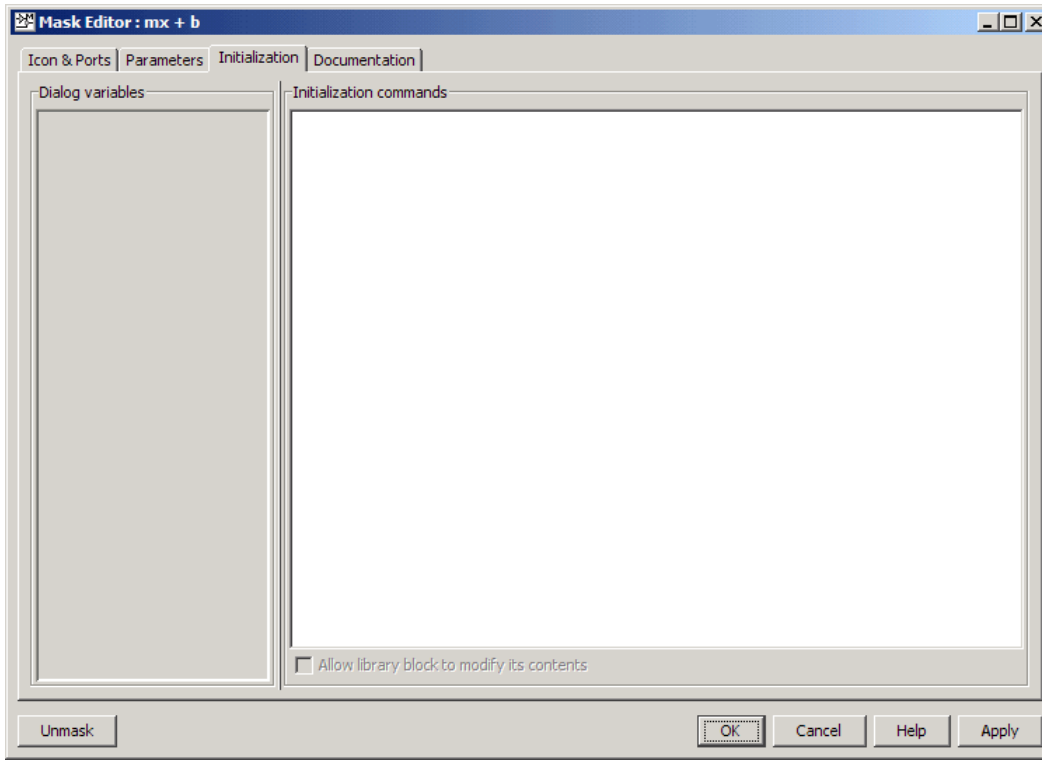
Permanently Delete Mask

To delete a mask permanently, first remove it as described in “Remove and Cache Mask” on page 26-43, 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.

Calculate Values Used Under the Mask

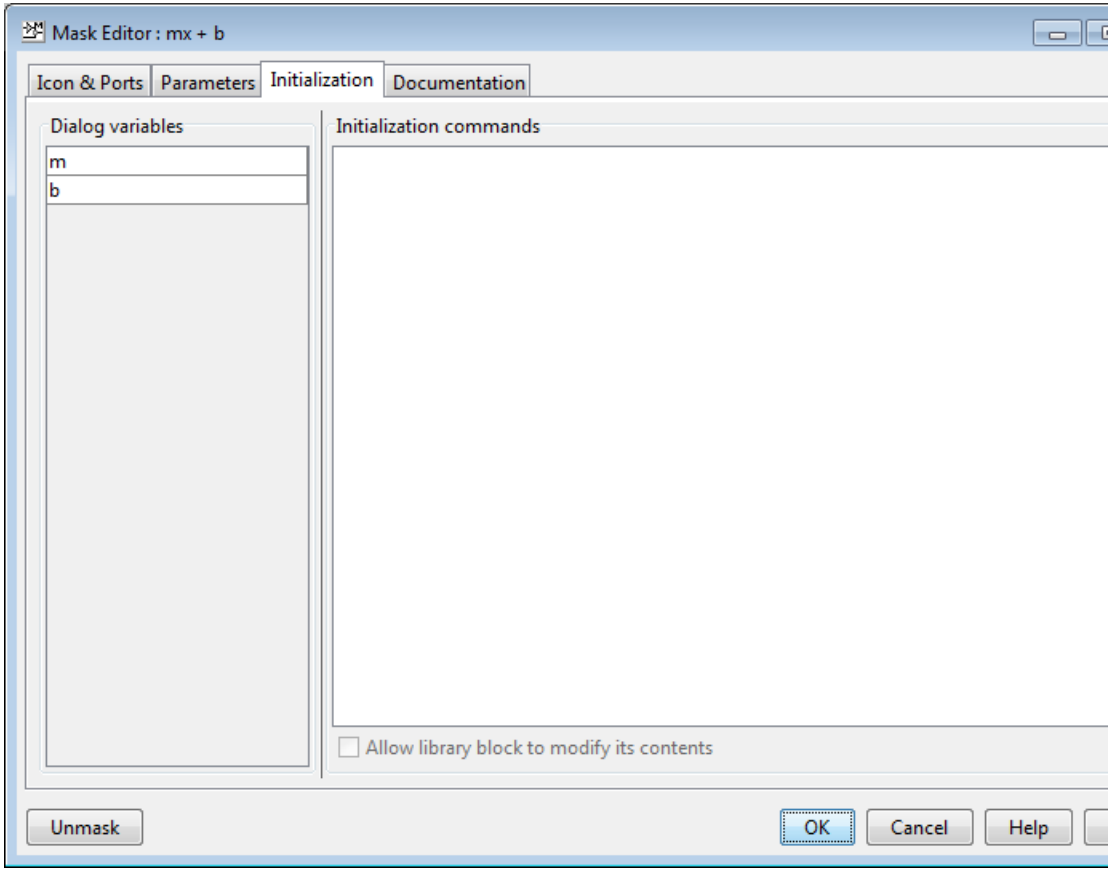
The `masking_example` assigns the values input using the Mask Parameters dialog box directly to block parameters underneath the mask, as described in "How Mask Parameters Work" on page 26-4. The assignment occurs because the block parameter and the mask parameter have the same name, so the search that always occurs when a block parameter needs a value finds the mask parameter value automatically, as described in "Symbol Resolution" on page 4-76.

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.

Tip To use a masked subsystem in a referenced model that uses model arguments, do not create in the mask workspace a variable that derives its value from a mask parameter. Instead, use blocks under the masked subsystem to perform the calculations for the mask workspace variable.

Control Masks Programmatically

In this section...

Use Simulink.Mask and Simulink.MaskParameter

Use instances of Simulink.Mask and Simulink.MaskParameter to perform the following mask operations:

- Create, copy, and delete masks
- Create, edit, and delete mask parameters
- Determine the block that owns the mask
- Get workspace variables defined for a mask

In this example, the variable pmask stores the mask object obtained using Simulink.Mask.get.

```
pmask = Simulink.Mask.get(gcbh);
```

```
pmask =

  Simulink.Mask handle
  Package: Simulink

  Properties:
                    Type: ''
             Description: ''
                    Help: ''
          Initialization: ''
          SelfModifiable: 'off'
                 Display: 'fprintf('myMask')'
               IconFrame: 'on'
```

```
            IconOpaque: 'on'
    RunInitForIconRedraw: 'off'
            IconRotate: 'none'
            PortRotate: 'default'
             IconUnits: 'autoscale'
            Parameters: []
```

In this example, the variable `aparam` stores a mask parameter and is used to set the properties of the mask parameter using `Simulink.MaskParameter.set`.

```
aparam = pmask.Parameters(1);
```

```
aparam =

  Simulink.MaskParameter handle
  Package: Simulink

  Properties:
           Type: 'edit'
    TypeOptions: {0x1 cell}
           Name: 'Myparam'
         Prompt: ''
          Value: '[]'
       Evaluate: 'on'
        Tunable: 'on'
        Enabled: 'on'
        Visible: 'on'
        ToolTip: 'on'
       Callback: ''
          Alias: ''
        TabName: ''
```

```
aparam.set('Name','MyParam');
```

For more examples, see `Simulink.Mask` and `Simulink.MaskParameter`.

Use `get_param` and `set_param`

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 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.

Note You cannot set the `MaskVariables` parameter from the mask initialization code.

Create Dynamic Mask Dialog Boxes

In this section...

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 "Callback Code Execution" on page 26-9). 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 26-57). 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: Right-click the block and select **Mask > Create Mask**.
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** to use the literal value from the pop-up menu options.
4. Enter the following three values in the **Popups (one per line)** field:

```
2
5
User-defined
```

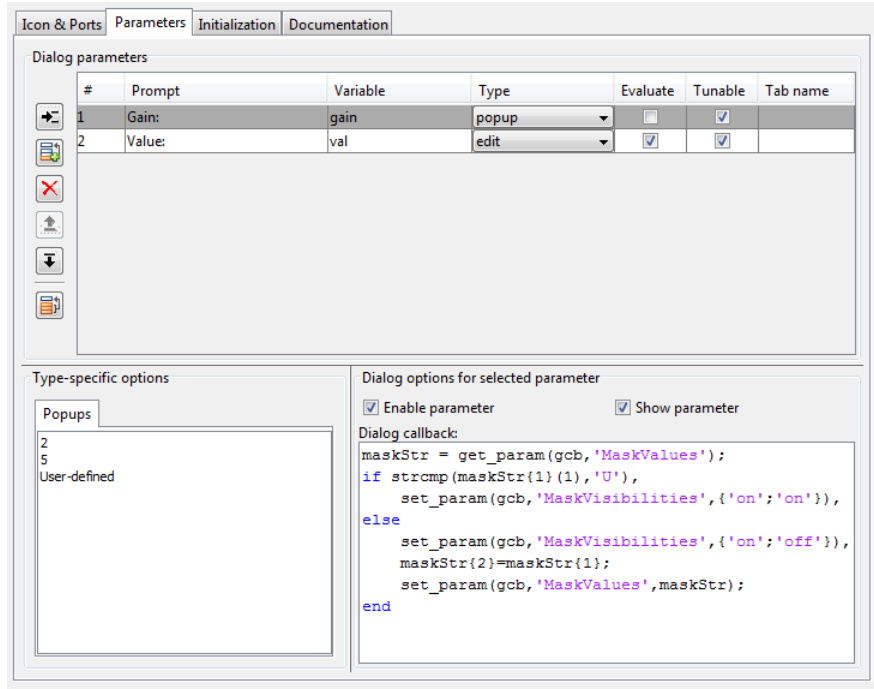
5. Enter the following code in the **Dialog callback** field:

```
% 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 **Dialog options for selected parameter** 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.

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.

Create 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.

Create 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 "Modify and Lock Libraries" on page 28-21).

2 Right-click the block in the library.

3 Select **Mask > Edit Mask**. 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 Code Placement" on page 26-7). 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')
```

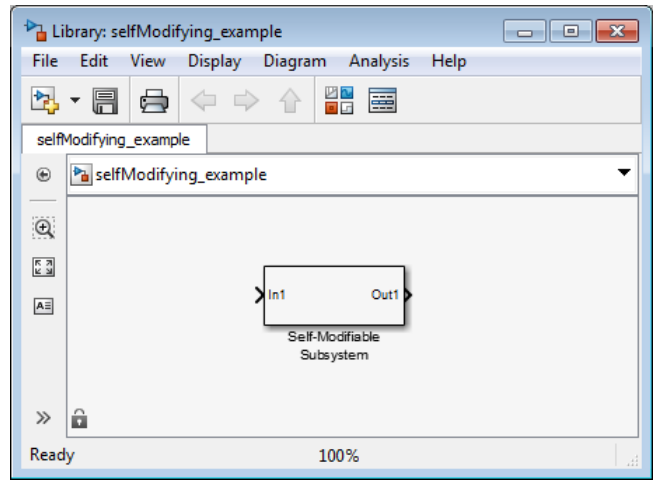
2 Specify that the block is self-modifying by using the following command:

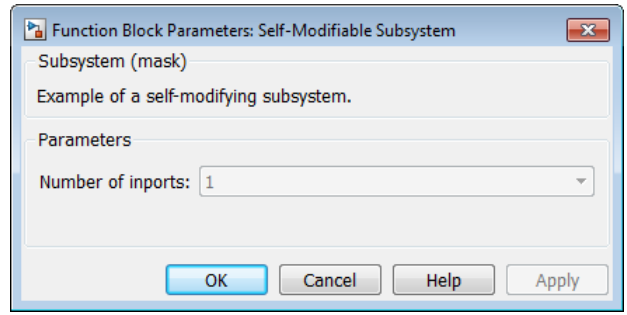
```
set_param(block_name,'MaskSelfModifiable','on')
```

where `block_name` is the full path to the block in the library.

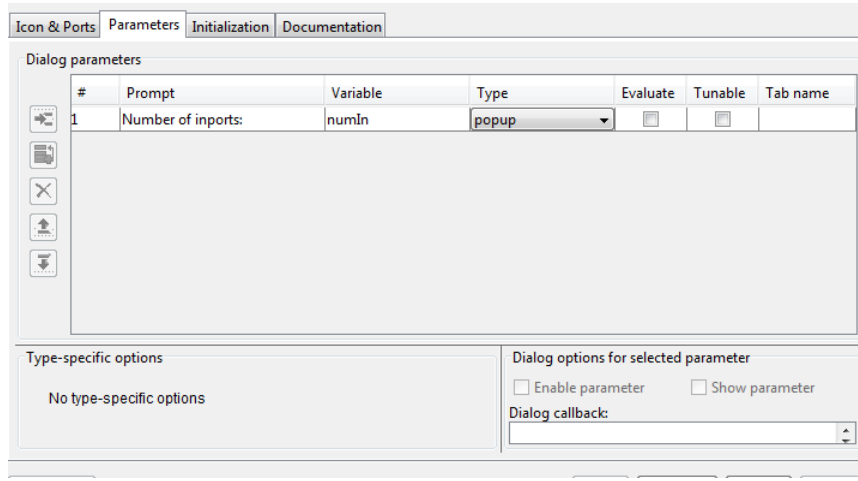
Self-Modifying Mask Example

The library `selfModifying_example` contains a masked subsystem that modifies its number of input ports based on a selection made in the subsystem's Mask Parameters dialog box.

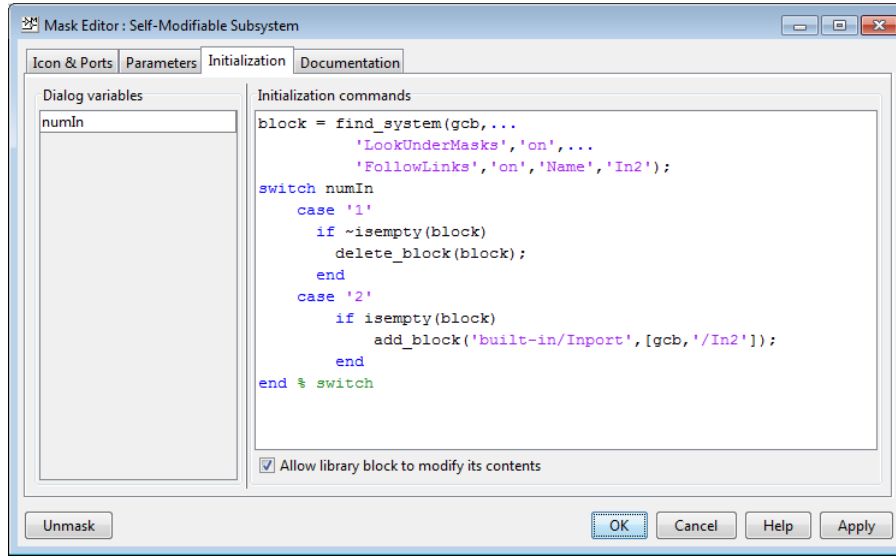




Right-click the subsystem then select **Mask > Edit Mask**. The Mask Editor opens. The Mask Editor **Parameters** pane defines one mask parameter variable `numIn` that stores the value for the **Number of inports** option. This Mask Parameters dialog box callback adds or removes Input ports inside the 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.



Evaluate Blocks Under Self-Modifying Mask

This example shows how to force Simulink to evaluate blocks inside self-modifying masks.

Simulink evaluates elements of models containing masks in the following order:

1. **Mask Parameters** dialog box
2. Mask initialization code
3. Blocks or masked subsystems under the mask

Consider the following case:

A block named `myBlock` inside subsystem `mySubsys` masked by a self-modifying mask depends on mask parameter `myParam` to update itself.

`myParam` is exposed to the user through the **Mask Parameters** dialog box. `mySubsys` is updated through MATLAB code written in the **Mask Initialization** pane.

In this model, the sequence of updates is as follows:

1. A user makes modifies `myParam` through the **Mask Parameters** dialog box.
2. The mask initialization code receives this change and modifies `mySubsys` under the mask.
3. `myBlock`, which lies under `mySubsys`, modifies itself based on the change to `myParam`.

In this sequence, `myBlock`, which lies under `mySubsys`, will not be evaluated when the mask initialization code executes. Instead, only the masked subsystem `mySubsys` is evaluated at that time and gets updated. Meanwhile, `myBlock`, which needs to change, remains unmodified.

You can force Simulink to evaluate such blocks earlier by using the `Simulink.Mask.eval` method in the masked subsystem's initialization code:

```
Simulink.Block.eval(mySubsys/myBlock);
```

How Do I Debug Masks That Use MATLAB Code?

In this section...

Code Written in Mask Editor

Debug initialization commands and parameter callbacks entered directly into the Mask Editor in one of the following ways:

- Remove the terminating semicolon from a command to echo its results to the MATLAB Command Window.
- Place a `keyboard` command in the code to stop execution and give control to the keyboard.

Code Written Using MATLAB Editor/Debugger

Note You cannot debug icon drawing commands using the MATLAB Editor/Debugger. Use the syntax examples provided in the Mask Editor's **Icons & Ports** pane to help solve errors in the icon drawing commands.

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. However, when debugging parameter callbacks, you can only access the base workspace of the block. If you need the value of a mask parameter, use `get_param`.

27

Creating Custom Blocks

When to Create Custom Blocks

Custom blocks expand the modeling functionality provided with the Simulink product. Use a custom block to:

- Model behaviors that are not provided with a Simulink built-in solution.
- Build more advanced models.
- Encapsulate model components into a library block that you can copy into multiple models.
- Provide custom graphical user interfaces or analysis routines.

Types of Custom Blocks

In this section...

MATLAB Function Blocks

A MATLAB Function block allows you to use the MATLAB language to define custom functionality. These blocks are 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 using a MATLAB function than using a Simulink 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 Interpreted MATLAB Function block allows you to use a MATLAB function to define a SISO block.
- The MATLAB Function block allows you to define a custom block with multiple inputs and outputs that you can deploy to an embedded processor.

Each of these blocks has advantages in particular modeling applications. For example, you can generate code from models containing MATLAB Function blocks while you cannot generate code for models containing an 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 using a graphical representation rather than using hand-written code.
- The custom functionality is a function of continuous or discrete system states.
- You can model the custom functionality using existing Simulink blocks.

Once you have a Simulink subsystem that models the required behavior, you can convert it into a custom block by:

1. Masking the block to hide the block 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.

For more information, see “Libraries” and “Masking”.

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.
- You cannot model the custom functionality 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 using the MATLAB language. (See“Write Level-2 MATLAB S-Functions”). 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 using a C MEX wrapper. (See “C/C++ S-Functions”.)
- 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 “C/C++ S-Functions”.)
- The Legacy Code Tool transforms existing C or C++ functions into C MEX S-functions. (See “Integrate C Functions Using Legacy Code Tool”.)

The S-function target in the Simulink Coder 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 “Generated S-Function Block” in the Simulink Coder User’s Guide for details and limitations on using the S-function target.

Comparing MATLAB S-Functions to MATLAB Functions for Code Generation

MATLAB S-functions and MATLAB functions for code generation have some fundamental differences.

- The Simulink Coder product can generate code for both MATLAB S-functions and MATLAB functions for code generation. However, MATLAB S-functions require a Target Language Compiler (TLC) file for code generation. MATLAB functions for code generation do not require a TLC-file.
- MATLAB S-functions can use any MATLAB function while MATLAB functions for code generation are a subset of the MATLAB language. For a list of supported functions for code generation, see “Functions Supported for Code Generation — Alphabetical List” on page 31-2.
- MATLAB S-functions can model discrete and continuous state dynamics while MATLAB functions for code generation 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 "Integrate C Functions Using Legacy Code Tool" for more information.

See "Integration Options" in the Simulink Coder User's Guide for more information.

See "S-Functions Incorporate Legacy C Code" in the Simulink Developing 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 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
Interpreted MATLAB Function	No. Must have a single vector input and output.	No.	Supports only n-D, real, or complex signals with a data type of double.
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	Proportional to the complexity of the subsystem. Library	Natively supported.

Speed and Code Generation Requirements (Continued)

Custom Block Type	Speed of Updating the Diagram	Simulation Overhead	Code Generation Support
	time the library is loaded.	blocks introduce no additional overhead.	
Fcn	Very fast.	Minimal, but these blocks also provide limited functionality.	Natively supported.
Interpreted MATLAB Function	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.
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 27-16 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 Interpreted MATLAB Function 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	Minimal, but proportional to the complexity of the	Might require a TLC-file.

Speed and Code Generation Requirements (Continued)

Custom Block Type	Speed of Updating the Diagram	Simulation Overhead	Code Generation Support
	when updating the diagram.	algorithm and the efficiency of the code.	

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 28-7 for more information.
Fcn, Interpreted MATLAB Function	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.
MATLAB Function	Supports multiple input and output ports, including bus signals. See "How Structure Inputs and Outputs Interface with Bus Signals" on page 29-81 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 "Integrate C Functions Using 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, Interpreted MATLAB Function, MATLAB Function	All create an `mdlOutputs` 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.
Interpreted MATLAB Function	Supports 2-D, n-D, and complex signals, but the signal must have a data type of double. Does not support frame-based signals.
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, Interpreted MATLAB Function	Does not incur greater update cost than other Simulink blocks.
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, Simulink 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 "Simulink Engine Interaction 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 "Capture Performance Data" on page 22-31 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.
Interpreted MATLAB Function	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 an Interpreted MATLAB Function 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 MATLAB is able to optimize it, or if the code uses the highly optimized MATLAB library functions.

Custom Block Type	Simulation Overhead
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, a function for this block and a MATLAB function run at about the same speed. To further reduce the algorithm cost, you can disable debugging for all the MATLAB Function blocks in your model. If the MATLAB Function block uses simulation-only capabilities to call out to the MATLAB interpreter, it incurs all the costs that a MATLAB S-function or Interpreted MATLAB Function block incur. Calling out to the MATLAB interpreter from a MATLAB Function block produces a warning to prevent you from doing so unintentionally.
MATLAB S-function	Incurs the same algorithm costs as the Interpreted MATLAB Function 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 Interpreted MATLAB Function block. In addition, the Simulink engine calls the MATLAB interpreter for each block method you implement whereas for the Interpreted MATLAB Function block, it calls the MATLAB interpreter only for the `mdlOutputs` 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 with Simulink Coder.

Custom Block Type	Code Generation Support
Subsystem	Supports code generation.
Fcn	Supports code generation.
Interpreted MATLAB Function	Does not support code generation.
MATLAB Function	Supports code generation. However, if your MATLAB Function block calls out to the MATLAB interpreter, it will build with the Simulink Coder product only if the calls to the MATLAB interpreter do not affect the block outputs. Under this condition, the Simulink Coder 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 Simulink Coder product automatically omits the block during code generation.
C MEX S-function	Supports code generation. For noninlined S-functions, the Simulink Coder 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 “Insert S-Function Code” in the Simulink Coder 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 “Create Block Callback Functions” on page 4-58.

GUIDE, the MATLAB graphical user interface development environment, provides tools for easily creating custom user interfaces. See “GUI Building” for more information on using GUIDE.

Create a Custom Block

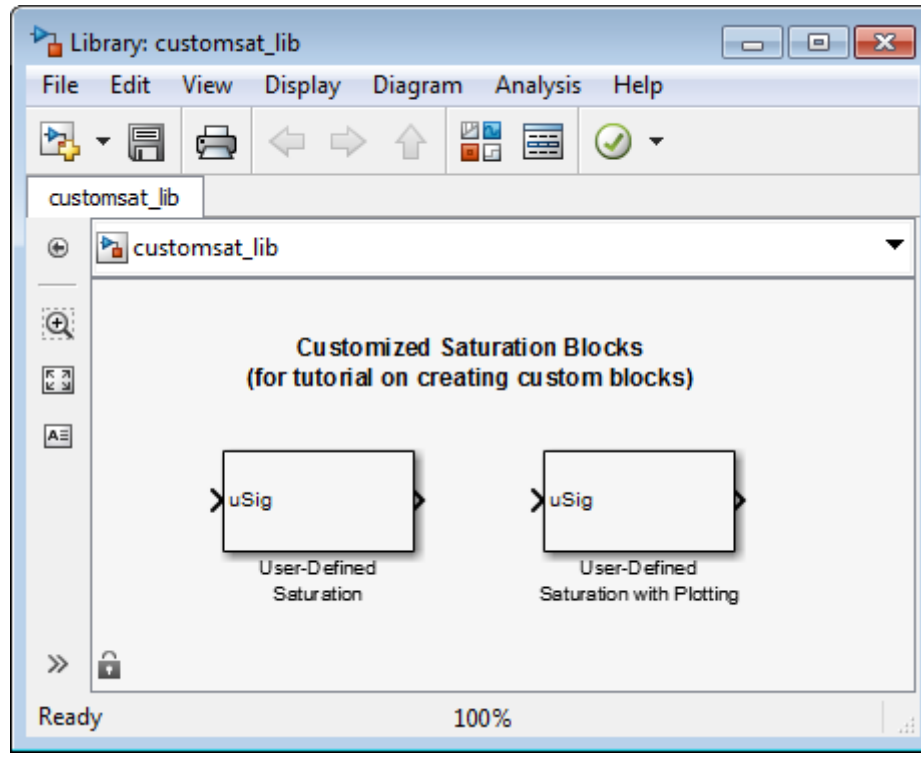
In this section...

How to Design a Custom Block

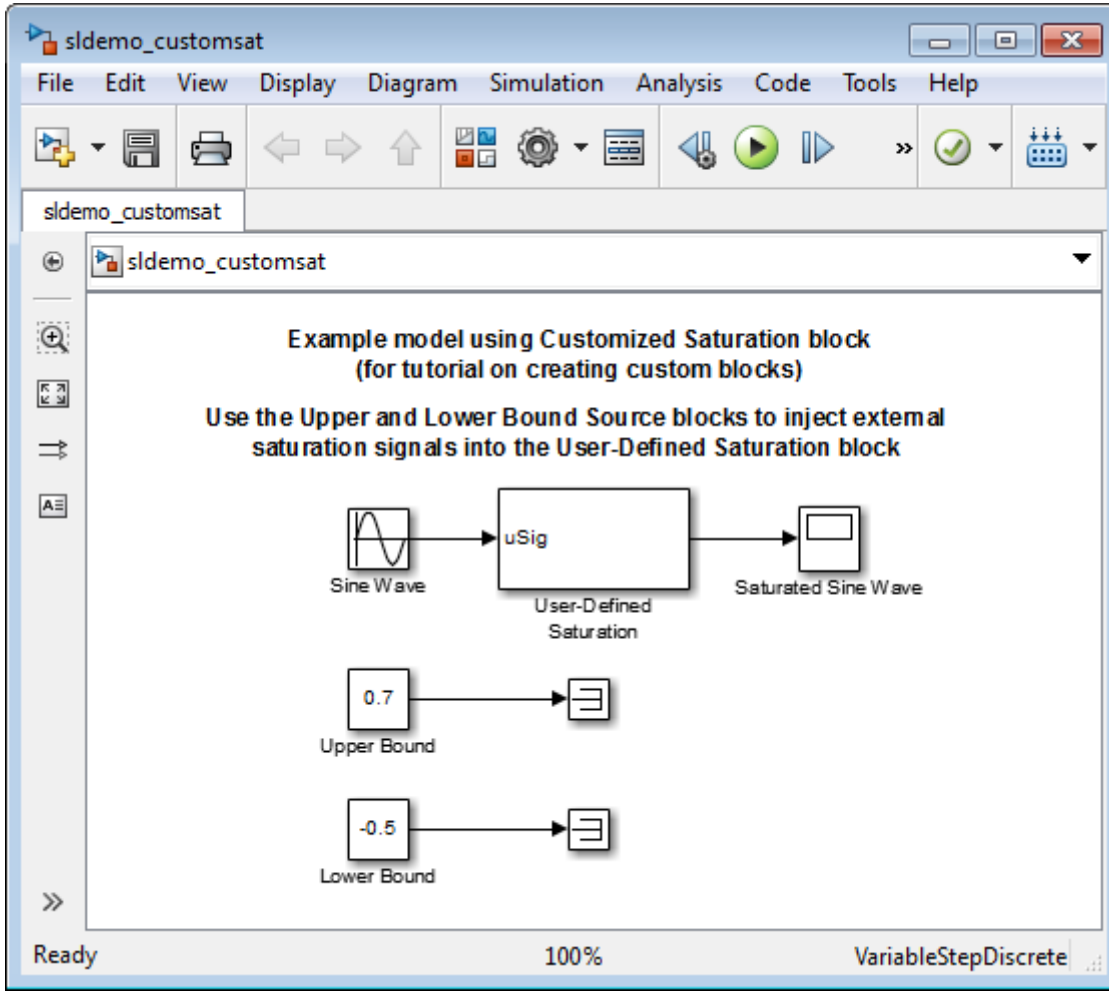
In general, use the following process to design a custom block:

1. "Defining Custom Block Behavior" on page 27-20
2. "Deciding on a Custom Block Type" on page 27-21
3. "Placing Custom Blocks in a Library" on page 27-27
4. "Adding a Graphical User Interface to a Custom Block" on page 27-28

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` contains the two versions of the customized saturation block.



The example model `sldemo_customsat` 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 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 27-7 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 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

After you define the S-function parameters and functionality, 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;
```

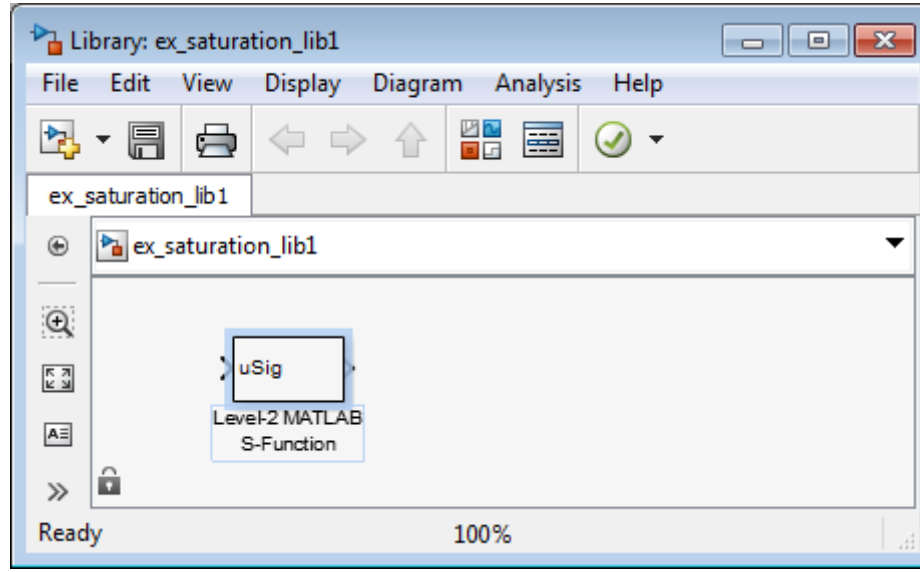
```
%end Outputs function
```

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:

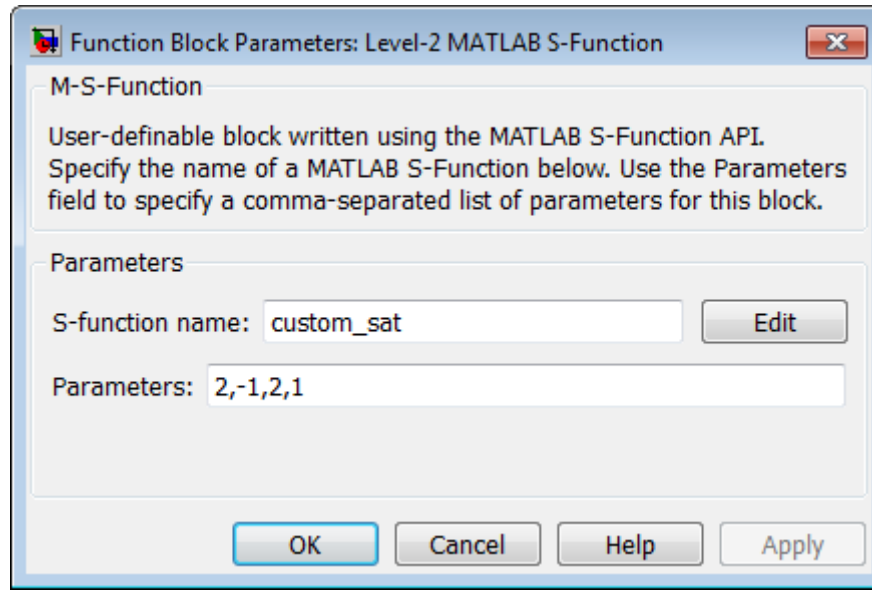
1. In the Simulink Library Browser window, select **File > New > Library**. A new library window opens.

2. From the User-Defined Functions library, drag a new Level-2 MATLAB S-Function block into your new library. Save your library with the filename `saturation_lib`.



3. Double-click the block to open its Function Block Parameters dialog box.

4. In the **S-function name** box, enter the name of the S-function. For example, enter `custom_sat`. In the **Parameters** box enter the following default values `2,-1,2,1`.



5 Click **OK**. The parameters changes you entered are saved and the dialog box closes.

At this point, you have created a custom saturation block that you can share 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 ports corresponds to the input signal and the saturation limits.

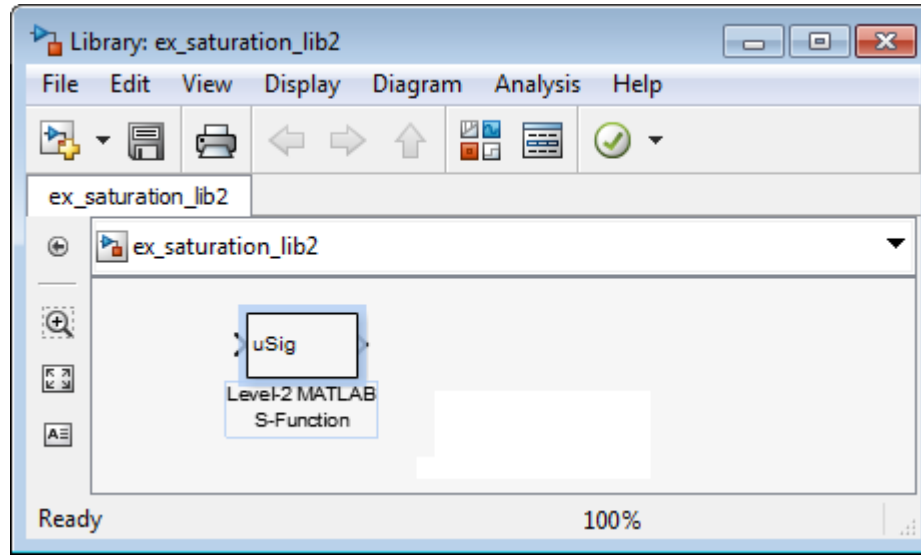
To mask the block:

1 Open the custom library you created, `saturation_lib`. Right-click the custom saturation block, and from the context menu, select **Diagram > Mask→Create Mask** . 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. For each new parameter, click the Add parameter button, and set up each of the parameter 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'`

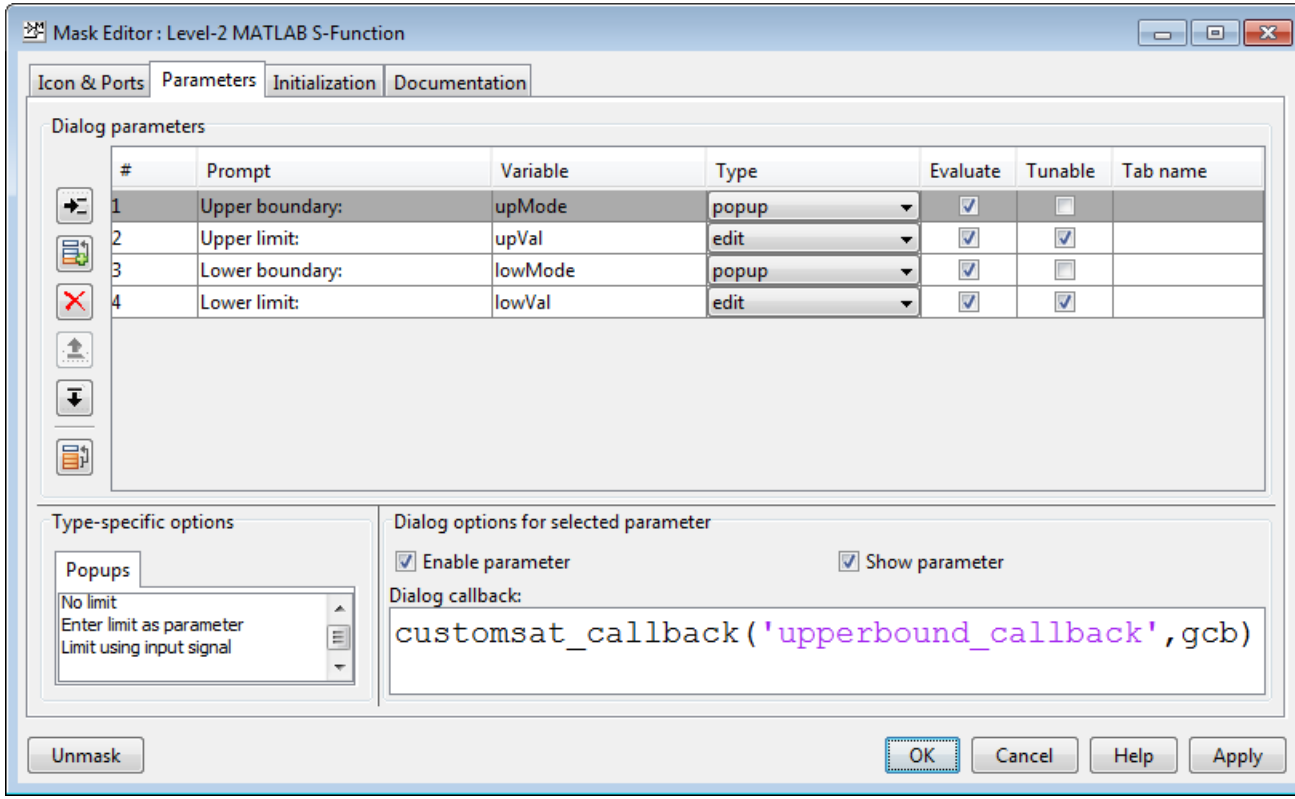
Prompt	Variable	Type	Tunable	Popups	Action for Dialog Callback
Lower boundary:	`lowMode`	`popup`	No	No limit | Enter limit as parameter | Limit using input signal	`'lowerbound_callback'`
Lower limit:	`lowVal`	`edit`	Yes	N/A	`'lowerparam_callback'`

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 the check box **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.
```

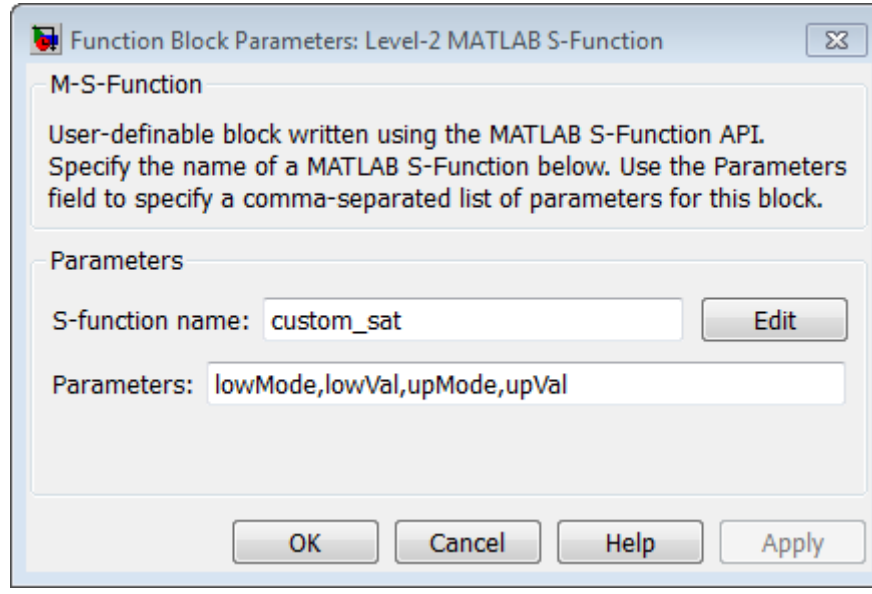
6 On the Mask Editor dialog box, click **OK** to complete the mask parameters dialog.

7 To map the S-function parameters to the mask parameters, right-click the Level-2 MATLAB S-Function block and select **Mask > Look Under Mask**. The Function Block Parameters dialog box opens.

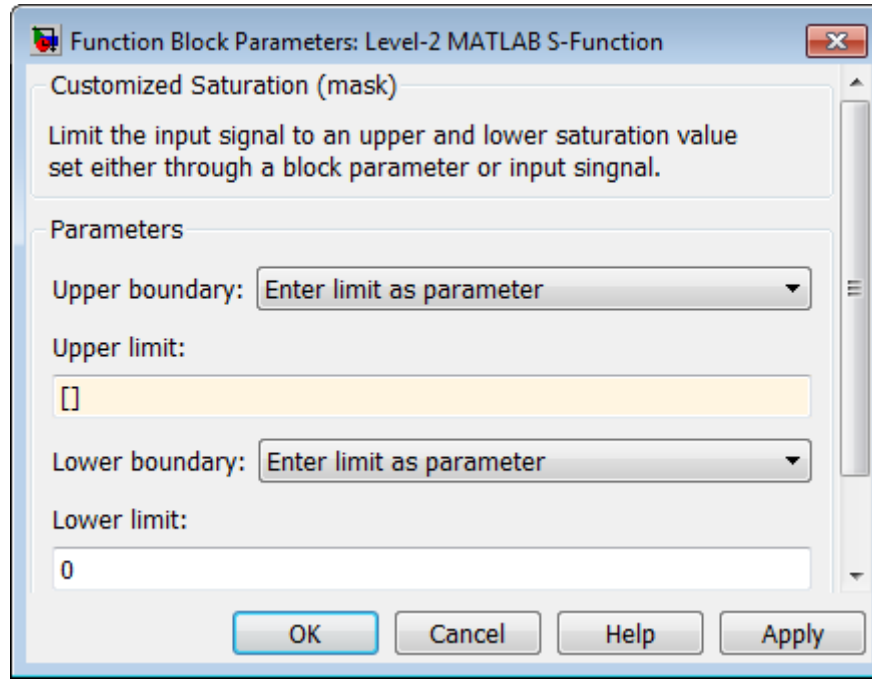
8 Change the entry in the **Parameters** field as follows.

```
lowMode,lowVal,upMode,upVal
```

The following figure shows the new Block Parameters dialog.



9 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 mask parameter dialog box. This function invokes local functions corresponding to each mask parameter through a call to `feval`.

The following local function 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` local function 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
```

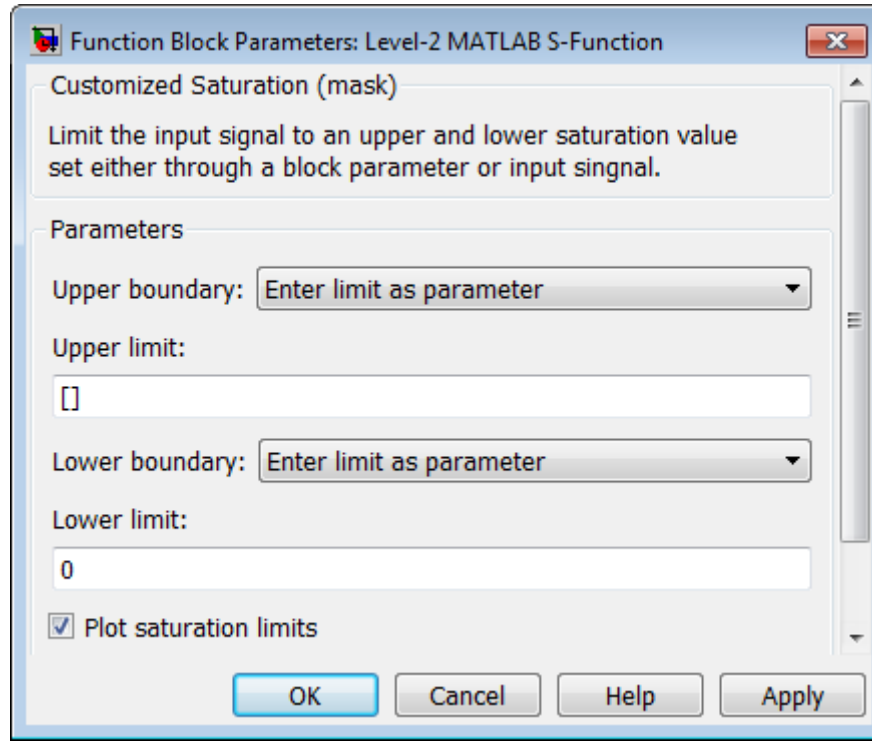
Adding Block Functionality Using Block Callbacks

The User-Defined Saturation with Plotting block in `customsat_lib` 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.
   a. Right-click the Level-2 MATLAB S-Function block in `saturation_lib` and select **Edit Mask**.
   b. On the Mask Editor **Parameters** pane, add a fifth mask parameter with the following properties.

Prompt	Variable	Type	Tunable	Popups	Action for Dialog Callback
Plot saturation limits	`plotcheck`	`checkbox`	No	NA	`customsat_callback('plotsaturation`

c 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 `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 local functions over the previous local functions 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;
```

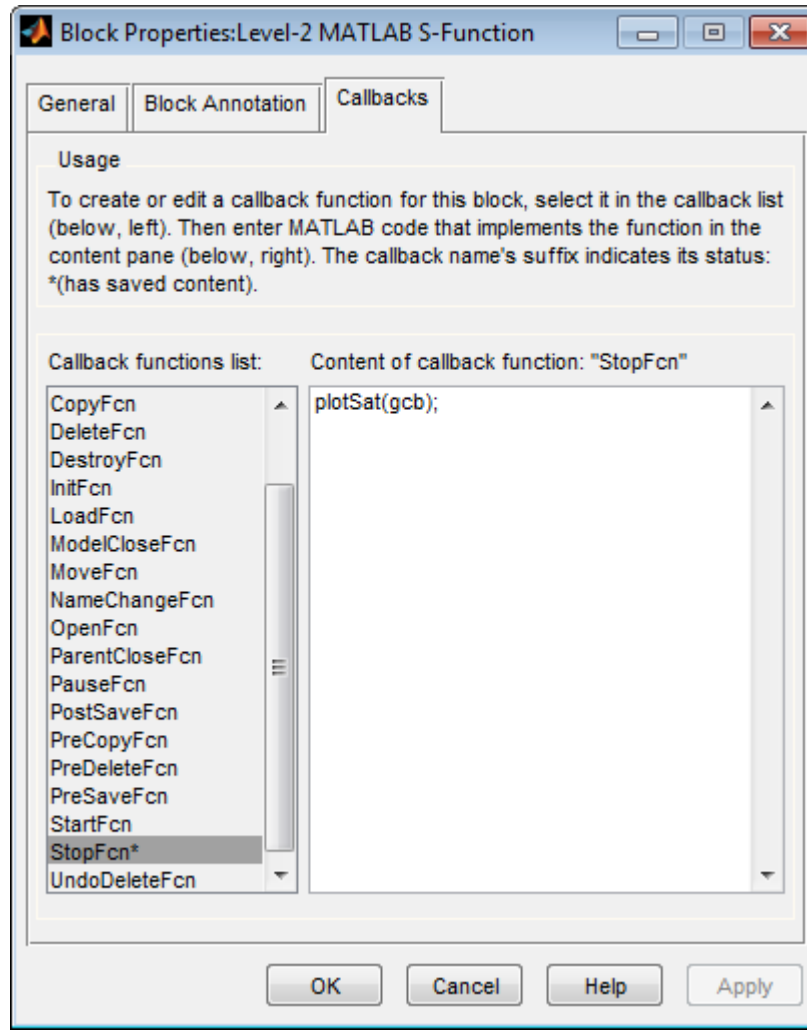
```
end

% 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 **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"
CopyFcn
DeleteFcn
DestroyFcn
InitFcn
LoadFcn
ModelCloseFcn
MoveFcn
NameChangeFcn
OpenFcn
ParentCloseFcn
PauseFcn
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 "Libraries" for more general information on Simulink libraries.

Creating Custom Blocks from MATLAB Functions

The Simulink product provides a number of examples that show how to incorporate MATLAB functions into a custom block.

- The Single Hydraulic Cylinder Simulation, `sldemo_hydcyl`, 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`.
- The Radar Tracking Model, `sldemo_radar`, uses an Interpreted MATLAB Function 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 example, `sldemo_eml_galaxy`, uses several MATLAB Function blocks to construct two galaxies and calculate the effects of gravity as these two galaxies nearly collide. The example also uses MATLAB Function blocks to plot the simulation results using a subset of MATLAB functions not supported for code generation. However, because these MATLAB Function blocks have no outputs, the Simulink Coder product optimizes them away during code generation.

Creating Custom Blocks from S-Functions

The Simulink model `sfundemos` contains various examples of MATLAB and C MEX S-functions. For more information on writing MATLAB S-functions, see "Write Level-2 MATLAB S-Functions". For more information on writing C MEX S-functions, see "C/C++ S-Functions". For a list of available S-function examples, see "S-Function Examples" in Writing S-Functions.

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Working with Block Libraries

About Block Libraries and Linked Blocks

Block Libraries

A *block library* is a collection of blocks that serve as prototypes for instances of blocks in a Simulink model.

Simulink comes with two built-in block libraries: the Simulink block library and the Simulink Coder block library. The latter is included with Simulink to support sharing models that contain Simulink Coder blocks. Many additional MathWorks products and associated block libraries are available. You cannot change a built-in block library in any way.

Benefits of Block Libraries

Block libraries are a useful componentization technique for:

- Providing frequently-used, and seldom changed, modeling utilities
- Reusing components repeatedly in a model or in multiple models

For additional information about how libraries compare to other Simulink componentization techniques, see “Componentization Guidelines” on page 12-17.

Library Browser

Simulink provides a Library Browser that you can use to display block libraries, search for blocks by name, and copy library blocks into models. All installed libraries appear in the Library Browser when you open it. See “Populate a Model” on page 4-4 for information about how to use the Simulink Library Browser.

Linked Blocks

When you copy a block from a library into a model, Simulink creates a *linked block* in the model, and connects it to the library block using a *library link*. The library block is the *prototype block*, and the linked block in the model is an *instance* of the library block. The linked block appearance and behavior

are the same as the library block. For most purposes, you can ignore the underlying link and just think of a linked block as a clone of the library block.

Copying a block from a library to another library or model does not always create a linked block. Library blocks that support linking include subsystems, masked blocks, and charts. However, the block author can choose not to make the copy a linked block by modifying the `CopyFcn`, as done by the Simulink Subsystem block.

Create and Work with Linked Blocks

In this section...

About Linked Blocks

A *linked block* is an instance of a library block and contains a link to that 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 linked block to update whenever the corresponding prototype in the library changes ("Update a Linked Block" on page 28-5). This ensures that your model always uses the latest version of the block.

Note The data tip for a linked block shows the name of the library block it references (see "Block Tool Tips" on page 23-2).

You can change the values of a linked block's parameters (including in an existing mask). You cannot add a new mask for linked blocks or edit the mask setup, that is, add or remove mask parameters or change mask behavior.

Also, you cannot set callback parameters for a linked block. If the linked block's prototype is a subsystem, you can make nonstructural changes to the contents of the linked subsystem (see "Modify Linked Blocks" on page 28-6).

Create a Linked Block

To create a linked block in a model or another library:

1. Open your model.
2. Open the Simulink Library Browser (see "Copy Blocks to Your Model" on page 4-4), or another library.
3. Use the Library Browser to find the library block that serves as a prototype of the block you want to create (see "Browse Block Libraries" on page 4-4 and "Search Block Libraries" on page 4-5).
4. Drag the library block from the Library Browser's **Library** pane and drop it into your model.

Update a Linked Block

Simulink updates out-of-date linked blocks in a model or library when you:

- Load the model or library.
- Run the simulation.
- Use the `find_system` command.
- Query the `LinkStatus` parameter of a block, using the `get_param` command (see "Check and Set Link Status Programmatically" on page 28-16).

Note Querying the `StaticLinkStatus` parameter of a block does not update any out-of-date linked blocks.

- Save changes to a library block, then Simulink automatically refreshes all links to the block in open Model Editor windows.

When you edit a library block (in the Model Editor or at the command line), then Simulink indicates stale links which are open in the Model Editor by displaying the linked blocks grayed out. Simulink refreshes any stale links to edited blocks when you activate the Model Editor window, even if you have not saved the library yet.

To manually refresh links:

- Select **Simulation > Update Diagram** (or press **Ctrl+D**).

- Select **Diagram > Refresh Blocks** (or press **Ctrl+K**) to refresh links.
- Select **Go To Library Link**.

Modify Linked Blocks

You cannot make structural changes to linked 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 linked block's link to its library prototype (see "Disable Links to Library Blocks" on page 28-11).

Parameterized Links

If you change parameter values inside a linked block, you create a *parameterized link*. You can change the values of any masked subsystem linked 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 linked subsystem block whose parameter values of inner blocks differ from their corresponding library blocks is called a *parameterized link*. Changing the top-level mask values does not create 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 file. When you reopen the system, Simulink copies the library block into the loaded model and applies the saved changes.

Tip To determine whether a linked block's parameter values differ from those of its library prototype, open the linked block's block diagram in an editor window. The linked block's library link indicator (if displayed) changes to a red arrow and the title bar of the editor window displaying the subsystem displays "Parameterized Link" if the linked block's parameter values differ from the library block's parameter values.

See "Display Library Links" on page 28-8.

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.

Find a Linked Block's Prototype

To find the source library and the prototype of a linked block, right-click the linked block and select **Library Link > Go To Library Link**.

Alternatively, select the linked block and select **Diagram > Library Link > Go To Library Link**.

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 first opens it and then selects the library block.

Find Linked Blocks in a Model

Use the `libinfo` command to get information about the linked blocks in the model and which library blocks they link to. The `ReferenceBlock` property gives the path of the library block to which a block links.

Work with Library Links

In this section...

Display 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, select **Display > Library Links** and from the submenu, select one of these options:
   a. **None** — displays no links
   b. **Disabled** — displays only disabled links (the default for new models)
   c. **User Defined** — displays only links to user libraries
   d. **All** — displays all links
2. Observe the library link indicators.

   The library link indicator is a badge in the bottom left corner of each block. You can right-click the link badge to access link menu options.

The color and icon of the link badge indicates the status of the link. If you open a linked block, the Model Editor displays the same link badge at bottom left. You can right-click the link badge in the corner of the canvas to access link options such as **Go To Library Block**.

Link Badge	Status
Black links 	Active link
Grey separated links 	Inactive link
Black links with a red star icon 	Active and modified (parameterized link)
White links, black background 	Locked link

Lock Links to Blocks in a Library

You can lock links to a library. Lockable library links enable control of end user editing, to prevent unintentional disabling of these links. This ensures robust usage of mature stable libraries.

To lock links to a library, either:

- In your library window, select **Diagram > Lock Links To Library**.
- At the command line, use the `LockLinksToLibrary` property:

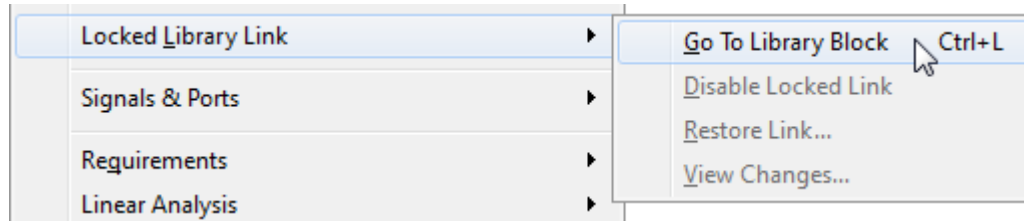
```
set_param('MyModelName', 'LockLinksToLibrary', 'on')
```

where `MyModelName` is the library file.

When you copy a block to a model from a library with locked links:

- The link is locked.
- You cannot disable locked links from the Model Editor.

  If you select **Diagram** or right-click the linked block, you see the **Library Link** menu has changed to **Locked Library Link**, and the only enabled option is now **Go To Library Block**.



- If you display library links, the locked link icon has a black background.

- If you open a locked link, the window title is **Locked Link: *`blockname`***. The bottom left corner shows a lock icon and a link badge.

- You cannot edit locked link contents. If you try to make a structural change to a locked link (such as editing the diagram), you see a message stating that you cannot modify the link because it is either locked or inside another locked link.

  - The mask and block parameter dialogs are disabled for blocks inside locked links. For a resolved linked block with a mask, its parameter dialog is always disabled.
  - You cannot parameterize locked links in the Model Editor.
- You can disable locked links only from the command line as follows:

```
set_param(gcb, 'LinkStatus', 'inactive')
```

To unlock links to a library:

- In your library window, select **Diagram > Unlock Links To Library**
- At the command line:

```
set_param('MyModelName', 'LockLinksToLibrary', 'off')
```

  The status of a link (locked or not) is determined by the library state when you copy the block. If you copy a block from a library with locked links, the link is locked. If you later unlock the library links, any existing linked blocks do not change to unlocked links until you refresh links.

If you use sublibraries as an organizational tool, when you lock links to a library, you might want also to lock links to any sublibraries.

Disable Links to Library Blocks

To make a structural change to a linked block, you need to disable the link between the block and the library block that serves as its prototype.

You cannot disable *locked* links from the Model Editor. See “Lock Links to Blocks in a Library” on page 28-9.

Note When you use the Model Editor to make a structural change (such as editing the diagram) to a block with an active library link, Simulink offers to disable the library link for you (unless the link is locked). 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 of change is undefined.

To disable a link:

1. In the Model Editor window, right-click a linked block and select **Library Link > Disable Link**.
2. Alternatively, select a linked block and select the menu item **Diagram > Library Link > Disable Link**.

   The library link is disabled and the library link indicator changes to gray. 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.

To disable a link from the command-line, set the `LinkStatus` property to `inactive` as follows:

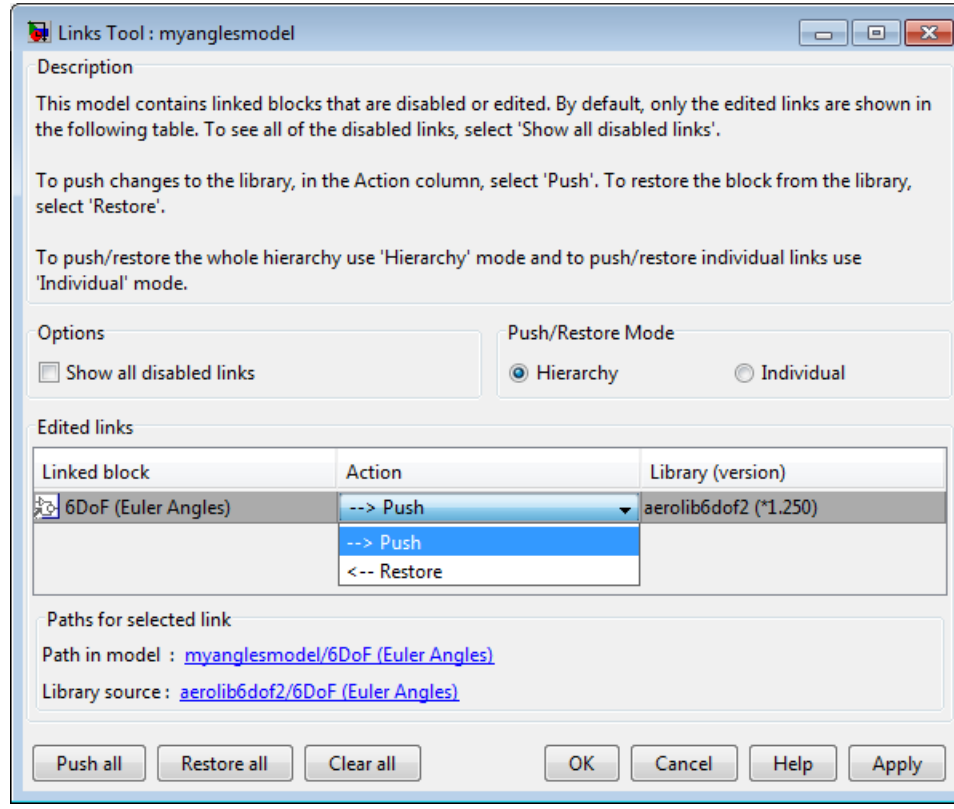
```
set_param(gcb, 'LinkStatus', 'inactive')
```

Restore Disabled or Parameterized Links

After you make changes to a disabled linked block, you may want to restore its link to the 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 block with a disabled library link.
2. From the **Diagram** menu (or right-click context menu), select **Library Link > Resolve Link**.

The Links Tool window opens.



The **Edited links** table has the following columns:

- **Linked block** — List of linked blocks. The list of links includes library links with structural changes (disabled links), parameterized library links (edited 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 Select the check box **Show all disabled links** if you want to view disabled links as well as parameterized links.

4 Under **Push/Restore Mode**, choose a mode of action:

- If you want to act on individual links, select **Individual**.
- If you want to act on the whole link hierarchy, leave the default setting on **Hierarchy**. See "Pushing or Restoring Link Hierarchies" on page 28-15.

5 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.

6 From the **Action** list, select **Push** or **Restore** for the currently selected block.

Action Choice	Links Tool Action
`Push`	The Links Tool looks for all changes in the link hierarchy and pushes all links with changes to their libraries. **Push** replaces the version of the block in the library with the version in the model.
`Restore`	The Links Tool looks for all disabled or edited links in the link hierarchy and restores them all with their corresponding library blocks. **Restore** replaces the version of the block in the model with the version in the library.
`Push Individual`	In **Individual** mode, the disabled or edited block is pushed to the library, preserving the changes inside it without acting on the hierarchy. All other links are unaffected.
`Restore Inidividual`	In **Individual** mode, the disabled or edited block is restored from the library, and all other links are unaffected.

To select the same action for all linked blocks, click **Push all**, **Restore all**, or **Clear all**.

7 When you click **OK** or **Apply**, the Links Tool performs the push or restore actions you selected in the edited links table.

After resolving a link, the versions in the library and the linked block now match.

Note Changes you push 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 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.

Pushing or Restoring Link Hierarchies

Caution Be cautious using Push or Restore in hierarchy mode if you have a large hierarchy of edited and disabled links. Ensure that you want to push or restore the whole hierarchy of links.

Pushing a hierarchy of disabled links affects the disabled links inside and outside in the hierarchy for a given link. If you push changes from a disabled link in the middle of a hierarchy, the inside links are pushed and the outside links are restored if without changes. This operation does not affect outside (parent) links with changes unless you also explicitly selected them for push. The Links Tool starts from the lowest links (the deepest inside) and then moves upward in the hierarchy.

Some simple examples:

1 Link A contains link B and both have changes.

- Push A. The Links Tool pushes both A and B.
- Push B. The Links Tool pushes B and not A.

2 Link A contains link B. A has no changes, and B has changes.

- Push B. The Links Tool pushes B and restores A. When parent links are unmodified, they are restored.

If you have a hierarchy of parameterized links, the Links Tool can manipulate only the top level.

Check and Set Link Status Programmatically

All blocks have a `LinkStatus` parameter and a `StaticLinkStatus` parameter that indicate whether the block is a linked block.

Use `get_param(gcb, 'StaticLinkStatus')` to query the link status without updating out-of-date linked blocks.

Use `get_param` and `set_param` to query and set the `LinkStatus`, which can have the following values.

Get LinkStatus Value	Description
`none`	Block is not a linked 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`	Disabled link.

Set LinkStatus Value	Description
`none`	Breaks link. Use `none` to break a link, e.g., `set_param(gcb, 'LinkStatus', 'none')`
`inactive`	Disables link. Use `Inactive` to disable a link, e.g., `set_param(gcb, 'LinkStatus', 'inactive')`
`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. This is equivalent to `Restore Individual` in the Links Tool.
`propagate`	Pushes any changes made to the disabled link to the library block and re-establishes its link. This is equivalent to `Push Individual` in the Links Tool.
`restoreHierarchy`	Restores all disabled links in the hierarchy with their corresponding library blocks. This is equivalent to `Restore` in hierarchy mode in the Links Tool.
`propagateHierarchy`	Pushes all links with changes in the hierarchy to their libraries. This is equivalent to `Push` in hierarchy mode in the Links Tool. See "Restore Disabled or Parameterized Links" on page 28-12.

Note Using `get_param` to query a block's `LinkStatus` also resolves any out-of-date block links. Use `get_param` to update library links in a model programmatically. Querying the `StaticLinkStatus` property does not resolve any out-of-date links. 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.

If you call `get_param` on a block inside a library link, Simulink resolves the link if necessary. This operation may involve loading part of the library and executing callbacks.

Break a Link to a Library Block

You can break the link between a linked block and its library block to cause the linked 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 masked subsystem model as a standalone model, without the libraries (see "Masking").

To break the link between a linked block and its library block, you can use any of the following actions.

- Disable the link, then right-click the block and choose **Library Link > Break Link** .
- At the command line, change the value of the `LinkStatus` parameter to `'none'` using this command:

  ```
  set_param(gcb, 'LinkStatus', 'none')
  ```

- Right-click and drag to copy a block, and you see an offer to break links, unless the parent library has `LockLinksToLibrary` set to `on`. If your copied block will be a locked link, then you do not see the option to break links.

  To copy and break links to multiple blocks simultaneously, select multiple blocks and then drag. Any locked links are ignored and not broken.

- When saving the model, you can break links by supplying arguments to the `save_system` command. See save_system.

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.

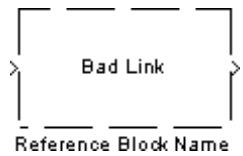
For example, suppose a block invokes a function that is supplied with the library. Now suppose that a new version of the library eliminates the function. Running a model with an unlinked copy of the block results in invocation of a now nonexistent function, causing the simulation to fail. To avoid such problems, you should generally avoid breaking links to libraries.

Fix 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 linked 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
"linked-block-path".
```

The unresolved linked block appears like this (colored red).



To fix a bad link, you must do one of the following:

- Delete the unresolved block and copy the library block back into your model.
- Add the folder that contains the required library to the MATLAB path and select either **Diagram > Update Diagram** or **Diagram > Refresh Blocks**.
- Double-click the unresolved 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**.

Create Block Libraries

In this section...

Create a Library

You can create your own block library and add it to the Simulink Library Browser (see "Add Libraries to the Library Browser" on page 28-32). To create a library:

1 Select **Library** from the **New** submenu of the **File** menu.

Simulink creates a model 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 may need to provide a mask (see "Masking") for the block. You can also provide a mask for a subsystem in a library, but you do not need to have a mask to create links to it in models.

---

3 Save the library's file under a new name.

Create a Sublibrary

If your library contains many blocks, consider grouping the blocks into a hierarchy of sublibraries. Creating a sublibrary entails inserting a reference in the Simulink model 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. Add a Subsystem block to the parent library.
3. Delete the subsystem's default input and output ports.
4. Create a mask for the subsystem that displays text or an image that conveys the sublibrary's purpose.
5. Set the subsystem's OpenFcn parameter to the name of the sublibrary's model file.
6. Save the parent library.

Modify and Lock Libraries

When you open a library, it is automatically locked and you cannot modify its contents. To unlock the library, select **Diagram > Unlock Library**.

When you close the library window, Simulink locks the library.

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.

To unlock a block library from the MATLAB command line, use the following command:

```
set_param('library_name', 'Lock', 'off');
```

You must then relock the library from the MATLAB command line to prevent further changes. Use the following command to relock a block library:

```
set_param('library_name', 'Lock', 'on');
```

If you want to control end user editing of linked blocks and prevent unintentional disabling of links, you can lock links to a library. See "Lock Links to Blocks in a Library" on page 28-9.

When you save a library, Simulink checks file permissions and offers to try to make the library writable if necessary.

Make 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

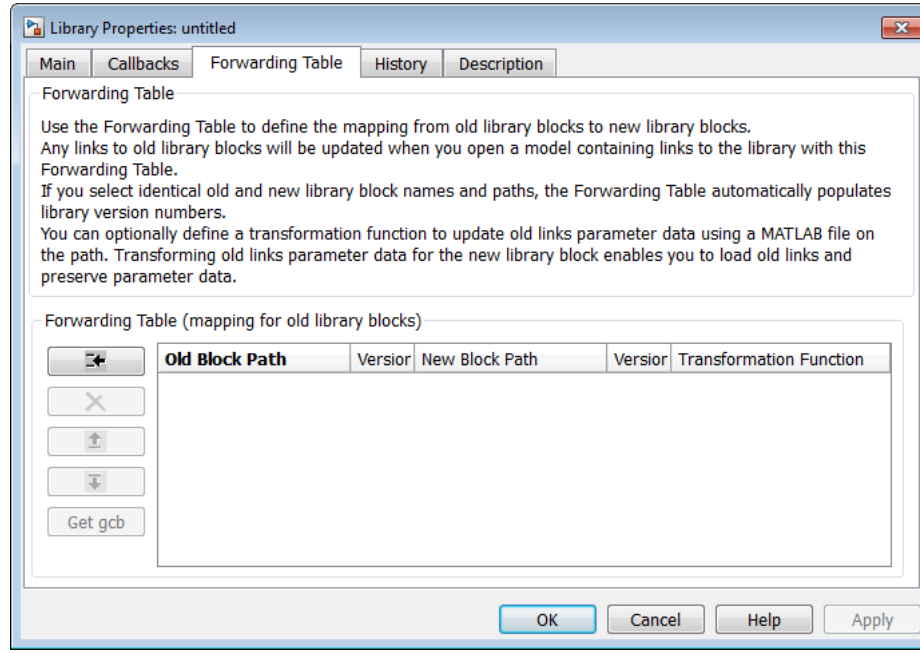
You can create forwarding tables for libraries to specify how to update links in models to reflect changes in the parameters. Use the Forwarding Table to map old library blocks to new library blocks. For example, if you rename or move a block in a library, you can use a forwarding table to enable Simulink to update models that link to the block.

After you specify the forwarding table entry in a library, any links to old library blocks will be updated when you load a model containing links to old blocks. Library authors can use the forwarding tables to automatically transform old links into updated links without any loss of functionality and data. Use the forwarding table to solve compatibility issues with models containing old links that cannot load in the current version of Simulink. Library authors do not need to run `slupdate` to upgrade old links, and can reduce maintenance of legacy blocks.

To set up a forwarding table for a library,

1. Select **Diagram > Unlock Library**.
2. Select **File > Library Properties > Library Properties**. The Library Properties dialog box opens.

3 Select the Forwarding Table tab.



4 Define the mapping from old library blocks to new library blocks.

a Click the Add New Entry button. A new row appears in the table.

b Enter values in **Old Block Path** and **New Block Path** columns.

Click **GCB** to get the path of the currently selected block.

If you select identical old and new library block names and paths, the Forwarding Table automatically populates library version numbers in the **Version** columns. The `LibraryVersion` property is the model version of the library at the time the link was created.

c (Optional) You can define a transformation function to update old link parameter data using a MATLAB file on the path. Specify the function in the **Transformation Function** column. Transforming old link parameter data for the new library block enables you to load old links and preserve parameter data.

If you do not want to specify a transformation function, do not edit the field. When you save the library, the column will display `No Transformation`.

5 Click **OK** to apply changes and close the dialog box.

After specifying the forwarding table mapping, when you open a model containing links to the library, links to old library blocks will be updated.

To view an example of a forwarding table:

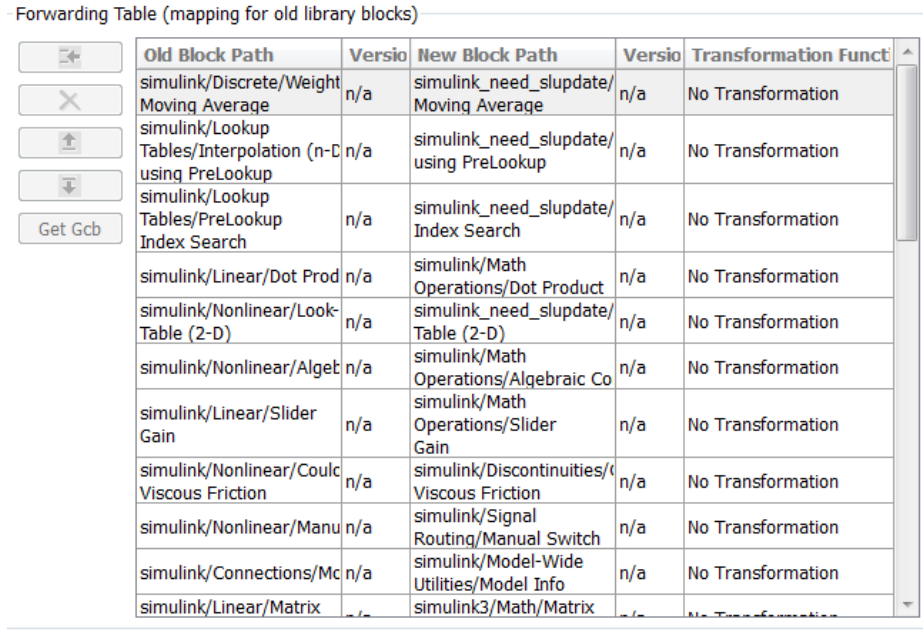
1 Enter

```
open_system('simulink')
```

2 Select **File > Library Properties > Library Properties**

3 Click the Forwarding Table tab.

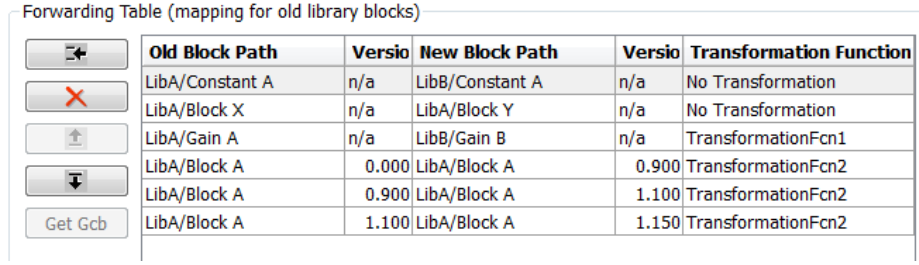
4 View how the forwarding table specifies the mapping of old blocks to new blocks. You cannot make changes because the library is locked. Do not edit the forwarding table for your Simulink library.



5 Click **OK** to close the dialog

The following example shows a forwarding table that defines:

- A block with the same name moving to a different library (`Constant A`)
- A block changing name in the same library (`Block X` to `Block Y`)
- A block changing name, moving library, and applying a transformation function (`Gain A` to `Gain B`)
- A block with three version updates (`Block A`) using a transformation function. When you select identical old and new library block names and paths, the Forwarding Table automatically populates version numbers in the **Version** columns. If this is the first entry with identical names, version starts at `0`, and the new version number is set to the `ModelVersion` of the library. For subsequent entries, the first version is set to the previous entry's new version, and the new version is set to the current `ModelVersion` of the library.



Old Block Path	Versio	New Block Path	Versio	Transformation Function
LibA/Constant A	n/a	LibB/Constant A	n/a	No Transformation
LibA/Block X	n/a	LibA/Block Y	n/a	No Transformation
LibA/Gain A	n/a	LibB/Gain B	n/a	TransformationFcn1
LibA/Block A	0.000	LibA/Block A	0.900	TransformationFcn2
LibA/Block A	0.900	LibA/Block A	1.100	TransformationFcn2
LibA/Block A	1.100	LibA/Block A	1.150	TransformationFcn2

At the command line you can create a simple forwarding table specifying 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.

Writing Transformation Functions. You can use transformation functions to add or remove parameters and define parameter values. Transforming old link parameter data for the new library block enables you to load old links and preserve parameter data that differs from library values. Define your transformation function using a MATLAB file on the path, then specify the function in the Forwarding Table **Transformation Function** column.

The transformation function in your MATLAB file must be like the following:

```
function outData = TransformationFcn(inData)
```

where `inData` is a structure with fields `ForwardingTableEntry` and `InstanceData`, and `ForwardingTableEntry` is a structure with fields `__slOldName__`, `__slNewName__`, `__slOldVersion__` , `__slNewVersion__`.

This general transformation function can have many local functions defined in it. The function calls the appropriate local functions based on old block names and versions. Use this to combine many local functions into a single transformation function, to avoid having many transformation functions on the MATLAB path.

`InstanceData` and `NewInstanceData` are structures with fields `Name` and `Value`. Instance data means the names and values of parameters that are different from the library values.

`outData` is a structure with fields `NewInstanceData` and `NewBlockPath`.

The following example code shows how to define a transformation function that adds a parameter with value `uint8` to update a Compare To Constant block:

```
function [outData] = TransformationCompConstBlk(inData)
% Example transformation Function for old 'Compare To Const' block.
%
% If instanceData of old 'Compare To Const' block does not have
% the 'OutDataTypestr' parameter,
% add the parameter with value 'uint8'.
%
% In the Simulink library the 'ForwardingTableEntry' would be of type:
% ||__slOldName__||A||__slNewName__||B||__slTransformationFcn__||TX
%
% Exact entry is:
% ||__slOldName__||fixpt_lib_4/Logic & Comparison/Compare\nTo Constant||__slNewName__||
% simulink/Logic and Bit\nOperations/Compare\nTo Constant||__slTransformationFcn__||TransformationCompConstB
%
%

outData.NewBlockPath = '';
outData.NewInstanceData = [];

instanceData = inData.InstanceData;
% Get the field type 'Name' from instanceData
[ParameterNames{1:length(instanceData)}] = instanceData.Name;

if (~ismember('OutDataTypeStr',ParameterNames))
```

```
    % OutDataTypeStr parameter is not present in old link. Add it and set value uint8
    instanceData(end+1).Name = 'OutDataTypeStr';
    instanceData(end).Value = 'uint8';
end

outData.NewInstanceData = instanceData;
```

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 "Using Mask Parameter Aliases to Create Backward-Compatible Parameter Name Changes" on page 28-28).

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.

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 new library. **File > New > Library**
2. Open the model `masking_example` described in "How Mask Parameters Work" on page 26-4. Drag the masked block named `mx+b` into your new library and rename it to `Line`.
3. Right-click the block and select **Properties**. In the Block Properties dialog, select the **Block Annotation** tab. In the **Enter text and tokens for annotation** box, enter

   ```
   m = %<m>
   b = %<b>
   ```

   The block displays the value of its `m` and `b` parameters,

4. Right-click the block, and select **Mask > Mask Parameters**. In the Block Parameter dialog, enter `0.5` for the **Slope** and `0` for the **Intercept**.

5. Save the new library with the filename `mylibrary`.

6. Create a new Simulink model. **File** > **New** > **Model**.

7. From the `mylibrary` window, drag an instance of the Line block to your new model. Rename the instance `LineA`.

8. Right-click the block and select **Mask > Mask Parameters**. In the Block Parameters dialog, change the value **Slope** to `-0.5`. and change the value **Intercept**. to `30`. Select **Display > Library Links > User Defined**.

9. Add a Scope and Clock block to your model and connect them to your block. Save the new model with the filename `mymodel`.

10. From the **Simulation** menu, select **Model Configuration Parameters**. From the **Type** list, select `Fixed-step`. From the **Solver** list, select `discrete (no continuous states`. In the **Fixed-step size** box, enter `0.1`. Simulate model.

    Note that the model simulates without error.

11. Save and close `mymodel`.

12. Open `mylibrary`.

13. Edit mask. Right-click block, select **Edit mask**. In the Mask Editor dialog,

    - Select the **Parameters** tab. In the **Dialog parameters** section and **Variable** column, change the variable m to `slope` and `b` to `intercept.`
    - Select the Icon & Ports tab. In the Icon Drawing commends box, change the variable `m` to `slope` and `b` to `intercept`.

14. Right-click the Line block, select **Properties**. In the Block Properties dialog, .

    - Select the **Block Annotation** tab . In the **Enter text and tokens of annotation** box, rename the `m` parameter to `slope` and the `b` parameter to `intercept`.

15 Click **Ok** and save `mylibrary`.

16 Reopen `mymodel`.

Note that LineA 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.

17 Close `mymodel`.

18 In the `Library: mylibrary` window, select the Line block.

19 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 `slope` and `intercept` parameters.

20 Reopen `mymodel`.

Note that LineA appearance, not the annotation, 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 the LineA `slope` parameter.

21 Change LineA block annotation property to reflect LineA parameter name changes, replace

```
m = %<m>
b = %<b>
```

with

```
m = %<slope>
b = %<intercept>
```

LineA now appears with m = -0.5 and b = 30.

Note that LineA annotation shows that, thanks to parameter aliasing, Simulink has correctly applied the parameter values stored for LineA in the `mymodels` file to the block renamed parameters.

Add Libraries to the Library Browser

In this section...

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 `slblocks.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;
```

Add More Descriptive Information in slblocks.m

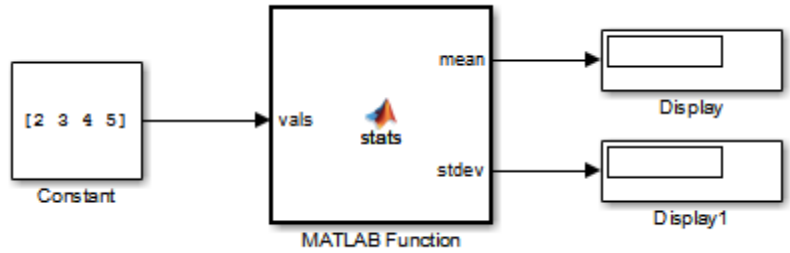
You can review other descriptive information you may wish to include in your `slblocks.m` file by examining the comments in the Simulink library `slblocks.m` file: *`matlabroot`*`/toolbox/simulink/blocks/slblocks.m`.

29

Using the MATLAB Function Block

Integrate MATLAB Algorithm in Model

Here is an example of a Simulink model that contains a MATLAB Function block:



The MATLAB Function block contains the following algorithm:

```
function [mean,stdev] = stats(vals)
% #codegen

% calculates a statistical mean and a standard
% deviation for the values in vals.

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 “Create Model That Uses MATLAB Function Block” on page 29-9.

Defining Local Variables for Code Generation

If you intend to generate code from the MATLAB algorithm in a MATLAB Function block, you must explicitly assign the class, size, and complexity of local variables before using them in operations or returning them as outputs (see “Data Definition for Code Generation” on page 34-2. In the example

function `stats`, the local variable `len` is defined before being used to calculate mean and standard deviation:

```
len = length(vals);
```

Generally, once you assign properties to a variable, you cannot redefine its class, size, or complexity elsewhere in the function body, but there are exceptions (see “Reassignment of Variable Properties” on page 33-9).

What Is a MATLAB Function Block?

The MATLAB Function block allows you to add MATLAB functions to Simulink models for deployment to desktop and 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. From the MATLAB Function block, you can generate readable, efficient, and compact C/C++ code for deployment to desktop and embedded applications. .

Calling Functions in MATLAB Function Blocks

MATLAB Function blocks can call any of the following types of functions:

- **Local functions**

  Local functions are defined in the body of the MATLAB Function block. In the preceding example, `avg` is a local function. See "Call Local Functions" on page 41-9.

- **MATLAB toolbox functions that support code generation**

  From MATLAB Function blocks, you can call toolbox functions that support code generation. When you build your model with Simulink Coder, these functions generate C code that is optimized to meet the memory and performance requirements of desktop and embedded environments. In the preceding example, `length`, `sqrt`, and `sum` are examples of toolbox functions that support code generation. See "Call Supported Toolbox Functions" on page 41-10. For a complete list of supported functions, see "Functions Supported for Code Generation — Alphabetical List" on page 31-2.

- **MATLAB functions that do not support code generation**

  From MATLAB Function blocks, you can also call *extrinsic* functions. These are functions on the MATLAB path that the compiler dispatches to MATLAB software for execution because the target language does not support them. These functions do not generate code; they execute only in the MATLAB workspace during simulation of the model. The Simulink Coder software attempts to compile all MATLAB functions unless you explicitly declare them to be extrinsic by using `coder.extrinsic`. See "Declaring MATLAB Functions as Extrinsic Functions" on page 41-12.

The code generation software detects calls to many common visualization functions, such as `plot`, `disp`, and `figure`. For MEX code generation, it automatically calls out to MATLAB for these functions. For standalone code generation, it does not generate code for these visualization functions. This capability removes the requirement to declare these functions extrinsic using the `coder.extrinsic` function.

See “Resolution of Function Calls in MATLAB Generated Code” on page 41-2.

Why Use MATLAB Function Blocks?

MATLAB Function blocks provide the following capabilities:

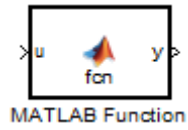
- **Allow you to build MATLAB functions into embeddable applications** — MATLAB Function blocks support a subset of MATLAB toolbox functions that generate efficient C/C++ code (see "Functions Supported for Code Generation"). With this support, you can use Simulink Coder to generate embeddable C code from MATLAB Function blocks that implement 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 a 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 Ports and Data Manager (see "Ports and Data Manager" on page 29-37) or in the Model Explorer (see "Model Explorer Overview" on page 9-2).

Create Model That Uses MATLAB Function Block

In this section...

Adding a MATLAB Function Block to a Model

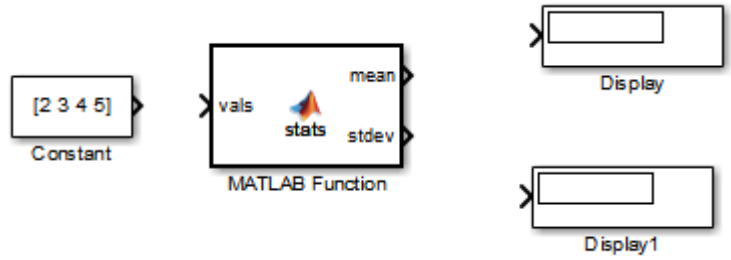
1 Create a new model with the Simulink product and add a MATLAB Function block to it from the User-Defined Function library:



2 Add the following Source and Sink blocks to the model:

- From the Sources library, add a Constant block to the left of the 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 MATLAB Function block.

The model should now have the following appearance:



3 In the Simulink Editor, select **File > Save As** and save the model as `call_stats_block1`.

Programming the MATLAB Function Block

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 a MATLAB Function Block to a Model" on page 29-9. Double-click the MATLAB Function block `fcn` to open it for editing.

   A default function signature appears, along with the `%#codegen` directive. The directive indicates that you intend to generate code from this algorithm and turns on appropriate error checking (see "Compilation Directive %#codegen" on page 41-8.

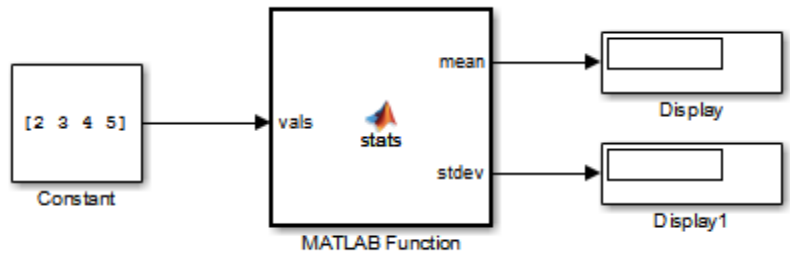
2 Edit the function header line as follows:

```
function [mean,stdev] = stats(vals)
%#codegen
```

   The 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 Save the model as `call_stats_block2`.

4 Complete the connections to the MATLAB Function block as shown.



5 In the MATLAB Function Block Editor, enter a line space after the function header and add the following code:

```
% calculates a statistical mean and a standard
% deviation for the values in vals.

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;
```

More about `length`

The function `length` is an example of a toolbox function that supports code generation. When you simulate this model, C code is generated for this function in the simulation application.

More about `len`

The class, size, and complexity of local variable `len` matches the output of the toolbox function `length`, which returns a real scalar of type `double`.

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 "Define and Initialize Persistent Variables" on page 33-10.

More about `plot`

The function `plot` is not supported for code generation. The code generation software detects calls to many common visualization functions, such as `plot`, `disp`, and `figure`. For MEX code generation, it automatically calls out to MATLAB for these functions. For standalone code generation, it does not generate code for these visualization functions.

6 Save the model as `call_stats_block2`.

Building the Function and Checking for Errors

After programming a 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 MATLAB Function block, you must set up your C compiler by running the `mex -setup` command, as described in the documentation for `mex`. 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 "Build MEX-Files".

Supported Compilers for Simulation Builds. To view a list of compilers for building models containing 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 for MATLAB Function blocks.

Supported Compilers for Code Generation. To generate code for models that contain MATLAB Function blocks, you can use any of the C compilers supported by Simulink software for code generation with Simulink Coder. 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 Simulink Coder.

How to Generate Code for the MATLAB Function Block

1. Open the `call_stats_block2` model that you saved at the end of "Programming the MATLAB Function Block" on page 29-10.

2. Double-click its MATLAB Function block `stats` to open it for editing.

3. In the MATLAB Function Block Editor, select **Build Model > Build** to compile and build the example model.

   If no errors occur, the **Simulation Diagnostics** window displays a message indicating success. Otherwise, this window helps you locate errors, as described in "How to Locate and Fix Errors" on page 29-13.

How to Locate and Fix Errors

If errors occur during the build process, the **Simulation Diagnostics** window lists the errors with links to the offending code.

The following exercise shows how to locate and fix an error in a MATLAB Function block.

1. In the `stats` function, change the local function `avg` to a fictitious local function `aug` and then compile again to see the following messages in window:

   The **Simulation Diagnostics** window displays each detected error 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 MATLAB functions. This information helps you diagnose error messages and understand type propagation rules. For more information about the report, see "MATLAB Function Reports" on page 29-51.

3. In the diagnostic message for the selected error, click the blue link after the function name to display the offending code.

The offending line appears highlighted in the MATLAB Function Block editor:

4 Correct the error by changing `aug` back to `avg` and recompile.

Defining Inputs and Outputs

In the `stats` function header for the MATLAB Function block you defined in "Programming the MATLAB Function Block" on page 29-10, 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 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 MATLAB Function Block" on page 29-10. Double-click the MATLAB Function block `stats` to open it for editing.

2 In the MATLAB Function Block editor, select **Edit Data**.

The Ports and Data Manager opens to help you define arguments for MATLAB Function blocks.

The left pane displays the argument `vals` and the return values `mean` and `stdev` that you have already created for the 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**.

3 In the left pane of the Ports and Data Manager, click anywhere in the row for `vals` to highlight it.

The right pane displays the **Data** properties dialog box for `vals`. By default, the class, 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 left 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. For example, you can enter `[2 3]` in the **Size** field to specify `vals` as a 2-by-3 matrix. See "Type Function Arguments" on page 29-64 and "Size Function Arguments" on page 29-72 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 a MATLAB Function block function is `1`, just as it would be in MATLAB.

For more information, see "Ports and Data Manager" on page 29-37).

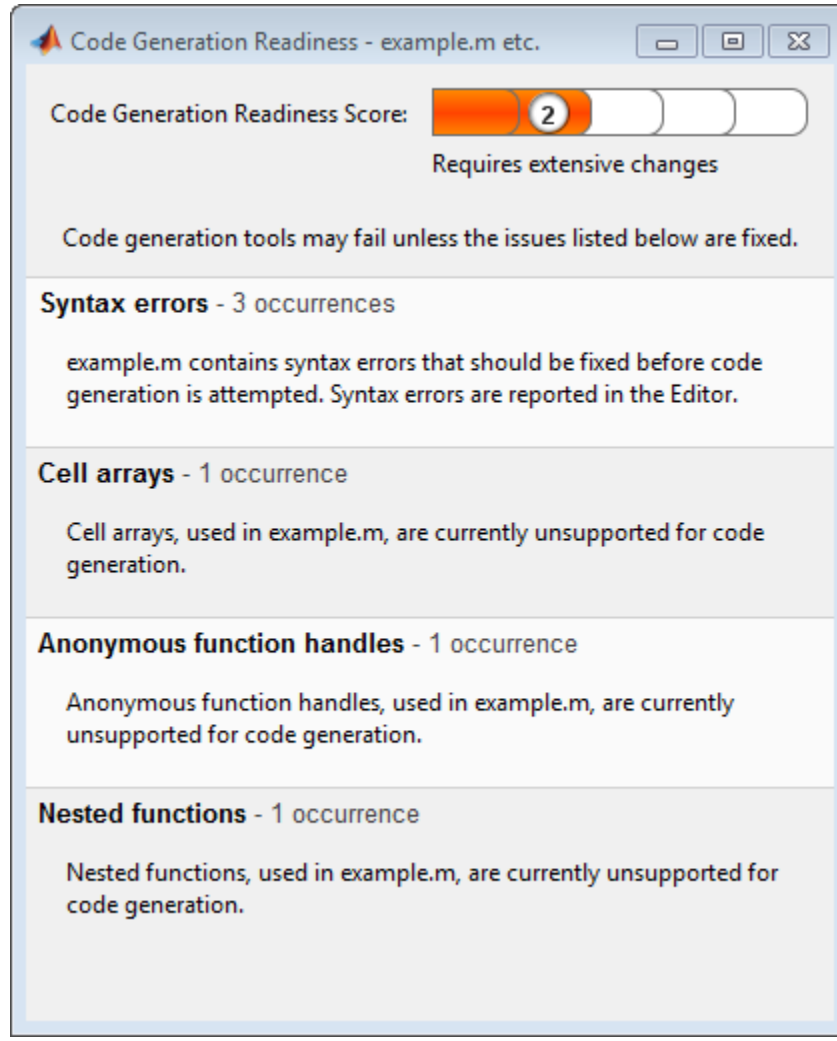
Code Generation Readiness Tool

In this section...

What Information Does the Code Generation Readiness Tool Provide?

The code generation readiness tool screens MATLAB code for features and functions that are not supported for code generation. The tool provides a report that lists the source files that contain unsupported features and functions. The report also provides an indication of how much work you must do to make the MATLAB code suitable for code generation. The tool might not detect all code generation issues. Under certain circumstances, it might report false errors. Because the tool might not detect all issues, or might report false errors, generate a MEX function to verify that your code is suitable for code generation before generating C code.

Summary Tab

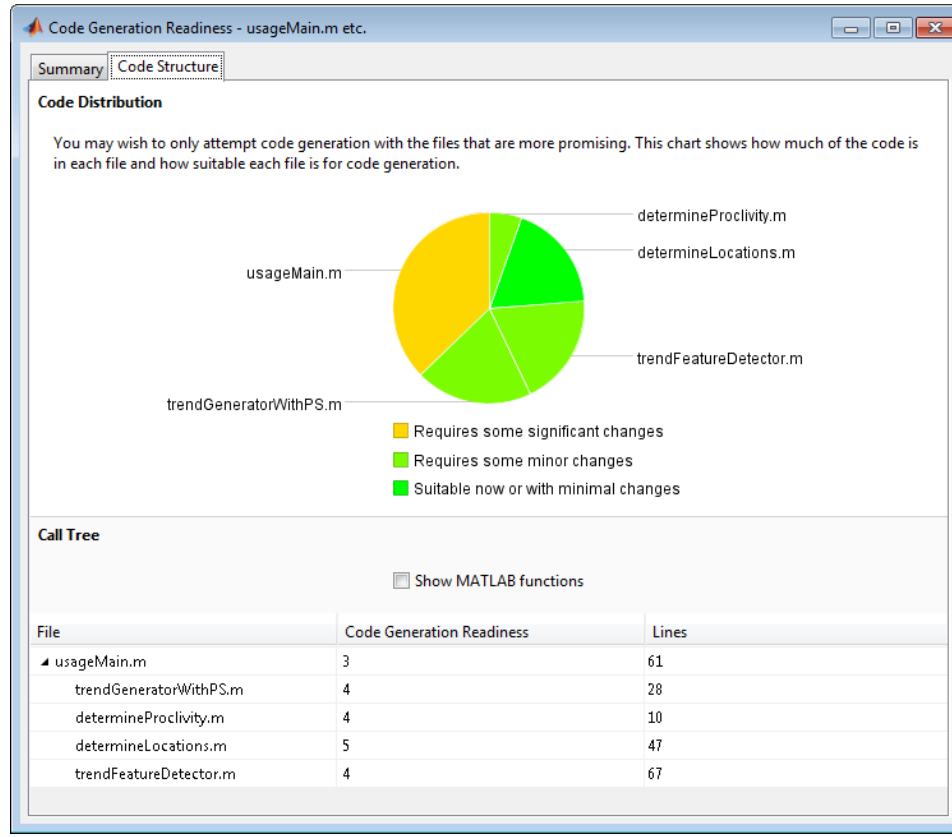


The **Summary** tab provides a **Code Generation Readiness Score** which ranges from 1 to 5. A score of 1 indicates that the tool has detected issues that require extensive changes to the MATLAB code to make it suitable for code generation. A score of 5 indicates that the tool has not detected any code generation issues; the code is ready to use with no or minimal changes.

On this tab, the tool also provides information about:

- MATLAB syntax issues. These issues are reported in the MATLAB editor. Use the code analyzer to learn more about the issues and how to fix them.
- Unsupported MATLAB function calls.
- Unsupported MATLAB language features, such as recursion, cell arrays, nested functions, and function handles.
- Unsupported data types.

Code Structure Tab



If the code that you are checking calls other MATLAB functions, or you are checking multiple entry-point functions, the tool displays the **Code Structure Tab**.

This tab provides information about the relative size of each file and how suitable each file is for code generation.

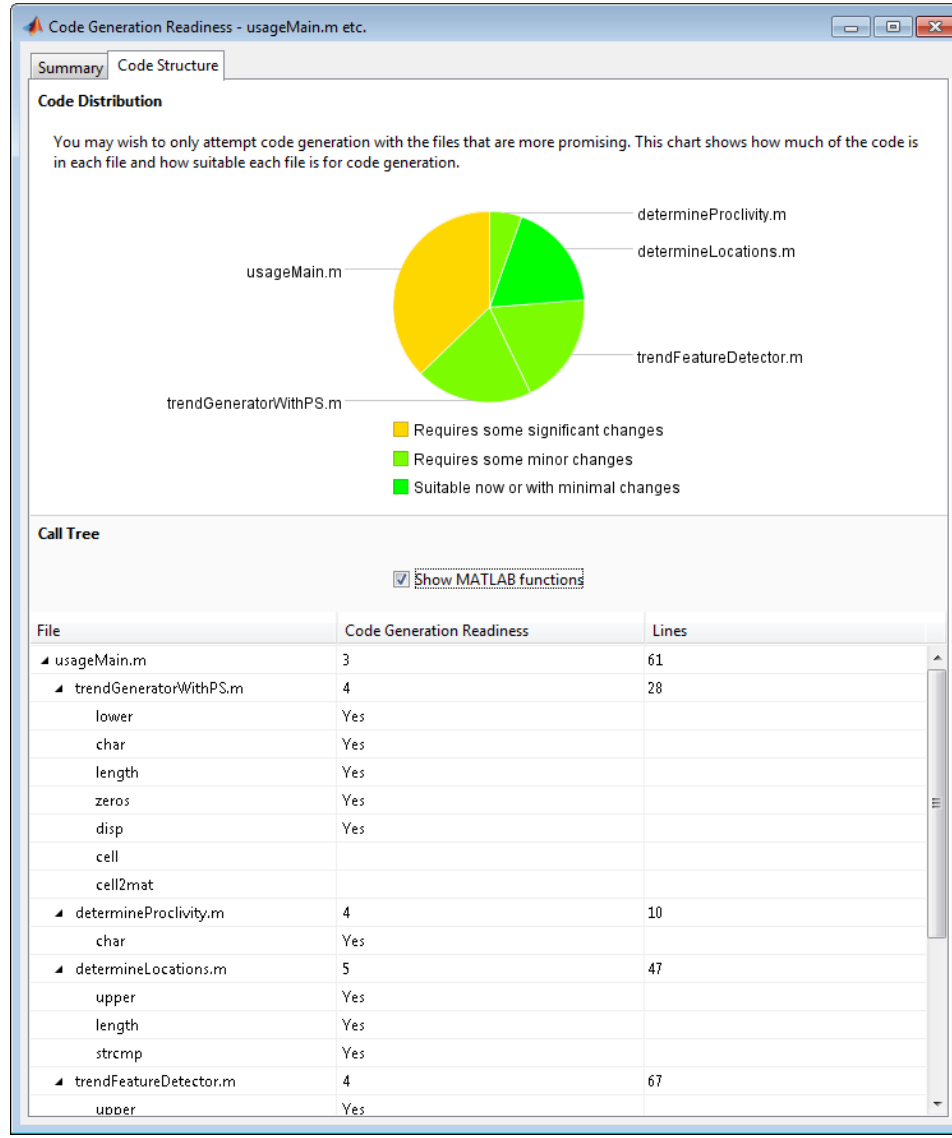
Code Distribution

The **Code Distribution** pane provides a pie chart that shows the relative sizes of the files and how suitable each file is for code generation. This information is useful during the planning phase of a project for estimation and scheduling purposes. If the report indicates that there are multiple files not yet suitable for code generation, consider fixing files that require minor changes before addressing files with significant issues.

Call Tree

The **Call Tree** pane provides information on the nesting of function calls. For each called function, the report provides a **Code Generation Readiness** score which ranges from `1` to `5`. A score of `1` indicates that the tool has detected issues that require extensive changes to the MATLAB code to make it suitable for code generation. A score of `5` indicates that the tool has not detected any code generation issues; the code is ready to use with no or minimal changes. The report also lists the number of lines of code in each file.

Show MATLAB Functions. If you select **Show MATLAB Functions**, the report also lists all the MATLAB functions called by your function code. For each of these MATLAB functions, if the function is supported for code generation, the report sets **Code Generation Readiness** to `Yes`.


Code Generation Readiness - usageMain.m etc.
Summary
Code Structure
Code Distribution
You may wish to only attempt code generation with the files that are more promising. This chart shows how much of the code is in each file and how suitable each file is for code generation.
determineProclivity.m
determineLocations.m
usageMain.m
trendFeatureDetector.m
trendGeneratorWithPS.m
Requires some significant changes
Requires some minor changes
Suitable now or with minimal changes
Call Tree
Show MATLAB functions
File
Code Generation Readiness
Lines
usageMain.m 3 61
trendGeneratorWithPS.m 4 28
lower Yes
char Yes
length Yes
zeros Yes
disp Yes
cell
cell2mat
determineProclivity.m 4 10
char Yes
determineLocations.m 5 47
upper Yes
length Yes
strcmp Yes
trendFeatureDetector.m 4 67
upper Yes

See Also

- “Check Code Using the Code Generation Readiness Tool” on page 29-22

Check Code Using the Code Generation Readiness Tool

In this section...

Run Code Generation Readiness Tool at the Command Line

1. Navigate to the folder that contains the file that you want to check for code generation readiness.
2. At the MATLAB command prompt, enter:

   ```
   coder.screener('filename')
   ```

   The **Code Generation Readiness** tool opens for the file named `filename`, provides a code generation readiness score, and lists issues that must be fixed prior to code generation.

Run the Code Generation Readiness Tool From the Current Folder Browser

1. In the current folder browser, right-click the file that you want to check for code generation readiness.
2. From the context menu, select `Check Code Generation Readiness`.

   The **Code Generation Readiness** tool opens for the selected file and provides a code generation readiness score and lists issues that must be fixed prior to code generation.

Debugging a MATLAB Function Block

In this section...

How Debugging Affects Simulation Speed

Debugging a MATLAB Function block slows simulation. For maximum simulation speed, disable debugging as described in "Enabling and Disabling Debugging" on page 29-23.

Enabling and Disabling Debugging

There are two levels of debugging available when using MATLAB Function blocks, model level debugging and block level debugging.

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 MATLAB Function block by clicking **Breakpoints > Enable Debugging** in the MATLAB Function Block Editor. If **Enable Debugging** is unavailable, then the **Simulation Target** pane in the Configuration Parameters dialog is controlling debugging.

Debugging the Function in Simulation

In "Create Model That Uses MATLAB Function Block" on page 29-9, you created an example model with a MATLAB Function block that calculates the mean and standard deviation for a set of input values.

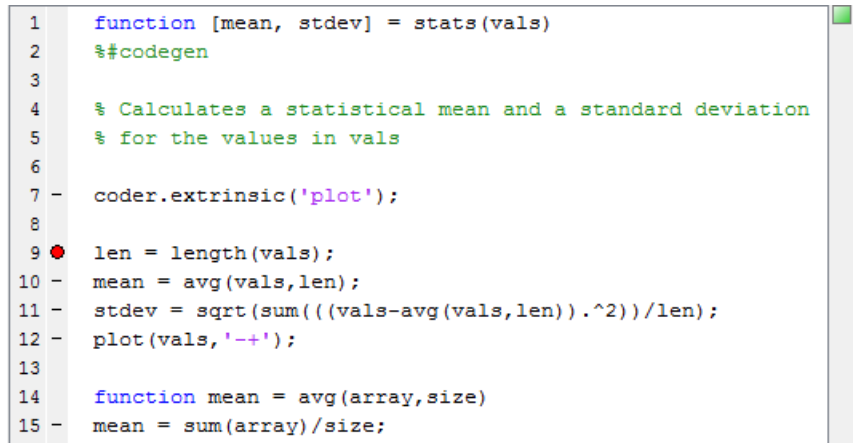
To debug the MATLAB Function in this model:

1 Open the`call_stats_block2` model and double-click its MATLAB Function block `stats` to open it for editing.

2 In the MATLAB Function Block Editor, click the dash (-) character in the left margin of the line:

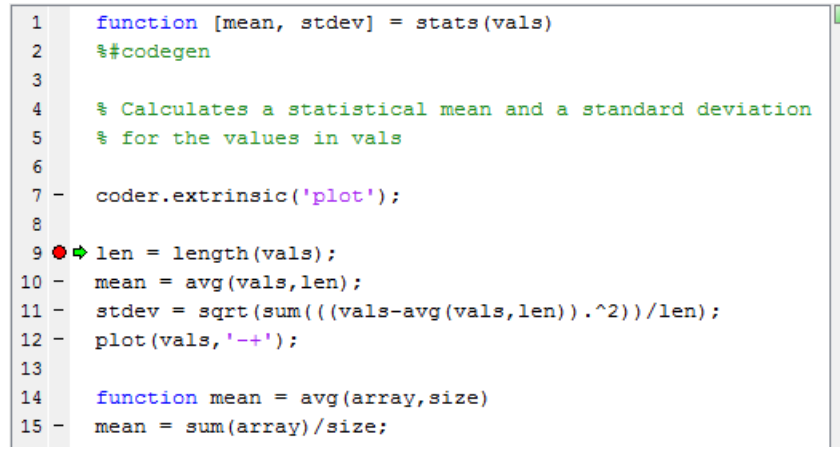
```
len = length(vals);
```

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.



4 Select **Step** to advance execution.

The execution arrow advances to the next line of `stats`, which calls the local function `avg`.

5 Select **Step In**.

Execution advances to enter the local function `avg`. Once you are in a local function, you can use the **Step** or **Step In** commands to advance execution. If the local function calls another local function, use the **Step In** icon to enter it. If you want to execute the remaining lines of the local function, use **Step Out**.

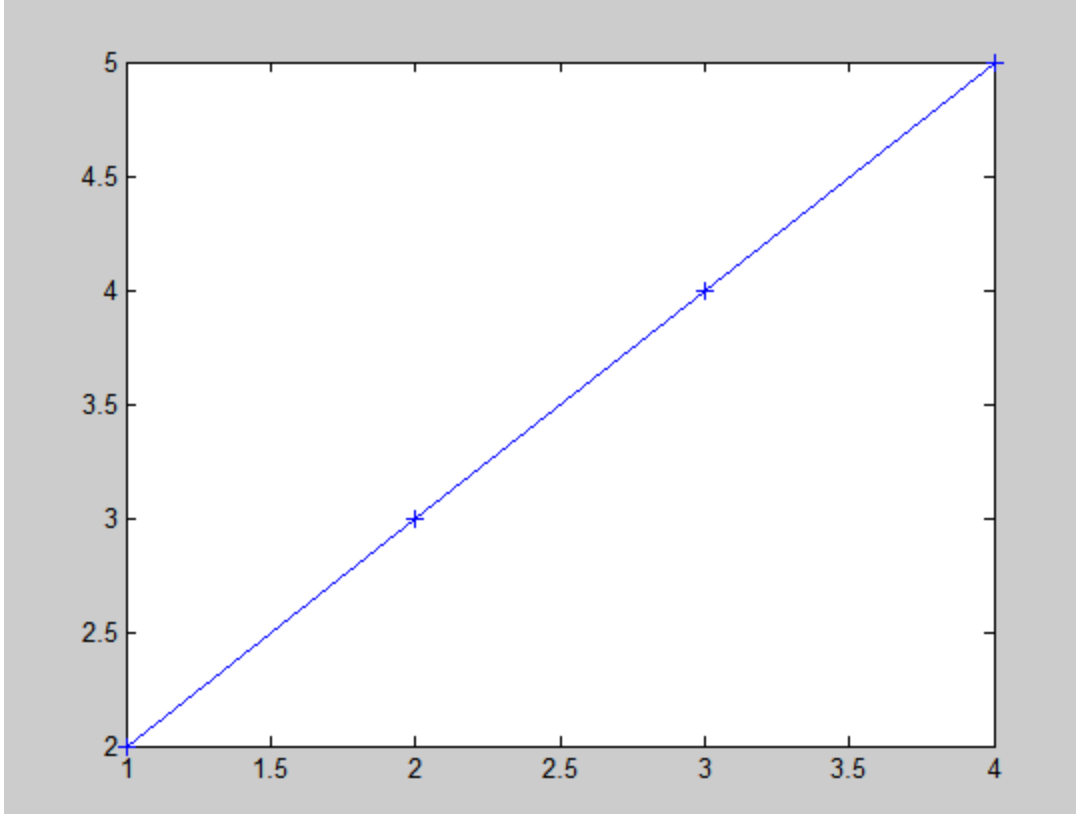
6 Select **Step** to execute the only line in the local function `avg`. When the local function `avg` finishes executing, a green arrow pointing down under its last line appears.

7 Select **Step** again to return to the function `stats`.

Execution advances to the line after the call to the local function `avg`.

8 **Step** again twice to calculate the `stdev` and to execute the `plot` function.

The plot function executes in MATLAB:



In the MATLAB Function Block Editor, a green arrow points down under the last line of code, indicating the completion of the function `stats`.

9 Select **Continue** to continue execution of the model.

The computed values of `mean` and `stdev` now appear in the Display blocks.

10 In the MATLAB Function Block Editor, select **Quit Debugging** to stop simulation.

Watching Function Variables During Simulation

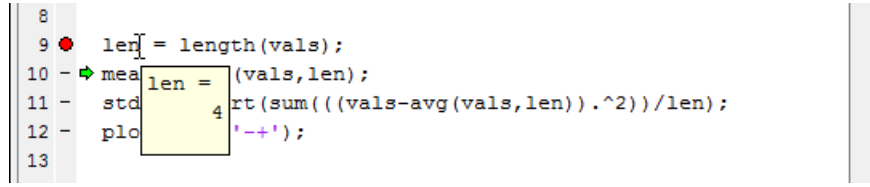
While you simulate a MATLAB Function block, you can use several tools to keep track of variable values in the function.

Watching with the Interactive Display

To display the value of a variable in the function of a MATLAB Function block during simulation:

1 In the MATLAB Function Block 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:



Watching with the Command Line Debugger

You can report the values for a 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 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 a MATLAB local function.
`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 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 a MATLAB Function block 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 MATLAB Function Block 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 MATLAB Function Block Editor displays the shape and base type only.

Checking for Data Range Violations

When you enable debugging, 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 Ports and Data Manager, select the input or output of interest.

   The data properties dialog box opens.

2. In the data properties dialog box, select the General tab and enter a limit range, as described in "Setting General Properties" on page 29-44.

Debugging Tools

Use the following tools during a MATLAB Function block debugging session:

Tool Button	Description	Shortcut Key
 **Build**	Access this tool from the **Editor** tab by selecting **Build Model > Build**. Check for errors and build a simulation application (if no errors are found) for the model containing this MATLAB Function block.	**Ctrl+B**
 **Update Diagram**	Access this tool from the **Editor** tab by selecting **Build Model > Update Diagram**. Check for errors based on the latest changes you make to the MATLAB Function block.	**Ctrl+D**
 **Update Ports**	Access this tool from the **Editor** tab by selecting **Build Model > Update Ports**. Updates the ports of the MATLAB Function block with the latest changes made to the function argument and return values without closing the MATLAB Function Block Editor.	**Ctrl+Shift+A**
 **Run Model**	Start simulation of the model containing the MATLAB Function block. If execution is paused at a breakpoint, continues debugging.	**F5**
 **Stop Model**	Stop simulation of the model containing the MATLAB Function block. Alternatively, from the **Editor** tab, select **Quit Debugging** if execution is paused at a breakpoint.	**Shift+F5**

Tool Button	Description	Shortcut Key
 **Set/Clear**	Access this tool by selecting **Breakpoints > Set/Clear**. Set a new breakpoint or clear an existing breakpoint for the selected line of code in the MATLAB Function block. The presence of the text cursor or highlighted text selects the line. A breakpoint indicator appears in the on the selected line. Alternatively, click the hyphen character (-) next to the line number. A breakpoint indicator appears in place of the hyphen. Click the breakpoint indicator to clear the breakpoint.	**F12**
 **Clear All**	Access this tool by selecting **Breakpoints > Clear All**. Clear all existing breakpoints in the MATLAB Function block code.	**None**
 **Step**	Step through the execution of the next line of code in the MATLAB Function block. 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.	**F10**
 **Step In**	Step through the execution of the next line of code in the MATLAB Function block. If the line calls a local function, step into the first line of the local function. You can use this tool only after execution has stopped at a breakpoint.	**F11**

Tool Button	Description	Shortcut Key
 **Step Out**	Step out of line-by-line execution of the current function or local function. If in a local function, the debugger continues to the line following the call to this local function. You can use this tool only after execution has stopped at a breakpoint.	**Shift+F11**
 **Continue**	Continue debugging after a pause, such as stopping at a breakpoint. You can use this tool only after execution has stopped at a breakpoint.	**F5**
 **Quit Debugging**	Exit debug mode. You can use this tool only after execution has stopped at a breakpoint.	**Shift+F5**

MATLAB Function Block Editor

In this section...

Customizing the MATLAB Function Block Editor

Use the toolbar icons to customize the appearance of the MATLAB Function Block Editor in the same manner as the MATLAB editor. See "Adjust Desktop Appearance".

MATLAB Function Block Editor Tools

Use the following tools to work with the MATLAB Function block:

Tool Button	Description
 **Edit Data**	Opens the Ports and Data Manager dialog to add or modify arguments for the current MATLAB Function block (see "Ports and Data Manager" on page 29-37).
 **View Report**	Opens the MATLAB Function report for the MATLAB Function block. For more information, see "MATLAB Function Reports" on page 29-51.

Tool Button	Description
 **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 29-23 for more information on debugging
 **Go To Diagram**	Displays the MATLAB function in its native diagram without closing the editor.

See "Defining Inputs and Outputs" on page 29-14 for an example of defining an input argument for a MATLAB Function block.

Editing and Debugging MATLAB Function Block Code

Commenting Out a Block of Code

To comment out a block of code in the MATLAB Function Block 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 a Comment tool from the Editor tab.

Note To uncomment a block of code, follow the same steps, but select **Uncomment** instead of **Comment**.

Manual Indenting

To indent a block of code manually:

1. Highlight the text that you would like to indent.
2. Select one of the Indent tools on the Editor tab:

Tool	Description
	Applies smart indenting to selected text.
	Move selected text right one indent level.
	Move selected text left one indent level.

Opening a Selection

You can open a local function, function, file, or variable from within a file in the MATLAB Function Block 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 "Opening Files and Functions in the Command Window".

Note If you open a 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 29-37.

Evaluating a Selection

You can use the **Evaluate a Selection** menu option to report the value for a 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 a 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 for <selection>** from the context menu.

3 Select:

- **Input** if your input data is provided by the Simulink model via an input port to the 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 29-44.

Ports and Data Manager

The Ports and Data Manager provides a convenient method for defining objects and modifying their properties in a MATLAB Function block that is open and has focus.

The Ports and Data Manager provides the same data definition capabilities for individual MATLAB Function blocks. as the Model Explorer provides across the model hierarchy (see "Model Explorer Overview" on page 9-2).

Ports and Data Manager Dialog Box

The Ports and Data Manager dialog box allows you to add and define data arguments, input triggers, and function call outputs for MATLAB Function blocks. Using this dialog, you can also modify properties for the MATLAB Function block and the objects it contains.

The dialog box consists of two panes:

- The **Contents** (left) pane lists the objects that have been defined for the MATLAB Function block.
- The **Dialog** (right) 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 box, it displays the properties of the MATLAB Function block.

Opening the Ports and Data Manager

To open the Ports and Data Manager from the MATLAB Function Block Editor, select **Edit Data** on the Editor tab. The Ports and Data Manager appears for the 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
 **Go to Block Editor**	Displays the MATLAB function in the MATLAB Function Block Editor.
 **Show Block Dialog**	Displays the default MATLAB function properties (see "MATLAB Function Block Properties" on page 29-38). Use this button to return to the settings used by the block after viewing data associated with the block arguments.

MATLAB Function Block Properties

This section describes each property of a MATLAB Function block.

Name. Name of the MATLAB Function block, following the same naming conventions as for Simulink blocks (see "Manipulate Block Names" on page 23-26).

Update method. Method for activating the MATLAB Function block. You can choose from the following update methods:

Update Method	Description
Inherited (default)	Input from the Simulink model activates the MATLAB Function block. If you define an input trigger, the 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 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 MATLAB Function block samples at the rate of the fastest data input. If you do not

Update Method	Description
	define data inputs, the MATLAB Function block samples as defined by its parent subsystem's execution behavior.
Discrete	The 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 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 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 Simulink Coder 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**, MATLAB adds additional checks during code generation 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 MATLAB Function block 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 enable debugging for the MATLAB Function block, the debugger displays the error and lets you examine the data.

If you did not enable debugging, the block generates a run-time error:

```
Overflow detected. Enable debugging for more information.
```

Note that the code generated by Simulink Coder 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 code.

Lock Editor. Option for locking the MATLAB Function Block Editor. When enabled, this option prevents users from making changes to the MATLAB Function block.

Treat these inherited Simulink signal types as fi objects.

Setting that determines whether to treat inherited fixed-point and integer signals as Fixed-Point Toolbox™ `fi` objects ("Ways to Construct fi Objects").

- When you select `Fixed-point`, the MATLAB Function block treats all fixed-point inputs as Fixed-Point Toolbox `fi` objects.
- When you select `Fixed-point & Integer`, the MATLAB Function block treats all fixed-point and integer inputs as Fixed-Point Toolbox `fi` objects.

MATLAB Function block fimath. Setting that defines `fimath` properties for the MATLAB Function block. The block associates the `fimath` properties you specify with the following objects:

- All fixed-point and integer input signals to the MATLAB Function block that you choose to treat as `fi` objects.
- All `fi` and `fimath` objects constructed in the MATLAB Function block.

You can select one of the following options for the **MATLAB Function block fimath**.

Setting	Description
Same as MATLAB	When you select this option, the block uses the same `fimath` properties as the current default fimath. The edit box appears dimmed and displays the current global fimath in read-only form.

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 MATLAB Function Blocks". For more information on `fimath` objects, see "fimath Object Construction".

Description. Description of the MATLAB Function block.

Document link. Link to documentation for the MATLAB Function block. To document a 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 MATLAB Function block evaluates the expression when you click the blue **Document link** text.

Adding Data to a MATLAB Function Block

You can define data arguments for MATLAB Function blocks using the following methods:

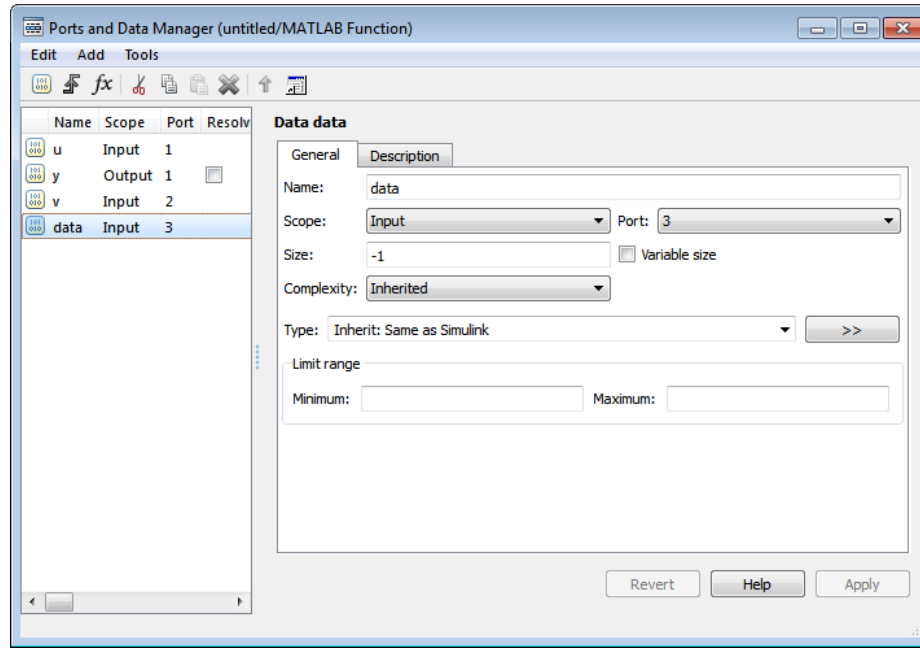
Method	For Defining	Reference
Define data directly in the MATLAB Function block code	Input and output data	See "Defining Inputs and Outputs" on page 29-14.
Use the Ports and Data Manager	Input, output, and parameter data in the MATLAB Function	See "Defining Data in the Ports and Data

Method	For Defining	Reference
	block that is open and has focus	Manager" on page 29-43.
Use the Model Explorer	Input, output, and parameter data in MATLAB Function blocks at all levels of the model hierarchy	See "Model Explorer Overview" on page 9-2

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, select **Add > Data**

The Ports and Data Manager adds a default definition of the data to the MATLAB Function block.



2 Modify data properties.

3 Return to the MATLAB Function block properties at any time by selecting **Tools > Block Dialog**.

Setting General Properties. 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.
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 "Model Workspaces" on page 4-67). • `Input`— Data provided by the model via an input port to the MATLAB Function block. • `Output`— Data provided by the 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 29-14 and "Add Parameter Arguments" on page 29-75.
Port	Index of the port associated with the data argument. This property applies only to input and output data.

Property	Description
Tunable	Indicates whether the parameter used as the source of this data item is tunable (see "Tunable Parameters" on page 3-9). This property applies only to parameter data. Clear this option if the parameter must be a constant expression, such as for MATLAB toolbox functions supported for code generation (see "Functions Supported for Code Generation — Alphabetical List" on page 31-2).
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 "Symbol Resolution" on page 4-76 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 29-72. This property does not apply to Data Store Memory data. For more details, see "Size Function Arguments" on page 29-72.
Variable Size	Indicates whether the size of this data item is variable. 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 "Data Types" on page 43-2). • Using the Data Type Assistant to specify a data **Mode**, then specifying the data type based on that mode. **Note** To display the Data Type Assistant, click the Show data type assistant button:  For more information, see "Specifying Argument Types" on page 29-64.
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 for instructions on autoscaling fixed-point data.
Limit range	Specify the range of acceptable values for input or output data. The 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. You can set the following properties on the Description tab:

Property	Description
Save final value to base workspace	The 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 MATLAB Function block evaluates the link and displays the documentation.

Adding Input Triggers to a MATLAB Function Block

An input trigger is an event on the input port that causes the MATLAB Function block to execute. See "Triggered Subsystems" on page 7-20.

You can define the following types of triggers in 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 29-48.

Use the Ports and Data Manager to add input triggers to a 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, select **Add > Input Trigger**.

The Ports and Data Manager adds a default definition of the new input trigger to the MATLAB Function block and displays the Trigger properties dialog.

2 Modify trigger properties.

3 Return to the MATLAB Function block properties at any time by selecting **Tools > Block Dialog**.

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 MATLAB Function blocks.

To open the Trigger properties dialog, select an input trigger in the Contents pane.

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.
Port	Index of the port associated with the input trigger. The default value is `1`.
Trigger	Type of event that triggers execution of the MATLAB Function block. You can select one of the following types of triggers: • `Rising` (default) — Triggers execution of the 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 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 MATLAB Function block when the control signal is either rising or falling.

Property	Description
	• `Function call`— Triggers execution of the 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 MATLAB Function block evaluates the link and displays the documentation.

Adding Function Call Outputs to a MATLAB Function Block

A function call output is an event on the output port of a 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 7-30.

Use the Ports and Data Manager to add and modify function call outputs to a 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, select **Add > Function Call Output**.

   The Ports and Data Manager adds a default definition of the new function call output to the MATLAB Function block and displays the Function Call properties dialog.

2. Modify function call output properties.

3. Return to the MATLAB Function block properties at any time by selecting **Tools > Block Dialog**.

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 MATLAB Function blocks.

To open the Function Call properties dialog, select a function call output in the Contents pane.

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.
Port	Index of the port associated with the function call output. Function call output ports are numbered sequentially after input and output ports.
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 MATLAB Function block evaluates the link and displays the documentation.

MATLAB Function Reports

In this section...

About MATLAB Function Reports

Whenever you build a Simulink model that contains MATLAB Function blocks, Simulink automatically generates a report in HTML format for each MATLAB Function block in your model. The report helps you debug your MATLAB functions and verify that they are suitable for code generation. The report provides links to your 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 If you have a Stateflow license, there is one report for each Stateflow chart, regardless of the number of MATLAB functions it contains.

Location of MATLAB Function Reports

The code generation software provides a report for each MATLAB Function block in the model `model_name` at the following location:

```
slprj/_sfprj/
model_name/_self/
sfun/html/
```

Opening MATLAB Function Reports

Use one of the following methods:

- In the MATLAB Function Block Editor, select **View Report**.
- In the **Simulation Diagnostics** window, select the **`report`** link if compilation errors occur.

Description of MATLAB Function Reports

When you build the MATLAB function, the code generation software generates an HTML report. 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 MATLAB function

Viewing Your MATLAB Function Code

To view your MATLAB function code, click the **MATLAB code** tab. The report displays the MATLAB code for the function highlighted in the list on this tab.

The **MATLAB code** tab provides:

- A list of the 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 that you can use to sort your functions by:
  - Size
  - Complexity
  - Class

Viewing Local Functions

The report annotates the local function 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 local function `subfcn` and `fcn2` contains the local function `subfcn2`, the report displays:

```
fcn1 > subfcn1
fcn2 > subfcn2
```

Viewing Specializations

If your MATLAB function calls the same function with different types of inputs, the 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) %#codegen
% Specializations
y = y + subfcn(single(u));
y = y + subfcn(double(u));
```

The report numbers the specializations in the list of functions.

```
fcn > subfcn > 1
fcn > subfcn > 2
```

Viewing Call Stack Information

The 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 local functions 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 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.

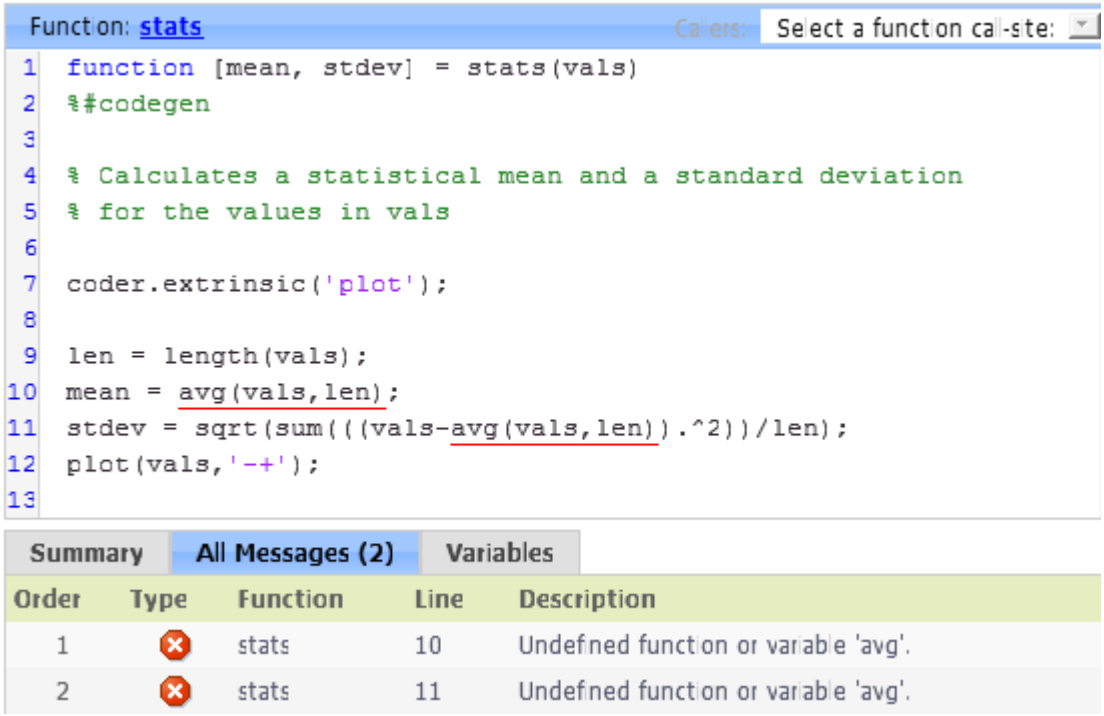
The report provides information about warnings and errors by listing all errors and warnings in chronological order in the **All Messages** tab.

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.

To locate the offending line of code for an error or warning in the list, click the message in the list. The 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 fix errors only in the source file.



Viewing Error and Warning Information in Your MATLAB Code

If errors or warnings occurred during compilation, the 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 report provides compile-time type information for the variables and expressions in your MATLAB code, including name, type, size, complexity, and class. It 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:

- On the **Variables** tab, view the list
- In your MATLAB code, place your pointer over the variable name

Viewing Variables in the Variables Tab

To view a list of all the variables in your MATLAB function, click the **Variables** tab. The report displays a complete list of variables in the order that they appear in the function selected on the **MATLAB code** tab. Clicking a variable in the list highlights all instances of that variable, and scrolls the MATLAB code pane so that you can view the first instance.

The report provides the following information about each variable, as applicable.

- Order
- Name
- Type
- Size
- Complexity
- Class

- DataTypeMode (DT mode) — for fixed-point data types only. For more information, see "DataTypeMode".
- 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 "Create and Use Fixed-Point Code Generation Reports".

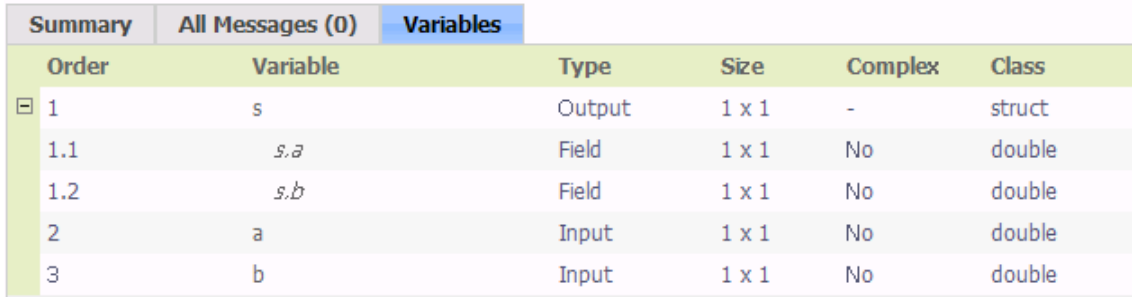
It only displays a column if at least one variable in the code has information in that column. For example, if the code does not contain any fixed-point data types, the report does not display the `DT mode`, `WL` or `FL` columns.

Sorting Variables in the Variables Tab. By default, the report lists the variables in the order that they appear in the selected function.

You can sort the variables by clicking the column headings on 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.

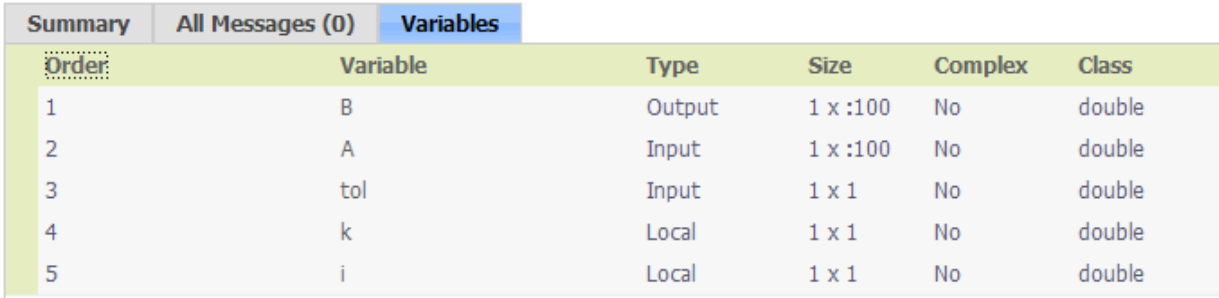
Viewing Structures on the Variables Tab. You can expand structures listed on the **Variables** tab to display the field properties.



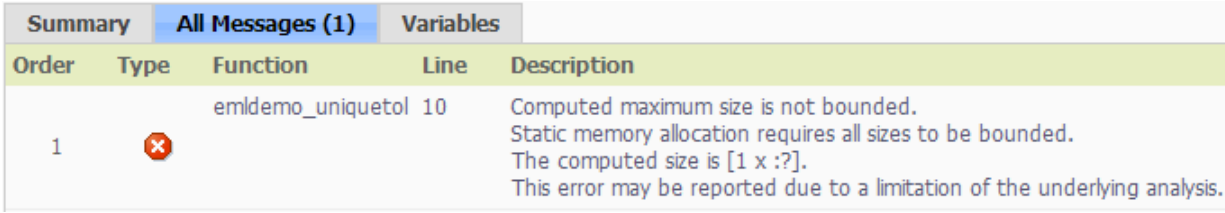
If you sort the variables by type, size, complexity or class, a structure and its fields might not appear sequentially in the list. To restore the list to the original order, click the **Order** column heading.

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 `:`.

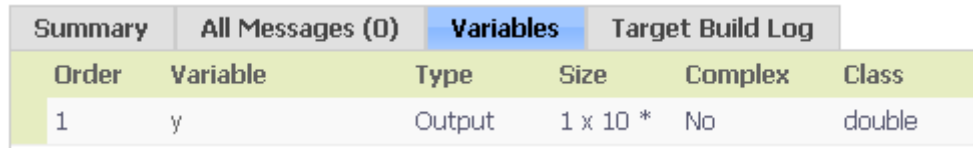
In the following report, variable *A* is variable-size. Its maximum computed size is 1×100.



If the code generation software cannot compute the maximum size of a variable-size array, the report displays the size as `:?`.



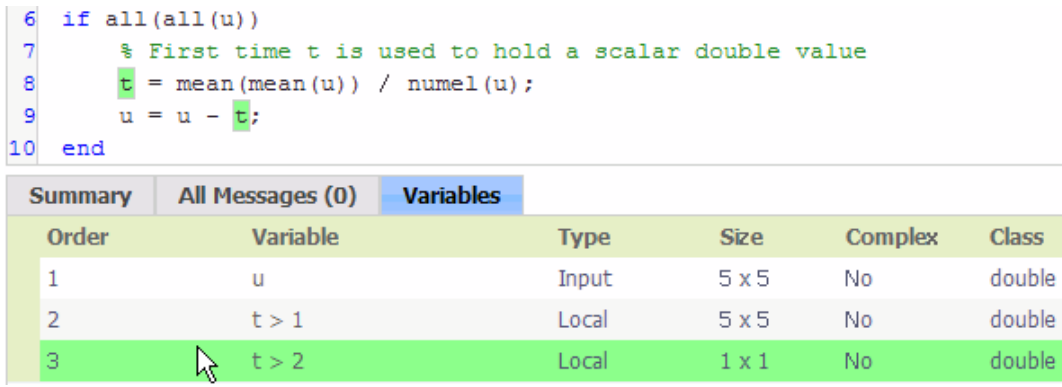
If you declare a variable-size array and then subsequently fix the dimensions of this array in the code, the report appends `*` to the size of the variable. In the generated C code, this variable appears as a variable-size array, but the size of its dimensions do not change during execution.



For more information on how to use the size information for variable-sized arrays, see "Variable-Size Data Definition for Code Generation".

Viewing Renamed Variables in the Variables Tab. If your MATLAB function reuses a variable with different size, type, or complexity, the code generation software attempts to create separate, uniquely named variables in the generated code. For more information, see "Reuse the Same Variable with Different Properties". The report numbers the renamed variables in the list on the **Variables** tab. When you place your pointer over a renamed variable, the 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 report displays two variables, `t>1` and `t>2` in the list on the **Variables** tab.

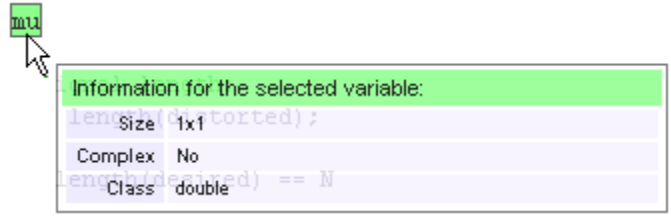


Viewing Simulation Minimum and Maximum Values in the Variables Tab. If you have a Simulink Fixed Point license, and you simulate your model using the Fixed-Point Tool set up to log the minimum and maximum values, you can view these values in the MATLAB Function Report. For more information, see "Log Simulation Minimum and Maximum Values for a MATLAB Function Block".

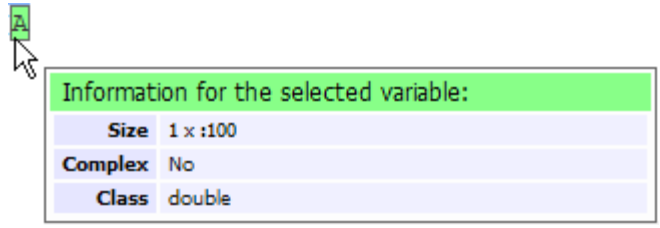
Viewing Information About Variables and Expressions in Your MATLAB Function Code

To view information about a particular variable or expression in your MATLAB function code, on the MATLAB code pane, place your pointer over the variable name or expression. The report highlights variables and expressions in different colors:

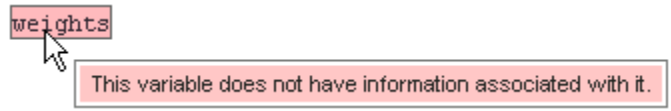
Green, when the variable has data type information at this location in the code.



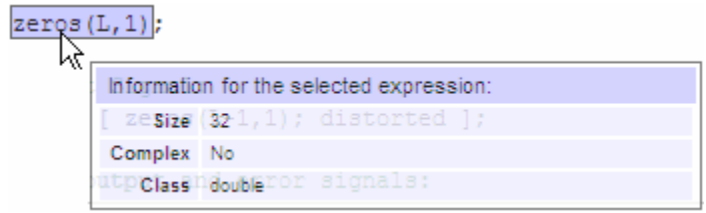
For variable-size arrays, the **Size** field includes information on the computed maximum size of the array. The size of each array dimension that varies is prefixed with a colon `:`. Here the array `A` is variable-sized with a maximum computed size of `1 x 100`.



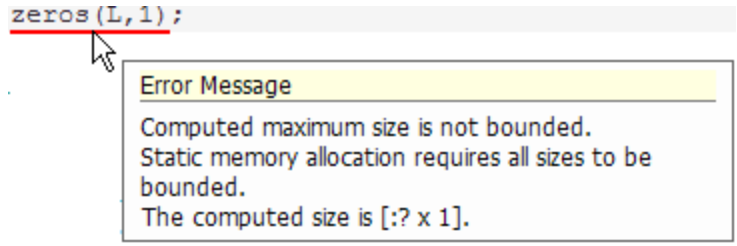
Pink, when the variable has no data type information.



Purple, information about expressions. You can also view information about expressions in your MATLAB code. On the MATLAB code pane, place your pointer over an expression . The report highlights expressions in purple and provides more detailed information.



Red, when there is error information for an expression. If the code generation software cannot compute the maximum size of a variable-size array, the report underlines the variable name and provides error information.



Keyboard Shortcuts for the MATLAB Function Report

You can use the following keyboard shortcuts to navigate between the different panes in the MATLAB Function 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

Report Limitations

The report displays information about the variables and expressions in your 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 full information for unrolled loops. It displays data types of one arbitrary iteration.

Dead Code

The report does not display information about any dead code.

Structures

The report does not provide complete information about structures.

- On the **MATLAB code** pane, the report does not provide information about all structure fields in the `struct()` constructor.
- On 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 through the list of variables, the report does not display the column headings on the **Variables** tab.

Multiline Matrices

On the **MATLAB code** pane, the report does not support selection of multiline matrices. It supports only 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];
```

Type Function Arguments

In this section...

About Function Arguments

You create function arguments for a MATLAB Function block by entering them in its function header in the MATLAB Function Block Editor. When you define arguments, the Simulink software creates corresponding ports on the MATLAB Function block that you can attach to signals. You can select a *data type mode* for each argument that you define for a 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 MATLAB Function block 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.

Specifying Argument Types

To specify the type of a MATLAB Function block function argument:

1. From the MATLAB Function Block Editor, select **Edit Data** to open the Ports and Data Manager.

2. In the left pane, select the argument of interest.

3. In the **Data** properties dialog box (right pane), click the Show data type assistant button  to display the Data Type Assistant. Then, choose an option from the **Mode** drop-down menu.

   The **Data** properties dialog box 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 MATLAB Function block 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 29-66.
`Built in`	Select from the drop-down list of supported data types, as described in "Built-In Data Types for Arguments" on page 29-67.
`Fixed point`	Specify the fixed-point data properties as described in "Specifying Simulink® Fixed Point™ Data Properties" on page 29-68.
`Expression`	Enter an expression that evaluates to a data type, as described in "Specifying Argument Types with Expressions" on page 29-68.

Mode	What to Specify
`Bus Object`	In the **Bus object** field, enter the name of a `Simulink.Bus` object to define the properties of a MATLAB structure. You must define the bus object in the base workspace. See "How Structure Inputs and Outputs Interface with Bus Signals" on page 29-81. **Note** You can click the **Edit** button to create or modify `Simulink.Bus` objects using the Simulink Bus Editor (see "Manage Bus Objects with the Bus Editor" on page 48-24).
`Enumerated`	In the Enumerated field, enter the name of a `Simulink.IntEnumType` object that you define in the base workspace. See "Enumerated Types Supported in MATLAB Function Blocks" on page 29-105 and "Define Enumerated Data Types for MATLAB Function Blocks" on page 29-106.

Inheriting Argument Data Types

MATLAB Function block function arguments can inherit their data types, including fixed point types, from the signals to which they are connected. , and set data type mode using one of these methods:

1. Select the argument of interest in the Ports and Data Manager
2. In the **Data** properties dialog, select `Inherit: Same as Simulink` from the **Type** drop-down menu.

See "Built-In Data Types for Arguments" on page 29-67 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**.

After you build the model, the **Compiled Type** column of the Ports and Data Manager gives the actual type inherited from Simulink in the compiled simulation application.

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 MATLAB Function blocks can have inherited data types, sizes, and complexities like ordinary 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 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 MATLAB Function block function arguments as expressions in the Ports and Data Manager.

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".
   - `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

Specifying Simulink Fixed Point Data Properties

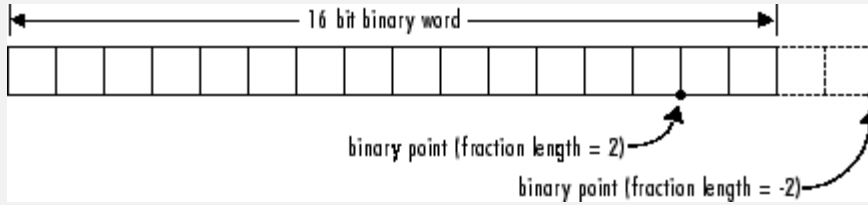
MATLAB Function blocks can represent signals and parameter values as fixed-point numbers. To simulate models that use fixed-point data in MATLAB Function blocks, you must install the Simulink Fixed Point product on your system.

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. 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. Specify **Minimum**, **Maximum**, or both Limit range properties.
2. 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, Simulink 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. For instructions on autoscaling fixed-point data, see "Scaling".

Using Data Type Override with the MATLAB Function Block

If you set the Data Type Override mode to `Double` or `Single` in Simulink, the MATLAB Function block sets the type of all inherited input signals and parameters to `fi double` or `fi single` objects respectively (see "MATLAB Function Block with Data Type Override" 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 29-37) 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 **Analysis** menu, select **Fixed-Point Tool**.
2. Set the value of the **Data type override** parameter to `Double` or `Single`.

Size Function Arguments

In this section...

Specifying Argument Size

To examine or specify the size of an argument, follow these steps:

1. From the MATLAB Function Block Editor, select **Edit Data**.
2. Enter the size of the argument in the **Size** field of the Data properties dialog, located in the **General** pane.

Note The default value is `-1`, indicating that size is inherited, as described in "Inheriting Argument Sizes from Simulink" on page 29-72.

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 "Add Parameter Arguments" on page 29-75.

After you compile the model, the **Compiled Size** column in the **Contents** pane displays the actual size used in the compiled simulation application.

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 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

- Number of dimensions equals the length of the vector.
- 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 displays the actual size used in the compiled simulation application.

Add Parameter Arguments

Parameter arguments for 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 MATLAB Function block.

To add a parameter argument to a function for a MATLAB Function block.

1. In the MATLAB Function Block Editor, add an argument to the function header of the 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 MATLAB Function block. For information on declaring parameters for masked subsystems, see "How Mask Parameters Work" on page 26-4.

2. Bring focus to the MATLAB Function block.

   The new argument appears as an input port in the Simulink diagram.

3. In the MATLAB Function Block Editor, select **Edit Data**.

4. Select the new argument.

5. Set **Scope** to `Parameter`.

6. Examine the 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 MATLAB Function block to maintain MATLAB consistency. As a result, you can test functions in a MATLAB Function block by copying and pasting them to MATLAB.

Resolve Signal Objects for Output Data

In this section...

Implicit Signal Resolution

MATLAB Function blocks participate in signal resolution with Simulink signal objects. By default, output data from 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.

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 "Symbol Resolution" on page 4-76 and "Explicit and Implicit Symbol Resolution" on page 4-80 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 > Model 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 a MATLAB Function Block

To disable implicit signal resolution for a MATLAB Function block in your model, follow these steps:

1 Right-click the MATLAB Function block and select **Block Parameters (Subsystem)** 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 a 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 **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**.

Types of Structures in MATLAB Function Blocks

In MATLAB Function blocks, you can define structure data as inputs or outputs that interact with bus signals. MATLAB Function blocks also support arrays of buses (for more information, see "Combine Buses into an Array of Buses" on page 48-77). You can also define structures inside MATLAB functions that are not part of MATLAB Function blocks (see "Structure Definition for Code Generation" on page 36-2.

The following table summarizes how to create different types of structures in 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 MATLAB function for interfacing to other environments. See "Create Structures in MATLAB Function Blocks" on page 29-84.
Output	Create structure data with scope of `Output`.	
Local	Create a local variable implicitly in a MATLAB function.	See "Define Scalar Structures for Code Generation" on page 36-4.
Persistent	Declare a variable to be persistent in a MATLAB function.	See "Make Structures Persistent" on page 36-9.
Parameter	Create structure data with scope of `Parameter`	See "Define and Use Structure Parameters" on page 29-91.

Structures in MATLAB Function blocks can contain fields of any type and size, including muxed signals, buses, and arrays of structures.

Attach Bus Signals to MATLAB Function Blocks

For an example of how to use structures in a MATLAB Function block, open the model emldemo_bus_struct.

In this model, a 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`.

To explore the MATLAB function `fcn`, double-click the MATLAB Function block. Notice that the code 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`.

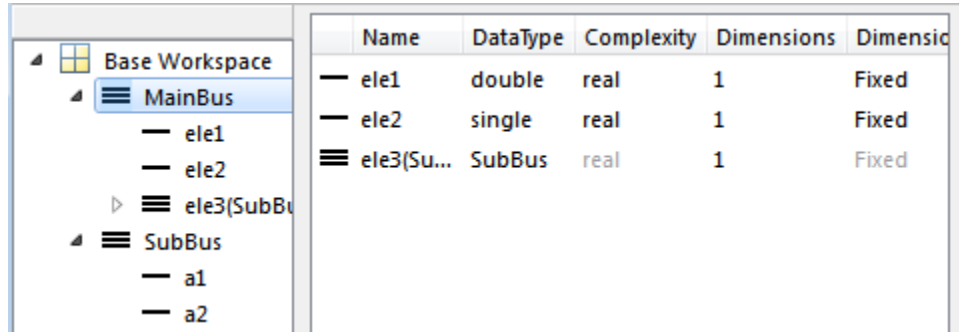
Structure Definitions in Example

Here are the definitions of the structures in the MATLAB Function block in the example, as they appear in the Ports and Data Manager:

Name	Scope	Port	Resolve Signal	DataType	Size
inbus	Input	1		Inherit: Same as Simulink	-1
outbus	Output	1	☐	Bus: MainBus	1
outbus1	Output	2	☐	Bus: SubBus	1

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 “Create Structures in MATLAB Function Blocks” on page 29-84). 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 "Index Substructures and Fields" on page 29-83). 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 MATLAB Function blocks, see "Create Structures in MATLAB Function Blocks" on page 29-84.

How Structure Inputs and Outputs Interface with Bus Signals

Buses in a Simulink model appear inside the MATLAB Function block as structures; structure outputs from the MATLAB Function block appear as buses in Simulink models. When you create structure inputs, the 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 MATLAB function.

You connect structure inputs and outputs from 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 MATLAB Function blocks

Working with Virtual and Nonvirtual Buses

MATLAB Function blocks supports nonvirtual buses only (see "Virtual and Nonvirtual Buses" on page 48-10). When models that contain MATLAB Function block inputs and outputs are built, hidden converter blocks are used to convert bus signals for code generation from MATLAB, as follows:

- Converts incoming virtual bus signals to nonvirtual buses for inputs to structures in MATLAB Function blocks
- Converts outgoing nonvirtual bus signals from MATLAB Function blocks to virtual bus signals

Rules for Defining Structures in MATLAB Function Blocks

Follow these rules when defining structures in MATLAB Function blocks:

- For each structure input or output in a MATLAB Function block, you must define a `Simulink.Bus` object in the base workspace to specify its type. For more information, see Simulink.Bus.
- MATLAB Function blocks support nonvirtual buses only (see "Working with Virtual and Nonvirtual Buses" on page 29-81).

Index Substructures and Fields

As in MATLAB, you index substructures and fields structures in MATLAB Function blocks by using dot notation. However, for code generation from MATLAB, you must reference field values individually (see "Structure Definition for Code Generation" on page 36-2).

For example, in the emldemo_bus_struct model described in "Attach Bus Signals to MATLAB Function Blocks" on page 29-79, the MATLAB function uses dot notation to index fields and substructures:

```
function [outbus, outbus1] = fcn(inbus)
%#codegen
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 the code generation software 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`

Create Structures in MATLAB Function Blocks

Here is the workflow for creating a structure in a MATLAB Function block:

1. Decide on the type (or scope) of the structure (see "Types of Structures in MATLAB Function Blocks" on page 29-78).
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 MATLAB Function block, as described in "Adding Data to a MATLAB Function Block" on page 29-42. 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 MATLAB Function Blocks" on page 29-82.
Output	1. Create a `Simulink.Bus` object in the base workspace to define the structure output. 2. Add data to the 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 MATLAB function, as described in "Structure Definition for Code Generation" on page 36-2. 4. Make sure the number, type, and size of fields in the output structure variable definition match the properties of the `Simulink.Bus` object.

For Structure Scope:	Follow These Steps:
Local	Define the structure implicitly as a local variable in the MATLAB function, as described in "Structure Definition for Code Generation" on page 36-2. By default, local variables in MATLAB Function blocks are temporary.
Persistent	Define the structure implicitly as a persistent variable in the MATLAB function, as described in "Make Structures Persistent" on page 36-9.
Parameter	**1** Create a structure variable in the base workspace. **2** Add data to the MATLAB Function block with the following properties: • **Name** = same name as the structure variable you created in step 1. • **Scope** = `Parameter` See "Define and Use Structure Parameters" on page 29-91.

Assign Values to Structures and Fields

You can assign values to any structure, substructure, or field in a MATLAB Function block. 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 "Create Structures in MATLAB Function Blocks" on page 29-84).
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.

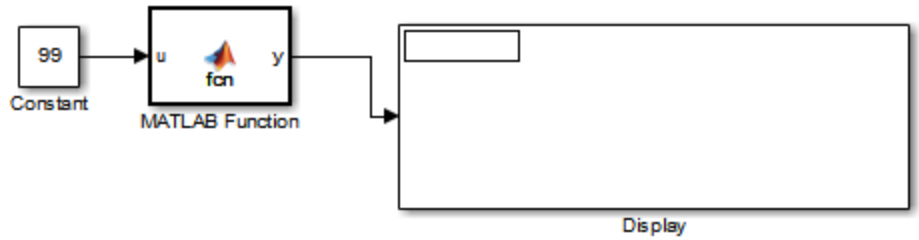
For example, the following table presents valid and invalid structure assignments based on the specifications for the model described in "Attach Bus Signals to MATLAB Function Blocks" on page 29-79:

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`.

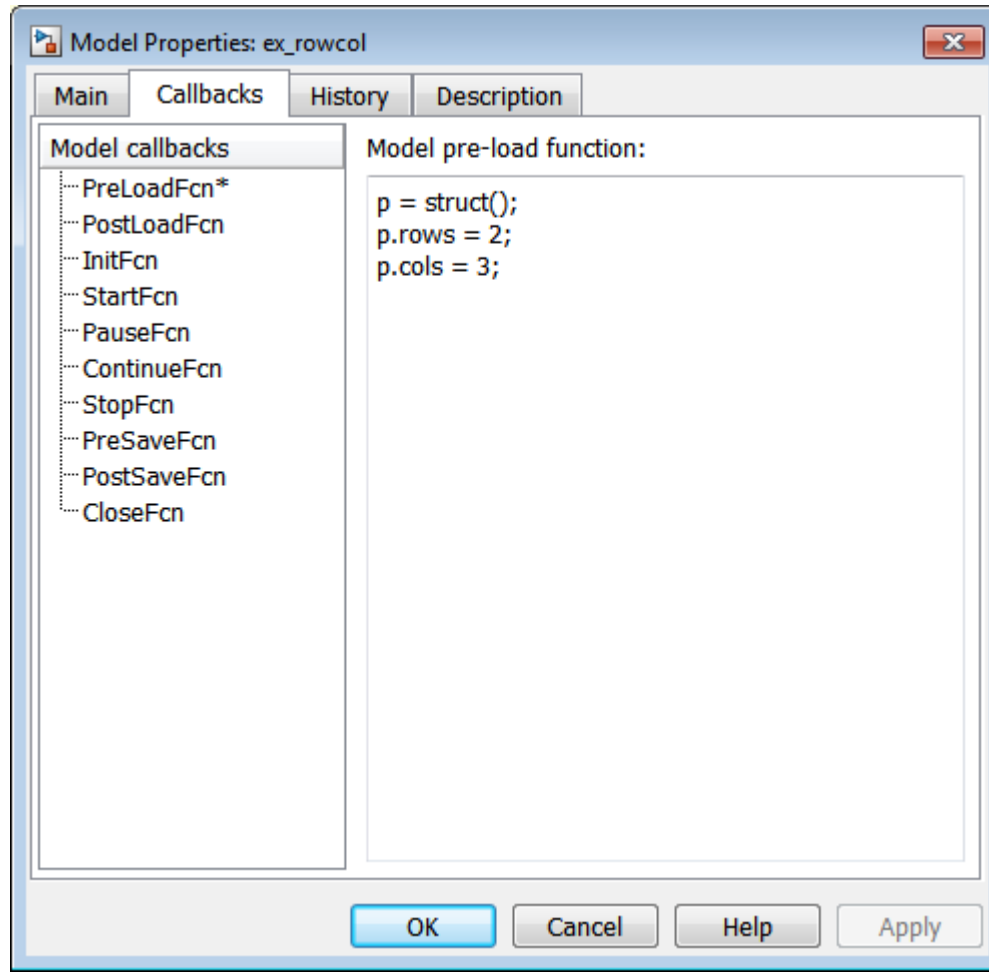
Assignment	Valid or Invalid?	Rationale
`outbus1 = inbus.ele3;`	Valid	Both `outbus1` and `inbus.ele3` have the same type and size because each is defined by the `Simulink.Bus` object `SubBus`.
`outbus1 = inbus;`	Invalid	The structure `outbus1` is defined by a different `Simulink.Bus` object than the structure `inbus`.

Initialize a Matrix Using a Non-Tunable Structure Parameter

The following simple example uses a non-tunable structure parameter input to initialize a matrix output. The model looks like this:



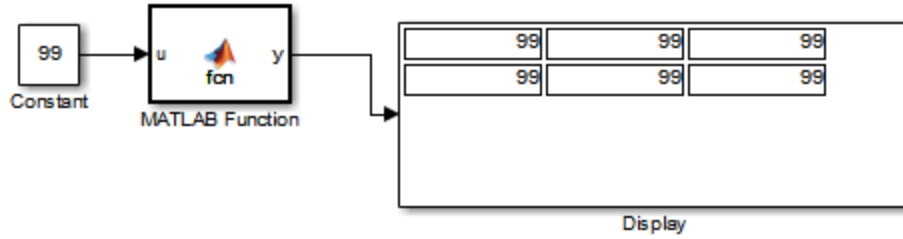
This model defines a structure variable `p` in its pre-load callback function, as follows:



The structure `p` has two fields, `rows` and `cols`, which specify the dimensions of a matrix. The 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`:


99
Constant
u
fcn
y
MATLAB Function
99
99
99
99
99
99
Display

Define and Use Structure Parameters

In this section...

Defining Structure Parameters

To define structure parameters in 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 "Structure Parameters" on page 24-16.

2. In the Ports and Data Manager, add data in the 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 MATLAB Function block. (These FIMATH properties appear in the properties dialog box for MATLAB Function blocks.)

Limitations of Structures and Buses in MATLAB Function Blocks

- Structures in MATLAB Function blocks support a subset of the operations available for MATLAB structures (see “Structures”).
- You cannot use variable-size data with arrays of buses (see “Array of Buses Limitations” on page 48-81).

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 MATLAB Function Blocks Implement Variable-Size Data

You can define variable-size arrays and matrices as inputs, outputs, and local data in 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 using variable-size data in Simulink, see “Variable-Size Signal Basics” on page 49-2.

Enable Support for Variable-Size Data

Support for variable-size data is enabled by default for MATLAB Function blocks. To modify this property for individual blocks:

1. In the MATLAB Function Block Editor, select **Edit Data**.
2. Select or clear the check box **Support variable-size arrays**.

Declare Variable-Size Inputs and Outputs

1. In the MATLAB Function Block Editor, select **Edit Data**.
2. Select **Add > Data**
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.

Filter a Variable-Size Signal

In this section...

About the Example

The following example appears throughout this section to illustrate how 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

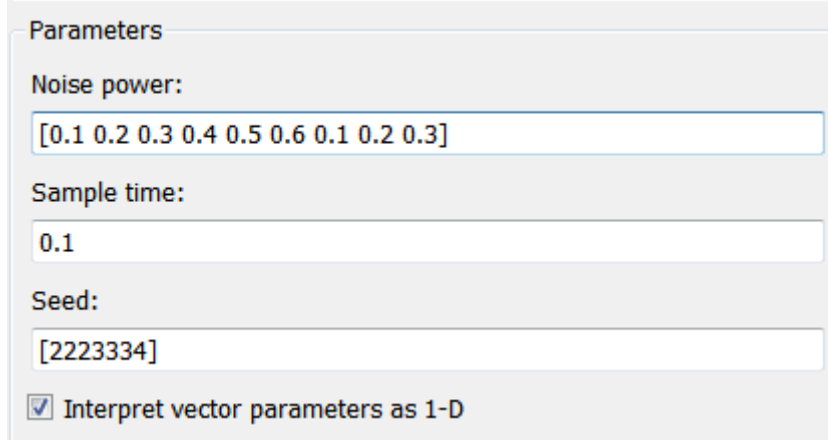
Open the example model by typing `emldemo_process_signal` at the MATLAB command prompt. The model contains the following blocks:

Simulink Block	Description
Band-Limited White Noise	Generates a set of normally distributed random values as the source of the white noise signal.
MATLAB Function `uniquify`	Filters out signal values that are not unique to within a specified tolerance of each other.

Simulink Block	Description
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.

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) %#codegen
```

```
y = uniquetol(u,0.2);
```

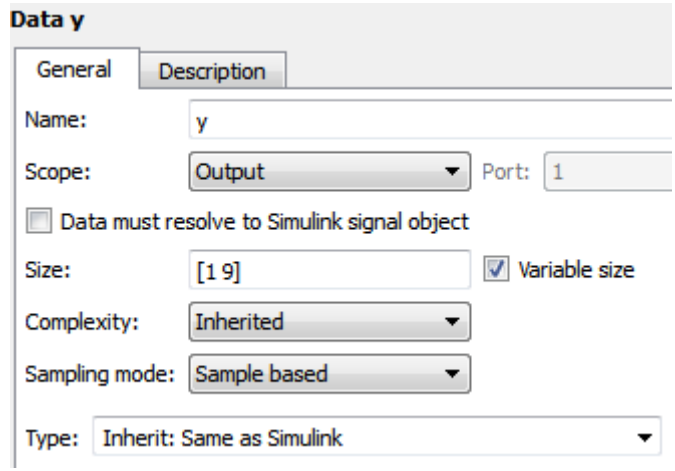
The `uniquify` function calls an external MATLAB function `uniquetol` to filter the signal values. `uniquify` passes the 1-by-9 vector of white noise signal values as the first argument and the tolerance value as the second argument. Here is the code for `uniquetol`:

```
function B = uniquetol(A,tol) %#codegen

A = sort(A);
coder.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:

```
coder.varsize('B',[1 100]);
```

In this statement, `coder.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, shown here as [1 9].

MATLAB Function Block: avg

This block averages signal values filtered by the `uniquify` block as follows:

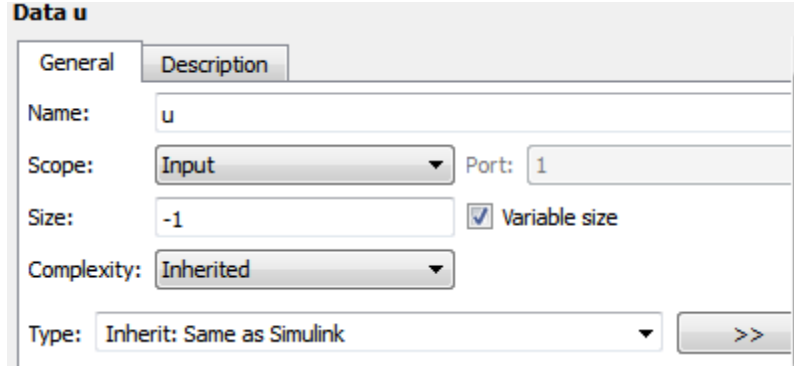
If number of signal values:	The MATLAB Function block:
> 1 and divisible by 2	Averages every consecutive pair of values
> 1 but *not* divisible by 2	Drops the first (smallest) value and average the remaining consecutive pairs
= 1	Returns the value unchanged

The `avg` function outputs the results to the **Average values** scope. Here is the code:

```
function y = avg(u) %#codegen

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`.



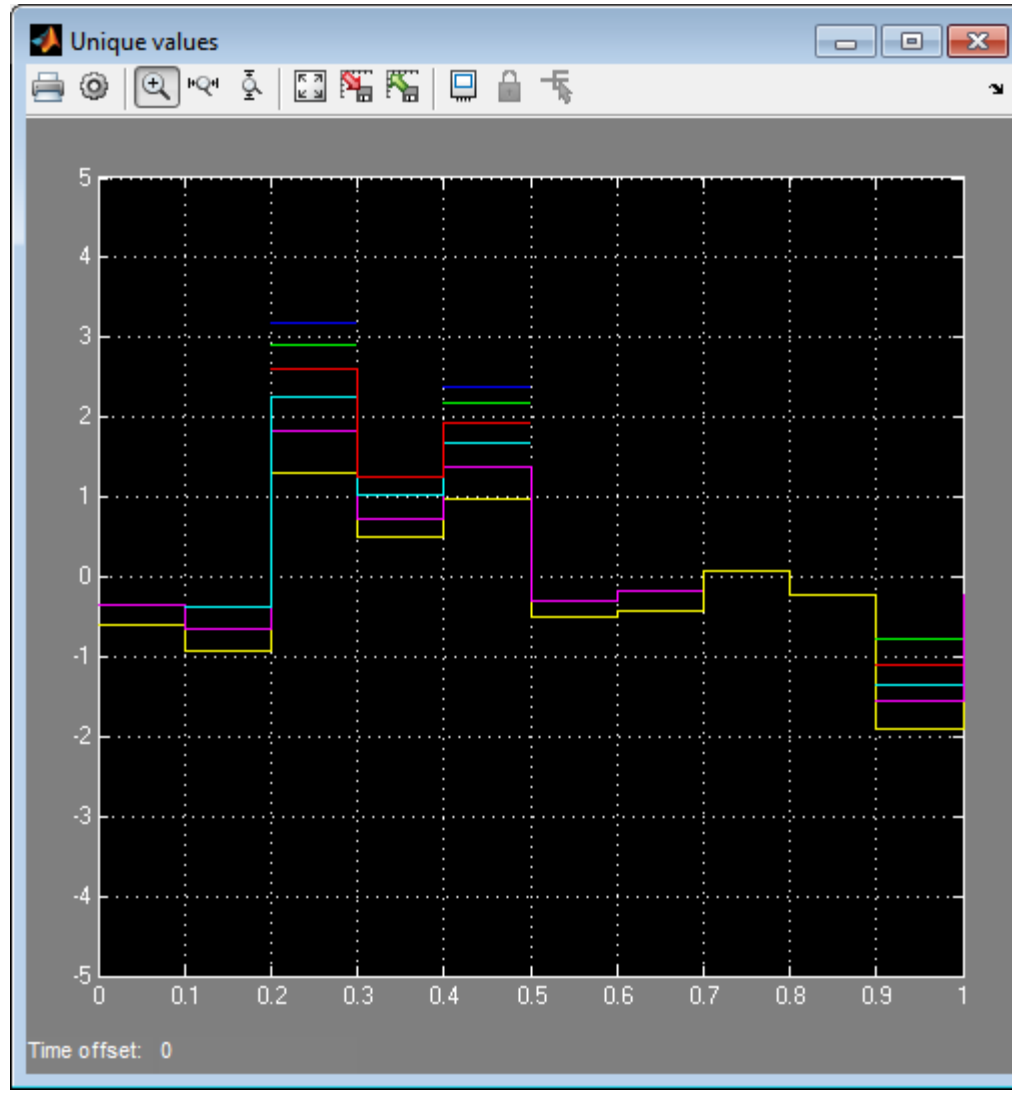
The `avg` function calls an external MATLAB function `nway` to calculate the average of every two consecutive signal values. Here is the code for `nway`:

```
function B = nway(A,n) %#codegen

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
```

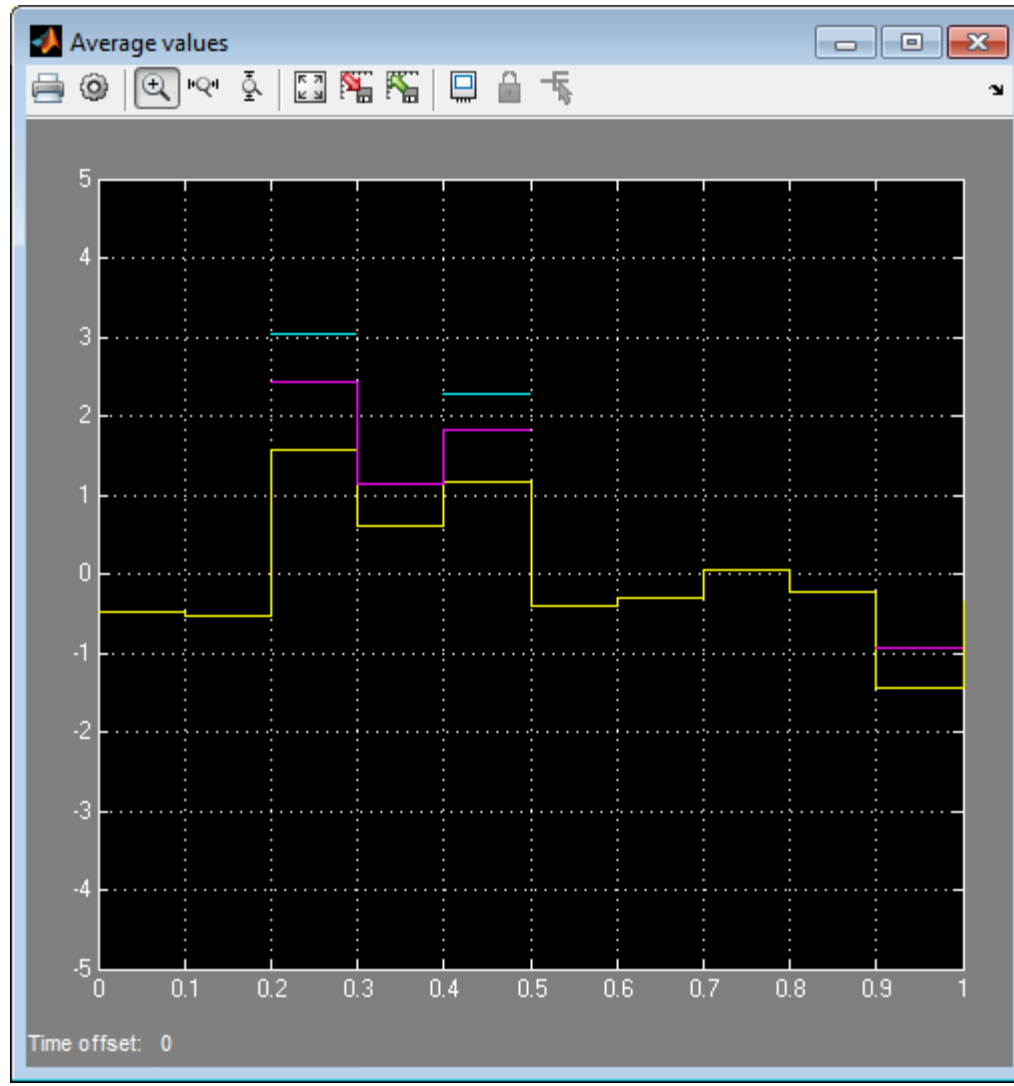
Variable-Size Results

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
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Time offset: 0

Enumerated Types Supported in 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, 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 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 43-6.

Define Enumerated Data Types for MATLAB Function Blocks

You define enumerated data types for MATLAB Function blocks in the same way as for other Simulink blocks:

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.

Add Inputs, Outputs, and Parameters as Enumerated Data

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 a MATLAB Function block:

1. In the MATLAB Function Block Editor, select **Edit Data**.
2. In the Ports and Data Manager, select **Add > Data**.
3. 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.
4. In the **Type** field, specify an enumerated type.

   To specify an explicit enumerated type:

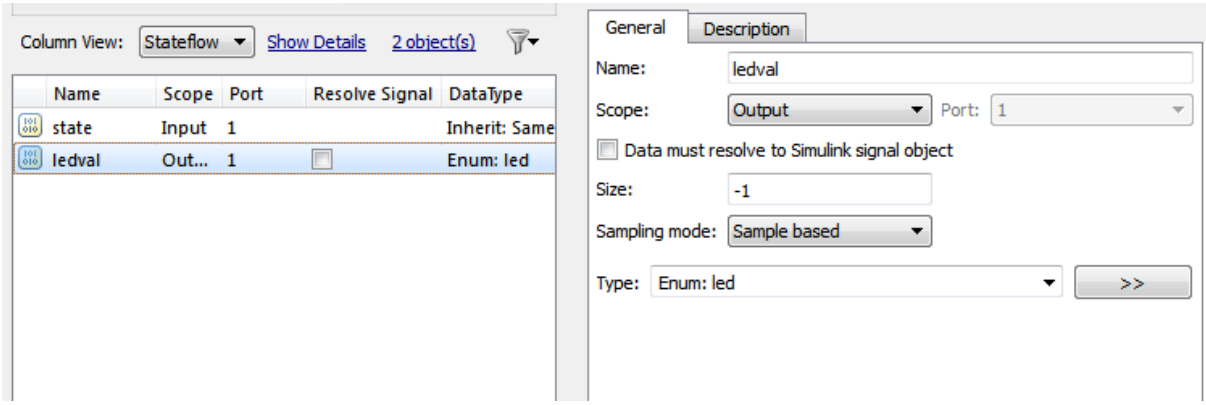
   a. Select `Enum:<class name>` from the drop-down menu in the **Type** field.

   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:led` in the **Type** field. (See "Define Enumerated Data Types for MATLAB Function Blocks" on page 29-106.)

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 `ledval` has an explicit enumerated type, `led`:



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 `switchmode` from a Simulink signal:

Name	Scope	Port	Resolve Signal	DataType	Compiled Type
ledval	Output	1	☐	Enum: led	led
state	Input	1		Inherit: Same as Simulink	switchmode

5 Click **Apply**.

Basic Approach for Adding Enumerated Data to MATLAB Function Blocks

Here is the basic workflow for using enumerated data in MATLAB Function blocks:

Step	Action	How?
1	Define an enumerated data type that inherits from `Simulink.IntEnumType`.	See "Define Enumerated Data Types for MATLAB Function Blocks" on page 29-106.
2	Add the enumerated data to your MATLAB Function block.	See "Add Inputs, Outputs, and Parameters as Enumerated Data" on page 29-107.
3	Instantiate the enumerated type in your MATLAB Function block.	See "Instantiate Enumerated Data in MATLAB Function Blocks" on page 29-110.
4	Simulate and/or generate code.	See "Enumerations".

Instantiate Enumerated Data in MATLAB Function Blocks

To instantiate an enumerated type in a MATLAB Function block, use dot notation to specify *`ClassName.EnumName`*. For example, the following MATLAB function `checkState` instantiates the enumerated types `myMode` and `myLED` from “Control an LED Display” on page 29-111. The dot notation appears highlighted in the code.

```
function led = checkState(state)
%#codegen

if state == myMode.ON
    led = myLED.GREEN;
else
    led = myLED.RED;
end
```

Control an LED Display

In this section...

About the Example

The following example illustrates how 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 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: `switchmode` to represent the set of allowable modes and `led` 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.

Class Definition: switchmode

Here is the class definition of the `switchmode` enumerated data type:

```
classdef(Enumeration) switchmode < 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, `switchmode.m`.

Class Definition: led

Here is the class definition of the `led` enumerated data type:

```
classdef(Enumeration) led < Simulink.IntEnumType
    enumeration
        GREEN(1),
        RED(8),
    end
end
```

This definition must reside on the MATLAB path in a file called `led.m`. The set of allowable values do not need to be consecutive integers.

Simulink Model

Open the example model by typing `emldemo_led_switch` at the MATLAB command prompt. 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 `switchmode`	Converts the value of type `int32` to the enumerated type `switchmode`. In the Data Type 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 Type Conversion block parameters have these settings: • Output minimum: `[]`

Simulink Block	Description
	• Output maximum: `[]` • Output data type: `Enum:switchmode` For more information about specifying enumerated types in Simulink models, see "Specify an Enumerated Data Type" on page 43-26.
MATLAB Function `checkState`	Evaluates enumerated data input `state` to determine the color to output as enumerated data `ledval`. See "MATLAB Function Block: checkState" on page 29-113.
Display	Displays the enumerated value of output `led`.

MATLAB Function Block: checkState

The function `checkState` in the 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 ledval = checkState(state)
%#codegen

if state == switchmode.ON
    ledval = led.GREEN;
else
    ledval = led.RED;
end
```

The input `state` inherits its enumerated type `switchmode` from the Simulink step signal; the enumerated type of output `ledval` is explicitly declared as `Enum:led`:

Name	Scope	Port	Resolve Signal	DataType	Compiled Type
ledval	Output	1	☐	Enum: led	led
state	Input	1		Inherit: Same as Simulink	switchmode

Explicit enumerated type declarations must include the prefix `Enum:`. For more information, see "Define Enumerated Data Types for MATLAB Function Blocks" on page 29-106.

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 44-25.

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 44-19).

The code generation software supports the following enumerated data operations:

- Assignment (=)
- Relational operations (==, ~=, <, >, <=, >=,)
- Cast
- Indexing

For more information, see “Enumerated Data”.

Using Enumerated Data in MATLAB Function Blocks

In this section...

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, the code generation software 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.

Limitations of Enumerated Types

Enumerated types in MATLAB Function blocks are subject to the limitations imposed by the code generation software. See "Enumerated Data Definition for Code Generation" on page 37-2.

Share Data Globally

In this section...

When Do You Need to Use Global Data?

You might need to use global data with a MATLAB Function block if:

- You have multiple MATLAB functions that use global variables and you want to call these functions from MATLAB Function blocks.
- You have an existing model that uses a large amount of global data and you are adding a 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 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 46-2.) 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 29-118.

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 MATLAB Function block to map the data to data store memory. This difference allows global data in 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 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 MATLAB Function Block

To use global data in your MATLAB Function block, or in any code that this block calls, you must:

1. Declare a global variable in your MATLAB Function block, or in any code that is called by the 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 MATLAB Function block.

For more information, see “How to Use Data Store Memory Blocks” on page 29-120 and “How to Use Simulink.Signal Objects” on page 29-122.

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 29-120
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 29-122
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 29-122

How to Use Data Store Memory Blocks

1. Add a MATLAB Function block to your model.
2. Double-click the MATLAB Function block to open its editor.
3. Declare a global variable in the MATLAB Function block code, or in any MATLAB file that the 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 MATLAB Function block code.
   b. Set **Data type** to an explicit data type.

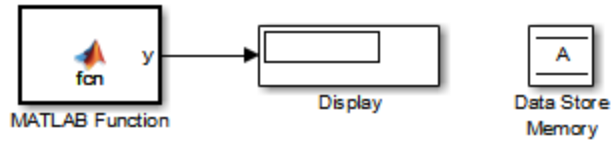
      The data type cannot be `auto`.
   c. Set **Signal type** to `real`.

      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 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 29-37.

Example: Using Data Store Memory with the MATLAB Function Block



This simple model demonstrates how a MATLAB Function block uses the global data stored in Data Store Memory block `A`.

1

2 Double-click the MATLAB Function block to open the MATLAB Function Block Editor.

   The MATLAB Function block modifies the value of global data `A` each time it executes.

```
function y = fcn
%#codegen
global A;
A = A+1;
y = A;
```

3 In the MATLAB Function Block Editor, select **Edit Data**.

4 In the Ports and Data Manager, 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 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 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.

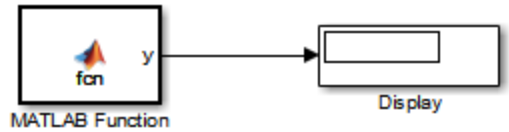
   b. Set the **Scope** of the data to `Data Store Memory`.

3. Declare a global variable with the same name in the code for your MATLAB Function block.

```
global Sig;
```

For more information on using the Ports and Data Manager, see “Ports and Data Manager” on page 29-37.

Example: Using a Simulink.Signal Object with a MATLAB Function Block



1. Open the `simulink_signal_local` model. At the MATLAB command line, enter:

   ```
   addpath(fullfile(docroot, 'toolbox', 'simulink', 'examples'))
   simulink_signal_local
   ```

2. Double-click the MATLAB Function block to open its editor.

   The MATLAB Function block modifies the value of global data `A` each time it executes.

   ```
   function y = fcn
   %#codegen
   global A;
   A = A+1;
   y = A;
   ```

3. From the MATLAB Function Block Editor menu, select **Edit Data**.

4. In the Ports and Data Manager, 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**.

6 In the left pane of the Model Explorer, 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 attributes for `A`, including.

Attribute	Value
Data type	`double`
Complexity	`real`
Dimensions	`1`
Sample mode	`Sample based`
Initial value	`5`

8 Simulate the model.

The 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 "Data Store Diagnostics" on page 46-38.

Note If you pass data store memory arrays to functions, optimizations such as `A=foo(A)` might result in the code generation software marking the entire contents of the array as read or written even though only some elements were accessed.

Limitations of Using Shared Data in MATLAB Function Blocks

There is no Data Store Memory support for:

- MATLAB structures
- Variable-sized data

Add Frame-Based Signals

In this section...

About Frame-Based Signals

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 have an available DSP System Toolbox license. For more information about using frame-based signals, see "What Is Frame-Based Processing?".

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, use the data property called **Sampling mode** to specify that your output is a frame-based signal for downstream processing.

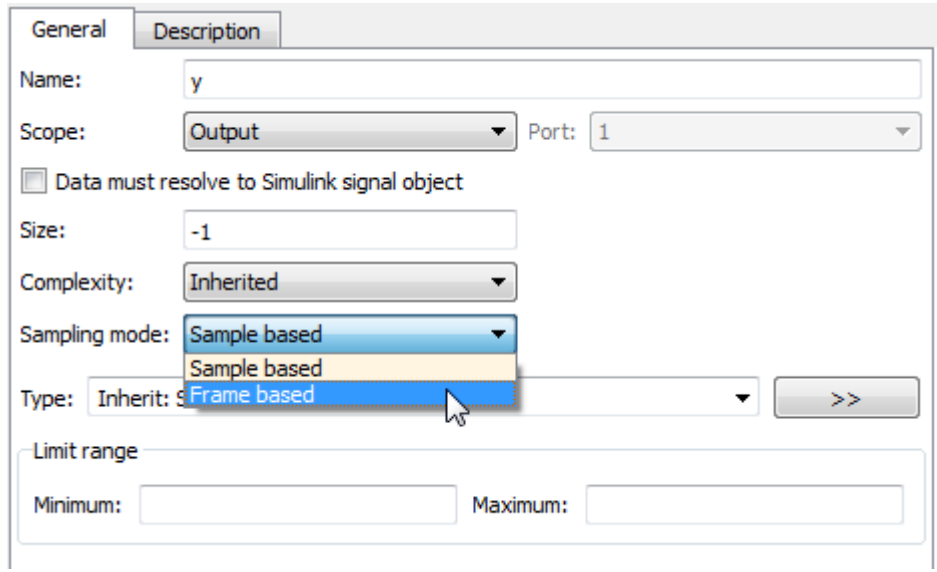
Supported Types for Frame-Based Data

MATLAB Function blocks accept frame-based signals of any data type *except* bus objects. For a list of supported types, see "Supported Variable Types" on page 33-18.

Adding Frame-Based Data in MATLAB Function Blocks

To add frame-based data to a MATLAB Function block, follow these steps:

1. Add an input or output, as described in "Adding Data to a MATLAB Function Block" on page 29-42.
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.

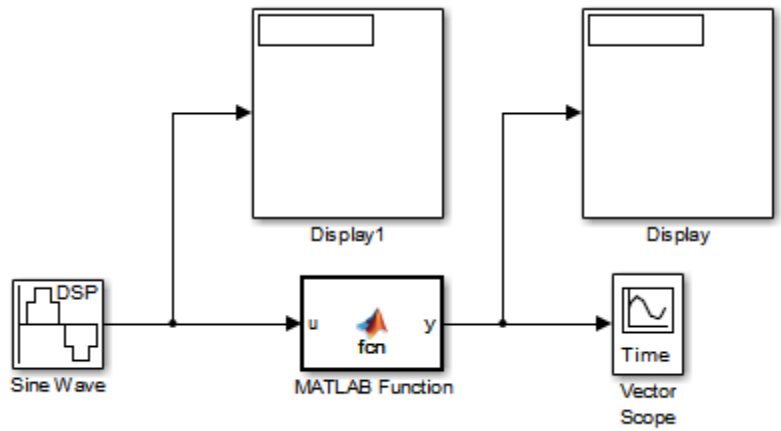
Note For more information on how to set data properties, see "Defining Data in the Ports and Data Manager" on page 29-43.

Examples of Frame-Based Signals in MATLAB Function Blocks

This topic presents examples of how to work with frame-based signals in MATLAB Function blocks.

Multiplying a Frame-Based Signal by a Constant Value

In the following example, a 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.

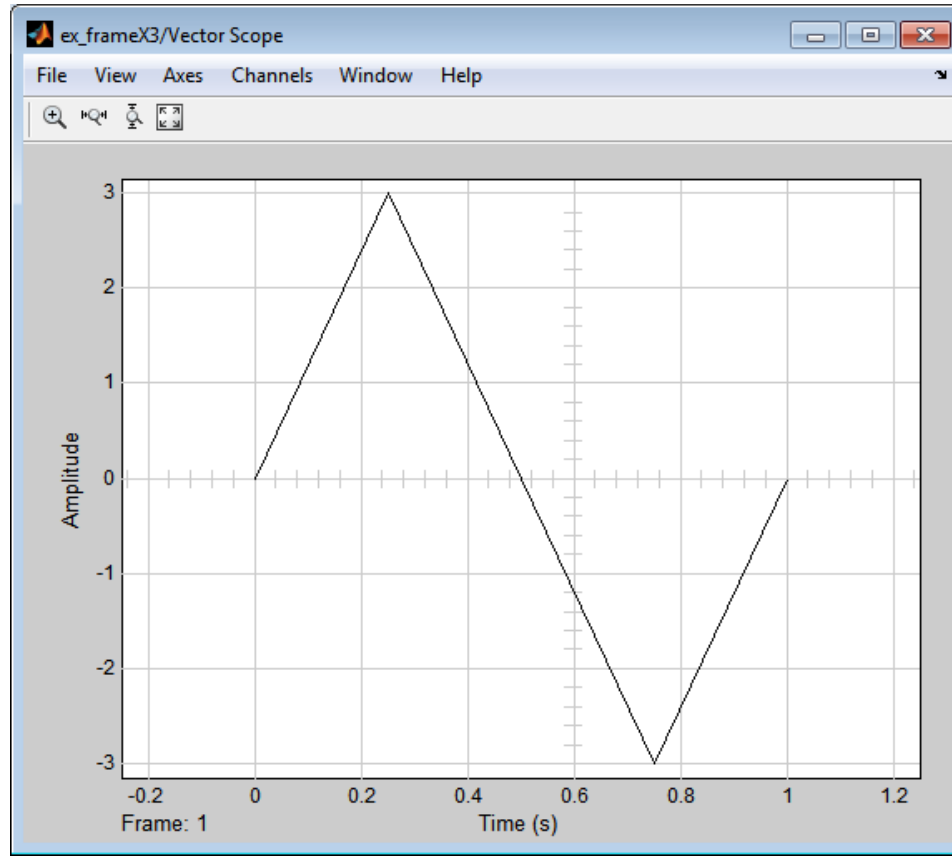


The MATLAB Function block contains the following code:

```
function y  = fcn(u)
y = u*3;
```

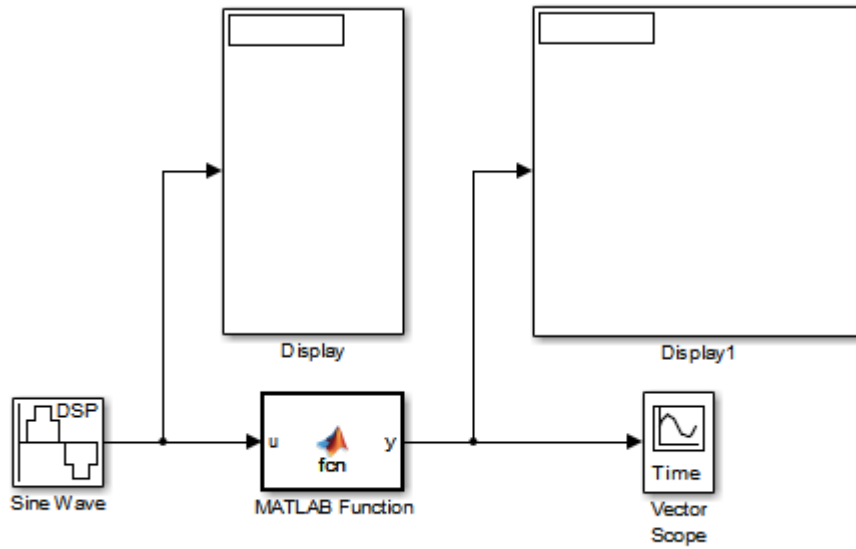
Input `u` and output `y` inherit size, complexity, and data type from the input sine wave signal, a 5-by-1 vector of signed, generalized fixed-point values. For `y` to output a frame of data, you must explicitly set **Sampling mode** to `Frame based` (see "Adding Frame-Based Data in MATLAB Function Blocks"

on page 29-127). When you simulate this model, the MATLAB Function block multiplies each input signal by 3 and outputs the result as a frame.



Adding a Channel to a Frame-Based Signal

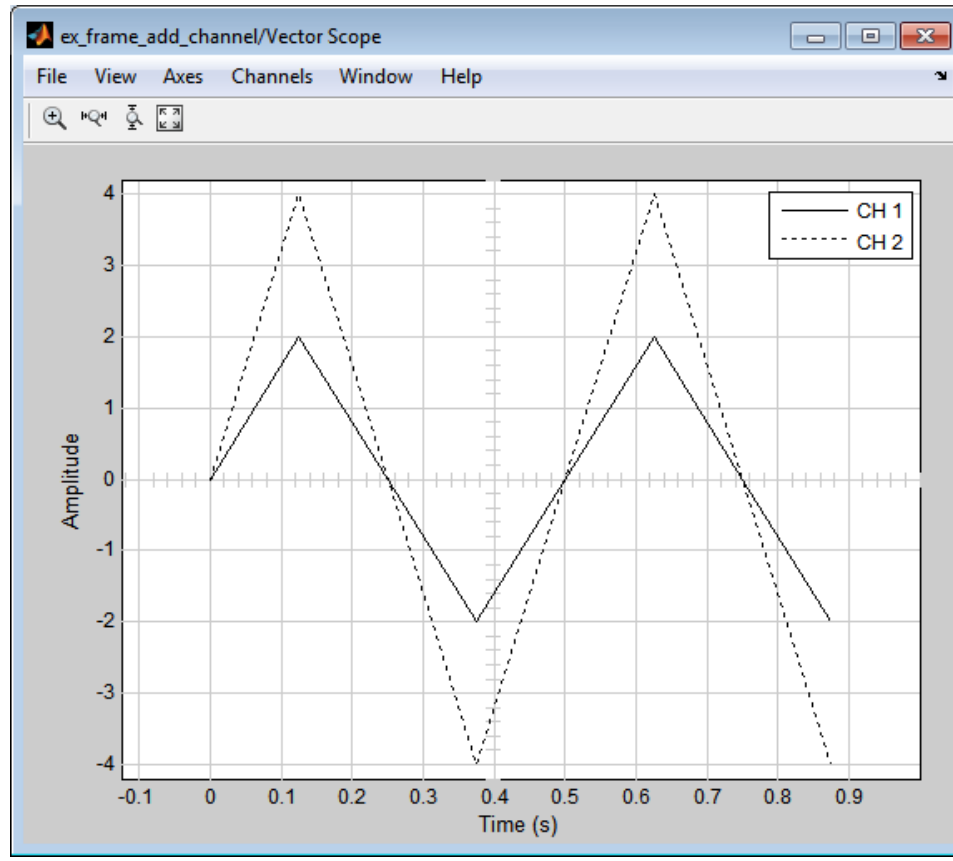
In the following example, a MATLAB Function block adds a channel to a frame-based single-channel input and outputs the multichannel result. The input signal is a sine wave that contains 8 samples per frame.



The MATLAB Function block contains the following code:

```
function y = fcn(u)
a = [0;4;0;-4;0;4;0;-4];
y = [u a];
```

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 MATLAB Function Blocks" on page 29-127). 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 MATLAB Function block outputs the new multichannel signal.


ex_frame_add_channel/Vector Scope
File View Axes Channels Window Help
CH 1
CH 2
Amplitude
Time (s)
4
3
2
1
0
-1
-2
-3
-4
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

Create Custom Block Libraries

In this section...

When to Use MATLAB Function 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 a MATLAB Function block library.

As with other Simulink block libraries, you can specialize each instance of 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 29-145).

For more information about Simulink block libraries, see "About Block Libraries and Linked Blocks" on page 28-2.

How to Create Custom MATLAB Function Block Libraries

Here is a basic workflow for creating custom block libraries with MATLAB Function blocks. To work through these steps with an example, see "Example: Creating a Custom Signal Processing Filter Block Library" on page 29-133.

1. Add polymorphic MATLAB code to 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 29-150.

3. Optionally, customize your library code using masking.

4. Add instances of 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 MATLAB Function Block Libraries" on page 29-132 to show you how to:

- Create a library of signal processing filter algorithms using 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 a 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 MATLAB Function Library Blocks

1. In Simulink, create a library model by selecting **File > New > Library**
2. Drag three 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 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  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 code generation 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 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 MATLAB Function blocks inherit these properties. To explicitly configure data to inherit properties:

1. Open a MATLAB Function block and select **Edit Data**.
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 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 29-37
- "Inheriting Argument Data Types" on page 29-66

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 Right-click the my_conv_filter block and select **Subsystem & Model Reference > Create Subsystem from Selection**.

   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 > Create Mask** 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 Parameter icon:

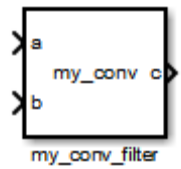
   f Assign the following properties to the new dialog parameter:

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 **Block Parameters (Subsystem)** from the context menu.

b In the subsystem parameters dialog box, select the **Treat as atomic unit** check box.

The dialog box expands to display new fields.

c To generate a reusable function, select the Code Generation tab and in the **Function packaging** 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.

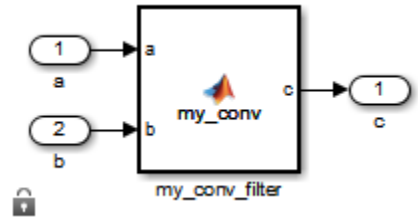
---

d Click **OK**.

3 Define the `shape` parameter in the MATLAB Function `my_conv`:

a Right-click the my_conv_filter subsystem and select **Mask > 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 MATLAB Function Block Editor.

d In the MATLAB Function Block Editor, select **Edit Data**.

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 29-135.

h Click **Apply**, close the Ports and Data Manager, and return to the MATLAB Function Block Editor.

4 Use the shape parameter to determine the size of the convolution to output:

a In the MATLAB Function Block 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 MATLAB Function Block Editor.

See Also.

- "Masking"

Step 4: Add Instances of 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.

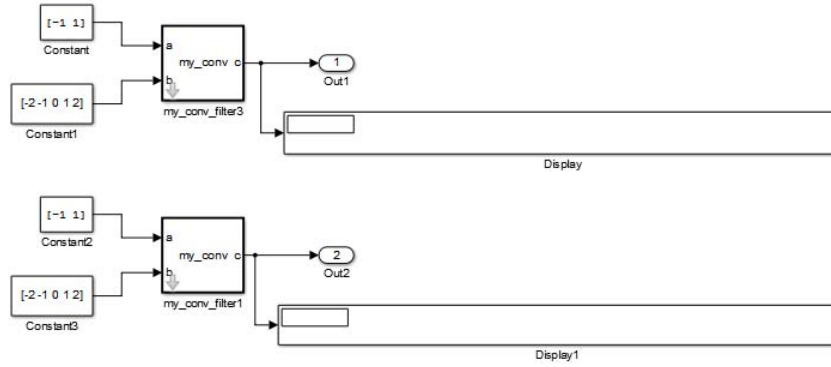
1 Open a new Simulink model.

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. Your model should look something like this:



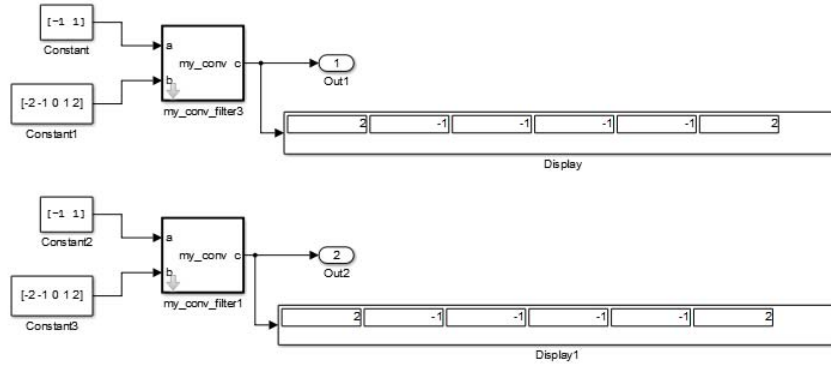
Both library instances share the same size, type, and complexity for inputs `a` and `b` respectively.

4 Double-click each library instance.

The `shape` parameter defaults to **full** for both instances.

5 Simulate the model.

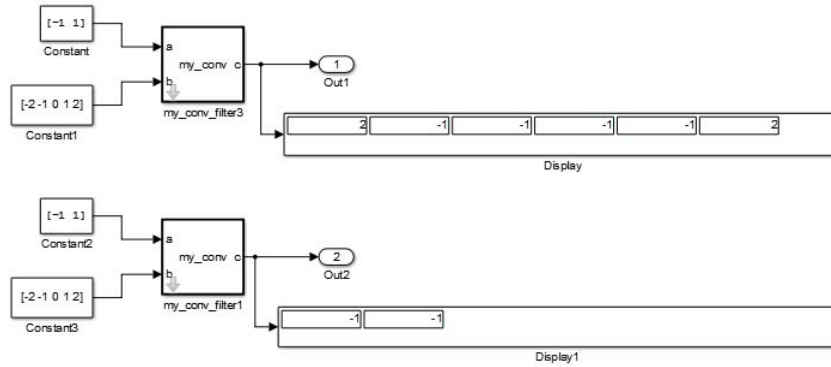
Each library instance outputs the same result, the full 2D convolution:



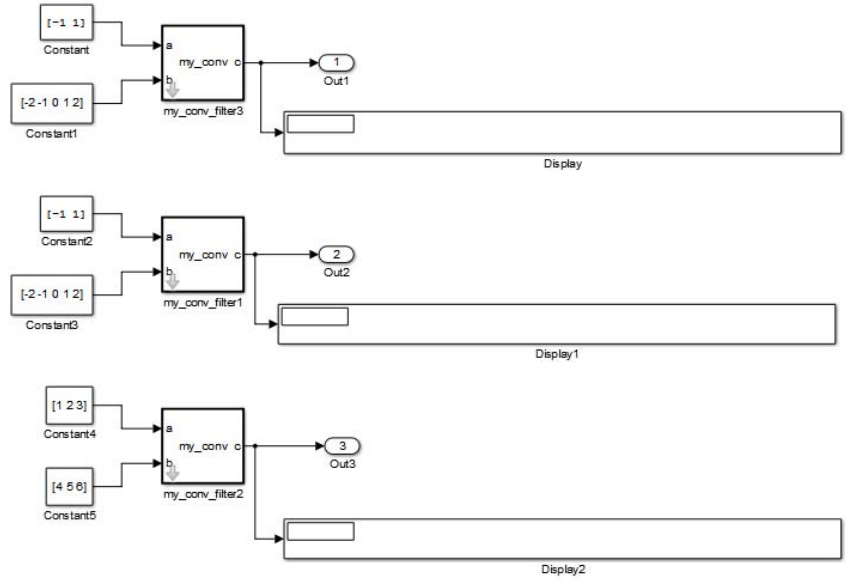
6 Specialize the second instance, my_conv_filter1 by setting the value of its `shape` parameter to **same**.

7 Now simulate the model again.

This time, the outputs have different sizes: my_conv_filter3 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`:

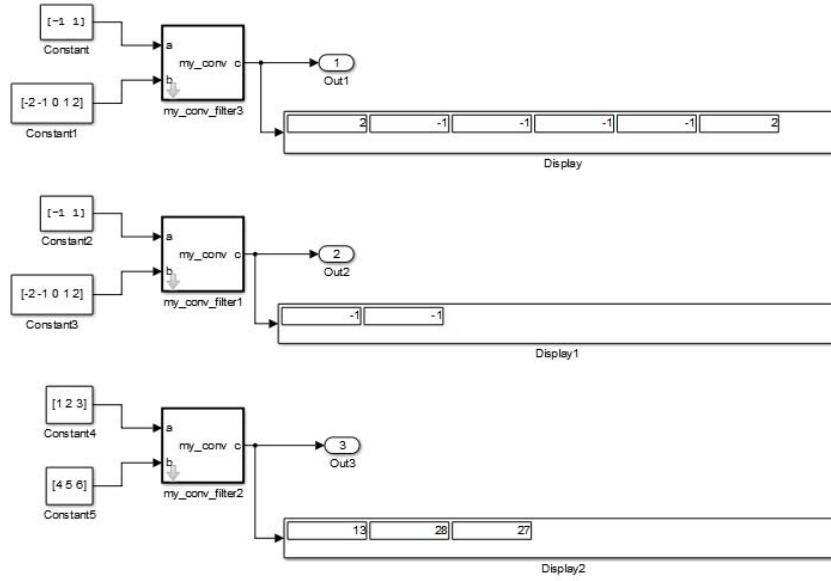


8 Now, add a third instance by copying my_conv_filter1. Specialize the new instance, my_conv_filter2, so that it does not inherit the same size inputs as the first two instances:



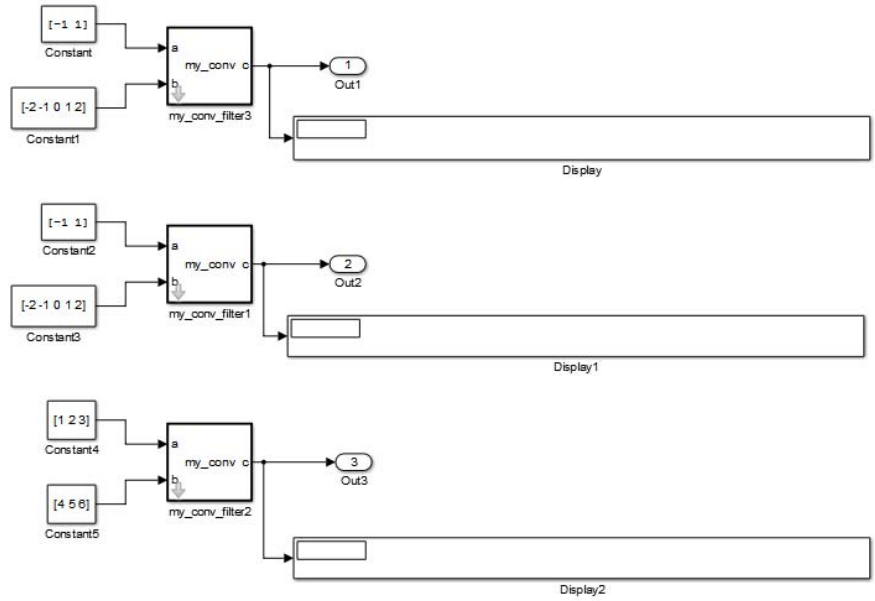
9 Simulate the model again.

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 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 MATLAB Library Blocks to a Simulink Model” on page 29-141:



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 the MATLAB Function block my_conv_filter and select **Block Parameters (Subsystem)** 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 **Function packaging** 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
Code Generation	**Target selection**	Enter **ert.tlc** for `System target file`
Code Generation > **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 sp_algorithm_tes_my_conv_filter(const real32_T rtu_a[2], const real32_T
  rtu_b[5], rtB_my_conv_filter_sp_algorithm *localB)
{
  int32_T jA;
  int32_T jA_0;
  real32_T s;
  int32_T jC;

  /* MATLAB Function Block: '<S1>/my_conv_filter' */
  /* MATLAB Function 'my_conv_filter/my_conv_filter': '<S4>:1' */
  /* '<S4>:1:4' */
  for (jC = 0; jC < 6; jC++) {
    if (5 < jC + 2) {
```

```
      jA = jC - 4;
    } else {
      jA = 0;
    }

    if (2 < jC + 1) {
      jA_0 = 2;
    } else {
      jA_0 = jC + 1;
    }

    s = 0.0F;
    while (jA + 1 <= jA_0) {
      s += rtu_b[jC - jA] * rtu_a[jA];
      jA++;
    }

    localB->c[jC] = s;
  }

  /* end of MATLAB Function Block: '<S1>/my_conv_filter' */
}
```

However, a separate function is generated for my_conv_filter2:

```
/* Output and update for atomic system: '<Root>/my_conv_filter2' */
void sp_algorithm_te_my_conv_filter2(const real_T rtu_a[3], const real_T rtu_b[3],
  rtB_my_conv_filter_sp_algorit_h *localB)
{
  int32_T jA;
  int32_T jA_0;
  real_T s;
  int32_T jC;

  /* MATLAB Function Block: '<S3>/my_conv_filter' */
  /* MATLAB Function 'my_conv_filter/my_conv_filter': '<S6>:1' */
  /* '<S6>:1:4' */
  for (jC = 0; jC < 5; jC++) {
    if (3 < jC + 2) {
```

```
      jA = jC - 2;
    } else {
      jA = 0;
    }

    if (3 < jC + 1) {
      jA_0 = 3;
    } else {
      jA_0 = jC + 1;
    }

    s = 0.0;
    while (jA + 1 <= jA_0) {
      s += rtu_b[jC - jA] * rtu_a[jA];
      jA++;
    }

    localB->c[jC] = s;
  }

  /* end of MATLAB Function Block: '<S3>/my_conv_filter' */
}
```

Note Generating C code for this model requires a Simulink Coder or Embedded Coder license.

Debugging MATLAB Function Library Blocks

You debug MATLAB Function library blocks the same way you debug any 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 a MATLAB Function Block” on page 29-23

Properties You Can Specialize Across Instances of Library Blocks

You can specialize instances of 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 a MATLAB Function library block can resolve to different `aParam` parameters defined in their parent mask subsystems.
Sampling mode (input)	Yes	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**.

Use Traceability in MATLAB Function Blocks

In this section...

Extent of Traceability in MATLAB Function Blocks

Like other Simulink blocks, 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 "Include MATLAB Code as Comments in Generated Code" on page 29-156.

For information about how traceability works in Simulink blocks, see "About Code Tracing".

Traceability Requirements

To enable traceability comments in your code, you must have a license for 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 a MATLAB Function block.

Basic Workflow for Using Traceability

The workflow for using traceability is described in "Trace Model Objects to Generated Code". Here are the basic steps:

1. Open the MATLAB Function block in your Simulink model.
2. Define your system target file to be an Embedded Real-Time (`ERT`) target.
   a. In the model, select **Simulation > Model Configuration Parameters**.
   b. In the **Code Generation** pane, enter `ert.tlc` for the system target file.
3. Enable traceability options.
   a. In the **Code Generation > Report** pane, select **Create code generation report**.

      This action automatically selects the **Open report automatically** and **Code-to-model** options.
   b. Select **Model-to-code**.

      This action automatically selects all options in the **Traceability Report Contents** section.
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 **Code Generation > 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 a MATLAB Function Block" on page 29-153

Tutorial: Using Traceability in a MATLAB Function Block

This example shows how to trace between source code and generated code in a MATLAB Function block in the `eml_fire` 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 MATLAB Function Block Editor.
3. In the Simulink model window, select **Simulation > Model Configuration Parameters**.
4. In the **Code Generation** 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 **Code Generation > Report** pane, select the **Create code generation report** option.

   This action automatically selects the **Open 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 **Code Generation > Interface** pane. In the **Software environment** section, select the **continuous time** option. Then click **Apply**.

Note Because this example model contains a block with a continuous sample time, you must perform this step before generating code.

---

8 In the **Code Generation** 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, which appear as links inside `/*...*/` brackets, as in this example.

```
for (b_x = 0; b_x < 256; b_x++) {
           /* '<S2>:1:19' */
           /* '<S2>:1:21' */
           yb = loopVar_i + 2;

           /* '<S2>:1:22' */
           xb = b_x - 1;
```

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 function appears highlighted in the MATLAB Function Block Editor.

12 You can also trace a line in a MATLAB function to a line of generated code. For example, right-click in line 21 of your function and select **Code Generation > Navigate to Code** from the context menu.

The code location for line 21 appears highlighted in `eml_fire.c`.

Include MATLAB Code as Comments in Generated Code

If you have a Simulink Coder license, you can include MATLAB source code as comments in the code generated for a 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 an Embedded Coder license), the traceability tags are hyperlinks to the source code. For more information on traceability for the MATLAB Function block, see "Use Traceability in MATLAB Function Blocks" on page 29-151.

  For examples and information on the location of the comments in the generated code, see "Location of Comments in Generated Code" on page 29-157.

- 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 an 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 29-160.

How to Include MATLAB Code as Comments in the Generated Code

To include MATLAB source code as comments in the code generated for a MATLAB Function block:

1. In the model, select **Simulation > Model Configuration Parameters**.
2. In the **Code Generation > Comments** pane, select **MATLAB source 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)
%#codegen
% Convert polar to Cartesian
x = r * cos(theta);
y = r * sin(theta);
```

Commented C Code.

```
/* MATLAB Function 'straightline': '<S1>:1' */
        /*  Convert polar to Cartesian */
        /* '<S1>:1:4' x = r * cos(theta); */
        /* '<S1>:1:5' y = r * sin(theta); */
        straightline0_Y.x = straightline0_U.r * cos(straightline0_U.theta);

        /* Outport: '<Root>/y' incorporates:
         *  Inport: '<Root>/r'
         *  Inport: '<Root>/theta'
         *  MATLAB Function Block: '<Root>/straightline'
         */
        straightline0_Y.y = straightline0_U.r * sin(straightline0_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)
%#codegen
if u > v
    y = v + 10;
elseif u == v
    y = u * 2;
else
    y = v - 10;
end
```

Commented C Code.

```
/* MATLAB Function 'MLFcn': '<S1>:1' */
        /* '<S1>:1:3' if u > v */
        if (MLFcn_U.u > MLFcn_U.v) {
          /* Outport: '<Root>/y' */
          /* '<S1>:1:4' y = v + 10; */
          MLFcn_Y.y = MLFcn_U.v + 10.0;
        } else if (MLFcn_U.u == MLFcn_U.v) {
          /* Outport: '<Root>/y' */
          /* '<S1>:1:5' elseif u == v */
          /* '<S1>:1:6' y = u * 2; */
          MLFcn_Y.y = MLFcn_U.u * 2.0;
        } else {
          /* Outport: '<Root>/y' */
          /* '<S1>:1:7' else */
          /* '<S1>:1:8' y = v - 10; */
          MLFcn_Y.y = MLFcn_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)
%#codegen
y = 0;
for i=1:u
    y = y + 1;
end
```

Commented C Code.

```
/* MATLAB Function 'MLFcn': '<S1>:1' */
        /* '<S1>:1:3' y = 0; */
        rtb_y = 0.0;

        /* '<S1>:1:5' for i=1:u */
        for (i = 1.0; i <= MLFcn_U.u; i++) {
          /* '<S1>:1:6' y = y + 1; */
          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.

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.

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 a 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 > Model Configuration Parameters**.
2. In the **Code Generation > 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 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.

Enhance Code Readability for MATLAB Function Blocks

In this section...

Requirements for Using Readability Optimizations

To use readability optimizations in your code, you must have an 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 the MATLAB Function block.

For more information, see "Target" and "Control Code Style" in the 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 a 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 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 29-167
2	Enable the conversion.	"Enabling the Conversion" on page 29-168
3	Generate code for your model.	"Generating Code for Your Model" on page 29-169

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
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 29-164.
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 a 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

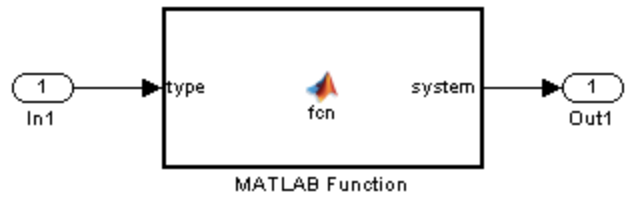
`if (x == 1) {`
`  block1`
`} else if (x == 2) {`
`  block2`
`} else if (x == 1) {  // duplicate`
`  block3`
`} else if (x == 3) {`
`  block4`
`} else if (x == 1) {  // duplicate`
`  block5`
`} else {`
	`switch (x) {`
	`  case 1:`
	`  block1; break;`
	`  case 2:`
	`  block2; break;`
	`  case 3:`
	`  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 a MATLAB Function block. Assume that the output data type is `double` and the input data type is `Controller`, an enumerated type that you define. (For more information, see "Define Enumerated Data Types for MATLAB Function Blocks" on page 29-106.)



The block contains the following code:

```
function system = fcn(type)
%#codegen

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 "Use Traceability in MATLAB Function Blocks" on page 29-151.

Verifying the Contents of the Block

Check that the block follows all the rules in "Rules for Conversion" on page 29-163.

Construct	How the Construct Follows the Rules
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 **Code Generation** pane, select `ert.tlc` for the **System target file**.

   This step specifies an embedded real-time target for your model.

3 In the **Code Generation > 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 MATLAB Function blocks in a model
- 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 Code for Flow Graphs" in the Stateflow documentation.

Generating Code for Your Model

In the **Code Generation** pane of the Configuration Parameters dialog box, click **Build** in the lower right corner.

The code for the 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.

Speed Up Simulation with Basic Linear Algebra Subprograms

In this section...

How MATLAB Function Blocks Use the Basic Linear Algebra Subprograms (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, MATLAB Function blocks call BLAS library routines to speed simulation whenever possible, except in these cases:

- Your C/C++ compiler does not support the BLAS library
- The size of the matrix is below a minimum threshold

  MATLAB for code generation uses a heuristic to evaluate matrix size against the overhead of calling an external library.
- When you are generating C/C++ code for MATLAB functions using Simulink Coder.

  Simulink Coder uses BLAS only for simulation.

When to Disable BLAS Library Support

Consider disabling BLAS library support for MATLAB Function blocks when:

- You want your simulation results to more closely agree with code generated by Simulink Coder for your 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, automatic truncation to a 32-bit matrix size occurs.

- Your platform does not provide a robust implementation of BLAS routines.

How to Disable BLAS Library Support

MATLAB Function blocks enable BLAS library support by default, but you can disable this feature explicitly for all MATLAB Function blocks in your Simulink model. Follow these steps:

1. Open your MATLAB Function block.
2. In the MATLAB Function Block Editor, select **Simulation Target**.

   The Configuration Parameters dialog box opens with **Simulation Target** selected.
3. Clear the **Use BLAS library for faster simulation** check box and click **Apply**.

Supported Compilers

MATLAB Function blocks use the BLAS library on all C compilers **except**:

- Watcom
- Intel
- Borland

The default MATLAB compiler for Windows, 32–bit platforms, `lcc`, supports the BLAS library. To install a different C compiler, use the `mex -setup` command, as described in "Build MEX-Files".

Control Run-Time Checks

In this section...

Types of Run-Time Checks

In simulation, the code generated for your MATLAB Function block includes the following run-time checks:

- Memory integrity checks

  These checks detect violations of memory integrity in code generated for MATLAB Function blocks and stop execution with a diagnostic message.

  Caution For safety, these checks are enabled by default. Without memory integrity checks, violations result in unpredictable behavior.

- Responsiveness checks in code generated for MATLAB Function blocks

  These checks enable periodic checks for Ctrl+C breaks in the generated code. 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

MATLAB Function blocks enable run-time checks by default, but you can disable them explicitly for all MATLAB Function blocks in your Simulink model. Follow these steps:

1. Open your MATLAB Function block.
2. In the MATLAB Function Block Editor, select **Simulation Target**.

   The Configuration Parameters dialog box opens with **Simulation Target** selected.
3. Clear the **Ensure memory integrity** or **Ensure responsiveness** check boxes, as applicable, and click **Apply**.

Track Object Using MATLAB Code

In this section...

Learning Objectives

In this tutorial, you will learn how to:

- Use the 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.

- Use `coder.extrinsic` to call MATLAB code from a MATLAB Function block.

  This capability allows you to do rapid prototyping. You can call existing MATLAB code from Simulink without having to make this code suitable for code generation.

- Check that existing MATLAB code is suitable for code generation before generating code.

  You must prepare your code before generating code.

- Specify variable-size inputs when generating code.

Tutorial Prerequisites

What You Need to Know

To complete this tutorial, you should have basic familiarity with MATLAB software. You should also understand how to create and simulate a basic Simulink model.

Required Products

To complete this tutorial, you must install the following products:

- MATLAB
- MATLAB Coder
- Simulink
- Simulink Coder
- C compiler

For a list of supported compilers, see .

You must set up the C compiler before generating C code. See "Setting Up Your C Compiler" on page 29-182.

For instructions on installing MathWorks products, see the MATLAB installation documentation for your platform. If you have installed MATLAB and want to check which other MathWorks products are installed, enter `ver` in the MATLAB Command Window.

Example: The Kalman Filter

- "Reference" on page 29-179

Description

This section describes the example used by the tutorial. You do not have to be familiar with the algorithm to complete the tutorial.

The example for this tutorial uses a Kalman filter to estimate the position of an object moving in a two-dimensional space from a series of noisy inputs based on past positions. The position vector has two components, `x` and `y`, indicating its horizontal and vertical coordinates.

Kalman filters have a wide range of applications, including control, signal and image processing; radar and sonar; and financial modeling. They are recursive filters that estimate the state of a linear dynamic system from a series of incomplete or noisy measurements. The Kalman filter algorithm relies on the state-space representation of filters and uses a set of variables stored in the state vector to characterize completely the behavior of the system. It updates the state vector linearly and recursively using a state transition matrix and a process noise estimate.

Algorithm

This section describes the algorithm of the Kalman filter and is implemented in the MATLAB version of the filter supplied with this tutorial.

The algorithm predicts the position of a moving object based on its past positions using a Kalman filter estimator. It estimates the present position by updating the Kalman state vector, which includes the position (*x* and *y*), velocity (*Vx* and *Vy*), and acceleration (*Ax* and *Ay*) of the moving object. The Kalman state vector, `x_est`, is a persistent variable.

```
% Initial conditions
persistent x_est p_est
if isempty(x_est)
    x_est = zeros(6, 1);
    p_est = zeros(6, 6);
end
```

`x_est` is initialized to an empty `6x1` column vector and updated each time the filter is used.

The Kalman filter uses the laws of motion to estimate the new state:

$$X = X_0 + Vx.dt$$
$$Y = Y_0 + Vy.dt$$
$$Vx = Vx_0 + Ax.dt$$
$$Vy = Vy_0 + Ay.dt$$

These laws of motion are captured in the state transition matrix `A`, which is a matrix that contains the coefficient values of `x`, `y`, V_x, V_y, A_x, and A_y.

```
% Initialize state transition matrix
dt=1;
A=[ 1 0 dt 0 0 0;...
    0 1 0 dt 0 0;...
    0 0 1 0 dt 0;...
    0 0 0 1 0 dt;...
    0 0 0 0 1 0 ;...
    0 0 0 0 0 1 ];
```

Filtering Process

The filtering process has two phases:

- Predicted state and covariance

  The Kalman filter uses the previously estimated state, `x_est`, to predict the current state, `x_prd`. The predicted state and covariance are calculated in:

  ```
  % Predicted state and covariance
  x_prd = A * x_est;
  p_prd = A * p_est * A' + Q;
  ```

- Estimation

  The filter also uses the current measurement, `z`, and the predicted state, `x_prd`, to estimate a more accurate approximation of the current state. The estimated state and covariance are calculated in:

  ```
  % Measurement matrix
  H = [ 1 0 0 0 0 0; 0 1 0 0 0 0 ];
  Q = eye(6);
  R = 1000 * eye(2);
  ```

```
% Estimation
S = H * p_prd' * H' + R;
B = H * p_prd';
klm_gain = (S \ B)';

% Estimated state and covariance
x_est = x_prd + klm_gain * (z - H * x_prd);
p_est = p_prd - klm_gain * H * p_prd;

% Compute the estimated measurements
y = H * x_est;
```

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.
- Example MATLAB code files for each step of the tutorial.

  Throughout this tutorial, you work with Simulink models that call MATLAB files containing a Kalman filter algorithm.
- A MAT-file that contains example input data.
- A MATLAB file for plotting.

Location of Files

The tutorial files are available in the following folder: `docroot\toolbox\simulink\examples\kalman`. To run the tutorial, you must copy these files to a local folder. For instructions, see "Copying Files Locally" on page 29-181.

Names and Descriptions of Files

Type	Name	Description
MATLAB function files	`ex_kalman01`	Baseline MATLAB implementation of a scalar Kalman filter.
	`ex_kalman02`	Version of the original algorithm suitable for code generation.
	`ex_kalman03`	Version of Kalman filter suitable for code generation and for use with frame-based and packet-based inputs.
	`ex_kalman04`	Disabled inlining for code generation.
Simulink model files	`ex_kalman00`	Simulink model without a MATLAB Function block.
	`ex_kalman11`	Complete Simulink model with a MATLAB Function block for scalar Kalman filter.
	`ex_kalman22`	Simulink model with a MATLAB Function block for a Kalman filter that accepts fixed-size (frame-based) inputs.
	`ex_kalman33`	Simulink model with a MATLAB Function block for a Kalman filter that accepts variable-size (packet-based) inputs.
	`ex_kalman44`	Simulink model to call `ex_kalman04.m`, which has inlining disabled.
MATLAB data file	`position`	Contains the input data used by the algorithm.
Plot files	`plot_trajectory`	Plots the trajectory of the object and the Kalman filter estimated position.

Tutorial Steps

Copying Files Locally

Copy the tutorial files to a local working folder:

1. Create a local *`solutions`* folder, for example, `c:\simulink\kalman\solutions`.

2. Change to the `docroot\toolbox\simulink\examples` folder. At the MATLAB command line, enter:

   ```
   cd(fullfile(docroot, 'toolbox', 'simulink', 'examples'))
   ```

3. Copy the contents of the `kalman` subfolder to your local *`solutions`* folder, specifying the full path name of the *`solutions`* folder:

   ```
   copyfile('kalman', 'solutions')
   ```

   For example:

   ```
   copyfile('kalman', 'c:\simulink\kalman\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 in the tutorial, you can view the solutions to see how the code should look.

4. Create a local *work* folder, for example, `c:\simulink\kalman\work`.

5. Copy the following files from your *solutions* folder to your *work* folder.

   - `ex_kalman01`
   - `ex_kalman00`
   - `position`
   - `plot_trajectory`

   Your *work* folder now contains all the files that you need to get started with the tutorial.

Setting Up Your C Compiler

Before generating code for your Simulink model, you must set up your C compiler. For many 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 set up 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.

About the ex_kalman00 Model

First, examine the `ex_kalman00` model supplied with the tutorial to understand the problem that you are trying to solve using the Kalman filter.

1. Open the `ex_kalman00` model 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" for more information.

b At the MATLAB command line, enter:

```
ex_kalman00
```

This model is an incomplete model to demonstrate how to integrate MATLAB code with Simulink. The complete model is `ex_kalman11`, which is also supplied with this tutorial.

InitFcn Model Callback Function. The model uses this callback function to:

- Load position data from a MAT-file.
- Set up data used by the Index generator block, which provides the second input to the Selector block.

To view this callback:

1 Select **File > Model Properties > Model Properties**.

2 Select the **Callbacks** tab.

3 Select `InitFcn` in the **Model callbacks** pane.

The callback appears.

```
load position.mat;
[R,C]=size(position);
idx=(1:C)';
t=idx-1;
```

Source Blocks. The model uses two Source blocks to provide position data and a scalar index to a Selector block.

Selector Block. The model uses a Selector block that selects elements of its input signal and generates an output signal based on its index input and its **Index Option** settings. By changing the configuration of this block, you can generate different size signals.

To view the Selector block settings, double-click the Selector block to view the function block parameters.

In this model, the **Index Option** for the first port is `Select all` and for the second port is `Index vector (port)`. Because the input is a `2 x 310` position matrix, and the index data increments from `1` to `310`, the Selector block simply outputs one `2x1` output at each sample time.

MATLAB Function Block. The model uses a MATLAB Function block to plot the trajectory of the object and the Kalman filter estimated position. This function:

- First declares the `figure`, `hold`, and `plot_trajectory` functions as extrinsic because these MATLAB visualization functions are not supported for code generation. When you call an unsupported MATLAB function, you must declare it to be extrinsic so MATLAB can execute it, but does not try to generate code for it.
- Creates a figure window and holds it for the duration of the simulation. Otherwise a new figure window appears for each sample time.
- Calls the `plot_trajectory` function, which plots the trajectory of the object and the Kalman filter estimated position.

Simulation Stop Time. The simulation stop time is `309`, because the input to the filter is a vector containing `310` elements and Simulink uses zero-based indexing.

Adding a 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 `ex_kalman11` in your *`solutions`* subfolder to see the modified model.

For the purposes of this tutorial, you add the MATLAB Function block to the `ex_kalman00.mdl` model supplied with the tutorial. You would have to develop your own test bench starting with an empty Simulink model.

Adding the MATLAB Function Block. To add a MATLAB Function block to the `ex_kalman00` model:

1. Open `ex_kalman00` in Simulink.

   ```
   ex_kalman00
   ```

2. Add a 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 MATLAB Function block and drag it into the `ex_kalman00` model. Place the block just above the red text annotation that reads `Place MATLAB Function Block here.`
   d. Delete the red text annotations from the model.
   e. Save the model in the current folder as `ex_kalman11`.

Calling Your MATLAB Code from the MATLAB Function Block. To call your MATLAB code from the MATLAB Function block:

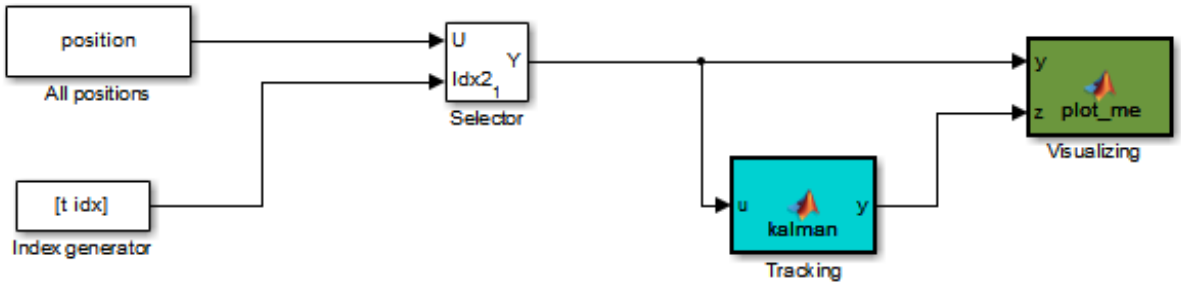
1. Double-click the MATLAB Function block to open the MATLAB Function Block Editor.
2. Delete the default code displayed in the editor.
3. Copy the following code to the MATLAB Function block.

   ```
   function y = kalman(u)
   %#codegen

   y = ex_kalman01(u);
   ```

4. Save the model.

Connecting the MATLAB Function Block Input and Output.

1 Connect the MATLAB Function block input and output so that your model looks like this.



See “Connect Blocks” on page 4-12 for more information.

2 Save the model.

You are now ready to check your model for errors, as described in “Checking the ex_kalman11 Model” on page 29-186.

Checking the ex_kalman11 Model

To check the model:

1 In the Simulink model window, select **Simulation > Update Diagram**.

Simulink checks the model and generates a warning telling you to add the `%#codegen` compilation directive to the `ex_kalman01` file. Adding this directive indicates that the file is intended for code generation and turns on code generation error checking.

2 Open `ex_kalman01` file and add the `%#codegen` compilation directive after the function declaration.

```
function y = ex_kalman01(z)  %#codegen
```

3 Modify the function name to `ex_kalman02` and save the file as `ex_kalman02.m`.

4. Modify the model to call `ex_kalman02` by updating the code in the MATLAB Function block.

```
function y = kalman(u)
%#codegen

y = ex_kalman02(u);
```

5. Save the model and update diagram again.

   This time the model updates successfully.

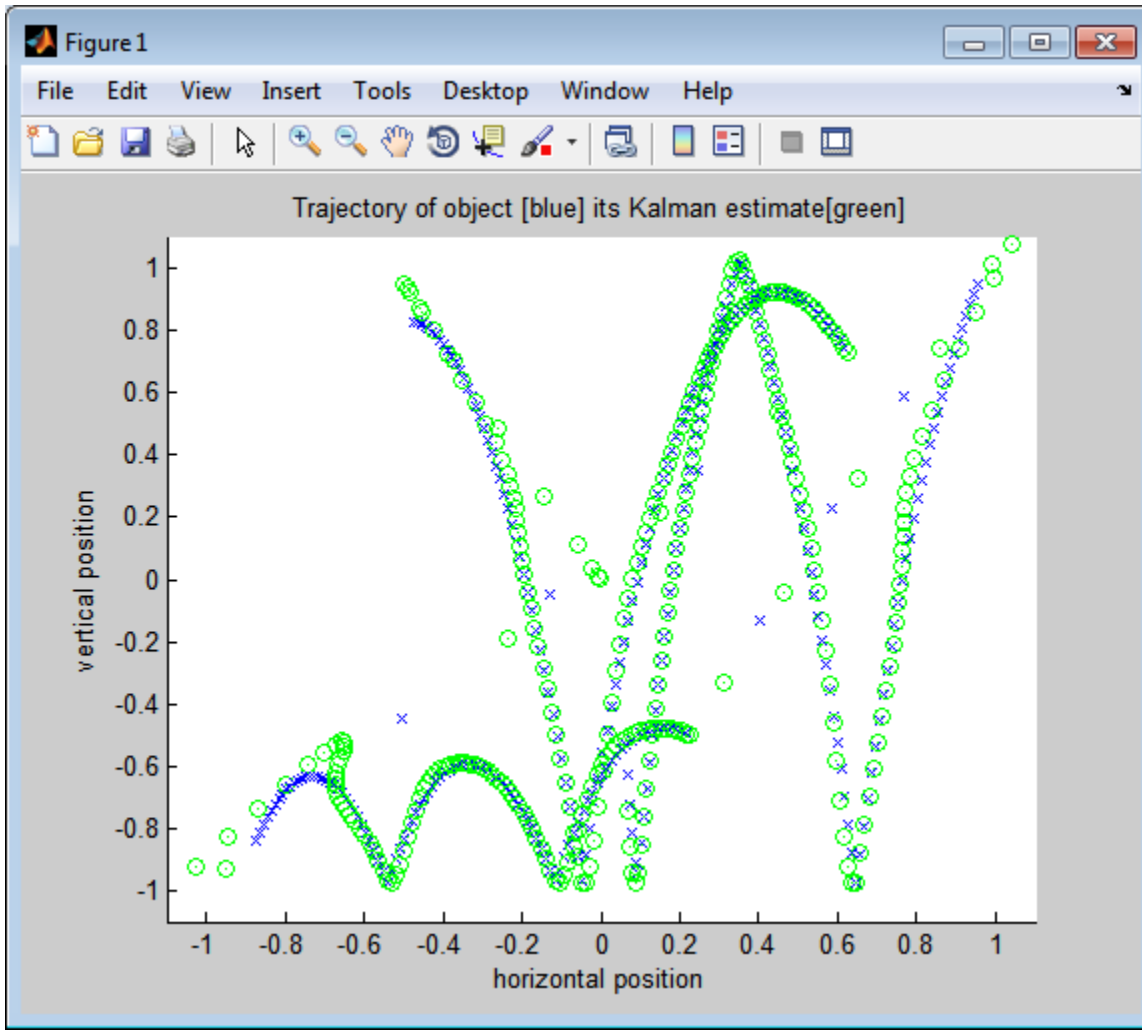
   You are now ready to simulate your model, as described in "Simulating the ex_kalman11 Model" on page 29-187.

Simulating the ex_kalman11 Model

To simulate the model:

1. In the Simulink model window, select **Simulation > Run**.

   As Simulink runs the model, it plots the trajectory of the object in blue and the Kalman filter estimated position in green. Initially, you see that it takes a short time for the estimated position to converge with the actual position of the object. Then three sudden shifts in position occur—each time the Kalman filter readjusts and tracks the object after a few iterations.



2 The simulation stops.

You have proved that your MATLAB algorithm works in Simulink. You are now ready to modify the filter to accept a fixed-size input, as described in “Modifying the Filter to Accept a Fixed-Size Input” on page 29-189.

Modifying the Filter to Accept a Fixed-Size Input

The filter you have worked on so far in this tutorial uses a simple batch process that accepts one input at a time, so you must call the function repeatedly for each input. In this part of the tutorial, you learn how to modify the algorithm to accept a fixed-sized input, which makes the algorithm suitable for frame-based processing. You then modify the model to provide the input as fixed-size frames of data and call the filter passing in the data one frame at a time.

Modifying Your MATLAB Code. To modify the code yourself, work through the exercises in this section. Otherwise, open the supplied file `ex_kalman03.m` in your *`solutions`* subfolder to see the modified algorithm.

You can now modify the algorithm to process a vector containing more than one input. You need to find the length of the vector and call the filter code for each element in the vector in turn. You do this by calling the filter algorithm in a `for`-loop.

1. Open `ex_kalman02.m` in the MATLAB Editor. At the MATLAB command line, enter:

   ```
   edit ex_kalman02.m
   ```

2. Add a `for`-loop around the filter code.

   a. Before the comment:

   ```
   % Predicted state and covariance
   ```

   insert:

   ```
   for i=1:size(z,2)
   ```

   b. After:

   ```
   % Compute the estimated measurements
   y = H * x_est;
   ```

   insert:

   ```
   end
   ```

c Select the code between the `for`-statement and the end statement, right-click to open the context menu and select **Smart Indent** to indent the code.

Your filter code should now look like this:

```
for i=1:size(z,2)
  % Predicted state and covariance
  x_prd = A * x_est;
  p_prd = A * p_est * A' + Q;

  % Estimation
  S = H * p_prd' * H' + R;
  B = H * p_prd';
  klm_gain = (S \ B)';

  % Estimated state and covariance
  x_est = x_prd + klm_gain * (z - H * x_prd);
  p_est = p_prd - klm_gain * H * p_prd;

  % Compute the estimated measurements
  y = H * x_est;
end
```

3 Modify the line that calculates the estimated state and covariance to use the i^{th} element of input `z`.

Change:

```
x_est = x_prd + klm_gain * (z - H * x_prd);
```

to:

```
x_est = x_prd + klm_gain * (z(1:2,i) - H * x_prd);
```

4 Modify the line that computes the estimated measurements to append the result to the i^{th} element of the output `y`.

Change:

```
y = H * x_est;
```

to:

```
y(:,i) = H * x_est;
```

The code analyzer message indicator in the top right turns orange to indicate that the code analyzer has detected warnings. The code analyzer underlines the offending code in orange and places a orange marker to the right.

5. Move your pointer over the orange marker to view the error information.

   The code analyzer detects that `y` must be fully defined before subscripting it and that you cannot grow variables through indexing in generated code.

6. To address this warning, preallocate memory for the output `y`, which is the same size as the input `z`. Add this code before the `for`-loop.

   ```
   % Pre-allocate output signal:
   y=zeros(size(z));
   ```

   The orange marker disappears and 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.

   ### Why Preallocate the Outputs?

   You must preallocate outputs here because the code generation 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”.

7. Change the function name to `ex_kalman03` and save the file as `ex_kalman03.m` in the current folder.

You are ready to begin the next task in the tutorial, “Modifying Your Model to Call the Updated Algorithm” on page 29-191.

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 `ex_kalman22.mdl` in your *`solutions`* subfolder to see the modified model.

Next, update your model to provide the input as fixed-size frames of data and call `ex_kalman03` passing in the data one frame at a time.

1. Open `ex_kalman11` model in Simulink.

   ```
   ex_kalman11
   ```

2. Double-click the MATLAB Function block to open the MATLAB Function Block Editor.

3. Replace the code that calls `ex_kalman02` with a call to `ex_kalman03`.

   ```
   function y = kalman(u)
   %#codegen

   y = ex_kalman03(u);
   ```

4. Close the editor.

5. Modify the `InitFcn` callback:

   a. Select **File > Model Properties > Model Properties**.

      The Model Properties dialog box opens.

   b. In this dialog box, select the **Callbacks** tab.

   c. Select `InitFcn` in the **Model callbacks** pane.

   d. Replace the existing callback with:

      ```
      load position.mat;
      [R,C]=size(position);
      FRAME_SIZE=5;
      idx=(1:FRAME_SIZE:C)';
      LEN=length(idx);
      t=(1:LEN)'-1;
      ```

      This callback sets the frame size to `5`, and the index to increment by `5`.

   e. Click **Apply** and close the Model Properties dialog box.

6. Update the Selector block to use the correct indices.

   a. Double-click the Selector block to view the function block parameters.

The Function Block Parameters dialog box opens.

b Set the second **Index Option** to `Starting index (port)`.

c Set the **Output Size** for the second input to `FRAME_SIZE`, click **Apply** and close the dialog box.

Now, the **Index Option** for the first port is `Select all` and for the second port is `Starting index (port)`. Because the index increments by `5` each sample time, and the output size is `5`, the Selector block outputs a `2x5` output at each sample time.

7 Change the model simulation stop time to `61`. Now the frame size is `5`, so the simulation completes in a fifth of the sample times.

a In the Simulink model window, select **Simulation > Model Configuration Parameters**.

b In the left pane of the Configuration Parameters dialog box, select **Solver**.

c In the right pane, set **Stop time** to `61`.

d Click **Apply** and close the dialog box.

8 Save the model as `ex_kalman22.mdl`.

Testing Your Modified Algorithm. To simulate the model:

1 In the Simulink model window, select **Simulation > Run**.

As Simulink runs the model, it plots the trajectory of the object in blue and the Kalman filter estimated position in green as before when you used the batch filter.

2 The simulation stops.

You have proved that your algorithm accepts a fixed-size signal. You are now ready for the next task, "Using the Filter to Accept a Variable-Size Input" on page 29-194.

Using the Filter to Accept a Variable-Size Input

In this part of the tutorial, you learn how to specify variable-size data in your Simulink model. Then you test your Kalman filter algorithm with variable-size inputs and see that the algorithm is suitable for processing packets of data of varying size. For more information on using variable-size data in Simulink, see "Variable-Size Signal Basics" on page 49-2.

Updating the Model to Use Variable-Size Inputs. To modify the model yourself, work through the exercises in this section. Otherwise, open the supplied model `ex_kalman33.mdl` in your *`solutions`* subfolder to see the modified model.

1. Open `ex_kalman22.mdl` in Simulink.

   ```
   ex_kalman22
   ```

2. Modify the `InitFcn` callback:

   a. Select **File > Model Properties > Model Properties**.

   The Model Properties dialog box opens.

   b. Select the **Callbacks** tab.

   c. Select `InitFcn` in the **Model callbacks** pane.

   d. Replace the existing callback with:

   ```
   load position.mat;
   idx=[ 1 1 ;2 3 ;4 6 ;7 10 ;11 15 ;16 30 ;
        31 70 ;71 100 ;101 200 ;201 250 ;251 310];
   LEN=length(idx);
   t=(0:1:LEN-1)';
   ```

   This callback sets up indexing to generate eleven different size inputs. It specifies the start and end indices for each sample time. The first sample time uses only the first element, the second sample time uses the second and third elements, and so on. The largest sample, `101` to `200`, contains 100 elements.

   e. Click **Apply** and close the **Model Properties** dialog box.

3. Update the Selector block to use the correct indices.

a Double-click the Selector block to view the function block parameters.

The Function Block Parameters dialog box opens.

b Set the second **Index Option** to `Starting and ending indices (port)`, then click **Apply** and close the dialog box.

This setting means that the input to the index port specifies the start and end indices for the input at each sample time. Because the index input specifies different starting and ending indices at each sample time, the Selector block outputs a variable-size signal as the simulation progresses.

4 Use the Ports and Data Manager to set the MATLAB Function input `x` and output `y` as variable-size data.

a Double-click the MATLAB Function block to open the MATLAB Function Block Editor.

b From the editor menu, select **Edit Data**.

c In the Ports and Data Manager left pane, select the input `u`.

The Ports and Data Manager displays information about `u` in the right pane.

d On the **General** tab, select the **Variable size** check box and click **Apply**.

e In the left pane, select the output `y`.

f On the **General** tab:

i Set the **Size** of `y` to `[2 100]` to specify a 2-D matrix where the upper bounds are `2` for the first dimension and `100` for the second, which is the maximum size input specified in the `InitFcn` callback.

ii Select the **Variable size** check box.

iii Click **Apply**.

g Close the Ports and Data Manager.

5 Now do the same for the other MATLAB Function block. Use the Ports and Data Manager to set the Visualizing block inputs `y` and `z` as variable-size data.

a Double-click the Visualizing block to open the MATLAB Function Block Editor.

b From the editor menu, select **Edit Data**.

c In the Ports and Data Manager left pane, select the input `y`.

d On the **General** tab, select the **Variable size** check box and click **Apply**.

e In the left pane, select the input `z`.

f On the **General** tab, select the **Variable size** check box and click **Apply**.

g Close the Ports and Data Manager.

6 Change the model simulation stop time to `10`. This time, the filter processes one of the eleven different size inputs each sample time.

7 Save the model as `ex_kalman33.mdl`.

Testing Your Modified Model. To simulate the model:

1 In the Simulink model window, select **Simulation > Run**.

As Simulink runs the model, it plots the trajectory of the object in blue and the Kalman filter estimated position in green as before.

Note that the signal lines between the Selector block and the Tracking and Visualization blocks change to show that these signals are variable-size.

2 The simulation stops.

You have successfully created an algorithm that accepts variable-size inputs. Next, you learn how to debug your MATLAB Function block, as described in "Debugging the MATLAB Function Block" on page 29-196.

Debugging the MATLAB Function Block

You can debug your MATLAB Function block just like you can debug a function in MATLAB.

1 Double-click the MATLAB Function block that calls the Kalman filter to open the MATLAB Function Block Editor.

2. In the editor, click the dash (-) character in the left margin of the line:

   ```
   y = kalman03(u);
   ```

   A small red ball appears in the margin of this line, indicating that you have set a breakpoint.

3. In the Simulink model window, select **Simulation > Run**.

   The simulation pauses when execution reaches the breakpoint and a small green arrow appears in the left margin.

4. Place the pointer over the variable `u`.

   The value of `u` appears adjacent to the pointer.

5. From the MATLAB Function Block Editor menu, select **Step In**.

   The `kalman03.m` file opens in the editor and you can now step through this code using **Step**, **Step In**, and **Step Out**.

6. Select **Step Out**.

   The `kalman03.m` file closes and the MATLAB Function block code reappears in the editor.

7. Place the pointer over the output variable `y`.

   You can now see the value of `y`.

8. Click the red ball to remove the breakpoint.

9. From the MATLAB Function Block Editor menu, select **Quit Debugging**.

10. Close the editor.

11. Close the figure window.

    Now you are ready for the next task, “Generating C Code” on page 29-198.

Generating C Code

You have proved that your algorithm works in Simulink. Next you generate code for your model.

Note Before generating code, you must check that your MATLAB code is suitable for code generation. If you call your MATLAB code as an extrinsic function, you must remove extrinsic calls before generating code.

---

1. Rename the MATLAB Function block to `Tracking`. To rename the block, double-click the annotation `MATLAB Function` below the MATLAB Function block and replace the text with `Tracking`.

   When you generate code for the MATLAB Function block, Simulink Coder uses the name of the block in the generated code. It is good practice to use a meaningful name.

2. Before generating code, ensure that Simulink Coder 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 > Model Configuration Parameters**.

      The Configuration Parameters dialog box opens.

   b. In the left pane of the Configuration Parameters dialog box, select **Report** under **Code Generation**.

   c. In the right pane, select **Create code generation report**.

      The **Open report automatically** option is also selected.

   d. Click **Apply** and close the Configuration Parameters dialog box.

   e. Save your model.

3. To generate code for the Tracking block:

   a. In your model, select the Tracking block.

b In the Simulink model window, select **Code > C/C++ Code > Build Selected Subsystem**.

4 The Simulink software generates an error informing you that it cannot log variable-size signals as arrays. You need to change the format of data saved to the MATLAB workspace. To change this format:

- In the Simulink model window, select **Simulation > Model Configuration Parameters**.

  The Configuration Parameters dialog box opens.

- In the left pane of the Configuration Parameters dialog box, select **Data Import/Export**.
- In the right pane, under **Save to workspace options**, set **Format** to `Structure with time`.

  The logged data is now a structure that has two fields: a time field and a signals field, enabling Simulink to log variable-size signals.

- Click **Apply** and close the Configuration Parameters dialog box.
- Save your model.

5 Repeat step `3` to generate code for the Tracking block.

The Simulink Coder software generates C code for the block and launches the code generation report.

For more information on using the code generation report, see "Reports for Code Generation".

6 In the left pane of the code generation report, click the `Tracking.c` link to view the generated C code. Note that in the code generated for the MATLAB Function block, `Tracking`, there is no code for the `ex_kalman03` function because inlining is enabled by default.

7 Modify your filter algorithm to disable inlining:

a In `ex_kalman03.m`, after the function declaration, add:

```
coder.inline('never');
```

b Change the function name to `ex_kalman04` and save the file as `ex_kalman04.m` in the current folder.

c In your `ex_kalman33` model, double-click the Tracking block.

The MATLAB Function Block Editor opens.

d Modify the call to the filter algorithm to call `ex_kalman04`.

```
function y = kalman(u)
%#codegen

y = ex_kalman04(u);
```

e Save the model as `ex_kalman44.mdl`.

8 Generate code for the updated model.

a Select the Tracking block.

b In the model window, select **Code > C/C++Code > Build Selected Subsystem**.

The **Build code for Subsystem** dialog box appears.

c Click the **Build** button.

The Simulink Coder software generates C code for the block and launches the code generation report.

d In the left pane of the code generation report, click the `Tracking.c` link to view the generated C code.

This time the `ex_kalman04` function has code because you disabled inlining.

```
/* Forward declaration for local functions */
static void Tracking_ex_kalman04(const real_T z_data[620], const int32_T
  z_sizes[2], real_T y_data[620], int32_T y_sizes[2]);

/* Function for MATLAB Function Block: '<Root>/Tracking' */
static void Tracking_ex_kalman04(const real_T z_data[620], const int32_T   48
     z_sizes[2], real_T y_data[620], int32_T y_sizes[2])
```

Best Practices Used in This Tutorial

Best Practice — Saving Incremental Code Updates

Save your code before making modifications. This practice provides a fallback in case of error and a baseline for testing and validation. Use a consistent file naming convention. For example, add a two-digit suffix to the file name for each file in a sequence.

Key Points to Remember

- Back up your MATLAB code before you modify it.
- Decide on a naming convention for your files and save interim versions frequently. For example, this tutorial uses a two-digit suffix to differentiate the various versions of the filter algorithm.
- For simulation purposes, before generating code, call your MATLAB code using `coder.extrinsic` to check that your algorithm is suitable for use in Simulink. This practice provides these benefits:
  - You do not have to make the MATLAB code suitable for code generation.
  - You can debug your MATLAB code in MATLAB while calling it from Simulink.
- Create a Simulink Coder 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.

Where to Learn More

- “Next Steps” on page 29-202
- “Product Help” on page 29-202

Next Steps

To:	See:
Learn how to generate C code from your MATLAB code using `codegen`	"C Code Generation at the Command Line"
Learn more about code generation from MATLAB	"Getting Started with Simulink Coder"
Use variable-size data	"Variable-Size Data Definition for Code Generation" on page 35-3
Speed up fixed-point MATLAB code	See "Fixed-Point Code Acceleration and Generation Workflow".
Integrate custom C code into generated code	"Custom C/C++ Code Integration"
Integrate custom C code into a MATLAB function	`coder.ceval`
Generate HDL from MATLAB code	`www.mathworks.com/products/slhdlcoder`

Product Help

MathWorks product documentation is available online from the Open Help Browser button  on the MATLAB toolstrip.

For:	See:
Code generation from MATLAB code	"When to Generate Code from MATLAB Algorithms" on page 30-2
A list of functions that are suitable for code generation	"Functions Supported for Code Generation — Alphabetical List" on page 31-2

Filter Audio Signal Using MATLAB Code

In this section...

Learning Objectives

In this tutorial, you will learn how to:

- Use the 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 "What Is a MATLAB Function Block?" on page 29-6 and "Create Model That Uses MATLAB Function Block" on page 29-9.

- Use `coder.extrinsic` to call MATLAB code from a MATLAB Function block.

  This capability allows you to call existing MATLAB code from Simulink without first having to make this code suitable for code generation, allowing for rapid prototyping.

- Check that existing MATLAB code is suitable for code generation.
- Convert a MATLAB algorithm from batch processing to streaming.
- Use persistent variables in code that is suitable for code generation.

  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" on page 29-204

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 "Start the Simulink Software" and "Simulink User Interface".

Required Products

To complete this tutorial, you must install the following products:

- MATLAB
- MATLAB Coder
- Simulink
- Simulink Coder
- DSP System Toolbox

> **Note** If you do not have a DSP System Toolbox license, see "Track Object Using MATLAB Code" on page 29-175.

- C compiler

  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/C++ Compiler".

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\simulink\examples\lms`. To run the tutorial, you must copy these files to a local folder. For instructions, see "Copying Files Locally" on page 29-209.

Names and Descriptions of Files

Type	Name	Description
MATLAB files	`lms_01`	Baseline MATLAB implementation of batch filter. Not suitable for code generation.
	`lms_02`	Filter modified from batch to streaming.
	`lms_03`	Frame-based streaming filter with Reset and Adapt controls.
	`lms_04`	Frame-based streaming filter with Reset and Adapt controls. Suitable for code generation.
	`lms_05`	Disabled inlining for code generation.
	`lms_06`	Demonstrates use of `coder.nullcopy`.
Simulink model files	`acoustic_environment`	Simulink model that provides an overview of the acoustic environment.
	`noise_cancel_00`	Simulink model without a MATLAB Function block.
	`noise_cancel_01`	Complete `noise_cancel_00` model including a MATLAB Function block.
	`noise_cancel_02`	Simulink model for use with `lms_02.m`.
	`noise_cancel_03`	Simulink model for use with `lms_03.m`.
	`noise_cancel_04`	Simulink model for use with `lms_04.m`.
	`noise_cancel_05`	Simulink model for use with `lms_05.m`.
	`noise_cancel_06`	Simulink model for use with `lms_06.m`.
	`design_templates`	Simulink model containing Adapt and Reset controls.

Tutorial Steps

- "Copying Files Locally" on page 29-209

Copying Files Locally

Copy the tutorial files to a local folder:

1. Create a local *`solutions`* folder, for example, `c:\test\lms\solutions`.

2. Change to the `docroot\toolbox\simulink\examples` folder. At the MATLAB command line, enter:

   ```
   cd(fullfile(docroot, 'toolbox', 'simulink', '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:\test\lms\work`.

5. Copy the following files from your *`solutions`* folder to your *`work`* folder.

   - `lms_01`
   - `lms_02`

- `noise_cancel_OO`
- `acoustic_environment`
- `design_templates`

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 the `acoustic_environment` model 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" for more information.

   b. At the MATLAB command line, enter:

      ```
      acoustic_environment
      ```

2. Ensure that your speakers are on.

3. To simulate the model, from the Simulink model window, select **Simulation > Run**.

   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 a MATLAB Function block to the model and calling the MATLAB code from this block. To learn how, see "Adding a MATLAB Function Block to Your Model" on page 29-211.

Adding a 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` in your *`solutions`* subfolder to see the modified model.

For the purposes of this tutorial, you add the MATLAB Function block to the `noise_cancel_00` model supplied with the tutorial. In practice, you would have to develop your own test bench starting with an empty Simulink model.

To add a MATLAB Function block to the `noise_cancel_00` model:

1. Open `noise_cancel_00` in Simulink.

   ```
   noise_cancel_00
   ```

2. Add a 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 MATLAB Function block and drag it into the `noise_cancel_00` model. Place the block just above the red text annotation `Place 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 `coder.extrinsic` function to call your MATLAB code from the 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 suitable for code generation.
- Using `coder.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 "Ways to Debug MATLAB Files".

How to Call MATLAB Code As an Extrinsic Function. To call your MATLAB code from the MATLAB Function block:

1. Double-click the MATLAB Function block to open the MATLAB Function Block Editor.

2. Delete the default code displayed in the MATLAB Function Block Editor.

3. Copy the following code to the MATLAB Function block.

```
function [ Signal_Out, Weights ] = LMS(Noise_In, Signal_In) %#codegen
    % Extrinsic:
    coder.extrinsic('lms_O1');

    % Compute LMS:
    [ ~, Signal_Out, Weights ] = lms_O1(Noise_In, Signal_In);
end
```

Why Use the Tilde (~) Operator?

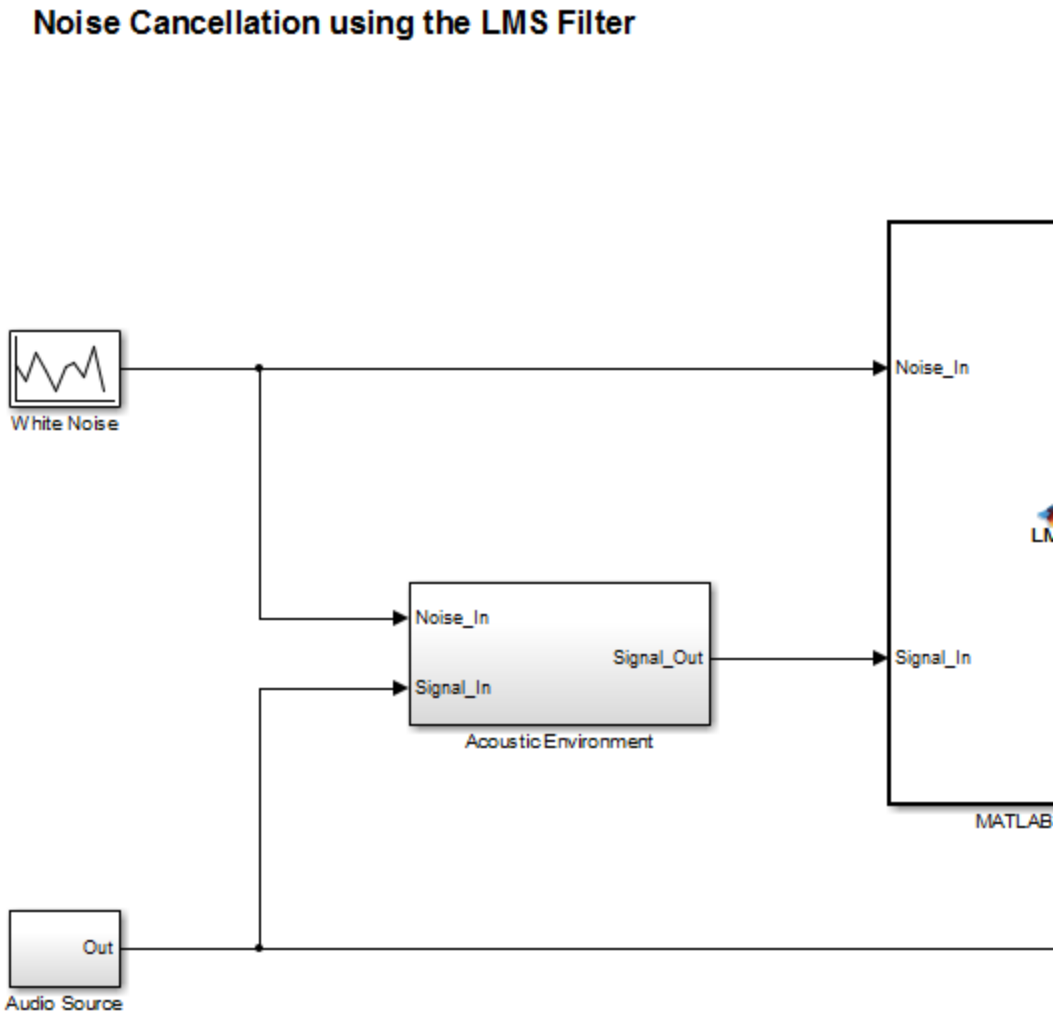
Because the `LMS` function does not use the first output from `lms_O1`, replace this output with the MATLAB ~ operator. MATLAB ignores inputs and outputs specified by ~. This syntax helps avoid confusion in your program code and unnecessary clutter in your workspace, and allows you to reuse existing algorithms without modification.

4. Save the model.

   The `lms_O1` 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.

Connecting the MATLAB Function Block Inputs and Outputs.

1. Connect the MATLAB Function block inputs and outputs so that your model looks like this.



See “Connect Blocks” on page 4-12 for more information.

2 In the 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?

For code generation, you must assign variables explicitly to have a specific class, size, and complexity before using them in operations or returning them as outputs in MATLAB functions. For more information, see "Expected Differences in Behavior After Compiling MATLAB Code" on page 30-9.

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 **Simulation > 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 MATLAB Function block `Signal_Out` output parameter to be frame-based rather than sample-based.

a Double-click the MATLAB Function block to open the MATLAB Function Block Editor.

b Select **Edit Data** 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 MATLAB Function Block Editor.

f Save the model.

2 Check the model again; select **Simulation > 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 29-216

Simulating the noise_cancel_01 Model

To simulate the model:

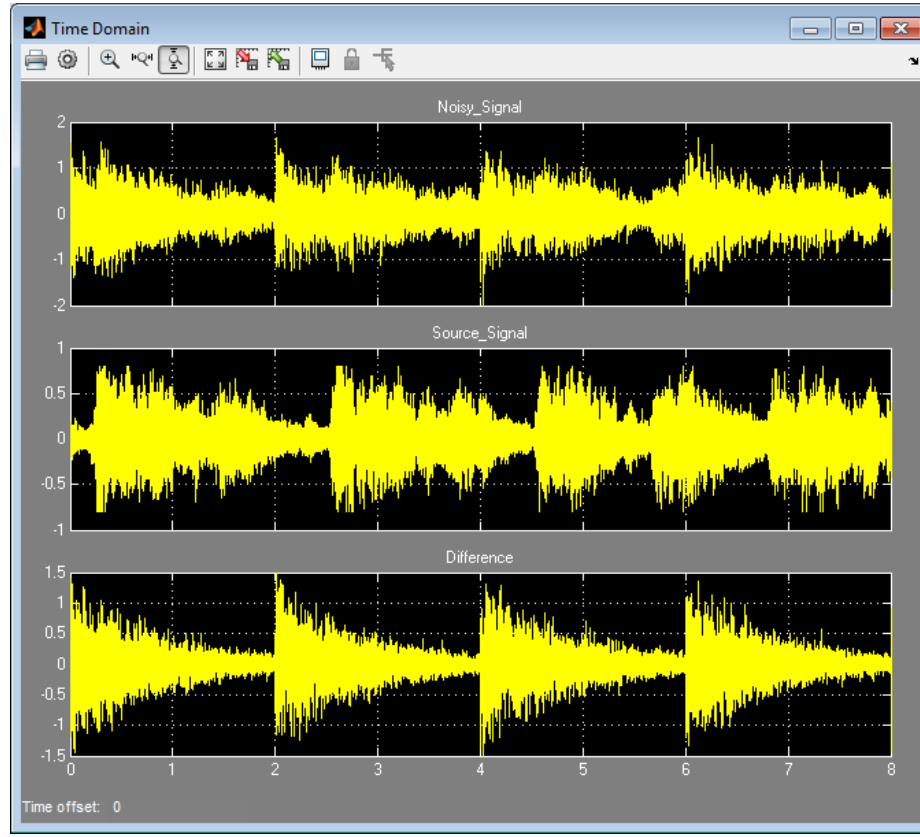
1 Ensure that you can see the **Time Domain** plots.

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 > Run** .

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. Right-click inside the model window and select **Model Properties** from the context menu.

   b. Select the **Callbacks** 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, 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` in your *`solutions`* subfolder to see the modified model.

1. In the `noise_cancel_01` model, double-click the MATLAB Function block to open the MATLAB Function Block Editor.
2. Modify the MATLAB Function block code to call `lms_02`.
   a. Modify the extrinsic call.

   ```
   % Extrinsic:
   coder.extrinsic('lms_02');
   ```

   b. Modify the call to the filter algorithm.

   ```
   % Compute LMS:
   [ ~, Signal_Out, Weights ] = lms_02(Noise_In, Signal_In);
   ```

   Modified MATLAB Function Block Code

   Your MATLAB Function block code should now look like this:

   ```
   function [ Signal_Out, Weights ] = LMS(Noise_In, Signal_In)
     % Extrinsic:
     coder.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. Right-click inside the model window and select **Model Properties** from the context menu.
   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.

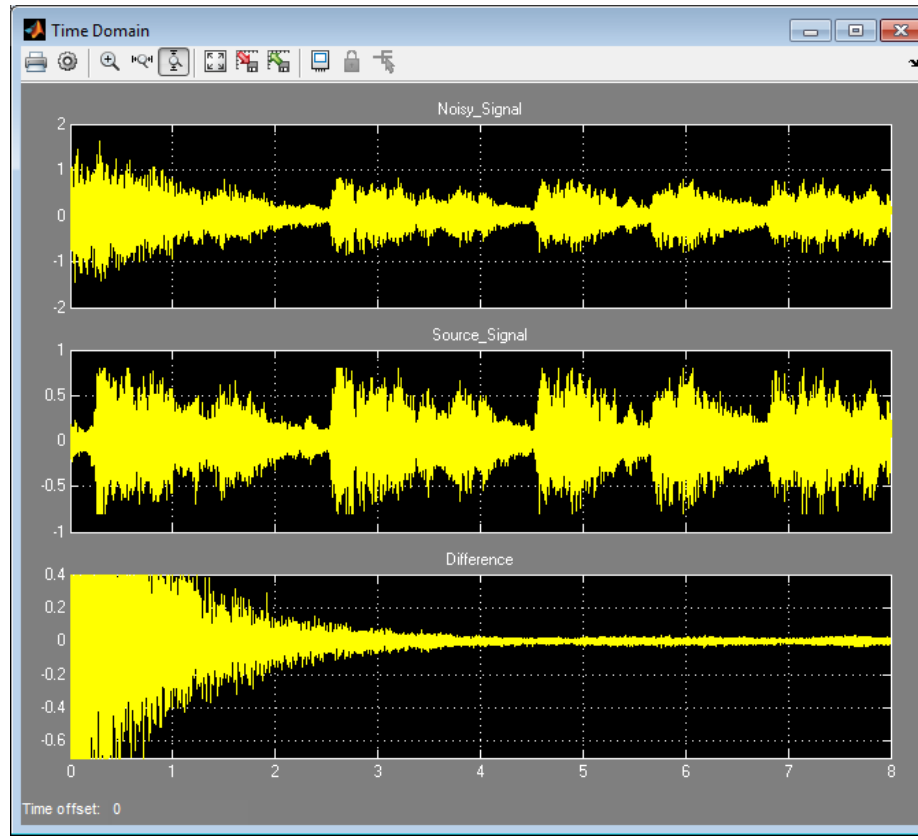
4 Save your model as `noise_cancel_02`.

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` in your *`solutions`* subfolder to see the modified model.

1. Open the `noise_cancel_02` model.
2. Double-click the MATLAB Function block to open the MATLAB Function Block Editor.
3. Modify the 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.

```
coder.extrinsic('lms_03');
```

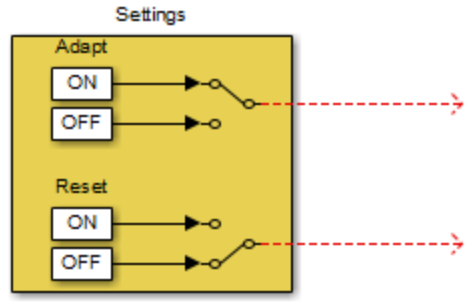
   c. Update the call to the LMS algorithm.

```
% Compute LMS:
[ ~, Signal_Out, Weights ] = ...
   lms_03(Noise_In, Signal_In, Reset, Adapt);
```

   d. Close the MATLAB Function Block Editor.

The `lms_03` function inputs `Reset` and `Adapt` now appear as input ports to the MATLAB Function block.

4 Open the `design_templates` model.



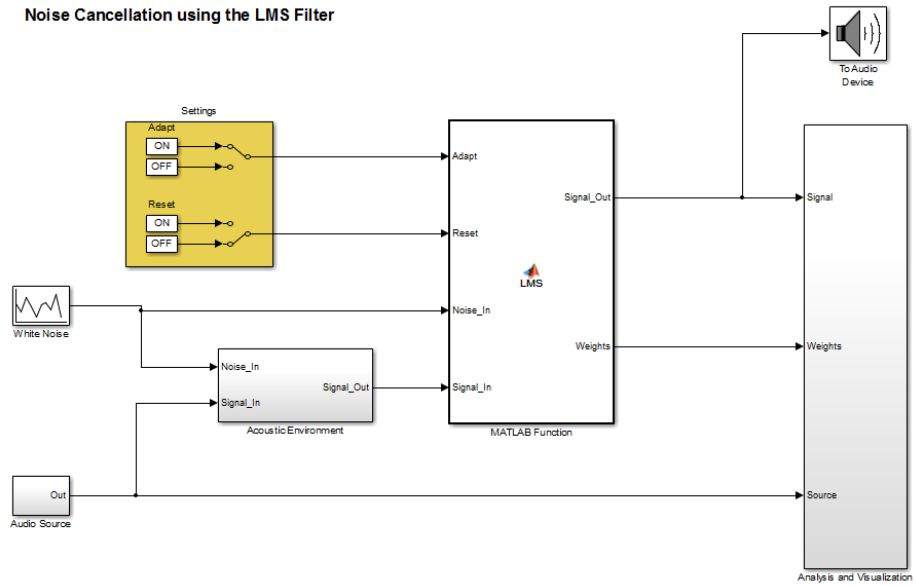
5 Copy the Settings block from this model to your `noise_cancel_02` model:

   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 MATLAB Function block. Your model should now appear as follows.



7 Save the model as `noise_cancel_03`.

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:

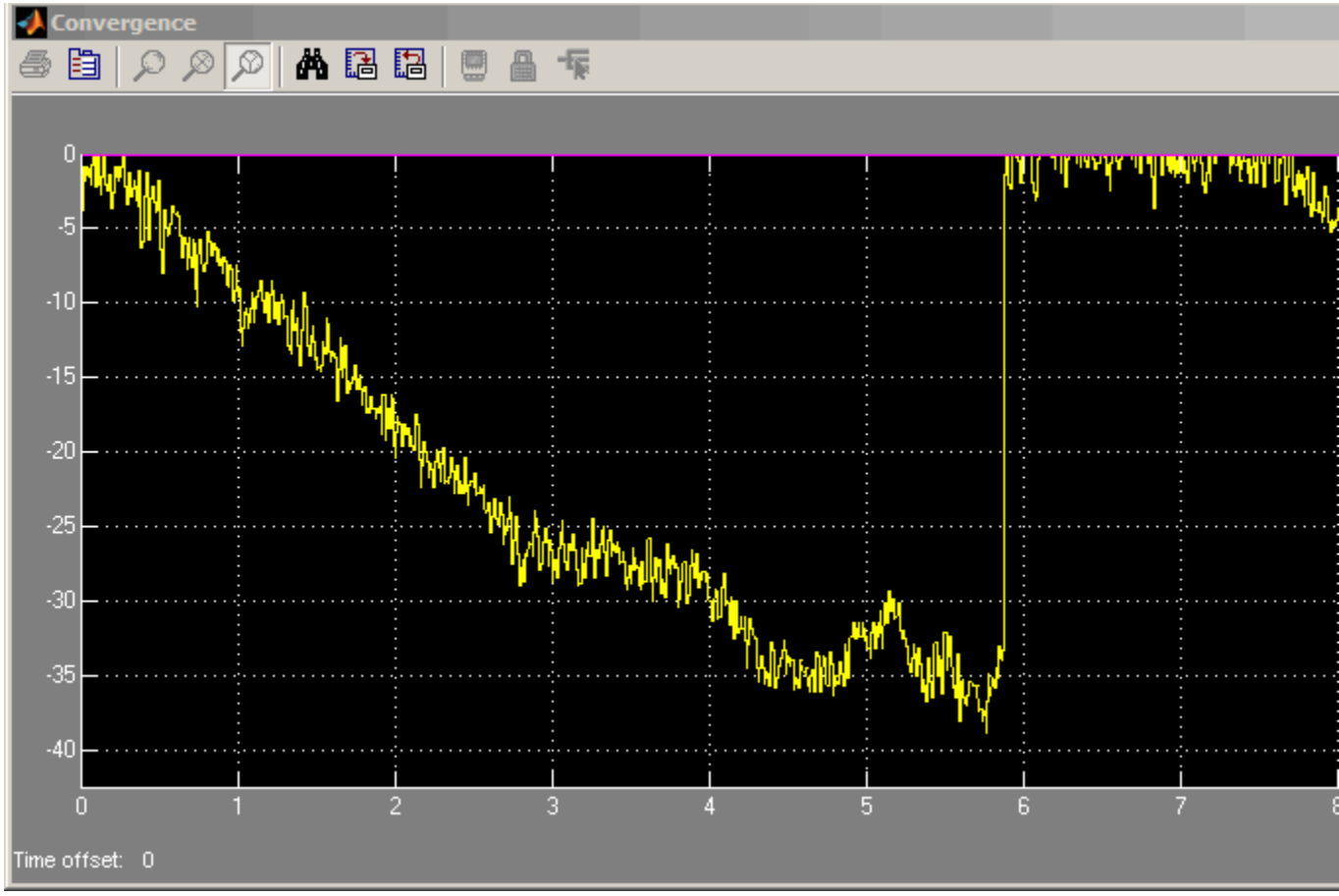
   a Double-click the Analysis and Visualization subsystem.

   b Double-click the Convergence scope.

2 In the Simulink model window, select **Simulation > Run**.

   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.

   The filter converges when `Adapt` is `ON` and `Reset` is `OFF`, then resets when you toggle`Reset`. The results might look something like this:



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 suitable for code generation. For code generation, you must remove the extrinsic call to your code.

Making Your Code Suitable for Code Generation. To modify the model and code yourself, work through the exercises in this section. Otherwise, open the supplied model `noise_cancel_04` and file `lms_04.m` in your *`solutions`* subfolder to see the modifications.

1. Rename the MATLAB Function block to `LMS_Filter`. Select the annotation `MATLAB Function` below the MATLAB Function block and replace the text with `LMS_Filter`.

   When you generate code for the MATLAB Function block, Simulink Coder 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 MATLAB Function block.

   The MATLAB Function Block Editor opens.

3. Delete the extrinsic declaration.

   ```
   % Extrinsic:
   coder.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 code generation by adding the `%#codegen` compilation directive after the function declaration.

```
function [ signal_out, err, weights_out ] = ...
    lms_04(signal_in, desired, reset, adapt) %#codegen
```

The code analyzer message indicator in the top right turns red to indicate that the code analyzer has detected code generation 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 code generation requires `signal_out` to be fully defined before subscripting it and 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 code generation 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”.

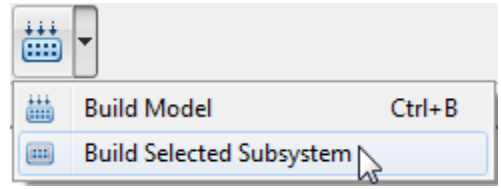
The red error markers for the two lines of code disappear. The code analyzer message indicator in the top right edge of the code turns green, which indicates that you have fixed all the errors and warnings detected by the code analyzer.

11 Save the file as `lms_04.m`.

Generating Code for noise_cancel_04.

1. Before generating code, ensure that Simulink Coder 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 > Model Configuration Parameters**.
   b. In the left pane of the Configuration Parameters dialog box, select **Code Generation > Report**.
   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, select the LMS Filter subsystem.
   b. From the Build Model tool menu, select **Build Selected Subsystem**.



      The **Build code for subsystem** dialog box appears. Click the **Build** button.

      The Simulink Coder software generates C code for the subsystem and launches the code generation report.

      For more information on using the code generation report, see .
   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:

      ```
      coder.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 MATLAB Function block.

      The MATLAB Function Block 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`.

4. Generate code for the updated model.

   a. In the model, select the LMS Filter subsystem.

   b. From the Build Model tool menu, select **Build Selected Subsystem**.

      The **Build code for subsystem** dialog box appears.

   c.

   d. Click the **Build** button.

      The Simulink Coder software generates C code for the subsystem and launches the code generation report.

   e. 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 */
   static void LMS_Filter_lms_05 ...
       (const real_T signal_in[64],const real_T ...
       desired[64], real_T reset, real_T adapt, ...
             real_T signal_out[64], ...
      real_T err[64], real_T weights_out[32]);

/* Function for MATLAB Function Block: 'root/LMS_Filter' */
   static void LMS_Filter_lms_05 ...
      (const real_T signal_in[64], const real_T ...
         desired[64], real_T reset, real_T adapt, ...
             real_T signal_out[64], ...
     real_T err[64], real_T 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 signal_out[i] = 0.0;`
	`81 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 `coder.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 `coder.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 `coder.nullcopy`:

   ```
   % Pre-allocate output and error signals:
   signal_out = coder.nullcopy(zeros(FrameSize, ChannelCount));
   err = coder.nullcopy(zeros(FrameSize, ChannelCount));
   ```

   Caution After declaring a variable with `coder.nullcopy`, you must explicitly initialize the variable in your MATLAB code before reading it. Otherwise, you might get unpredictable results.

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 MATLAB Function block.

   The MATLAB Function Block 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`.

Generate code for the updated model.

1. Select the LMS Filter subsystem.

2 From the Build Model tool menu, select **Build Selected Subsystem**.

The **Build code for subsystem** dialog box appears. Click the **Build** button.

The Simulink Coder 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`.

30

Design Considerations for C/C++ Code Generation

When to Generate Code from MATLAB Algorithms

Generating code from MATLAB algorithms for desktop and embedded systems allows you to perform your software design, implementation, and testing completely within the MATLAB workspace. You can:

- Verify that your algorithms are suitable for code generation
- Generate efficient, readable, and compact C/C++ code automatically, which eliminates the need to manually translate your MATLAB algorithms and minimizes the risk of introducing errors in the code.
- Modify your design in MATLAB code to take into account the specific requirements of desktop and embedded applications, such as data type management, memory use, and speed.
- Test the generated code and easily verify that your modified algorithms are functionally equivalent to your original MATLAB algorithms.
- Generate MEX functions to:
  - Accelerate MATLAB algorithms in certain applications.
  - Speed up fixed-point MATLAB code.
- Generate hardware description language (HDL) from MATLAB code.

When Not to Generate Code from MATLAB Algorithms

Do not generate code from MATLAB algorithms for the following applications. Use the recommended MathWorks product instead.

To:	Use:
Deploy an application that uses handle graphics	MATLAB Compiler™
Use Java	MATLAB Builder™ JA
Use toolbox functions that do not support code generation	Toolbox functions that you rewrite for desktop and embedded applications
Deploy MATLAB based GUI applications on a supported MATLAB host	MATLAB Compiler

To:	Use:
Deploy web-based or Windows applications	• MATLAB Builder NE • MATLAB Builder JA
Interface C code with MATLAB	MATLAB `mex` function

Which Code Generation Feature to Use

To...	Use...	Required Product	To Explore Further...
Generate MEX functions for verifying generated code	`codegen` function	MATLAB Coder	Try this in "MEX Function Generation at the Command Line".
Produce readable, efficient, and compact code from MATLAB algorithms for deployment to desktop and embedded systems.	MATLAB Coder user interface	MATLAB Coder	Try this in "C Code Generation Using the Project Interface".
	`codegen` function	MATLAB Coder	Try this in "C Code Generation at the Command Line".
Generate MEX functions to accelerate MATLAB algorithms	MATLAB Coder user interface	MATLAB Coder	See "Accelerate MATLAB Algorithms".
	`codegen` function	MATLAB Coder	
Integrate MATLAB code into Simulink	MATLAB Function block	Simulink	Try this in "Track Object Using MATLAB Code" on page 29-175.
Speed up fixed-point MATLAB code	`fiaccel` function	Fixed-Point Toolbox	Learn more in "Code Acceleration and Code Generation from MATLAB".
Integrate custom C code into MATLAB and generate efficient, readable code	`codegen` function	MATLAB Coder	Learn more in "Custom C/C++ Code Integration".

To...	Use...	Required Product	To Explore Further...
Integrate custom C code into code generated from MATLAB	`coder.ceval` function	MATLAB Coder	Learn more in `coder.ceval`.
Generate HDL from MATLAB code	MATLAB Function block	Simulink and HDL Coder	Learn more at `www.mathworks.com/products/slhdlcoder`.

Prerequisites for C/C++ Code Generation from MATLAB

To generate C/C++ or MEX code from MATLAB algorithms, you must install the following software:

- MATLAB Coder product
- C/C++ compiler

MATLAB Code Design Considerations for Code Generation

When writing MATLAB code that you want to convert into efficient, standalone C/C++ code, you must consider the following:

- Data types

  C and C++ use static typing. To determine the types of your variables before use, MATLAB Coder requires a complete assignment to each variable.

- Array sizing

  Variable-size arrays and matrices are supported for code generation. You can define inputs, outputs, and local variables in MATLAB functions to represent data that varies in size at run time.

- Memory

  You can choose whether the generated code uses static or dynamic memory allocation.

  With dynamic memory allocation, you potentially use less memory at the expense of time to manage the memory. With static memory, you get best speed performance, but with higher memory usage. Most MATLAB code takes advantage of the dynamic sizing features in MATLAB, therefore dynamic memory allocation typically enables you to generate code from existing MATLAB code without modifying it much. Dynamic memory allocation also allows some programs to compile even when upper bounds cannot be found.

  Static allocation reduces the memory footprint of the generated code, and therefore is suitable for applications where there is a limited amount of available memory, such as embedded applications.

- Speed

  Because embedded applications must run in real time, the code must be fast enough to meet the required clock rate.

  To improve the speed of the generated code:

  - Choose a suitable C/C++ compiler. The default compiler that MathWorks supplies with MATLAB for Windows 32-bit platforms is not a good compiler for performance.
  - Consider disabling run-time checks.

By default, for safety, the code generated for your MATLAB code contains memory integrity checks and responsiveness checks. Generally, these checks result in more generated code and slower simulation. Disabling run-time checks usually results in streamlined generated code and faster simulation. Disable these checks only if you have verified that array bounds and dimension checking is unnecessary.

See Also

- "Data Definition Basics"
- "Variable-Size Data"
- "Bounded Versus Unbounded Variable-Size Data" on page 35-4

Expected Differences in Behavior After Compiling MATLAB Code

In this section...

Why Are There Differences?

To convert MATLAB code to C/C++ code that works efficiently, the code generation process introduces optimizations that intentionally cause the generated code to behave differently — and sometimes produce different results — from the original source code. This section describes these differences.

Character Size

MATLAB supports 16-bit characters, but the generated code represents characters in 8 bits, the standard size for most embedded languages like C. See "Code Generation for Characters" on page 34-6.

Order of Evaluation in Expressions

Generated code does not enforce order of evaluation in expressions. For most expressions, order of evaluation is not significant. However, for expressions

with side effects, the generated code may produce the side effects in different order from the original MATLAB code. Expressions that produce side effects include those that:

- Modify persistent or global variables
- Display data to the screen
- Write data to files
- Modify the properties of handle class objects

In addition, the generated code does not enforce order of evaluation of logical operators that do not short circuit.

For more predictable results, it is good coding practice to split expressions that depend on the order of evaluation into multiple statements. For example, rewrite:

```
A = f1() + f2();
```

as

```
A = f1();
A = A + f2();
```

so that the generated code calls `f1` before `f2`.

Termination Behavior

Generated code does not match the termination behavior of MATLAB source code. For example, optimizations remove infinite loops from generated code if they have no side effects. As a result, the generated code may terminate even though the corresponding MATLAB code does not.

Size of Variable-Size N-D Arrays

For variable-size N-D arrays, the `size` function might return a different result in generated code than in MATLAB source code. The `size` function sometimes returns trailing ones (singleton dimensions) in generated code, but always drops trailing ones in MATLAB. For example, for an N-D array `X` with dimensions `[4 2 1 1]`, `size(X)` might return `[4 2 1 1]` in generated code,

but always returns `[4 2]` in MATLAB. See "Incompatibility with MATLAB in Determining Size of Variable-Size N-D Arrays" on page 35-26.

Size of Empty Arrays

The size of an empty array in generated code might be different from its size in MATLAB source code. See "Incompatibility with MATLAB in Determining Size of Empty Arrays" on page 35-27.

Floating-Point Numerical Results

The generated code might not produce the same floating-point numerical results as MATLAB in the following situations:

When computer hardware uses extended precision registers

Results vary depending on how the C/C++ compiler allocates extended precision floating-point registers. Computation results might not match MATLAB calculations because of different compiler optimization settings or different code surrounding the floating-point calculations.

For certain advanced library functions

The generated code might use different algorithms to implement certain advanced library functions, such as `fft`, `svd`, `eig`, `mldivide`, and `mrdivide`.

For example, the generated code uses a simpler algorithm to implement `svd` to accommodate a smaller footprint. Results might also vary according to matrix properties. For example, MATLAB might detect symmetric or Hermitian matrices at run time and switch to specialized algorithms that perform computations faster than implementations in the generated code.

For implementation of BLAS library functions

For implementations of BLAS library functions. Generated C/C++ code uses reference implementations of BLAS functions, which may produce different results from platform-specific BLAS implementations in MATLAB.

NaN and Infinity Patterns

The generated code might not produce exactly the same pattern of `NaN` and `inf` values as MATLAB code when these values are mathematically meaningless. For example, if MATLAB output contains a `NaN`, output from the generated code should also contain a `NaN`, but not necessarily in the same place.

Code Generation Target

The `coder.target` function returns different values in MATLAB than in the generated code. The intent is to help you determine whether your function is executing in MATLAB or has been compiled for a simulation or code generation target. See .

MATLAB Class Initial Values

MATLAB computes class initial values at class loading time before code generation. The code generation software uses the value that MATLAB computed, it does not recompute the initial value. If the initialization uses a function call to compute the initial value, the code generation software does not execute this function. If the function modifies a global state, for example, a persistent variable, code generation software might provide a different initial value than MATLAB. For more information, see "Defining Class Properties for Code Generation" on page 38-5.

Variable-Size Support for Code Generation

For incompatibilities with MATLAB in variable-size support for code generation, see:

- "Incompatibility with MATLAB for Scalar Expansion"
- "Incompatibility with MATLAB in Determining Size of Variable-Size N-D Arrays"
- "Incompatibility with MATLAB in Determining Size of Empty Arrays"
- "Incompatibility with MATLAB in Vector-Vector Indexing"
- "Incompatibility with MATLAB in Matrix Indexing Operations for Code Generation"

MATLAB Language Features Supported for C/C++ Code Generation

MATLAB supports the following language features in generated code:

- N-dimensional arrays
- Matrix operations, including deletion of rows and columns
- Variable-sized data (see "Variable-Size Data Definition for Code Generation" on page 35-3)
- Subscripting (see "Incompatibility with MATLAB in Matrix Indexing Operations for Code Generation" on page 35-29)
- Complex numbers (see "Code Generation for Complex Data" on page 34-4)
- Numeric classes (see "Supported Variable Types" on page 33-18)
- Double-precision, single-precision, and integer math
- Fixed-point arithmetic (see "Code Acceleration and Code Generation from MATLAB")
- Program control statements `if`, `switch`, `for`, and `while`
- All arithmetic, relational, and logical operators
- Local functions
- Persistent variables (see "Define and Initialize Persistent Variables" on page 33-10)
- Global variables.
- Structures
- Characters (see "Code Generation for Characters" on page 34-6)
- Function handles
- Frames (see "Add Frame-Based Signals" on page 29-126)
- Variable length input and output argument lists
- Subset of MATLAB toolbox functions
- MATLAB classes

- Ability to call functions (see "Resolution of Function Calls in MATLAB Generated Code" on page 41-2)

MATLAB Language Features Not Supported for C/C++ Code Generation

MATLAB does not support the following features in generated code:

- Anonymous functions
- Cell arrays
- Java
- Nested functions
- Recursion
- Sparse matrices
- `try/catch` statements

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Functions Supported for Code Generation

Functions Supported for Code Generation — Alphabetical List

You can generate efficient C/C++ code for a subset of MATLAB and toolbox functions that you call from MATLAB code. In generated code, each supported function has the same name, arguments, and functionality as its MATLAB or toolbox counterparts. However, to generate code for these functions, you must adhere to certain limitations when calling them from your MATLAB source code. These limitations appear in the list below.

To find supported functions by MATLAB category or toolbox, see "Functions Supported for Code Generation — Categorical List" on page 31-54.

Note For more information on code generation for fixed-point algorithms, refer to "Code Acceleration and Code Generation from MATLAB".

Function	Product	Remarks/Limitations
`abs`	MATLAB	—
`abs`	Fixed-Point Toolbox	—
`acos`	MATLAB	• Generates an error during simulation and returns `NaN` in generated code when the input value `x` is real, but the output should be complex. To get the complex result, make the input value complex by passing in `complex(x)`.
`acosd`	MATLAB	—
`acosh`	MATLAB	• Generates an error during simulation and returns `NaN` in generated code when the input value `x` is real, but the output should be complex. To get the complex result, make the input value complex by passing in `complex(x)`.
`acot`	MATLAB	—

Function	Product	Remarks/Limitations
`acotd`	MATLAB	—
`acoth`	MATLAB	—
`acsc`	MATLAB	—
`acscd`	MATLAB	—
`acsch`	MATLAB	—
`add`	Fixed-Point Toolbox	—
`all`	MATLAB	—
`all`	Fixed-Point Toolbox	—
`and`	MATLAB	—
`angle`	MATLAB	—
`any`	MATLAB	—
`any`	Fixed-Point Toolbox	—
`asec`	MATLAB	—
`asecd`	MATLAB	—
`asech`	MATLAB	—
`asin`	MATLAB	• Generates an error during simulation and returns `NaN` in generated code when the input value `x` is real, but the output should be complex. To get the complex result, make the input value complex by passing in `complex(x)`.
`asind`	MATLAB	—
`asinh`	MATLAB	—
`assert`	MATLAB	• Generates specified error messages at compile time only if all input arguments are constants or depend on constants. Otherwise, generates specified error messages at run time.

Function	Product	Remarks/Limitations
`atan`	MATLAB	—
`atan2`	MATLAB	—
`atan2d`	MATLAB	—
`atand`	MATLAB	—
`atanh`	MATLAB	• Generates an error during simulation and returns `NaN` in generated code when the input value `x` is real, but the output should be complex. To get the complex result, make the input value complex by passing in `complex(x)`.
`barthannwin`	Signal Processing Toolbox™	• Does not support variable-size inputs. • Window length must be a constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`bartlett`	Signal Processing Toolbox	• Does not support variable-size inputs. • Window length must be a constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`besselap`	Signal Processing Toolbox	• Does not support variable-size inputs. • Filter order must be a constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`beta`	MATLAB	—
`betainc`	MATLAB	—

Function	Product	Remarks/Limitations
`betaln`	MATLAB	—
`bi2de`	Communications System Toolbox	• Requires a Communications System Toolbox license to generate code.
`bin2dec`	MATLAB	• Does not match MATLAB when the input is empty.
`bitand`	MATLAB	• Does not support floating-point inputs. The arguments must belong to an unsigned integer class.
`bitand`	Fixed-Point Toolbox	• Not supported for slope-bias scaled `fi` objects.
`bitandreduce`	Fixed-Point Toolbox	—
`bitcmp`	MATLAB	• Does not support floating-point input for the first argument. The first argument must belong to an unsigned integer class.
`bitcmp`	Fixed-Point Toolbox	—
`bitconcat`	Fixed-Point Toolbox	—
`bitget`	MATLAB	• Does not support floating-point input for the first argument. The first argument must belong to an unsigned integer class.
`bitget`	Fixed-Point Toolbox	—
`bitmax`	MATLAB	—
`bitor`	MATLAB	• Does not support floating-point inputs. The arguments must belong to an unsigned integer class.
`bitor`	Fixed-Point Toolbox	• Not supported for slope-bias scaled `fi` objects.

Function	Product	Remarks/Limitations
`bitorreduce`	Fixed-Point Toolbox	—
`bitreplicate`	Fixed-Point Toolbox	—
`bitrevorder`	Signal Processing Toolbox	• Does not support variable-size inputs. • Computation performed at run time. • Requires DSP System Toolbox license to generate code.
`bitrol`	Fixed-Point Toolbox	—
`bitror`	Fixed-Point Toolbox	—
`bitset`	MATLAB	• Does not support floating-point input for the first argument. The first argument must belong to an unsigned integer class.
`bitset`	Fixed-Point Toolbox	—
`bitshift`	MATLAB	• Does not support floating-point input for the first argument. The first argument must belong to an unsigned integer class.
`bitshift`	Fixed-Point Toolbox	—
`bitsliceget`	Fixed-Point Toolbox	—
`bitsll`	Fixed-Point Toolbox	—
`bitsra`	Fixed-Point Toolbox	—
`bitsrl`	Fixed-Point Toolbox	—

Function	Product	Remarks/Limitations
`bitxor`	MATLAB	• Does not support floating-point inputs. The arguments must belong to an unsigned integer class.
`bitxor`	Fixed-Point Toolbox	• Not supported for slope-bias scaled `fi` objects.
`bitxorreduce`	Fixed-Point Toolbox	—
`blackman`	Signal Processing Toolbox	• Does not support variable-size inputs. • Window length must be a constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`blackmanharris`	Signal Processing Toolbox	• Does not support variable-size inputs. • Window length must be a constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`blanks`	MATLAB	—
`blkdiag`	MATLAB	—
`bohmanwin`	Signal Processing Toolbox	• Does not support variable-size inputs. • Window length must be a constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`bsxfun`	MATLAB	—

Function	Product	Remarks/Limitations
`buttap`	Signal Processing Toolbox	• Does not support variable-size inputs. • Filter order must be a constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`butter`	Signal Processing Toolbox	• Does not support variable-size inputs. • Filter coefficients must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`buttord`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`bwlookup`	Image Processing Toolbox™	• For best results, specify an input image of class `logical`.
`bwmorph`	Image Processing Toolbox	• The text string specifying the operation must be a constant and, for best results, specify an input image of class `logical`.
`cart2pol`	MATLAB	—
`cart2sph`	MATLAB	—
`cast`	MATLAB	—
`cat`	MATLAB	—
`ceil`	MATLAB	—

Function	Product	Remarks/Limitations
`ceil`	Fixed-Point Toolbox	—
`cfirpm`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`char`	MATLAB	—
`cheb1ap`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`cheb1ord`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`cheb2ap`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.

Function	Product	Remarks/Limitations
`cheb2ord`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`chebwin`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`cheby1`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`cheby2`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.

Function	Product	Remarks/Limitations

`chol`	MATLAB	• When there are two output arguments, either make the input matrix variable-size in both dimensions, or, if the input matrix must be fixed size, copy the input matrix to a variable-size matrix before calling `chol`.
		
		`coder.varsize('B');`
		`B = A;`
		`[B,p] = chol(B);`

`circshift`	MATLAB	—
`class`	MATLAB	—
`compan`	MATLAB	—
`complex`	MATLAB	—
`complex`	Fixed-Point Toolbox	—
`cond`	MATLAB	—
`conj`	MATLAB	—
`conj`	Fixed-Point Toolbox	—
`conv`	MATLAB	—
`conv`	Fixed-Point Toolbox	• Variable-sized inputs are only supported when the `SumMode` property of the governing `fimath` is set to `Specify precision` or `Keep LSB`. • For variable-sized signals, you may see different results between MATLAB and the generated code. - In generated code, the output for variable-sized signals is always computed using the `SumMode` property of the governing `fimath`.

Function	Product	Remarks/Limitations
		- In MATLAB, the output for variable-sized signals is computed using the `SumMode` property of the governing `fimath` when both inputs are nonscalar. However, if either input is a scalar, MATLAB computes the output using the `ProductMode` of the governing `fimath`.
`conv2`	MATLAB	—
`convergent`	Fixed-Point Toolbox	—
`convn`	MATLAB	—
`cordicabs`	Fixed-Point Toolbox	• Variable-size signals are not supported.
`cordicangle`	Fixed-Point Toolbox	• Variable-size signals are not supported.
`cordicatan2`	Fixed-Point Toolbox	• Variable-size signals are not supported.
`cordiccart2pol`	Fixed-Point Toolbox	• Variable-size signals are not supported.
`cordiccexp`	Fixed-Point Toolbox	• Variable-size signals are not supported.
`cordiccos`	Fixed-Point Toolbox	• Variable-size signals are not supported.
`cordicpol2cart`	Fixed-Point Toolbox	• Variable-size signals are not supported.
`cordicrotate`	Fixed-Point Toolbox	• Variable-size signals are not supported.
`cordicsin`	Fixed-Point Toolbox	• Variable-size signals are not supported.
`cordicsincos`	Fixed-Point Toolbox	• Variable-size signals are not supported.

Function	Product	Remarks/Limitations
`corrcoef`	MATLAB	• Row-vector input is only supported when the first two inputs are vectors and nonscalar.
`cos`	MATLAB	—
`cosd`	MATLAB	—
`cosh`	MATLAB	—
`cot`	MATLAB	—
`cotd`	MATLAB	—
`coth`	MATLAB	—
`cov`	MATLAB	—
`cross`	MATLAB	• If supplied, `dim` must be a constant.
`csc`	MATLAB	—
`cscd`	MATLAB	—
`csch`	MATLAB	—
`ctranspose`	MATLAB	—
`ctranspose`	Fixed-Point Toolbox	—
`cumprod`	MATLAB	• Logical inputs are not supported. Cast input to `double` first.
`cumsum`	MATLAB	• Logical inputs are not supported. Cast input to `double` first.
`cumtrapz`	MATLAB	—
`dct`	Signal Processing Toolbox	• Does not support variable-size inputs. • Requires DSP System Toolbox license to generate code. • Length of transform dimension must be a power of two. If specified, the pad or truncation value must be constant. Expressions or variables are allowed if their values do not change.

Function	Product	Remarks/Limitations
`de2bi`	Communications System Toolbox	• Requires a Communications System Toolbox license to generate code.
`deal`	MATLAB	—
`deblank`	MATLAB	• Supports only inputs from the `char` class. • Input values must be in the range 0-127.
`dec2bin`	MATLAB	• If input `d` is `double`, `d` must be less than `2^52`. • If input `d` is `single`, `d` must be less than `2^23`. • Unless you specify input `n` to be constant and `n` is large enough that the output has a fixed number of columns regardless of the input values, this function requires variable-sizing support. Without variable-sizing support, `n` must be at least `52` for `double`, `23` for `single`, `16` for `char`, `32` for `int32`, `16` for `int16`, and so on.
`dec2hex`	MATLAB	• If input `d` is `double`, `d` must be less than `2^52`. • If input `d` is `single`, `d` must be less than `2^23`. • Unless you specify input `n` to be constant and `n` is large enough that the output has a fixed number of columns regardless of the input values, this function requires variable-sizing support. Without variable-sizing support, `n` must be at least `13` for `double`, `6` for `single`, `4` for `char`, `8` for `int32`, `4` for `int16`, and so on.
`deconv`	MATLAB	—
`del2`	MATLAB	—
`det`	MATLAB	—

Function	Product	Remarks/Limitations
`detrend`	MATLAB	• If supplied and not empty, the input argument `bp` must satisfy the following requirements: - Be real - Be sorted in ascending order - Restrict elements to integers in the interval `[1, n-2]`, where `n` is the number of elements in a column of input argument `X` , or the number of elements in `X` when `X` is a row vector - Contain all unique values
`diag`	MATLAB	• If supplied, the argument representing the order of the diagonal matrix must be a real and scalar integer value.
`diag`	Fixed-Point Toolbox	• If supplied, the index, *k*, must be a real and scalar integer value that is not a `fi` object.
`diff`	MATLAB	• If supplied, the arguments representing the number of times to apply `diff` and the dimension along which to calculate the difference must be constants.
`disp`	Fixed-Point Toolbox	—
`divide`	Fixed-Point Toolbox	• Any non-`fi` input must be constant; that is, its value must be known at compile time so that it can be cast to a `fi` object. • Complex and imaginary divisors are not supported. • The syntax `T.divide(a,b)` is not supported.
`dot`	MATLAB	—
`double`	MATLAB	—
`double`	Fixed-Point Toolbox	—

Function	Product	Remarks/Limitations
`downsample`	Signal Processing Toolbox	• Does not support variable-size inputs.
`dpss`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`eig`	MATLAB	• `QZ` algorithm used in all cases, whereas MATLAB might use different algorithms for different inputs. Consequently, `V` might represent a different basis of eigenvectors, and the eigenvalues in `D` might not be in the same order as in MATLAB. • With one input, `[V,D] = eig(A)`, the results will be similar to those obtained using `[V,D] = eig(A,eye(size(A)),'qz')` in MATLAB, except that for code generation, the columns of `V` are normalized. • Options `'balance'`, `'nobalance'` are not supported for the standard eigenvalue problem, and `'chol'` is not supported for the symmetric generalized eigenvalue problem. • Outputs are always of complex type.
`ellip`	Signal Processing Toolbox	• Does not support variable-size inputs. • Inputs must be constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.

Function	Product	Remarks/Limitations
`ellipap`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`ellipke`	MATLAB	—
`ellipord`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`end`	Fixed-Point Toolbox	—
`epipolarLine`	Computer Vision System Toolbox	—
`eps`	MATLAB	—
`eps`	Fixed-Point Toolbox	• Supported for scalar fixed-point signals only. • Supported for scalar, vector, and matrix, `fi` single and `fi` double signals.
`eq`	MATLAB	—
`eq`	Fixed-Point Toolbox	• Not supported for fixed-point signals with different biases.
`erf`	MATLAB	—
`erfc`	MATLAB	—
`erfcinv`	MATLAB	—
`erfcx`	MATLAB	—
`erfinv`	MATLAB	—

Function	Product	Remarks/Limitations
`error`	MATLAB	• This is an extrinsic call.
`estimate Fundamental Matrix`	Computer Vision System Toolbox	—
`estimateUncalibratedRectification`	Computer Vision System Toolbox	—
`exp`	MATLAB	—
`expint`	MATLAB	—
`expm`	MATLAB	—
`expm1`	MATLAB	—
`extractFeatures`	Computer Vision System Toolbox	—
`eye`	MATLAB	• Dimensions must be real, nonnegative, integers.
`factor`	MATLAB	• For double precision input, the maximum value of *A* is `2^32-1`. • For single precision input, the maximum value of *A* is `2^24-1`.
`factorial`	MATLAB	—
`false`	MATLAB	• Dimensions must be real, nonnegative, integers.
`fft`	MATLAB	• Length of input vector must be a power of 2.
`fft2`	MATLAB	• Length of input matrix dimensions must each be a power of 2.
`fftn`	MATLAB	• Length of input matrix dimensions must each be a power of 2.
`fftshift`	MATLAB	—

Function	Product	Remarks/Limitations
`fi`	Fixed-Point Toolbox	• Use to create a fixed-point constant or variable. • The default constructor syntax without any input arguments is not supported. • The syntax `fi('PropertyName',PropertyValue...)` is not supported. To use property name/property value pairs, you must first specify the value `v` of the `fi` object as in `fi(v,'PropertyName',PropertyValue...)`. • Works for all input values when complete `numerictype` information of the `fi` object is provided. • Works only for constant input values (value of input must be known at compile time) when complete `numerictype` information of the `fi` object is not specified. • `numerictype` object information must be available for non-fixed-point Simulink inputs.
`filter`	MATLAB	—
`filter`	Fixed-Point Toolbox	• Variable-sized inputs are only supported when the `SumMode` property of the governing `fimath` is set to `Specify precision` or `Keep LSB`.
`filter2`	MATLAB	—
`filtfilt`	Signal Processing Toolbox	• Does not support variable-size inputs. • Filter coefficients must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.

Function	Product	Remarks/Limitations
`fimath`	Fixed-Point Toolbox	• Fixed-point signals coming in to a MATLAB Function block from Simulink are assigned the `fimath` object defined in the MATLAB Function dialog in the Model Explorer. • Use to create `fimath` objects in generated code.
`find`	MATLAB	• Issues an error if a variable-sized input becomes a row vector at run time. **Note** This limitation does not apply when the input is scalar or a variable-length row vector. • For variable-sized inputs, the shape of empty outputs, 0-by-0, 0-by-1, or 1-by-0, depends on the upper bounds of the size of the input. The output might not match MATLAB when the input array is a scalar or [] at run time. If the input is a variable-length row vector, the size of an empty output is 1-by-0, otherwise it is 0-by-1.
`fir1`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.

Function	Product	Remarks/Limitations
`fir2`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`fircls`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`fircls1`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`firls`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`firpm`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.

Function	Product	Remarks/Limitations
`firpmord`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`firrcos`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`fix`	MATLAB	—
`fix`	Fixed-Point Toolbox	—
`flattopwin`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`flipdim`	MATLAB	—
`fliplr`	MATLAB	—
`flipud`	MATLAB	—
`floor`	MATLAB	—
`floor`	Fixed-Point Toolbox	—
`freqspace`	MATLAB	—

Function	Product	Remarks/Limitations
`freqz`	Signal Processing Toolbox	• Does not support variable-size inputs. • `freqz` with no output arguments produces a plot only when the function call terminates in a semicolon. See "`freqz` With No Output Arguments". • Requires DSP System Toolbox license to generate code.
`fspecial`	Image Processing Toolbox	All inputs must be constants at compilation time. Expressions or variables are allowed if their values do not change.
`full`	MATLAB	—

`fzero`	MATLAB	• The first argument must be a function handle. Does not support structure, inline function, or string inputs for the first argument.
		• Supports up to three output arguments. Does not support the fourth output argument (the `output` structure).
		• Only supports the `TolX` and `FunValCheck` fields of an `options` input structure. Ignores all other options in an `options` input structure. You cannot use the `optimset` function to create the `options` structure. Create this structure directly, for example,
		`opt.TolX = tol;`
		`opt.FunValCheck = 'on';`
		The input structure field names must match exactly.

`gamma`	MATLAB	—
`gammainc`	MATLAB	—
`gammaln`	MATLAB	—

Function	Product	Remarks/Limitations
`gaussfir`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`gausswin`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`gcd`	MATLAB	—
`ge`	MATLAB	—
`ge`	Fixed-Point Toolbox	• Not supported for fixed-point signals with different biases.
`get`	Fixed-Point Toolbox	• The syntax `structure = get(o)` is not supported.
`getlsb`	Fixed-Point Toolbox	—
`getmsb`	Fixed-Point Toolbox	—
`gradient`	MATLAB	—
`gt`	MATLAB	—
`gt`	Fixed-Point Toolbox	• Not supported for fixed-point signals with different biases.
`hadamard`	MATLAB	—

Function	Product	Remarks/Limitations
`hamming`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`hankel`	MATLAB	—
`hann`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`hex2dec`	MATLAB	—
`hex2num`	MATLAB	• For `n = hex2num(S)`, `size(S,2) <= length(num2hex(0))`
`hilb`	MATLAB	—
`hist`	MATLAB	• Histogram bar plotting not supported; call with at least one output argument. • If supplied, the second argument `x` must be a scalar constant. • Inputs must be real.
`histc`	MATLAB	• The output of a variable-size array that becomes a column vector at run time is a column-vector, not a row-vector.
`horzcat`	Fixed-Point Toolbox	—
`hypot`	MATLAB	—

Function	Product	Remarks/Limitations
`idct`	Signal Processing Toolbox	• Does not support variable-size inputs. • Length of transform dimension must be a power of two. If specified, the pad or truncation value must be constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`idivide`	MATLAB	• For efficient generated code, MATLAB rules for divide by zero are supported only for the `'round'` option.
`ifft`	MATLAB	• Length of input vector must be a power of 2. • Output of `ifft` block is always complex. • Does not support the `'symmetric'` option.
`ifft2`	MATLAB	• Length of input matrix dimensions must each be a power of 2. • Does not support the `'symmetric'` option.
`ifftn`	MATLAB	• Length of input matrix dimensions must each be a power of 2. • Does not support the `'symmetric'` option.
`ifftshift`	MATLAB	—
`imag`	MATLAB	—
`imag`	Fixed-Point Toolbox	—
`ind2sub`	MATLAB	• The first argument should be a valid size vector. Size vectors for arrays with more than `intmax` elements are not supported.
`inf`	MATLAB	• Dimensions must be real, nonnegative, integers.
`int8`, `int16`, `int32`	MATLAB	—

Function	Product	Remarks/Limitations
`int8`, `int16`, `int32`	Fixed-Point Toolbox	—
`integralImage`	Computer Vision System Toolbox	—
`interp1`	MATLAB	• Supports only `linear` and `nearest` interpolation methods. • Does not handle evenly spaced `X` indices separately. • `X` must be strictly monotonically increasing or strictly monotonically decreasing; does not reorder indices.
`interp2`	MATLAB	• Supports only `5 <= nargin <= 7`. • `XI` and `YI` must be the same size. • Supports only `'linear'` and `'nearest'` methods. • For best performance, supply `X` and `Y` as vectors. • When the `X` or `Y` inputs are not vectors, `interp2` references only the first row of `X` and first column of `Y`. Supports "plaid" input for `X` and `Y` but does not verify that the input data is "plaid". • `X` and `Y` must contain monotonically increasing values. If your application provides monotonically decreasing values, first use `fliplr` and `flipud` to change `X`, `Y`, and `Z` to monotonically increasing form before calling `interp2`.

Function	Product	Remarks/Limitations

`intersect`	MATLAB	• When `rows` is not specified:
		  - Inputs must be row vectors.
		  - If a vector is variable-sized, its first dimension must have a fixed length of `1`.
		  - The input [] is not supported. Use a 1-by-0 input, for example zeros(1,0), to represent the empty set.
		  - Empty outputs are always row vectors, 1-by-0, never 0-by-0.
		• When `rows` is specified, outputs `ia` and `ib` are always column vectors. If these outputs are empty, they are 0-by-1, never 0-by-0, even if the output `c` is 0-by-0.
		• Inputs must already be sorted in ascending order. The first output is always sorted in ascending order.
		• Complex inputs must be `single` or `double`.

`intfilt`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`intmax`	MATLAB	—
`intmin`	MATLAB	—
`inv`	MATLAB	Singular matrix inputs can produce nonfinite values that differ from MATLAB results.
`invhilb`	MATLAB	—
`ipermute`	MATLAB	—
`isa`	MATLAB	—

Function	Product	Remarks/Limitations
`iscell`	MATLAB	—
`ischar`	MATLAB	—
`iscolumn`	MATLAB	—
`iscolumn`	Fixed-Point Toolbox	—
`isdeployed`	MATLAB Compiler	• Returns true and false as appropriate for MEX and SIM targets • Returns false for all other targets
`isempty`	MATLAB	—
`isempty`	Fixed-Point Toolbox	—
`isEpipoleInImage`	Computer Vision System Toolbox	—
`isequal`	MATLAB	—
`isequal`	Fixed-Point Toolbox	—
`isequaln`	MATLAB	—
`isfi`	Fixed-Point Toolbox	—
`isfield`	MATLAB	• Does not support cell input for second argument
`isfimath`	Fixed-Point Toolbox	—
`isfimathlocal`	Fixed-Point Toolbox	—
`isfinite`	MATLAB	—
`isfinite`	Fixed-Point Toolbox	—
`isfloat`	MATLAB	—

Function	Product	Remarks/Limitations
`isinf`	MATLAB	—
`isinf`	Fixed-Point Toolbox	—
`isinteger`	MATLAB	—
`isletter`	MATLAB	• Input values from the `char` class must be in the range 0-127
`islogical`	MATLAB	—
`ismatrix`	MATLAB	—
`ismcc`	MATLAB Compiler	• Returns true and false as appropriate for MEX and SIM targets. • Returns false for all other targets.
`ismember`	MATLAB	• The second input, `S`, must be sorted in ascending order. • Complex inputs must be `single` or `double`.
`isnan`	MATLAB	—
`isnan`	Fixed-Point Toolbox	—
`isnumeric`	MATLAB	—
`isnumeric`	Fixed-Point Toolbox	—
`isnumerictype`	Fixed-Point Toolbox	—
`isprime`	MATLAB	• For double precision input, the maximum value of *A* is `2^32-1`. • For single precision input, the maximum value of *A* is `2^24-1`.
`isreal`	MATLAB	—
`isreal`	Fixed-Point Toolbox	—

Function	Product	Remarks/Limitations
`isrow`	MATLAB	—
`isrow`	Fixed-Point Toolbox	—
`isscalar`	MATLAB	—
`isscalar`	Fixed-Point Toolbox	—
`issigned`	Fixed-Point Toolbox	—
`issorted`	MATLAB	—
`isspace`	MATLAB	• Input values from the `char` class must be in the range 0-127
`issparse`	MATLAB	—
`isstrprop`	MATLAB	• Supports only inputs from `char` and `integer` classes. • Input values must be in the range 0-127.
`isstruct`	MATLAB	—
`istrellis`	Communications System Toolbox	• Requires a Communications System Toolbox license to generate code.
`isvector`	MATLAB	—
`isvector`	Fixed-Point Toolbox	—
`kaiser`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.

Function	Product	Remarks/Limitations
`kaiserord`	Signal Processing Toolbox	• Does not support variable-size inputs. • Computation performed at run time. • Requires DSP System Toolbox license to generate code.
`kron`	MATLAB	—
`label2rgb`	Image Processing Toolbox	Referring to the standard syntax: `RGB = label2rgb(L, map, zerocolor, order)` • Submit at least two input arguments: the label matrix, `L`, and the colormap matrix, `map`. • `map` must be an `n-by-3`, `double`, colormap matrix. You cannot use a string containing the name of a MATLAB colormap function or a function handle of a colormap function. • If you set the boundary color `zerocolor` to the same color as one of the regions, `label2rgb` will not issue a warning. • If you supply a value for `order`, it must be `'noshuffle'`.
`lcm`	MATLAB	—
`ldivide`	MATLAB	—
`le`	MATLAB	—
`le`	Fixed-Point Toolbox	• Not supported for fixed-point signals with different biases.
`length`	MATLAB	—
`length`	Fixed-Point Toolbox	—

Function	Product	Remarks/Limitations
`levinson`	Signal Processing Toolbox	• Does not support variable-size inputs. • If specified, the order of recursion must be a constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`lineToBorderPoints`	Computer Vision System Toolbox	—

`linsolve`	MATLAB	• The option structure must be a constant.
		• Supports only a scalar option structure input. It does not support arrays of option structures.
		• Only optimizes these cases:
		  - `UT`
		  - `LT`
		  - `UHESS` = `true` (the `TRANSA` can be either `true` or `false`)
		  - `SYM` = `true` and `POSDEF` = `true`
		All other options are equivalent to using `mldivide`.

`linspace`	MATLAB	—
`log`	MATLAB	• Generates an error during simulation and returns `NaN` in generated code when the input value `x` is real, but the output should be complex. To get the complex result, make the input value complex by passing in `complex(x)`.
`log2`	MATLAB	—
`log10`	MATLAB	—
`log1p`	MATLAB	—
`logical`	MATLAB	—

Function	Product	Remarks/Limitations
`logical`	Fixed-Point Toolbox	—
`logspace`	MATLAB	—
`lower`	MATLAB	• Supports only `char` inputs. • Input values must be in the range 0-127.
`lowerbound`	Fixed-Point Toolbox	—
`lsb`	Fixed-Point Toolbox	• Supported for scalar fixed-point signals only. • Supported for scalar, vector, and matrix, `fi` single and double signals.
`lt`	MATLAB	—
`lt`	Fixed-Point Toolbox	• Not supported for fixed-point signals with different biases.
`lu`	MATLAB	—
`magic`	MATLAB	—
`matchFeatures`	Computer Vision System Toolbox	—
`max`	MATLAB	—
`max`	Fixed-Point Toolbox	—
`maxflat`	Signal Processing Toolbox	• Does not support variable-size inputs. • Inputs must be constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`mean`	MATLAB	—

Function	Product	Remarks/Limitations
`mean`	Fixed-Point Toolbox	—
`median`	MATLAB	—
`median`	Fixed-Point Toolbox	—
`meshgrid`	MATLAB	—
`min`	MATLAB	—
`min`	Fixed-Point Toolbox	—
`minus`	MATLAB	—
`minus`	Fixed-Point Toolbox	• Any non-`fi` input must be constant; that is, its value must be known at compile time so that it can be cast to a `fi` object.
`mldivide`	MATLAB	—
`mod`	MATLAB	• Performs all arithmetic in the output class. Hence, results might not match MATLAB due to different rounding errors.
`mode`	MATLAB	• Does not support third output argument `C` (cell array)
`mpower`	MATLAB	—
`mpower`	Fixed-Point Toolbox	• The exponent input, *k*, must be constant; that is, its value must be known at compile time. • Variable-sized inputs are only supported when the `SumMode` property of the governing `fimath` is set to `Specify precision` or `Keep LSB`. • For variable-sized signals, you may see different results between MATLAB and the generated code. - In generated code, the output for variable-sized signals is always computed

Function	Product	Remarks/Limitations
		using the `SumMode` property of the governing `fimath`. - In MATLAB, the output for variable-sized signals is computed using the `SumMode` property of the governing `fimath` when both inputs are nonscalar. However, if either input is a scalar, MATLAB computes the output using the `ProductMode` of the governing `fimath`.
`mpy`	Fixed-Point Toolbox	• When you provide complex inputs to the `mpy` function inside a MATLAB Function block, you must declare the input as complex before running the simulation. To do so, go to the **Ports and data manager** and set the **Complexity** parameter for all known complex inputs to `On`.
`mrdivide`	MATLAB	—
`mrdivide`	Fixed-Point Toolbox	—
`mtimes`	MATLAB	—
`mtimes`	Fixed-Point Toolbox	• Any non-`fi` input must be constant; that is, its value must be known at compile time so that it can be cast to a `fi` object. • Variable-sized inputs are only supported when the `SumMode` property of the governing `fimath` is set to `Specify precision` or `Keep LSB`. • For variable-sized signals, you may see different results between MATLAB and the generated code. - In generated code, the output for variable-sized signals is always computed using the `SumMode` property of the governing `fimath`.

Function	Product	Remarks/Limitations
		- In MATLAB, the output for variable-sized signals is computed using the `SumMode` property of the governing `fimath` when both inputs are nonscalar. However, if either input is a scalar, MATLAB computes the output using the `ProductMode` of the governing `fimath`.
NaN or `nan`	MATLAB	• Dimensions must be real, nonnegative, integers.
`nargchk`	MATLAB	• Output structure does not include stack information.
`nargin`	MATLAB	—
`nargout`	MATLAB	• For a function with no output arguments, returns `1` if called without a terminating semicolon. **Note** This behavior also affects extrinsic calls with no terminating semicolon. `nargout` is `1` for the called function in MATLAB.
`nargoutchk`	MATLAB	• Output structure does not include stack information.
`nchoosek`	MATLAB	—
`ndgrid`	MATLAB	—
`ndims`	MATLAB	—
`ndims`	Fixed-Point Toolbox	—
`ne`	MATLAB	—
`ne`	Fixed-Point Toolbox	• Not supported for fixed-point signals with different biases.

Function	Product	Remarks/Limitations
`nearest`	Fixed-Point Toolbox	—
`nextpow2`	MATLAB	—
`nnz`	MATLAB	—
`nonzeros`	MATLAB	—
`norm`	MATLAB	—
`normest`	MATLAB	—
`not`	MATLAB	—
`nthroot`	MATLAB	—
`null`	MATLAB	• Might return a different basis than MATLAB • Does not support rational basis option (second input)
`num2hex`	MATLAB	—
`numberofelements`	Fixed-Point Toolbox	• Returns the number of elements of `fi` objects in the generated code (works the same as `numel` for `fi` objects in generated code).
`numel`	MATLAB	• Returns the number of elements of `fi` objects in the generated code, rather than always returning 1.
`numerictype`	Fixed-Point Toolbox	• Fixed-point signals coming in to a MATLAB Function block from Simulink are assigned a `numerictype` object that is populated with the signal's data type and scaling information. • Returns the data type when the input is a non-fixed-point signal. • Use to create `numerictype` objects in the generated code.

Function	Product	Remarks/Limitations
`nuttallwin`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`ones`	MATLAB	• Dimensions must be real, nonnegative, integers.
`or`	MATLAB	—
`orth`	MATLAB	• Might return a different basis than MATLAB
`parzenwin`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`pascal`	MATLAB	—
`permute`	MATLAB	—
`permute`	Fixed-Point Toolbox	—
`pi`	MATLAB	—
`pinv`	MATLAB	—
`planerot`	MATLAB	—
`plus`	MATLAB	—
`plus`	Fixed-Point Toolbox	• Any non-`fi` input must be constant; that is, its value must be known at compile time so that it can be cast to a `fi` object.
`pol2cart`	MATLAB	—

Function	Product	Remarks/Limitations
`poly`	MATLAB	• Does not discard nonfinite input values • Complex input always produces complex output
`poly2trellis`	Communications System Toolbox	• Requires a Communications System Toolbox license to generate code.
`polyfit`	MATLAB	—
`polyval`	MATLAB	—
`pow2`	Fixed-Point Toolbox	—
`power`	MATLAB	• Generates an error during simulation and returns `NaN` in generated code when both `X` and `Y` are real, but `power(X,Y)` is complex. To get the complex result, make the input value `X` complex by passing in `complex(X)`. For example, `power(complex(X),Y)`. • Generates an error during simulation and returns `NaN` in generated code when both `X` and `Y` are real, but `X .^ Y` is complex. To get the complex result, make the input value `X` complex by using `complex(X)`. For example, `complex(X).^Y`.
`power`	Fixed-Point Toolbox	• The exponent input, *k*, must be constant; that is, its value must be known at compile time.
`primes`	MATLAB	—
`prod`	MATLAB	—
`qr`	MATLAB	—
`quad2d`	MATLAB	• Generates a warning if the size of the internal storage arrays is not large enough. If a warning occurs, a possible workaround is to divide the region of integration into pieces and sum the integrals over each piece.

Function	Product	Remarks/Limitations
`quadgk`	MATLAB	—
`quatconj`	Aerospace Toolbox	—
`quatdivide`	Aerospace Toolbox	—
`quatinv`	Aerospace Toolbox	—
`quatmod`	Aerospace Toolbox	—
`quatmultiply`	Aerospace Toolbox	—
`quatnorm`	Aerospace Toolbox	—
`quatnormalize`	Aerospace Toolbox	—
`rand`	MATLAB	—
`randi`	MATLAB	—
`randn`	MATLAB	—
`randperm`	MATLAB	—
`range`	Fixed-Point Toolbox	—
`rank`	MATLAB	—
`rcond`	MATLAB	—
`rcosfir`	Communications System Toolbox	• Requires a Communications System Toolbox license to generate code.
`rdivide`	MATLAB	—

Function	Product	Remarks/Limitations
`rdivide`	Fixed-Point Toolbox	—
`real`	MATLAB	—
`real`	Fixed-Point Toolbox	—
`reallog`	MATLAB	—
`realmax`	MATLAB	—
`realmax`	Fixed-Point Toolbox	—
`realmin`	MATLAB	—
`realmin`	Fixed-Point Toolbox	—
`realpow`	MATLAB	—
`realsqrt`	MATLAB	—
`rectwin`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`reinterpretcast`	Fixed-Point Toolbox	—
`rem`	MATLAB	• Performs all arithmetic in the output class. Hence, results might not match MATLAB due to different rounding errors.
`repmat`	MATLAB	—
`repmat`	Fixed-Point Toolbox	—

Function	Product	Remarks/Limitations
`resample`	Signal Processing Toolbox	• Does not support variable-size inputs. • The upsampling and downsampling factors must be specified as constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`rescale`	Fixed-Point Toolbox	—
`reshape`	MATLAB	—
`reshape`	Fixed-Point Toolbox	—

`rng`	MATLAB	• For library and executable code generation targets, and for MEX targets when extrinsic calls are disabled, supports only the `'default'` input and these `generator` inputs:
		  - `'twister'`
		  - `'v4'`
		  - `'v5normal'`
		  For these targets, the output of `s=rng` in the generated code differs from the MATLAB output. You cannot return the output of `s=rng` from the generated code and pass it to `rng` in MATLAB.
		• For MEX targets, if extrinsic calls are enabled, you cannot access the data in the structure returned by `rng`.

Function	Product	Remarks/Limitations
`roots`	MATLAB	• Output is always variable size • Output is always complex • Roots may not be in the same order as MATLAB • Roots of poorly conditioned polynomials may not match MATLAB
`rosser`	MATLAB	—
`rot90`	MATLAB	—
`round`	MATLAB	—
`round`	Fixed-Point Toolbox	—
`rsf2csf`	MATLAB	—
`schur`	MATLAB	Might sometimes return a different Schur decomposition in generated code than in MATLAB.
`sec`	MATLAB	—
`secd`	MATLAB	—
`sech`	MATLAB	—
`setdiff`	MATLAB	• When `rows` is not specified: - Inputs must be row vectors. - If a vector is variable-sized, its first dimension must have a fixed length of `1`. - The input [] is not supported. Use a 1-by-0 input, for example, zeros(1,0) to represent the empty set. - Empty outputs are always row vectors, 1-by-0, never 0-by-0.

Function	Product	Remarks/Limitations
		• When `rows` is specified, output `i` is always a column vector. If `i` is empty, it is 0-by-1, never 0-by-0, even if the output `c` is 0-by-0. • Inputs must already be sorted in ascending order. The first output is always sorted in ascending order. • Complex inputs must be `single` or `double`.

`setxor`	MATLAB	• When `rows` is not specified:
		  - Inputs must be row vectors.
		  - If a vector is variable-sized, its first dimension must have a fixed length of `1`.
		  - The input [] is not supported. Use a 1-by-0 input, such as zeros(1,0), to represent the empty set.
		  - Empty outputs are always row vectors, 1-by-0, never 0-by-0.
		• When `rows` is specified, outputs `ia` and `ib` are always column vectors. If these outputs are empty, they are 0-by-1, never 0-by-0, even if the output `c` is 0-by-0.
		• Inputs must already be sorted in ascending order. The first output is always sorted in ascending order.
		• Complex inputs must be `single` or `double`.

`sfi`	Fixed-Point Toolbox	—

Function	Product	Remarks/Limitations
`sgolay`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`shiftdim`	MATLAB	Second argument must be a constant.
`sign`	MATLAB	—
`sign`	Fixed-Point Toolbox	—
`sin`	MATLAB	—
`sind`	MATLAB	—
`single`	MATLAB	—
`single`	Fixed-Point Toolbox	—
`sinh`	MATLAB	—
`size`	MATLAB	—
`size`	Fixed-Point Toolbox	—
`sort`	MATLAB	—
`sort`	Fixed-Point Toolbox	—
`sortrows`	MATLAB	—
`sosfilt`	Signal Processing Toolbox	• Does not support variable-size inputs. • Computation performed at run time. • Requires DSP System Toolbox license to generate code.
`sph2cart`	MATLAB	—

Function	Product	Remarks/Limitations
`squeeze`	MATLAB	—
`sqrt`	MATLAB	• Generates an error during simulation and returns `NaN` in generated code when the input value `x` is real, but the output should be complex. To get the complex result, make the input value complex by passing in `complex(x)`.
`sqrt`	Fixed-Point Toolbox	• Complex and [Slope Bias] inputs error out. • Negative inputs yield a 0 result.
`sqrtm`	MATLAB	—
`std`	MATLAB	—
`storedInteger`	Fixed-Point Toolbox	—
`storedIntegerToDouble`	Fixed-Point Toolbox	—
`str2func`	MATLAB	• String must be constant/known at compile time
`strcmp`	MATLAB	• Arguments must be computable at compile time.
`strcmpi`	MATLAB	• Input values from the `char` class must be in the range 0-127.
`strjust`	MATLAB	—
`strncmp`	MATLAB	—
`strncmpi`	MATLAB	• Input values from the `char` class must be in the range 0-127.
`strtok`	MATLAB	—
`strtrim`	MATLAB	• Supports only inputs from the `char` class. • Input values must be in the range 0-127.
`struct`	MATLAB	—

Function	Product	Remarks/Limitations
`structfun`	MATLAB	• Does not support the `ErrorHandler` option. • The number of outputs must be less than or equal to three.
`sub`	Fixed-Point Toolbox	—
`sub2ind`	MATLAB	• The first argument should be a valid size vector. Size vectors for arrays with more than `intmax` elements are not supported.
`subsasgn`	Fixed-Point Toolbox	—
`subspace`	MATLAB	—
`subsref`	Fixed-Point Toolbox	—
`sum`	MATLAB	—
`sum`	Fixed-Point Toolbox	• Variable-sized inputs are only supported when the `SumMode` property of the governing `fimath` is set to `Specify precision` or `Keep LSB`.
`svd`	MATLAB	Uses a different `SVD` implementation than MATLAB. As the singular value decomposition is not unique, left and right singular vectors might differ from those computed by MATLAB.
`swapbytes`	MATLAB	Inheritance of the class of the input to `swapbytes` in a MATLAB Function block is supported only when the class of the input is `double`. For non-double inputs, the input port data types must be specified, not inherited.
`tan`	MATLAB	—
`tand`	MATLAB	—
`tanh`	MATLAB	—

Function	Product	Remarks/Limitations
`taylorwin`	Signal Processing Toolbox	• Does not support variable-size inputs. • Inputs must be constant • Requires DSP System Toolbox license to generate code.
`times`	MATLAB	—
`times`	Fixed-Point Toolbox	• Any non-`fi` input must be constant; that is, its value must be known at compile time so that it can be cast to a `fi` object. • When you provide complex inputs to the `times` function inside a MATLAB Function block, you must declare the input as complex before running the simulation. To do so, go to the **Ports and data manager** and set the **Complexity** parameter for all known complex inputs to `On`.
`toeplitz`	MATLAB	—
`trace`	MATLAB	—
`trapz`	MATLAB	—
`transpose`	MATLAB	—
`transpose`	Fixed-Point Toolbox	—
`triang`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`tril`	MATLAB	• If supplied, the argument representing the order of the diagonal matrix must be a real and scalar integer value.

Function	Product	Remarks/Limitations
`tril`	Fixed-Point Toolbox	• If supplied, the index, *k*, must be a real and scalar integer value that is not a `fi` object.
`triu`	MATLAB	• If supplied, the argument representing the order of the diagonal matrix must be a real and scalar integer value.
`triu`	Fixed-Point Toolbox	• If supplied, the index, *k*, must be a real and scalar integer value that is not a `fi` object.
`true`	MATLAB	• Dimensions must be real, nonnegative, integers.
`tukeywin`	Signal Processing Toolbox	• Does not support variable-size inputs. • All inputs must be constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`typecast`	MATLAB	• Value of string input argument `type` must be lower case • You might receive a size error when you use `typecast` with inheritance of input port data types in MATLAB Function blocks. To avoid this error, specify the block's input port data types explicitly.
`ufi`	Fixed-Point Toolbox	—
`uint8`, `uint16`, `uint32`	MATLAB	—
`uint8`, `uint16`, `uint32`	Fixed-Point Toolbox	—
`uminus`	MATLAB	—
`uminus`	Fixed-Point Toolbox	—

Function	Product	Remarks/Limitations

`union`	MATLAB	• When `rows` is not specified:
		  - Inputs must be row vectors.
		  - If a vector is variable-sized, its first dimension must have a fixed length of `1`.
		  - The input [] is not supported. Use a 1-by-0 input, such as zeros(1,0) to represent the empty set.
		  - Empty outputs are always row vectors, 1-by-0, never 0-by-0.
		• When `rows` is specified, outputs `ia` and `ib` are always column vectors. If these outputs are empty, they are 0-by-1, never 0-by-0, even if the output `c` is 0-by-0.
		• Inputs must already be sorted in ascending order. The first output is always sorted in ascending order.
		• Complex inputs must be `single` or `double`.

`unique`	MATLAB	• When `rows` is not specified:
		  - The first input must be a row vector.
		  - If the vector is variable-sized, its first dimension must have a fixed length of `1`.
		  - The input [] is not supported. Use a 1-by-0 input, such as zeros(1,0), to represent the empty set.
		  - Empty outputs are always row vectors, 1-by-0, never 0-by-0.
		• When `rows` is specified, outputs `m` and `n` are always column vectors. If these outputs are empty, they are 0-by-1, never 0-by-0, even if the output `b` is 0-by-0.
		• Complex inputs must be `single` or `double`.

Function	Product	Remarks/Limitations
`unwrap`	MATLAB	• Row vector input is only supported when the first two inputs are vectors and nonscalar • Performs all arithmetic in the output class. Hence, results might not match MATLAB due to different rounding errors
`upfirdn`	Signal Processing Toolbox	• Does not support variable-size inputs. • Filter coefficients, upsampling factor, and downsampling factor must be constants. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code
`uplus`	MATLAB	—
`uplus`	Fixed-Point Toolbox	—
`upper`	MATLAB	• Supports only `char` inputs. • Input values must be in the range 0-127.
`upperbound`	Fixed-Point Toolbox	—
`upsample`	Signal Processing Toolbox	• Does not support variable-size inputs. • Either declare input `n` as constant, or use the `assert` function in the calling function to set upper bounds for `n`. For example, `assert(n<10)`
`vander`	MATLAB	—
`var`	MATLAB	—

Function	Product	Remarks/Limitations
`vertcat`	Fixed-Point Toolbox	—
`wilkinson`	MATLAB	—
`xcorr`	Signal Processing Toolbox	• Does not support variable-size inputs. • Does not support the case where A is a matrix • Does not support partial (abbreviated) strings of biased, unbiased, coeff, or none • Computation performed at run time. • Requires DSP System Toolbox license to generate code
`xor`	MATLAB	—
`yulewalk`	Signal Processing Toolbox	• Does not support variable-size inputs. • If specified, the order of recursion must be a constant. Expressions or variables are allowed if their values do not change. • Requires DSP System Toolbox license to generate code.
`zeros`	MATLAB	• Dimensions must be real, nonnegative, integers.
`zp2tf`	MATLAB	—

Functions Supported for Code Generation — Categorical List

In this section...

In this section...

Aerospace Toolbox Functions

Function	Description
`quatconj`	Calculate conjugate of quaternion
`quatdivide`	Divide quaternion by another quaternion
`quatinv`	Calculate inverse of quaternion
`quatmod`	Calculate modulus of quaternion
`quatmultiply`	Calculate product of two quaternions
`quatnorm`	Calculate norm of quaternion
`quatnormalize`	Normalize quaternion

Arithmetic Operator Functions

See `Arithmetic Operators` for detailed descriptions of the following operator equivalent functions.

Function	Description
ctranspose	Complex conjugate transpose (')
idivide	Integer division with rounding option
isa	Determine if input is object of given class
ldivide	Left array divide
minus	Minus (-)
mldivide	Left matrix divide (\)
mpower	Equivalent of array power operator (.^)
mrdivide	Right matrix divide
mtimes	Matrix multiply (*)
plus	Plus (+)
power	Array power
rdivide	Right array divide
times	Array multiply
transpose	Matrix transpose (')
uminus	Unary minus (-)
uplus	Unary plus (+)

Bit-Wise Operation Functions

Function	Description
swapbytes	Swap byte ordering

Casting Functions

Data Type	Description
cast	Cast variable to different data type
char	Create character array (string)

Data Type	Description
`class`	Query class of object argument
`double`	Convert to double-precision floating point
`int8`, `int16`, `int32`	Convert to signed integer data type
`logical`	Convert to Boolean `true` or `false` data type
`single`	Convert to single-precision floating point
`typecast`	Convert data types without changing underlying data
`uint8`, `uint16`, `uint32`	Convert to unsigned integer data type

Communications System Toolbox Functions

Function	Remarks/Limitations
`bi2de`	—
`de2bi`	—
`istrellis`	—
`poly2trellis`	—
`rcosfir`	—

Complex Number Functions

Function	Description
`complex`	Construct complex data from real and imaginary components
`conj`	Return the conjugate of a complex number
`imag`	Return the imaginary part of a complex number
`isnumeric`	Return `true` for numeric arrays
`isreal`	Return `false` (0) for a complex number
`isscalar`	Return `true` if array is a scalar

Function	Description
real	Return the real part of a complex number
unwrap	Correct phase angles to produce smoother phase plots

Computer Vision System Toolbox Functions

Function	Description
epipolarLine	Compute epipolar lines for stereo images
estimateFundamentalMatrix	Estimate fundamental matrix from corresponding points in stereo image
estimateUncalibratedRectification	Uncalibrated stereo rectification
extractFeatures	Extract interest point descriptors
integralImage	Compute integral image
isEpipoleInImage	Determine whether image contains epipole
vision.KalmanFilter	Kalman filter for object tracking

Function	Description
lineToBorderPoints	Intersection points of lines in image and image border
matchFeatures	Find matching image features

Data Type Functions

Function	Description
deal	Distribute inputs to outputs
iscell	Determine whether input is cell array
nargchk	Validate number of input arguments
nargoutchk	Validate number of output arguments
str2func	Construct function handle from function name string
structfun	Apply function to each field of scalar structure

Derivative and Integral Functions

Function	Description
cumtrapz	Cumulative trapezoidal numerical integration
del2	Discrete Laplacian
diff	Differences and approximate derivatives
gradient	Numerical gradient
trapz	Trapezoidal numerical integration

Discrete Math Functions

Function	Description
`factor`	Return a row vector containing the prime factors of n
`gcd`	Return an array containing the greatest common divisors of the corresponding elements of integer arrays
`isprime`	Array elements that are prime numbers
`lcm`	Least common multiple of corresponding elements in arrays
`nchoosek`	Binomial coefficient or all combinations
`primes`	Generate list of prime numbers

Error Handling Functions

Function	Description
`assert`	Generate error when condition is violated
`error`	Display message and abort function

Exponential Functions

Function	Description
`exp`	Exponential
`expm`	Matrix exponential
`expm1`	Compute `exp(x)-1` accurately for small values of x
`factorial`	Factorial function
`log`	Natural logarithm
`log2`	Base 2 logarithm and dissect floating-point numbers into exponent and mantissa
`log10`	Common (base 10) logarithm
`log1p`	Compute `log(1+x)` accurately for small values of x

Function	Description
nextpow2	Next higher power of 2
nthroot	Real nth root of real numbers
reallog	Natural logarithm for nonnegative real arrays
realpow	Array power for real-only output
realsqrt	Square root for nonnegative real arrays
sqrt	Square root

Filtering and Convolution Functions

Function	Description
conv	Convolution and polynomial multiplication
conv2	2-D convolution
convn	N-D convolution
deconv	Deconvolution and polynomial division
detrend	Remove linear trends
filter	1-D digital filter
filter2	2-D digital filter

Fixed-Point Toolbox Functions

In addition to any function-specific limitations listed in the table, the following general limitations always apply to the use of Fixed-Point Toolbox functions in generated code or with `fiaccel`:

- `fipref` and `quantizer` objects are not supported.
- Word lengths greater than 128 bits are not supported.
- You cannot change the `fimath` or `numerictype` of a given `fi` variable after that variable has been created.
- The `boolean` value of the `DataTypeMode` and `DataType` properties are not supported.

- For all `SumMode` property settings other than `FullPrecision`, the `CastBeforeSum` property must be set to `true`.
- The `numel` function returns the number of elements of `fi` objects in the generated code.
- You can use parallel for (`parfor`) loops in code compiled with `fiaccel`, but those loops are treated like regular `for` loops.
- When you compile code containing `fi` objects with nontrivial slope and bias scaling, you may see different results in generated code than you achieve by running the same code in MATLAB.
- All general limitations of C/C++ code generated from MATLAB apply. See "MATLAB Language Features Not Supported for C/C++ Code Generation" for more information.

Function	Remarks/Limitations
`abs`	N/A
`add`	N/A
`all`	N/A
`any`	N/A
`bitand`	Not supported for slope-bias scaled `fi` objects.
`bitandreduce`	N/A
`bitcmp`	N/A
`bitconcat`	N/A
`bitget`	N/A
`bitor`	Not supported for slope-bias scaled `fi` objects.
`bitorreduce`	N/A
`bitreplicate`	N/A
`bitrol`	N/A
`bitror`	N/A
`bitset`	N/A
`bitshift`	N/A

Function	Remarks/Limitations
`bitsliceget`	N/A
`bitsll`	N/A
`bitsra`	N/A
`bitsrl`	N/A
`bitxor`	Not supported for slope-bias scaled `fi` objects.
`bitxorreduce`	N/A
`ceil`	N/A
`complex`	N/A
`conj`	N/A

`conv`	• Variable-sized inputs are only supported when the `SumMode` property of the governing `fimath` is set to `Specify precision` or `Keep LSB`.
	• For variable-sized signals, you may see different results between generated code and MATLAB.
	  - In the generated code, the output for variable-sized signals is always computed using the `SumMode` property of the governing `fimath`.
	  - In MATLAB, the output for variable-sized signals is computed using the `SumMode` property of the governing `fimath` when both inputs are nonscalar. However, if either input is a scalar, MATLAB computes the output using the `ProductMode` of the governing `fimath`.

`convergent`	N/A
`cordicabs`	Variable-size signals are not supported.
`cordicangle`	Variable-size signals are not supported.
`cordicatan2`	Variable-size signals are not supported.
`cordiccart2pol`	Variable-size signals are not supported.
`cordiccexp`	Variable-size signals are not supported.
`cordiccos`	Variable-size signals are not supported.

Function	Remarks/Limitations
`cordicpol2cart`	Variable-size signals are not supported.
`cordicrotate`	Variable-size signals are not supported.
`cordicsin`	Variable-size signals are not supported.
`cordicsincos`	Variable-size signals are not supported.
`ctranspose`	N/A
`diag`	If supplied, the index, *k*, must be a real and scalar integer value that is not a `fi` object.
`disp`	N/A
`divide`	• Any non-`fi` input must be constant; that is, its value must be known at compile time so that it can be cast to a `fi` object. • Complex and imaginary divisors are not supported. • Code generation in MATLAB does not support the syntax `T.divide(a,b)`.
`double`	N/A
`end`	N/A
`eps`	• Supported for scalar fixed-point signals only. • Supported for scalar, vector, and matrix, `fi` single and `fi` double signals.
`eq`	Not supported for fixed-point signals with different biases.
`fi`	• The default constructor syntax without any input arguments is not supported. • If the `numerictype` is not fully specified, the input to `fi` must be a constant, a `fi`, a single, or a built-in integer value. If the input is a built-in double value, it must be a constant. This limitation allows `fi` to autoscale its fraction length based on the known data type of the input. • `numerictype` object information must be available for nonfixed-point Simulink inputs.

Function	Remarks/Limitations
`filter`	• Variable-sized inputs are only supported when the `SumMode` property of the governing `fimath` is set to `Specify precision` or `Keep LSB`.
`fimath`	• Fixed-point signals coming in to a MATLAB Function block from Simulink are assigned a `fimath` object. You define this object in the MATLAB Function block dialog in the Model Explorer. • Use to create `fimath` objects in the generated code.
`fix`	N/A
`floor`	N/A
`ge`	Not supported for fixed-point signals with different biases.
`get`	The syntax `structure = get(o)` is not supported.
`getlsb`	N/A
`getmsb`	N/A
`gt`	Not supported for fixed-point signals with different biases.
`horzcat`	N/A
`imag`	N/A
`int8`, `int16`, `int32`	N/A
`iscolumn`	N/A
`isempty`	N/A
`isequal`	N/A
`isfi`	N/A
`isfimath`	N/A
`isfimathlocal`	N/A
`isfinite`	N/A
`isinf`	N/A
`isnan`	N/A
`isnumeric`	N/A

Function	Remarks/Limitations
`isnumerictype`	N/A
`isreal`	N/A
`isrow`	N/A
`isscalar`	N/A
`issigned`	N/A
`isvector`	N/A
`le`	Not supported for fixed-point signals with different biases.
`length`	N/A
`logical`	N/A
`lowerbound`	N/A
`lsb`	• Supported for scalar fixed-point signals only. • Supported for scalar, vector, and matrix, `fi` single and double signals.
`lt`	Not supported for fixed-point signals with different biases.
`max`	N/A
`mean`	N/A
`median`	N/A
`min`	N/A
`minus`	Any non-`fi` input must be constant; that is, its value must be known at compile time so that it can be cast to a `fi` object.

Function	Remarks/Limitations

`mpower`	• The exponent input, *k*, must be constant; that is, its value must be known at compile time.
	• Variable-sized inputs are only supported when the `SumMode` property of the governing `fimath` is set to `Specify precision` or `Keep LSB`.
	• For variable-sized signals, you may see different results between the generated code and MATLAB.
	  - In the generated code, the output for variable-sized signals is always computed using the `SumMode` property of the governing `fimath`.
	  - In MATLAB, the output for variable-sized signals is computed using the `SumMode` property of the governing `fimath` when the first input, *a*, is nonscalar. However, when *a* is a scalar, MATLAB computes the output using the `ProductMode` of the governing `fimath`.

`mpy`	When you provide complex inputs to the `mpy` function inside of a MATLAB Function block, you must declare the input as complex before running the simulation. To do so, go to the **Ports and data manager** and set the **Complexity** parameter for all known complex inputs to `On`.
`mrdivide`	N/A

`mtimes`	• Any non-`fi` input must be constant; that is, its value must be known at compile time so that it can be cast to a `fi` object.
	• Variable-sized inputs are only supported when the `SumMode` property of the governing `fimath` is set to `Specify precision` or `Keep LSB`.
	• For variable-sized signals, you may see different results between the generated code and MATLAB.
	  - In the generated code, the output for variable-sized signals is always computed using the `SumMode` property of the governing `fimath`.
	  - In MATLAB, the output for variable-sized signals is computed using the `SumMode` property of the governing `fimath` when both

Function	Remarks/Limitations
	inputs are nonscalar. However, if either input is a scalar, MATLAB computes the output using the `ProductMode` of the governing `fimath`.
`ndims`	N/A
`ne`	Not supported for fixed-point signals with different biases.
`nearest`	N/A
`numberofelements`	`numberofelements` and `numel` both work the same as MATLAB `numel` for `fi` objects in the generated code.
`numerictype`	• Fixed-point signals coming in to a MATLAB Function block from Simulink are assigned a `numerictype` object that is populated with the signal's data type and scaling information. • Returns the data type when the input is a nonfixed-point signal. • Use to create `numerictype` objects in generated code.
`permute`	N/A
`plus`	Any non-`fi` input must be constant; that is, its value must be known at compile time so that it can be cast to a `fi` object.
`pow2`	N/A
`power`	The exponent input, *k*, must be constant; that is, its value must be known at compile time.
`range`	N/A
`rdivide`	N/A
`real`	N/A
`realmax`	N/A
`realmin`	N/A
`reinterpretcast`	N/A
`repmat`	N/A
`rescale`	N/A
`reshape`	N/A

Function	Remarks/Limitations
`round`	N/A
`sfi`	N/A
`sign`	N/A
`single`	N/A
`size`	N/A
`sort`	N/A
`sqrt`	• Complex and [Slope Bias] inputs error out. • Negative inputs yield a 0 result.
`storedInteger`	N/A
`storedIntegerToDouble`	N/A
`sub`	N/A
`subsasgn`	N/A
`subsref`	N/A
`sum`	Variable-sized inputs are only supported when the `SumMode` property of the governing `fimath` is set to `Specify precision` or `Keep LSB`.
`times`	• Any non-`fi` input must be constant; that is, its value must be known at compile time so that it can be cast to a `fi` object. • When you provide complex inputs to the `times` function inside of a MATLAB Function block, you must declare the input as complex before running the simulation. To do so, go to the **Ports and data manager** and set the **Complexity** parameter for all known complex inputs to `On`.
`transpose`	N/A
`tril`	If supplied, the index, *k*, must be a real and scalar integer value that is not a `fi` object.
`triu`	If supplied, the index, *k*, must be a real and scalar integer value that is not a `fi` object.
`ufi`	N/A
`uint8`, `uint16`, `uint32`	N/A

Function	Remarks/Limitations
`uminus`	N/A
`uplus`	N/A
`upperbound`	N/A
`vertcat`	N/A

Histogram Functions

Function	Description
`hist`	Non-graphical histogram
`histc`	Histogram count

Image Processing Toolbox Functions

You must have the MATLAB Coder software installed to generate C/C++ code from MATLAB for these functions.

Function	Remarks/Limitations
`bwlookup`	For best results, specify an input image of class `logical`.
`bwmorph`	The text string specifying the operation must be a constant and, for best results, specify an input image of class `logical`.
`fspecial`	All inputs must be constants at compilation time. Expressions or variables are allowed if their values do not change.
`label2rgb`	Referring to the standard syntax: `RGB = label2rgb(L, map, zerocolor, order)` • Submit at least two input arguments: the label matrix, `L`, and the colormap matrix, `map`. • `map` must be an `n-by-3`, `double`, colormap matrix. You cannot use a string containing the name of a MATLAB colormap function or a function handle of a colormap function.

Function	Remarks/Limitations
	• If you set the boundary color `zerocolor` to the same color as one of the regions, `label2rgb` will not issue a warning. • If you supply a value for `order`, it must be `'noshuffle'`.

Input and Output Functions

Function	Description
`nargin`	Return the number of input arguments a user has supplied
`nargout`	Return the number of output return values a user has requested

Interpolation and Computational Geometry

Function	Description
`cart2pol`	Transform Cartesian coordinates to polar or cylindrical
`cart2sph`	Transform Cartesian coordinates to spherical
`interp1`	1-D data interpolation (table lookup)
`interp2`	2-D data interpolation (table lookup)
`meshgrid`	Generate `X` and `Y` arrays for 3-D plots
`pol2cart`	Transform polar or cylindrical coordinates to Cartesian
`sph2cart`	Transform spherical coordinates to Cartesian

Linear Algebra

Function	Description
`linsolve`	Solve linear system of equations
`null`	Null space

Function	Description
orth	Range space of matrix
rsf2csf	Convert real Schur form to complex Schur form
schur	Schur decomposition
sqrtm	Matrix square root

Logical Operator Functions

Function	Description
and	Logical AND (&&)
bitand	Bitwise AND
bitcmp	Bitwise complement
bitget	Bit at specified position
bitor	Bitwise OR
bitset	Set bit at specified position
bitshift	Shift bits specified number of places
bitxor	Bitwise XOR
not	Logical NOT (~)
or	Logical OR (||)
xor	Logical exclusive-OR

MATLAB Compiler Functions

Function	Description
isdeployed	Determine whether code is running in deployed or MATLAB mode
ismcc	Test if code is running during compilation process (using mcc)

Matrix and Array Functions

Function	Description
`abs`	Return absolute value and complex magnitude of an array
`all`	Test if all elements are nonzero
`angle`	Phase angle
`any`	Test for any nonzero elements
`blkdiag`	Construct block diagonal matrix from input arguments
`bsxfun`	Applies element-by-element binary operation to two arrays with singleton expansion enabled
`cat`	Concatenate arrays along specified dimension
`circshift`	Shift array circularly
`compan`	Companion matrix
`cond`	Condition number of a matrix with respect to inversion
`cov`	Covariance matrix
`cross`	Vector cross product
`cumprod`	Cumulative product of array elements
`cumsum`	Cumulative sum of array elements
`det`	Matrix determinant
`diag`	Return a matrix formed around the specified diagonal vector and the specified diagonal (0, 1, 2,...) it occupies
`diff`	Differences and approximate derivatives
`dot`	Vector dot product
`eig`	Eigenvalues and eigenvectors
`eye`	Identity matrix
`false`	Return an array of 0s for the specified dimensions
`find`	Find indices and values of nonzero elements
`flipdim`	Flip array along specified dimension
`fliplr`	Flip matrix left to right

Function	Description
flipud	Flip matrix up to down
full	Convert sparse matrix to full matrix
hadamard	Hadamard matrix
hankel	Hankel matrix
hilb	Hilbert matrix
ind2sub	Subscripts from linear index
inv	Inverse of a square matrix
invhilb	Inverse of Hilbert matrix
ipermute	Inverse permute dimensions of array
iscolumn	True if input is a column vector
isempty	Determine whether array is empty
isequal	Test arrays for equality
isequaln	Test arrays for equality, treating NaNs as equal
isfinite	Detect finite elements of an array
isfloat	Determine if input is floating-point array
isinf	Detect infinite elements of an array
isinteger	Determine if input is integer array
islogical	Determine if input is logical array
ismatrix	True if input is a matrix
isnan	Detect NaN elements of an array
isrow	True if input is a row vector
issparse	Determine whether input is sparse
isvector	Determine whether input is vector
kron	Kronecker tensor product
length	Return the length of a matrix
linspace	Generate linearly spaced vectors

Function	Description
`logspace`	Generate logarithmically spaced vectors
`lu`	Matrix factorization
`magic`	Magic square
`max`	Maximum elements of a matrix
`min`	Minimum elements of a matrix
`ndgrid`	Generate arrays for N-D functions and interpolation
`ndims`	Number of dimensions
`nnz`	Number of nonzero matrix elements
`nonzeros`	Nonzero matrix elements
`norm`	Vector and matrix norms
`normest`	2-norm estimate
`numel`	Number of elements in array or subscripted array
`ones`	Create a matrix of all 1s
`pascal`	Pascal matrix
`permute`	Rearrange dimensions of array
`pinv`	Pseudoinverse of a matrix
`planerot`	Givens plane rotation
`prod`	Product of array element
`qr`	Orthogonal-triangular decomposition
`rand`	Uniformly distributed pseudorandom numbers
`randi`	Uniformly distributed pseudorandom integers
`randn`	Normally distributed random numbers
`randperm`	Random permutation
`rank`	Rank of matrix
`rcond`	Matrix reciprocal condition number estimate
`repmat`	Replicate and tile an array

Function	Description
reshape	Reshape one array into the dimensions of another
rng	Control random number generation
rosser	Classic symmetric eigenvalue test problem
rot90	Rotate matrix 90 degrees
shiftdim	Shift dimensions
sign	Signum function
size	Return the size of a matrix
sort	Sort elements in ascending or descending order
sortrows	Sort rows in ascending order
squeeze	Remove singleton dimensions
sub2ind	Single index from subscripts
subspace	Angle between two subspaces
sum	Sum of matrix elements
toeplitz	Toeplitz matrix
trace	Sum of diagonal elements
tril	Extract lower triangular part
triu	Extract upper triangular part
true	Return an array of logical (Boolean) 1s for the specified dimensions
vander	Vandermonde matrix
wilkinson	Wilkinson's eigenvalue test matrix
zeros	Create a matrix of all zeros

Nonlinear Numerical Methods

Function	Description
`fzero`	Find root of continuous function of one variable
`quad2d`	Numerically evaluate double integral over planar region
`quadgk`	Numerically evaluate integral, adaptive Gauss-Kronrod quadrature

Polynomial Functions

Function	Description
`poly`	Polynomial with specified roots
`polyfit`	Polynomial curve fitting
`polyval`	Polynomial evaluation
`roots`	Polynomial roots

Relational Operator Functions

Function	Description
`eq`	Equal (==)
`ge`	Greater than or equal to (>=)
`gt`	Greater than (>)
`le`	Less than or equal to (<=)
`lt`	Less than (<)
`ne`	Not equal (~=)

Rounding and Remainder Functions

Function	Description
`ceil`	Round toward plus infinity
`ceil`	Round toward positive infinity
`convergent`	Round toward nearest integer with ties rounding to nearest even integer
`fix`	Round toward zero
`fix`	Round toward zero
`floor`	Round toward minus infinity
`floor`	Round toward negative infinity
`mod`	Modulus (signed remainder after division)
`nearest`	Round toward nearest integer with ties rounding toward positive infinity
`rem`	Remainder after division
`round`	Round toward nearest integer
`round`	Round `fi` object toward nearest integer or round input data using `quantizer` object

Set Functions

Function	Description
`intersect`	Find set intersection of two vectors
`ismember`	Array elements that are members of set
`issorted`	Determine whether set elements are in sorted order
`setdiff`	Find set difference of two vectors
`setxor`	Find set exclusive OR of two vectors
`union`	Find set union of two vectors
`unique`	Find unique elements of vector

Signal Processing Functions in MATLAB

Function	Description
`chol`	Cholesky factorization
`conv`	Convolution and polynomial multiplication
`fft`	Discrete Fourier transform
`fft2`	2-D discrete Fourier transform
`fftn`	N-D discrete Fourier transform
`fftshift`	Shift zero-frequency component to center of spectrum
`filter`	Filter a data sequence using a digital filter that works for both real and complex inputs
`freqspace`	Frequency spacing for frequency response
`ifft`	Inverse discrete Fourier transform
`ifft2`	2-D inverse discrete Fourier transform
`ifftn`	N-D inverse discrete Fourier transform
`ifftshift`	Inverse discrete Fourier transform shift
`svd`	Singular value decomposition
`zp2tf`	Convert zero-pole-gain filter parameters to transfer function form

Signal Processing Toolbox Functions

All of these functions require a DSP System Toolbox license to generate code. These functions do not support variable-size inputs, you must define the size and type of the function inputs. For more information, see “Specifying Inputs in Code Generation from MATLAB ”.

Note Many Signal Processing Toolbox functions require constant inputs in generated code. To specify a constant input for `codegen`, use `coder.Constant`.

Function	Remarks/Limitations
barthannwin	Window length must be a constant. Expressions or variables are allowed if their values do not change.
bartlett	Window length must be a constant. Expressions or variables are allowed if their values do not change.
besselap	Filter order must be a constant. Expressions or variables are allowed if their values do not change.
bitrevorder	—
blackman	Window length must be a constant. Expressions or variables are allowed if their values do not change.
blackmanharris	Window length must be a constant. Expressions or variables are allowed if their values do not change.
bohmanwin	Window length must be a constant. Expressions or variables are allowed if their values do not change.
buttap	Filter order must be a constant. Expressions or variables are allowed if their values do not change.
butter	Filter coefficients must be constants. Expressions or variables are allowed if their values do not change.
buttord	All inputs must be constants. Expressions or variables are allowed if their values do not change.
cfirpm	All inputs must be constants. Expressions or variables are allowed if their values do not change.
cheb1ap	All inputs must be constants. Expressions or variables are allowed if their values do not change.
cheb2ap	All inputs must be constants. Expressions or variables are allowed if their values do not change.
cheb1ord	All inputs must be constants. Expressions or variables are allowed if their values do not change.
cheb2ord	All inputs must be constants. Expressions or variables are allowed if their values do not change.
chebwin	All inputs must be constants. Expressions or variables are allowed if their values do not change.

Function	Remarks/Limitations
`cheby1`	All Inputs must be constants. Expressions or variables are allowed if their values do not change.
`cheby2`	All inputs must be constants. Expressions or variables are allowed if their values do not change.
`dct`	Length of transform dimension must be a power of two. If specified, the pad or truncation value must be constant. Expressions or variables are allowed if their values do not change.
`downsample`	—
`dpss`	All inputs must be constants. Expressions or variables are allowed if their values do not change.
`ellip`	Inputs must be constant. Expressions or variables are allowed if their values do not change.
`ellipap`	All inputs must be constants. Expressions or variables are allowed if their values do not change.
`ellipord`	All inputs must be constants. Expressions or variables are allowed if their values do not change.
`filtfilt`	Filter coefficients must be constants. Expressions or variables are allowed if their values do not change.
`fir1`	All inputs must be constants. Expressions or variables are allowed if their values do not change.
`fir2`	All inputs must be constants. Expressions or variables are allowed if their values do not change.
`fircls`	All inputs must be constants. Expressions or variables are allowed if their values do not change.
`fircls1`	All inputs must be constants. Expressions or variables are allowed if their values do not change.
`firls`	All inputs must be constants. Expressions or variables are allowed if their values do not change.
`firpm`	All inputs must be constants. Expressions or variables are allowed if their values do not change.

Function	Remarks/Limitations
`firpmord`	All inputs must be constants. Expressions or variables are allowed if their values do not change.
`firrcos`	All inputs must be constants. Expressions or variables are allowed if their values do not change.
`flattopwin`	All inputs must be constants. Expressions or variables are allowed if their values do not change.
`freqz`	`freqz` with no output arguments produces a plot only when the function call terminates in a semicolon. See "`freqz` With No Output Arguments".
`gaussfir`	All inputs must be constant. Expressions or variables are allowed if their values do not change.
`gausswin`	All inputs must be constant. Expressions or variables are allowed if their values do not change.
`hamming`	All inputs must be constant. Expressions or variables are allowed if their values do not change.
`hann`	All inputs must be constant. Expressions or variables are allowed if their values do not change.
`idct`	Length of transform dimension must be a power of two. If specified, the pad or truncation value must be constant. Expressions or variables are allowed if their values do not change.
`intfilt`	All inputs must be constant. Expressions or variables are allowed if their values do not change.
`kaiser`	All inputs must be constant. Expressions or variables are allowed if their values do not change.
`kaiserord`	—
`levinson`	If specified, the order of recursion must be a constant. Expressions or variables are allowed if their values do not change.
`maxflat`	All inputs must be constant. Expressions or variables are allowed if their values do not change.
`nuttallwin`	All inputs must be constant. Expressions or variables are allowed if their values do not change.

Function	Remarks/Limitations
`parzenwin`	All inputs must be constant. Expressions or variables are allowed if their values do not change.
`rectwin`	All inputs must be constant. Expressions or variables are allowed if their values do not change.
`resample`	The upsampling and downsampling factors must be specified as constants. Expressions or variables are allowed if their values do not change.
`sgolay`	All inputs must be constant. Expressions or variables are allowed if their values do not change.
`sosfilt`	—
`taylorwin`	All inputs must be constant. Expressions or variables are allowed if their values do not change.
`triang`	All inputs must be constant. Expressions or variables are allowed if their values do not change.
`tukeywin`	All inputs must be constant. Expressions or variables are allowed if their values do not change.
`upfirdn`	• Filter coefficients, upsampling factor, and downsampling factor must be constants. Expressions or variables are allowed if their values do not change. • Variable-size inputs are not supported.
`upsample`	Either declare input `n` as constant, or use the `assert` function in the calling function to set upper bounds for `n`. For example, `assert(n<10)`
`xcorr`	—
`yulewalk`	If specified, the order of recursion must be a constant. Expressions or variables are allowed if their values do not change.

Special Values

Symbol	Description
`eps`	Floating-point relative accuracy
`inf`	IEEE® arithmetic representation for positive infinity
`intmax`	Largest possible value of specified integer type
`intmin`	Smallest possible value of specified integer type
NaN or `nan`	Not a number
`pi`	Ratio of the circumference to the diameter for a circle
`realmax`	Largest positive floating-point number
`realmin`	Smallest positive floating-point number

Specialized Math

Symbol	Description
`beta`	Beta function
`betainc`	Incomplete beta function
`betaln`	Logarithm of beta function
`ellipke`	Complete elliptic integrals of first and second kind
`erf`	Error function
`erfc`	Complementary error function
`erfcinv`	Inverse of complementary error function
`erfcx`	Scaled complementary error function
`erfinv`	Inverse error function
`expint`	Exponential integral
`gamma`	Gamma function
`gammainc`	Incomplete gamma function
`gammaln`	Logarithm of the gamma function

Statistical Functions

Function	Description
corrcoef	Correlation coefficients
mean	Average or mean value of array
median	Median value of array
mode	Most frequent values in array
std	Standard deviation
var	Variance

String Functions

Function	Description
bin2dec	Convert binary number string to decimal number
bitmax	Maximum double-precision floating-point integer
blanks	Create string of blank characters
char	Create character array (string)
deblank	Strip trailing blanks from end of string
dec2bin	Convert decimal to binary number in string
dec2hex	Convert decimal to hexadecimal number in string
hex2dec	Convert hexadecimal number string to decimal number
hex2num	Convert hexadecimal number string to double-precision number
ischar	True for character array (string)
isletter	Array elements that are alphabetic letters
isspace	Array elements that are space characters
isstrprop	Determine whether string is of specified category
lower	Convert string to lowercase
num2hex	Convert singles and doubles to IEEE hexadecimal strings

Function	Description
strcmp	Compare strings (case sensitive)
strcmpi	Compare strings (case insensitive)
strjust	Justify character array
strncmp	Compare first n characters of strings (case sensitive)
strncmpi	Compare first n characters of strings (case insensitive)
strtok	Selected parts of string
strtrim	Remove leading and trailing white space from string
upper	Convert string to uppercase

Structure Functions

Function	Description
isfield	Determine whether input is structure array field
struct	Create structure
isstruct	Determine whether input is a structure

Trigonometric Functions

Function	Description
acos	Inverse cosine
acosd	Inverse cosine; result in degrees
acosh	Inverse hyperbolic cosine
acot	Inverse cotangent; result in radians
acotd	Inverse cotangent; result in degrees
acoth	Inverse hyperbolic cotangent
acsc	Inverse cosecant; result in radians
acscd	Inverse cosecant; result in degrees

Function	Description
acsch	Inverse cosecant and inverse hyperbolic cosecant
asec	Inverse secant; result in radians
asecd	Inverse secant; result in degrees
asech	Inverse hyperbolic secant
asin	Inverse sine
asinh	Inverse hyperbolic sine
atan	Inverse tangent
atan2	Four quadrant inverse tangent
atan2d	Four-quadrant inverse tangent, result in degrees
atand	Inverse tangent; result in degrees
atanh	Inverse hyperbolic tangent
cos	Cosine
cosd	Cosine; result in degrees
cosh	Hyperbolic cosine
cot	Cotangent; result in radians
cotd	Cotangent; result in degrees
coth	Hyperbolic cotangent
csc	Cosecant; result in radians
cscd	Cosecant; result in degrees
csch	Hyperbolic cosecant
hypot	Square root of sum of squares
sec	Secant; result in radians
secd	Secant; result in degrees
sech	Hyperbolic secant
sin	Sine
sind	Sine; result in degrees

Function	Description
`sinh`	Hyperbolic sine
`tan`	Tangent
`tand`	Tangent; result in degrees
`tanh`	Hyperbolic tangent

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System Objects Supported for Code Generation

System Objects Supported for Code Generation

In this section...

Code Generation for System Objects

You can generate C/C++ code for a subset of System objects provided by Communications System Toolbox, DSP System Toolbox, and Computer Vision System Toolbox. To use these System objects, you need to install the requisite toolbox.

System objects are MATLAB object-oriented implementations of algorithms. They extend MATLAB by enabling you to model dynamic systems represented by time-varying algorithms. System objects are well integrated into the MATLAB language, regardless of whether you are writing simple functions, working interactively in the command window, or creating large applications.

In contrast to MATLAB functions, System objects automatically manage state information, data indexing, and buffering, which is particularly useful for iterative computations or stream data processing. This enables efficient processing of long data sets. For general information on MATLAB objects, see "Begin Using Object-Oriented Programming".

Computer Vision System Toolbox System Objects

If you install Computer Vision System Toolbox software, you can generate C/C++ code for the following Computer Vision System Toolbox System objects. For more information on how to use these System objects, see "Use System Objects in MATLAB Code Generation".

Supported Computer Vision System Toolbox System Objects

Object	Description
Analysis & Enhancement	
`vision.BoundaryTracer`	Trace object boundaries in binary images
`vision.ContrastAdjuster`	Adjust image contrast by linear scaling
`vision.Deinterlacer`	Remove motion artifacts by deinterlacing input video signal
`vision.EdgeDetector`	Find edges of objects in images
`vision.ForegroundDetector`	Detect foreground using Gaussian Mixture Models. This object supports tunable properties in code generation.
`vision.HistogramEqualizer`	Enhance contrast of images using histogram equalization
`vision.TemplateMatcher`	Perform template matching by shifting template over image
Conversions	
`vision.Autothresholder`	Convert intensity image to binary image
`vision.ChromaResampler`	Downsample or upsample chrominance components of images
`vision.ColorSpaceConverter`	Convert color information between color spaces
`vision.DemosaicInterpolator`	Demosaic Bayer's format images
`vision.GammaCorrector`	Apply or remove gamma correction from images or video streams
`vision.ImageComplementer`	Compute complement of pixel values in binary, intensity, or RGB images
`vision.ImageDataTypeConverter`	Convert and scale input image to specified output data type
Feature Detection, Extraction, and Matching	

Supported Computer Vision System Toolbox System Objects (Continued)

Object	Description
`vision.CornerDetector`	Corner metric matrix and corner detector. This object supports tunable properties in code generation.
Filtering	
`vision.Convolver`	Compute 2-D discrete convolution of two input matrices
`vision.ImageFilter`	Perform 2-D FIR filtering of input matrix
`vision.MedianFilter`	2D median filtering
Geometric Transformations	
`vision.GeometricRotator`	Rotate image by specified angle
`vision.GeometricScaler`	Enlarge or shrink image size
`vision.GeometricShearer`	Shift rows or columns of image by linearly varying offset
`vision.GeometricTransformer`	Apply projective or affine transformation to an image
`vision.GeometricTransformEstimator`	Estimate geometric transformation from matching point pairs
`vision.GeometricTranslator`	Translate image in two-dimensional plane using displacement vector
Morphological Operations	
`vision.ConnectedComponentLabeler`	Label and count the connected regions in a binary image
`vision.MorphologicalClose`	Perform morphological closing on image
`vision.MorphologicalDilate`	Perform morphological dilation on an image
`vision.MorphologicalErode`	Perform morphological erosion on an image

Supported Computer Vision System Toolbox System Objects (Continued)

Object	Description
`vision.MorphologicalOpen`	Perform morphological opening on an image
Object Detection	
`vision.HistogramBasedTracker`	Track object in video based on histogram. This object supports tunable properties in code generation.
Sinks	
`vision.DeployableVideoPlayer`	Send video data to computer screen
`vision.VideoFileWriter`	Write video frames and audio samples to multimedia file
Sources	
`vision.VideoFileReader`	Read video frames and audio samples from compressed multimedia file
Statistics	
`vision.Autocorrelator`	Compute 2-D autocorrelation of input matrix
`vision.BlobAnalysis`	Compute statistics for connected regions in a binary image
`vision.Crosscorrelator`	Compute 2-D cross-correlation of two input matrices
`vision.Histogram`	Generate histogram of each input matrix. This object has no tunable properties.
`vision.LocalMaximaFinder`	Find local maxima in matrices
`vision.Maximum`	Find maximum values in input or sequence of inputs

Supported Computer Vision System Toolbox System Objects (Continued)

Object	Description
`vision.Mean`	Find mean value of input or sequence of inputs
`vision.Median`	Find median values in an input
`vision.Minimum`	Find minimum values in input or sequence of inputs
`vision.PSNR`	Compute peak signal-to-noise ratio (PSNR) between images
`vision.StandardDeviation`	Find standard deviation of input or sequence of inputs
`vision.Variance`	Find variance values in an input or sequence of inputs
Text & Graphics	
`vision.AlphaBlender`	Combine images, overlay images, or highlight selected pixels
`vision.MarkerInserter`	Draw markers on output image
`vision.ShapeInserter`	Draw rectangles, lines, polygons, or circles on images
`vision.TextInserter`	Draw text on image or video stream
Transforms	
`vision.DCT`	Compute 2-D discrete cosine transform
`vision.FFT`	Two-dimensional discrete Fourier transform
`vision.HoughLines`	Find Cartesian coordinates of lines that are described by rho and theta pairs
`vision.HoughTransform`	Find lines in images via Hough transform
`vision.IDCT`	Compute 2-D inverse discrete cosine transform
`vision.IFFT`	Two–dimensional inverse discrete Fourier transform
`vision.Pyramid`	Perform Gaussian pyramid decomposition

Supported Computer Vision System Toolbox System Objects (Continued)

Object	Description
Utilities	
`vision.ImagePadder`	Pad or crop input image along its rows, columns, or both

Communications System Toolbox System Objects

If you install Communications System Toolbox software, you can generate C/C++ code for the following Communications System Toolbox System objects. For information on how to use these System objects, see "Code Generation with System Objects".

Supported Communications System Toolbox System Objects

Object	Description
Source Coding	
`comm.DifferentialDecoder`	Decode binary signal using differential decoding
`comm.DifferentialEncoder`	Encode binary signal using differential coding
Channels	
`comm.AWGNChannel`	Add white Gaussian noise to input signal
`comm.LTEMIMOChannel`	Filter input signal through LTE MIMO multipath fading channel
`comm.MIMOChannel`	Filter input signal through MIMO multipath fading channel
`comm.BinarySymmetricChannel`	Introduce binary errors
Equalizers	
`comm.MLSEEqualizer`	Equalize using maximum likelihood sequence estimation
Filters	
`comm.IntegrateAndDumpFilter`	Integrate discrete-time signal with periodic resets

Supported Communications System Toolbox System Objects (Continued)

Object	Description
Measurements	
`comm.ACPR`	Measure adjacent channel power ratio
`comm.CCDF`	Measure complementary cumulative distribution function
`comm.EVM`	Measure error vector magnitude
`comm.MER`	Measure modulation error ratio
Sources	
`comm.BarkerCode`	Generate Barker code
`comm.HadamardCode`	Generate Hadamard code
`comm.KasamiSequence`	Generate a Kasami sequence
`comm.OVSFCode`	Generate OVSF code
`comm.PNSequence`	Generate a pseudo-noise (PN) sequence
`comm.WalshCode`	Generate Walsh code from orthogonal set of codes
Error Detection and Correction – Block Coding	
`comm.BCHDecoder`	Decode data using BCH decoder
`comm.BCHEncoder`	Encode data using BCH encoder
`comm.LDPCDecoder`	Decode binary low-density parity-check code
`comm.LDPCEncoder`	Encode binary low-density parity-check code
`comm.RSDecoder`	Decode data using Reed-Solomon decoder
`comm.RSEncoder`	Encode data using Reed-Solomon encoder
Error Detection and Correction – Convolutional Coding	
`comm.ConvolutionalEncoder`	Convolutionally encode binary data
`comm.ViterbiDecoder`	Decode convolutionally encoded data using Viterbi algorithm
Error Detection and Correction – Cyclic Redundancy Check Coding	

Supported Communications System Toolbox System Objects (Continued)

Object	Description
`comm.CRCDetector`	Detect errors in input data using cyclic redundancy code
`comm.CRCGenerator`	Generate cyclic redundancy code bits and append to input data
`comm.HDLCRCGenerator`	Generate CRC code bits and append to input data, optimized for HDL code generation
`comm.TurboDecoder`	Decode input signal using parallel concatenated decoding scheme
`comm.TurboEncoder`	Encode input signal using parallel concatenated encoding scheme
Interleavers – Block	
`comm.AlgebraicDeinterleaver`	Deinterleave input symbols using algebraically derived permutation vector
`comm.AlgebraicInterleaver`	Permute input symbols using an algebraically derived permutation vector
`comm.BlockDeinterleaver`	Deinterleave input symbols using permutation vector
`comm.BlockInterleaver`	Permute input symbols using a permutation vector
`comm.MatrixDeinterleaver`	Deinterleave input symbols using permutation matrix
`comm.MatrixInterleaver`	Permute input symbols using permutation matrix
`comm.MatrixHelicalScanDeinterleaver`	Deinterleave input symbols by filling a matrix along diagonals
`comm.MatrixHelicalScanInterleaver`	Permute input symbols by selecting matrix elements along diagonals
Interleavers – Convolutional	
`comm.ConvolutionalDeinterleaver`	Restore ordering of symbols using shift registers
`comm.ConvolutionalInterleaver`	Permute input symbols using shift registers

Supported Communications System Toolbox System Objects (Continued)

Object	Description
comm.HelicalDeinterleaver	Restore ordering of symbols using a helical array
comm.HelicalInterleaver	Permute input symbols using a helical array
comm.MultiplexedDeinterleaver	Restore ordering of symbols using a set of shift registers with specified delays
comm.MultiplexedInterleaver	Permute input symbols using a set of shift registers with specified delays
MIMO	
comm.OSTBCCombiner	Combine inputs using orthogonal space-time block code
comm.OSTBCEncoder	Encode input message using orthogonal space-time block code
Digital Baseband Modulation – Phase	
comm.BPSKDemodulator	Demodulate using binary PSK method
comm.BPSKModulator	Modulate using binary PSK method
comm.DBPSKModulator	Modulate using differential binary PSK method
comm.DPSKDemodulator	Demodulate using M-ary DPSK method
comm.DPSKModulator	Modulate using M-ary DPSK method
comm.DQPSKDemodulator	Demodulate using differential quadrature PSK method
comm.DQPSKModulator	Modulate using differential quadrature PSK method
comm.DBPSKDemodulator	Demodulate using M-ary DPSK method
comm.QPSKDemodulator	Demodulate using quadrature PSK method
comm.QPSKModulator	Modulate using quadrature PSK method
comm.PSKDemodulator	Demodulate using M-ary PSK method
comm.PSKModulator	Modulate using M-ary PSK method
comm.OQPSKDemodulator	Demodulate offset quadrature PSK modulated data

Supported Communications System Toolbox System Objects (Continued)

Object	Description
`comm.OQPSKModulator`	Modulate using offset quadrature PSK method
Digital Baseband Modulation – Amplitude	
`comm.GeneralQAMDemodulator`	Demodulate using arbitrary QAM constellation. This object has no tunable properties in code generation.
`comm.GeneralQAMModulator`	Modulate using arbitrary QAM constellation
`comm.PAMDemodulator`	Demodulate using M-ary PAM method
`comm.PAMModulator`	Modulate using M-ary PAM method
`comm.RectangularQAMDemodulator`	Demodulate using rectangular QAM method
`comm.RectangularQAMModulator`	Modulate using rectangular QAM method
Digital Baseband Modulation – Frequency	
`comm.FSKDemodulator`	Demodulate using M-ary FSK method
`comm.FSKModulator`	Modulate using M-ary FSK method
Digital Baseband Modulation – Trelllis Coded	
`comm.GeneralQAMTCMDemodulator`	Demodulate convolutionally encoded data mapped to arbitrary QAM constellation
`comm.GeneralQAMTCMModulator`	Convolutionally encode binary data and map using arbitrary QAM constellation
`comm.PSKTCMDemodulator`	Demodulate convolutionally encoded data mapped to M-ary PSK constellation
`comm.PSKTCMModulator`	Convolutionally encode binary data and map using M-ary PSK constellation
`comm.RectangularQAMTCMDemodulator`	Demodulate convolutionally encoded data mapped to rectangular QAM constellation
`comm.RectangularQAMTCMModulator`	Convolutionally encode binary data and map using rectangular QAM constellation
Digital Baseband Modulation – Continuous Phase	

Supported Communications System Toolbox System Objects (Continued)

Object	Description
`comm.CPFSKDemodulator`	Demodulate using CPFSK method and Viterbi algorithm
`comm.CPFSKModulator`	Modulate using CPFSK method
`comm.CPMDemodulator`	Demodulate using CPM method and Viterbi algorithm
`comm.CPMModulator`	Modulate using CPM method
`comm.GMSKDemodulator`	Demodulate using GMSK method and the Viterbi algorithm
`comm.GMSKModulator`	Modulate using GMSK method
`comm.MSKDemodulator`	Demodulate using MSK method and the Viterbi algorithm
`comm.MSKModulator`	Modulate using MSK method
RF Impairments	
`comm.MemorylessNonlinearity`	Apply memoryless nonlinearity to input signal
`comm.PhaseFrequencyOffset`	Apply phase and frequency offsets to input signal. The `PhaseOffset` property of this object is not tunable in code generation.
`comm.PhaseNoise`	Apply phase noise to complex baseband signal
`comm.ThermalNoise`	Add receiver thermal noise
Synchronization – Timing Phase	
`comm.EarlyLateGateTimingSynchronizer`	Recover symbol timing phase using early-late gate method
`comm.GardnerTimingSynchronizer`	Recover symbol timing phase using Gardner's method
`comm.GMSKTimingSynchronizer`	Recover symbol timing phase using fourth-order nonlinearity method
`comm.MSKTimingSynchronizer`	Recover symbol timing phase using fourth-order nonlinearity method

Supported Communications System Toolbox System Objects (Continued)

Object	Description
`comm.MuellerMullerTimingSynchronizer`	Recover symbol timing phase using Mueller-Muller method
Synchronization Utilities	
`comm.CPMCarrierPhaseSynchronizer`	Recover carrier phase of baseband CPM signal
`comm.DiscreteTimeVCO`	Generate variable frequency sinusoid
Converters	
`comm.BitToInteger`	Convert vector of bits to vector of integers
`comm.IntegerToBit`	Convert vector of integers to vector of bits
Sequence Operators	
`comm.Descrambler`	Descramble input signal
`comm.GoldSequence`	Generate Gold sequence
`comm.Scrambler`	Scramble input signal

DSP System Toolbox System Objects

If you install DSP System Toolbox software, you can generate C/C++ code for the following DSP System Toolbox System objects. For information on how to use these System objects, see “Code Generation with System Objects”.

Supported DSP System Toolbox System Objects

Object	Description
Estimation	
`dsp.BurgAREstimator`	Compute estimate of autoregressive model parameters using Burg method

Supported DSP System Toolbox System Objects (Continued)

Object	Description
`dsp.BurgSpectrumEstimator`	Compute parametric spectral estimate using Burg method
`dsp.CepstralToLPC`	Convert cepstral coefficients to linear prediction coefficients
`dsp.LevinsonSolver`	Solve linear system of equations using Levinson-Durbin recursion
`dsp.LPCToAutocorrelation`	Convert linear prediction coefficients to autocorrelation coefficients
`dsp.LPCToCepstral`	Convert linear prediction coefficients to cepstral coefficients
`dsp.LPCToLSF`	Convert linear prediction coefficients to line spectral frequencies
`dsp.LPCToLSP`	Convert linear prediction coefficients to line spectral pairs
`dsp.LPCToRC`	Convert linear prediction coefficients to reflection coefficients
`dsp.LSFToLPC`	Convert line spectral frequencies to linear prediction coefficients
`dsp.LSPToLPC`	Convert line spectral pairs to linear prediction coefficients
`dsp.RCToAutocorrelation`	Convert reflection coefficients to autocorrelation coefficients
`dsp.RCToLPC`	Convert reflection coefficients to linear prediction coefficients
Filters	
`dsp.AllpoleFilter`	IIR Filter with no zeros. Only the `Denominator` property is tunable for code generation.
`dsp.BiquadFilter`	Model biquadratic IIR (SOS) filters

Supported DSP System Toolbox System Objects (Continued)

Object	Description
`dsp.CICDecimator`	Decimate input using Cascaded Integrator-Comb filter
`dsp.CICInterpolator`	Interpolate signal using Cascaded Integrator-Comb filter
`dsp.DigitalFilter`	Filter each channel of input over time using discrete-time filter implementations. The `SOSMatrix` and `ScaleValues` properties at not supported for code generation.
`dsp.FIRDecimator`	Filter and downsample input signals
`dsp.FIRFilter`	Static or time-varying FIR filter. Only the `Numerator` property is tunable for code generation.
`dsp.FIRInterpolator`	Upsample and filter input signals
`dsp.FIRRateConverter`	Upsample, filter and downsample input signals
`dsp.IIRFilter`	Infinite Impulse Response (IIR) filter. Only the `Numerator` and `Denominator` properties are tunable for code generation.
`dsp.LMSFilter`	Compute output, error, and weights using LMS adaptive algorithm
Math Operations	
`dsp.ArrayVectorAdder`	Add vector to array along specified dimension
`dsp.ArrayVectorDivider`	Divide array by vector along specified dimension
`dsp.ArrayVectorMultiplier`	Multiply array by vector along specified dimension
`dsp.ArrayVectorSubtractor`	Subtract vector from array along specified dimension
`dsp.CumulativeProduct`	Compute cumulative product of channel, column, or row elements
`dsp.CumulativeSum`	Compute cumulative sum of channel, column, or row elements

Supported DSP System Toolbox System Objects (Continued)

Object	Description
`dsp.LDLFactor`	Factor square Hermitian positive definite matrices into lower, upper, and diagonal components
`dsp.LevinsonSolver`	Solve linear system of equations using Levinson-Durbin recursion
`dsp.LowerTriangularSolver`	Solve LX = B for X when L is lower triangular matrix
`dsp.LUFactor`	Factor square matrix into lower and upper triangular matrices
`dsp.Normalizer`	Normalize input
`dsp.UpperTriangularSolver`	Solve UX = B for X when U is upper triangular matrix
Quantizers	
`dsp.ScalarQuantizerDecoder`	Convert each index value into quantized output value
`dsp.ScalarQuantizerEncoder`	Perform scalar quantization encoding
`dsp.VectorQuantizerDecoder`	Find vector quantizer codeword for given index value
`dsp.VectorQuantizerEncoder`	Perform vector quantization encoding
Signal Management	
`dsp.Counter`	Count up or down through specified range of numbers
`dsp.DelayLine`	Rebuffer sequence of inputs with one-sample shift
Signal Operations	
`dsp.Convolver`	Compute convolution of two inputs
`dsp.Delay`	Delay input by specified number of samples or frames
`dsp.Interpolator`	Interpolate values of real input samples
`dsp.NCO`	Generate real or complex sinusoidal signals
`dsp.PeakFinder`	Determine extrema (maxima or minima) in input signal
`dsp.PhaseUnwrapper`	Unwrap signal phase

Supported DSP System Toolbox System Objects (Continued)

Object	Description
`dsp.VariableFractionalDelay`	Delay input by time-varying fractional number of sample periods
`dsp.VariableIntegerDelay`	Delay input by time-varying integer number of sample periods
`dsp.Window`	Generate or apply window function. This object has no tunable properties for code generation.
`dsp.ZeroCrossingDetector`	Calculate number of zero crossings of a signal
Sinks	
`dsp.AudioPlayer`	Write audio data to computer's audio device
`dsp.AudioFileWriter`	Write audio file
`dsp.UDPSender`	Send UDP packets to the network
Sources	
`dsp.AudioFileReader`	Read audio samples from an audio file
`dsp.AudioRecorder`	Read audio data from computer's audio device
`dsp.SignalSource`	Import variable from workspace
`dsp.SineWave`	Generate discrete sine wave. This object has no tunable properties for code generation.
`dsp.UDPReceiver`	Receive UDP packets from the network
Statistics	
`dsp.Autocorrelator`	Compute autocorrelation of vector inputs
`dsp.Crosscorrelator`	Compute cross-correlation of two inputs
`dsp.Histogram`	Output histogram of an input or sequence of inputs. This object has no tunable properties for code generation.
`dsp.Maximum`	Compute maximum value in input
`dsp.Mean`	Compute average or mean value in input

Supported DSP System Toolbox System Objects (Continued)

Object	Description
`dsp.Median`	Compute median value in input
`dsp.Minimum`	Compute minimum value in input
`dsp.RMS`	Compute root-mean-square of vector elements
`dsp.StandardDeviation`	Compute standard deviation of vector elements
`dsp.Variance`	Compute variance of input or sequence of inputs
Transforms	
`dsp.AnalyticSignal`	Compute analytic signals of discrete-time inputs
`dsp.DCT`	Compute discrete cosine transform (DCT) of input
`dsp.FFT`	Compute fast Fourier transform (FFT) of input
`dsp.IDCT`	Compute inverse discrete cosine transform (IDCT) of input
`dsp.IFFT`	Compute inverse fast Fourier transform (IFFT) of input

33

Defining MATLAB Variables for C/C++ Code Generation

Variables Definition for Code Generation

In the MATLAB language, variables can change their properties dynamically at run time so you can use the same variable to hold a value of any class, size, or complexity. For example, the following code works in MATLAB:

```
function x = foo(c) %#codegen
if(c>0)
  x = 0;
else
  x = [1 2 3];
end
disp(x);
end
```

However, statically-typed languages like C must be able to determine variable properties at compile time. Therefore, for C/C++ code generation, you must explicitly define the class, size, and complexity of variables in MATLAB source code before using them. For example, rewrite the above source code with a definition for *x*:

```
function x = foo(c) %#codegen
x = zeros(1,3);
if(c>0)
  x = 0;
else
  x = [1 2 3];
end
disp(x);
end
```

For more information, see “Best Practices for Defining Variables for C/C++ Code Generation” on page 33-3.

Best Practices for Defining Variables for C/C++ Code Generation

In this section...

Define Variables By Assignment Before Using Them

For C/C++ code generation, you should explicitly and unambiguously define the class, size, and complexity of variables before using them in operations or returning them as outputs. Define variables by assignment, but note that the assignment copies not only the value, but also the size, class, and complexity represented by that value to the new variable. For example:

Assignment:	Defines:
`a = 14.7;`	`a` as a real double scalar.
`b = a;`	`b` with properties of `a` (real double scalar).
`c = zeros(5,2);`	`c` as a real 5-by-2 array of doubles.
`d = [1 2 3 4 5; 6 7 8 9 0];`	`d` as a real 5-by-2 array of doubles.
`y = int16(3);`	`y` as a real 16-bit integer scalar.

Define properties this way so that the variable is defined on all execution paths during C/C++ code generation (see Defining a Variable for Multiple Execution Paths on page 33-4).

The data that you assign to a variable can be a scalar, matrix, or structure. If your variable is a structure, define the properties of each field explicitly (see Defining All Fields in a Structure on page 33-5).

Initializing the new variable to the value of the assigned data sometimes results in redundant copies in the generated code. To avoid redundant copies, you can define variables without initializing their values by using the `coder.nullcopy` construct as described in "Eliminate Redundant Copies of Variables in Generated Code" on page 33-7.

When you define variables, they are local by default; they do not persist between function calls. To make variables persistent, see "Define and Initialize Persistent Variables" on page 33-10.

Defining a Variable for Multiple Execution Paths

Consider the following MATLAB code:

```
...
if c > 0
  x = 11;
end
% Later in your code ...
if c > 0
  use(x);
end
...
```

Here, *x* is assigned only if `c > 0` and used only when `c > 0`. This code works in MATLAB, but generates a compilation error during code generation because it detects that *x* is undefined on some execution paths (when `c <= 0`),.

To make this code suitable for code generation, define *x* before using it:

```
x = 0;
...
if c > 0
  x = 11;
end
% Later in your code ...
if c > 0
  use(x);
end
...
```

Defining All Fields in a Structure

Consider the following MATLAB code:

```
...
if c > 0
  s.a = 11;
  disp(s);
else
  s.a = 12;
  s.b = 12;
end
% Try to use s
use(s);
...
```

Here, the first part of the `if` statement uses only the field *a*, and the `else` clause uses fields *a* and *b*. This code works in MATLAB, but generates a compilation error during C/C++ code generation because it detects a structure type mismatch. To prevent this error, do not add fields to a structure after you perform certain operations on the structure. For more information, see "Structure Definition for Code Generation" on page 36-2.

To make this code suitable for C/C++ code generation, define all fields of *s* before using it.

```
...
% Define all fields in structure s
s = struct( a ,0,  b , 0);
if c > 0
  s.a = 11;
  disp(s);
else
  s.a = 12;
  s.b = 12;
end
% Use s
use(s);
...
```

Use Caution When Reassigning Variables

In general, you should adhere to the "one variable/one type" rule for C/C++ code generation; that is, each variable must have a specific class, size and complexity. Generally, if you reassign variable properties after the initial assignment, you get a compilation error during code generation, but there are exceptions, as described in “Reassignment of Variable Properties” on page 33-9.

Use Type Cast Operators in Variable Definitions

By default, constants are of type `double`. To define variables of other types, you can use type cast operators in variable definitions. For example, the following code defines variable `y` as an integer:

```
...
x = 15; % x is of type double by default.
y = uint8(x); % z has the value of x, but cast to uint8.
...
```

Define Matrices Before Assigning Indexed Variables

When generating C/C++ code from MATLAB, you cannot grow a variable by writing into an element beyond its current size. Such indexing operations produce run-time errors. You must define the matrix first before assigning values to any of its elements.

For example, the following initial assignment is not allowed for code generation:

```
g(3,2) = 14.6; % Not allowed for creating g
               % OK for assigning value once created
```

For more information about indexing matrices, see “Incompatibility with MATLAB in Matrix Indexing Operations for Code Generation” on page 35-29.

Eliminate Redundant Copies of Variables in Generated Code

In this section...

When Redundant Copies Occur

During C/C++ code generation, MATLAB checks for statements that attempt to access uninitialized memory. If it detects execution paths where a variable is used but is potentially not defined, it generates a compile-time error. To prevent these errors, define all variables by assignment before using them in operations or returning them as function outputs.

Note, however, that variable assignments not only copy the properties of the assigned data to the new variable, but also initialize the new variable to the assigned value. This forced initialization sometimes results in redundant copies in C/C++ code. To eliminate redundant copies, define uninitialized variables by using the `coder.nullcopy` function, as described in "How to Eliminate Redundant Copies by Defining Uninitialized Variables" on page 33-7.

How to Eliminate Redundant Copies by Defining Uninitialized Variables

1. Define the variable with `coder.nullcopy`.
2. Initialize the variable before reading it.

   When the uninitialized variable is an array, you must initialize all of its elements before passing the array as an input to a function or operator — even if the function or operator does not read from the uninitialized portion of the array.

What happens if you access uninitialized data?

Uninitialized memory contains arbitrary values. Therefore, accessing uninitialized data may lead to segmentation violations or nondeterministic program behavior (different runs of the same program may yield inconsistent results).

Defining Uninitialized Variables

In the following code, the assignment statement `X = zeros(1,N)` not only defines *X* to be a 1-by-5 vector of real doubles, but also initializes each element of *X* to zero.

```
function X = fcn %#codegen

N = 5;
X = zeros(1,N);
for i = 1:N
   if mod(i,2) == 0
      X(i) = i;
   else
      X(i) = 0;
   end
end
```

This forced initialization creates an extra copy in the generated code. To eliminate this overhead, use `coder.nullcopy` in the definition of *X*:

```
function X = fcn2 %#codegen

N = 5;
X = coder.nullcopy(zeros(1,N));
for i = 1:N
   if mod(i,2) == 0
      X(i) = i;
   else
      X(i) = 0;
   end
end
```

Reassignment of Variable Properties

For C/C++ code generation, there are certain variables that you can reassign after the initial assignment with a value of different class, size, or complexity:

Dynamically sized variables

A variable can hold values that have the same class and complexity but different sizes. If the size of the initial assignment is not constant, the variable is dynamically sized in generated code. For more information, see "Variable-Size Data".

Variables reused in the code for different purposes

You can reassign the type (class, size, and complexity) of a variable after the initial assignment if each occurrence of the variable can have only one type. In this case, the variable is renamed in the generated code to create multiple independent variables. For more information, see "Reuse the Same Variable with Different Properties" on page 33-11.

Define and Initialize Persistent Variables

Persistent variables are local to the function in which they are defined, but they retain their values in memory between calls to the function. To define persistent variables for C/C++ code generation, use the `persistent` statement, as in this example:

```
persistent PROD_X;
```

The definition should appear at the top of the function body, after the header and comments, but before the first use of the variable. During code generation, the value of the persistent variable is initialized to an empty matrix by default. You can assign your own value after the definition by using the `isempty` statement, as in this example:

```
function findProduct(inputvalue) %#codegen
persistent PROD_X

if isempty(PROD_X)
   PROD_X = 1;
end
PROD_X = PROD_X * inputvalue;
end
```

Reuse the Same Variable with Different Properties

In this section...

When You Can Reuse the Same Variable with Different Properties

You can reuse (reassign) an input, output, or local variable with different class, size, or complexity if MATLAB can unambiguously determine the properties of each occurrence of this variable during C/C++ code generation. If so, MATLAB creates separate uniquely named local variables in the generated code. You can view these renamed variables in the code generation report (see "Viewing Variables in Your MATLAB Code" on page 29-56).

A common example of variable reuse is in `if-elseif-else` or `switch-case` statements. For example, the following function `example1` first uses the variable *t* in an `if` statement, where it holds a scalar double, then reuses *t* outside the `if` statement to hold a vector of doubles.

```
function y = example1(u) %#codegen
if all(all(u>0))
    % First, t is used to hold a scalar double value
    t = mean(mean(u)) / numel(u);
    u = u - t;
end
% t is reused to hold a vector of doubles
t = find(u > 0);
y = sum(u(t(2:end-1)));
```

To compile this example and see how MATLAB renames the reused variable *t*, see Variable Reuse in an if Statement on page 33-12.

When You Cannot Reuse Variables

You cannot reuse (reassign) variables if it is not possible to determine the class, size, and complexity of an occurrence of a variable unambiguously during code generation. In this case, variables cannot be renamed and a compilation error occurs.

For example, the following `example2` function assigns a fixed-point value to *x* in the `if` statement and reuses *x* to store a matrix of doubles in the `else` clause. It then uses *x* after the `if-else` statement. This function generates a compilation error because after the `if-else` statement, variable *x* can have different properties depending on which `if-else` clause executes.

```
function y = example2(use_fixpoint, data) %#codegen
  if use_fixpoint
   % x is fixed-point
      x = fi(data, 1, 12, 3);
  else
    % x is a matrix of doubles
      x = data;
  end
  % When x is reused here, it is not possible to determine its
  % class, size, and complexity
  t = sum(sum(x));
  y = t > 0;
end
```

Variable Reuse in an if Statement

To see how MATLAB renames a reused variable *t*:

1. Create a MATLAB file `example1.m` containing the following code.

```
function y = example1(u) %#codegen
if all(all(u>0))
    % First, t is used to hold a scalar double value
    t = mean(mean(u)) / numel(u);
    u = u - t;
end
% t is reused to hold a vector of doubles
t = find(u > 0);
```

```
y = sum(u(t(2:end-1)));
end
```

2 Compile `example1`.

For example, to generate a MEX function, enter:

```
codegen -o example1x -report example1.m -args {ones(5,5)}
```

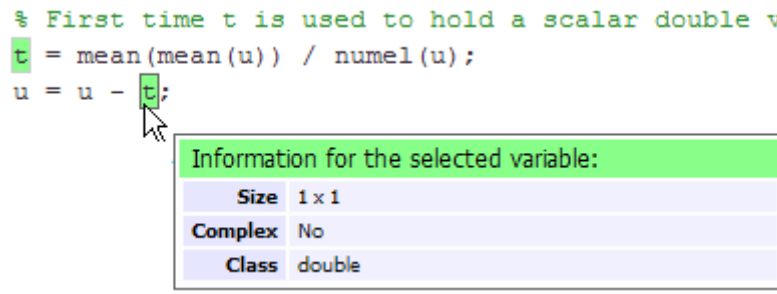
Note `codegen` requires a MATLAB Coder license.

When the compilation is complete, `codegen` generates a MEX function, `example1x` in the current folder, and provides a link to the code generation report.

3 Open the code generation report.

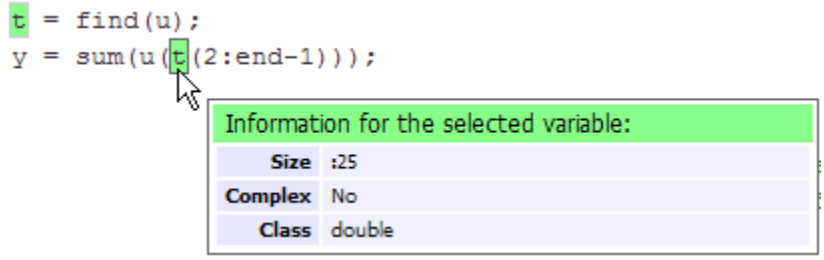
4 In the MATLAB code pane of the code generation report, place your pointer over the variable *t* inside the `if` statement.

The code generation report highlights both instances of *t* in the `if` statement because they share the same class, size, and complexity. It displays the data type information for *t* at this point in the code. Here, *t* is a scalar double.



5 In the MATLAB code pane of the report, place your pointer over the variable *t* outside the for-loop.

This time, the report highlights both instances of *t* outside the `if` statement. The report indicates that *t* might hold up to `25` doubles. The size of *t* is `:25`, that is, a column vector containing a maximum of `25` doubles.



6. Click the **Variables** tab to view the list of variables used in `example1`.

   The report displays a list of all the variables in `example1`. There are two uniquely named local variables *t>1* and *t>2*.

7. In the list of variables, place your pointer over *t>1*.

   The code generation report highlights both instances of *t* in the `if` statement.

8. In the list of variables, place your pointer over *t>2*

   The code generation report highlights both instances of *t* outside the `if` statement.

Limitations of Variable Reuse

The following variables cannot be renamed in generated code:

- Persistent variables.
- Global variables.
- Variables passed to C code using `coder.ref`, `coder.rref`, `coder.wref`.
- Variables whose size is set using `coder.varsize`.
- Variables whose names are controlled using `coder.cstructname`.
- The index variable of a `for`-loop when it is used inside the loop body.

- The block outputs of a MATLAB Function block in a Simulink model.
- Chart-owned variables of a MATLAB function in a Stateflow chart.

Avoid Overflows in for-Loops

When memory integrity checks are enabled, if the code generation software detects that a loop variable might overflow on the last iteration of the `for`-loop, it reports an error.

To avoid this error, use the workarounds provided in the following table.

Loop conditions causing the error	Workaround

• The loop counter increments by 1
• The end value equals the maximum value of the integer type
• The loop is not covering the full range of the integer type
	Rewrite the loop so that the end value is not equal to the maximum value of the integer type. For example, replace:
	`N=intmax('int16')`
	`for k=N-10:N`
	with:
	`for k=1:10`

• The loop counter decrements by 1
• The end value equals the minimum value of the integer type
• The loop is not covering the full range of the integer type
	Rewrite the loop so that the end value is not equal to the minimum value of the integer type. For example, replace:
	`N=intmin('int32')`
	`for k=N+10:-1:N`
	with:
	`for k=10:-1:1`

Loop conditions causing the error	Workaround

• The loop counter increments or decrements by 1
• The start value equals the minimum or maximum value of the integer type
• The end value equals the maximum or minimum value of the integer type
 	
The loop covers the full range of the integer type.
	Rewrite the loop casting the type of the loop counter start, step, and end values to a bigger integer or to double For example, rewrite:
	
	`M= intmin('int16');`
	`N= intmax('int16');`
	`for k=M:N`
	`  % Loop body`
	`end`
	
	to
	
	`M= intmin('int16');`
	`N= intmax('int16');`
	`for k=int32(M):int32(N)`
	`  % Loop body`
	`end`

• The loop counter increments or decrements by a value not equal to 1 • On last loop iteration, the loop variable value is not equal to the end value **Note** The software error checking might be too conservative and report the possibility of an infinite under these circumstances even though an infinite loop would never occur.	Rewrite the loop so that the loop variable on the last loop iteration is equal to the end value.

Supported Variable Types

You can use the following data types for C/C++ code generation from MATLAB:

Type	Description
`char`	Character array (string)
`complex`	Complex data. Cast function takes real and imaginary components
`double`	Double-precision floating point
`int8`, `int16`, `int32`	Signed integer
`logical`	Boolean `true` or `false`
`single`	Single-precision floating point
`struct`	Structure
`uint8`, `uint16`, `uint32`	Unsigned integer
Fixed-point	See “Fixed-Point Data Types”.

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Defining Data for Code Generation

Data Definition for Code Generation

To generate efficient standalone code, you must define the following types and classes of data differently than you normally would when running your code in the MATLAB environment:

Data	What's Different	More Information
Complex numbers	• Complexity of variables must be set at time of assignment and before first use • Expressions containing a complex number or variable always evaluate to a complex result, even if the result is zero **Note** Because MATLAB does not support complex integer arithmetic, you cannot generate code for functions that use complex integer arithmetic	"Code Generation for Complex Data" on page 34-4
Characters	Restricted to 8 bits of precision	"Code Generation for Characters" on page 34-6

Data	What's Different	More Information
Enumerated data	• Supports integer-based enumerated types only • Restricted use in `switch` statements and `for`-loops	"Enumerated Data"
Function handles	• Function handles must be scalar values • Same bound variable cannot reference different function handles • Cannot pass function handles to or from primary or extrinsic functions • Cannot view function handles from the debugger	"Function Handles"

Code Generation for Complex Data

In this section...

Restrictions When Defining Complex Variables

For code generation, you must set the complexity of variables at the time of assignment, either by assigning a complex constant or using the `complex` function, as in these examples:

```
x = 5 + 6i; % x is a complex number by assignment.
y = 7 + 8j; % y is a complex number by assignment.
x = complex(5,6); % x is the complex number 5 + 6i.
```

Once you set the type and size of a variable, you cannot cast it to another type or size. In the following example, the variable `x` is defined as complex and stays complex:

```
x = 1 + 2i; % Defines x as a complex variable.
y = int16(x); % Real and imaginary parts of y are int16.
x = 3; % x now has the value 3 + 0i.
```

Mismatches can also occur when you assign a real operand the complex result of an operation:

```
z = 3; % Sets type of z to double (real)
z = 3 + 2i; % ERROR: cannot recast z to complex
```

As a workaround, set the complexity of the operand to match the result of the operation:

```
m = complex(3); % Sets m to complex variable of value 3 + 0i
m = 5 + 6.7i; % Assigns a complex result to a complex number
```

Expressions Containing Complex Operands Yield Complex Results

In general, expressions that contain one or more complex operands always produce a complex result in generated code, even if the value of the result is zero. Consider the following example:

```
x = 2 + 3i;
y = 2 - 3i;
z = x + y;  % z is 4 + 0i.
```

In MATLAB, this code generates the real result `z = 4`. However, during code generation, the types for `x` and `y` are known, but their values are not. Because either or both operands in this expression are complex, `z` is defined as a complex variable requiring storage for both a real and an imaginary part. This means that `z` equals the complex result `4 + 0i` in generated code, not `4` as in MATLAB code.

There are two exceptions to this behavior:

- Functions that take complex arguments, but produce real results

  ```
  y = real(x); % y is the real part of the complex number x.
  y = imag(x); % y is the real-valued imaginary part of x.
  y = isreal(x); % y is false (0) for a complex number x.
  ```

- Functions that take real arguments, but produce complex results:

  ```
  z = complex(x,y); % z is a complex number for a real x and y.
  ```

Code Generation for Characters

The complete set of Unicode® characters is not supported for code generation. Characters are restricted to 8 bits of precision in generated code. Because many mathematical operations require more than 8 bits of precision, it is recommended that you do not perform arithmetic with characters if you intend to generate code from your MATLAB algorithm.

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Code Generation for Variable-Size Data

What Is Variable-Size Data?

Variable-size data is data whose size can 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.

For example, in the following MATLAB function `nway`, `B` is a variable-size array; its length is not known at compile time.

```
function B = nway(A,n)
% Compute average of every N elements of A and put them in B.
if ((mod(numel(A),n) == 0) && (n>=1 && n<=numel(A)))
    B = ones(1,numel(A)/n);
    k = 1;
    for i = 1 : numel(A)/n
         B(i) = mean(A(k + (0:n-1)));
         k = k + n;
    end
else
    error('n <= 0 or does not divide number of elements evenly');
end
```

Variable-Size Data Definition for Code Generation

In the MATLAB language, all data can vary in size. By contrast, the semantics of generated code constrains the class, complexity, and shape of every expression, variable, and structure field. Therefore, for code generation, you must use each variable consistently. Each variable must:

- Be either complex or real (determined at first assignment)
- Have a consistent shape

  For fixed-size data, the shape is the same as the size returned in MATLAB. For example, if `size(A) == [4 5]`, the shape of variable `A` is 4 x 5. For variable-size data, the shape can be abstract. That is, one or more dimensions can be unknown (such as `4x?` or `?x?`).

By default, the compiler detects code logic that attempts to change these fixed attributes after initial assignments, and flags these occurrences as errors during code generation. However, you can override this behavior by defining variables or structure fields as variable-size data. You can then generate standalone code for bounded and unbounded variable-size data.

For more information, see “Bounded Versus Unbounded Variable-Size Data” on page 35-4

Bounded Versus Unbounded Variable-Size Data

You can generate code for bounded and unbounded variable-size data. *Bounded variable-size data* has fixed upper bounds; this data can be allocated statically on the stack or dynamically on the heap. *Unbounded variable-size data* does not have fixed upper bounds; this data *must* be allocated on the heap. If you use unbounded data, you must use dynamic memory allocation so that the compiler:

- Does not check for upper bounds
- Allocates memory on the heap instead of the stack

You can control the memory allocation of variable-size data. For more information, see "Control Memory Allocation of Variable-Size Data" on page 35-5.

Control Memory Allocation of Variable-Size Data

All data whose size exceeds the dynamic memory allocation threshold is allocated on the heap. The default dynamic memory allocation threshold is 64 kilobytes. All data whose size is less than this threshold is allocated on the stack.

Dynamic memory allocation is an expensive operation; the performance cost may be too high for small data sets. If you use small variable-size data sets or data that does not change size at run time, disable dynamic memory allocation. See .

. You can control memory allocation for individual variables by specifying upper bounds. See “Specifying Upper Bounds for Variable-Size Data” on page 35-6.

Specify Variable-Size Data Without Dynamic Memory Allocation

In this section...

Fixing Upper Bounds Errors

If MATLAB cannot determine or compute the upper bound, you must specify an upper bound. See "Specifying Upper Bounds for Variable-Size Data" on page 35-6 and "Diagnosing and Fixing Errors in Detecting Upper Bounds" on page 35-22

Specifying Upper Bounds for Variable-Size Data

When to Specify Upper Bounds for Variable-Size Data

When using static allocation on the stack during code generation, MATLAB must be able to determine upper bounds for variable-size data. Specify the upper bounds explicitly for variable-size data from external sources, such as inputs and outputs.

Specifying Upper Bounds on the Command Line for Variable-Size Inputs

Use the `coder.typeof` construct with the `-args` option on the `codegen` command line (requires a MATLAB Coder license). For example:

```
codegen foo -args {coder.typeof(double(0),[3 100],1)}
```

This command specifies that the input to function `foo` is a matrix of real doubles with two variable dimensions. The upper bound for the first dimension is 3; the upper bound for the second dimension is 100. For a detailed explanation of this syntax, see .

Specifying Unknown Upper Bounds for Variable-Size Inputs

If you use dynamic memory allocation, you can specify that you don't know the upper bounds of inputs. To specify an unknown upper bound, use the infinity constant `Inf` in place of a numeric value. For example:

```
codegen foo -args {coder.typeof(double(0), [1 Inf])}
```

In this example, the input to function `foo` is a vector of real doubles without an upper bound.

Specifying Upper Bounds for Local Variable-Size Data

When using static allocation, MATLAB uses a sophisticated analysis to calculate the upper bounds of local data at compile time. However, when the analysis fails to detect an upper bound or calculates an upper bound that is not precise enough for your application, you need to specify upper bounds explicitly for local variables.

You do not need to specify upper bounds when using dynamic allocation on the heap. In this case, MATLAB assumes all variable-size data is unbounded and does not attempt to determine upper bounds.

Constraining the Value of a Variable That Specifies Dimensions of Variable-Size Data. Use the `assert` function with relational operators to constrain the value of variables that specify the dimensions of variable-size data. For example:

```
function y = dim_need_bound(n) %#codegen
assert (n <= 5);
L= ones(n,n);
M = zeros(n,n);
M = [L; M];
y = M;
```

This `assert` statement constrains input `n` to a maximum size of 5, defining `L` and `M` as variable-sized matrices with upper bounds of 5 for each dimension.

Specifying the Upper Bounds for All Instances of a Local Variable. Use the `coder.varsize` function to specify the upper bounds for all instances of a local variable in a function. For example:

```
function Y = example_bounds1(u) %#codegen
Y = [1 2 3 4 5];
coder.varsize('Y', [1 10]);
if (u > 0)
    Y = [Y Y+u];
else
    Y = [Y Y*u];
end
```

The second argument of `coder.varsize` specifies the upper bound for each instance of the variable specified in the first argument. In this example, the argument `[1 10]` indicates that for every instance of `Y`:

- First dimension is fixed at size 1
- Second dimension can grow to an upper bound of 10

By default, `coder.varsize` assumes dimensions of 1 are fixed size. For more information, see the `coder.varsize` reference page.

Using a Matrix Constructor with Nonconstant Dimensions

You can define a variable-size matrix by using a constructor with nonconstant dimensions. For example:

```
function y = var_by_assign(u) %#codegen
if (u > 0)
   y = ones(3,u);
else
   y = zeros(3,1);
end
```

If you are not using dynamic memory allocation, you must also add an `assert` statement to provide upper bounds for the dimensions. For example:

```
function y = var_by_assign(u) %#codegen
assert (u < 20);
if (u > 0)
   y = ones(3,u);
else
   y = zeros(3,1);
end
```

Variable-Size Data in Code Generation Reports

In this section...

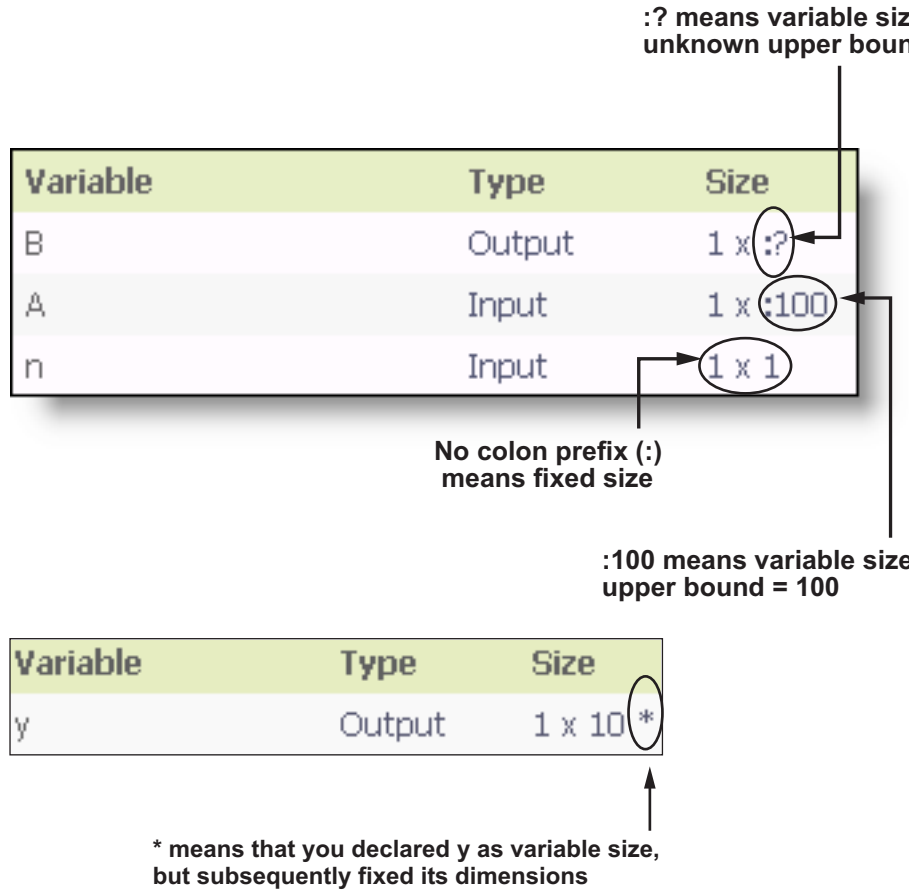
What Reports Tell You About Size

Code generation reports:

- Differentiate fixed-size from variable-size data
- Identify variable-size data with unknown upper bounds
- Identify variable-size data with fixed dimensions

  If you define a variable-size array and then subsequently fix the dimensions of this array in the code, the 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 does not change during execution.
- Provide guidance on how to fix size mismatch and upper bounds errors.

How Size Appears in Code Generation Reports



How to Generate a Code Generation Report

Define Variable-Size Data for Code Generation

In this section...

When to Define Variable-Size Data Explicitly

For code generation, you must assign variables to have a specific class, size, and complexity before using them in operations or returning them as outputs. Generally, you cannot reassign variable properties after the initial assignment. Therefore, attempts to grow a variable or structure field after assigning it a fixed size might cause a compilation error. In these cases, you must explicitly define the data as variable sized using one of these methods:

Method	See
Assign the data from a variable-size matrix constructor such as • `ones` • `zeros` • `repmat`	"Using a Matrix Constructor with Nonconstant Dimensions" on page 35-13
Assign multiple, constant sizes to the same variable before using (reading) the variable.	"Inferring Variable Size from Multiple Assignments" on page 35-13
Define all instances of a variable to be variable sized	"Defining Variable-Size Data Explicitly Using coder.varsize" on page 35-14

Using a Matrix Constructor with Nonconstant Dimensions

You can define a variable-size matrix by using a constructor with nonconstant dimensions. For example:

```
function y = var_by_assign(u) %#codegen
if (u > 0)
   y = ones(3,u);
else
   y = zeros(3,1);
end
```

Inferring Variable Size from Multiple Assignments

You can define variable-size data by assigning multiple, constant sizes to the same variable before you use (read) the variable in your code. When MATLAB uses static allocation on the stack for code generation, it infers the upper bounds from the largest size specified for each dimension. When you assign the same size to a given dimension across all assignments, MATLAB assumes that the dimension is fixed at that size. The assignments can specify different shapes as well as sizes.

When dynamic memory allocation is used, MATLAB does not check for upper bounds; it assumes all variable-size data is unbounded.

Inferring Upper Bounds from Multiple Definitions with Different Shapes

```
function y = var_by_multiassign(u) %#codegen
if (u > 0)
   y = ones(3,4,5);
else
   y = zeros(3,1);
end
```

When static allocation is used, this function infers that `y` is a matrix with three dimensions, where:

- First dimension is fixed at size 3

- Second dimension is variable with an upper bound of 4
- Third dimension is variable with an upper bound of 5

The code generation report represents the size of matrix `y` like this:

Variable	Type	Size
y	Output	3 x :4 x :5

When dynamic allocation is used, the function analyzes the dimensions of `y` differently:

- First dimension is fixed at size 3
- Second and third dimensions are unbounded

In this case, the code generation report represents the size of matrix `y` like this:

Variable	Type	Size
y	Output	3 x :? x :?

Defining Variable-Size Data Explicitly Using coder.varsize

Use the function `coder.varsize` to define one or more variables or structure fields as variable-size data. Optionally, you can also specify which dimensions vary along with their upper bounds (see "Specifying Which Dimensions Vary" on page 35-15). For example:

- Define `B` as a variable-size 2-by-2 matrix, where each dimension has an upper bound of 64:

  ```
  coder.varsize('B', [64 64]);
  ```

- Define `B` as a variable-size matrix:

```
coder.varsize('B');
```

When you supply only the first argument, `coder.varsize` assumes all dimensions of `B` can vary and that the upper bound is `size(B)`.

For more information, see the `coder.varsize` reference page.

Specifying Which Dimensions Vary

You can use the function `coder.varsize` to specify which dimensions vary. For example, the following statement defines `B` as a row vector whose first dimension is fixed at 2, but whose second dimension can grow to an upper bound of 16:

```
coder.varsize('B', [2, 16], [0 1])
```

The third argument specifies which dimensions vary. This argument must be a logical vector or a double vector containing only zeros and ones. Dimensions that correspond to zeros or `false` have fixed size; dimensions that correspond to ones or `true` vary in size. `coder.varsize` usually treats dimensions of size 1 as fixed (see "Defining Variable-Size Matrices with Singleton Dimensions" on page 35-16).

For more information about the syntax, see the `coder.varsize` reference page.

Allowing a Variable to Grow After Defining Fixed Dimensions

Function `var_by_if` defines matrix `Y` with fixed 2-by-2 dimensions before first use (where the statement `Y = Y + u` reads from `Y`). However, `coder.varsize` defines `Y` as a variable-size matrix, allowing it to change size based on decision logic in the `else` clause:

```
function Y = var_by_if(u) %#codegen
if (u > 0)
   Y = zeros(2,2);
   coder.varsize('Y');
   if (u < 10)
       Y = Y + u;
   end
else
```

```
   Y = zeros(5,5);
end
```

Without `coder.varsize`, MATLAB infers `Y` to be a fixed-size, 2-by-2 matrix and generates a size mismatch error during code generation.

Defining Variable-Size Matrices with Singleton Dimensions

A singleton dimension is any dimension for which `size(A,dim)` = 1. Singleton dimensions are fixed in size when:

- You specify a dimension with an upper bound of 1 in `coder.varsize` expressions.

  For example, in this function, `Y` behaves like a vector with one variable-size dimension:

  ```
  function Y = dim_singleton(u) %#codegen
  Y = [1 2];
  coder.varsize('Y', [1 10]);
  if (u > 0)
      Y = [Y 3];
  else
      Y = [Y u];
  end
  ```

- You initialize variable-size data with singleton dimensions using matrix constructor expressions or matrix functions.

  For example, in this function, both `X` and `Y` behave like vectors where only their second dimensions are variable sized:

  ```
  function [X,Y] = dim_singleton_vects(u) %#codegen
  Y = ones(1,3);
  X = [1 4];
  coder.varsize('Y','X');
  if (u > 0)
      Y = [Y u];
  else
      X = [X u];
  end
  ```

You can override this behavior by using `coder.varsize` to specify explicitly that singleton dimensions vary. For example:

```
function Y = dim_singleton_vary(u) %#codegen
Y = [1 2];
coder.varsize('Y', [1 10], [1 1]);
if (u > 0)
    Y = [Y Y+u];
else
    Y = [Y Y*u];
end
```

In this example, the third argument of `coder.varsize` is a vector of ones, indicating that each dimension of `Y` varies in size. For more information, see the `coder.varsize` reference page.

Defining Variable-Size Structure Fields

To define structure fields as variable-size arrays, use colon (`:`) as the index expression. The colon (`:`) indicates that all elements of the array are variable sized. For example:

```
function y=struct_example() %#codegen

  d = struct('values', zeros(1,0), 'color', 0);
  data = repmat(d, [3 3]);
  coder.varsize('data(:).values');

  for i = 1:numel(data)
      data(i).color = rand-0.5;
      data(i).values = 1:i;
  end

  y = 0;
  for i = 1:numel(data)
      if data(i).color > 0
          y = y + sum(data(i).values);
      end;
  end
```

The expression `coder.varsize('data(:).values')` defines the field `values` inside each element of matrix `data` to be variable sized.

Here are other examples:

- `coder.varsize('data.A(:).B')`

  In this example, `data` is a scalar variable that contains matrix `A`. Each element of matrix `A` contains a variable-size field `B`.

- `coder.varsize('data(:).A(:).B')`

  This expression defines field `B` inside each element of matrix `A` inside each element of matrix `data` to be variable sized.

C Code Interface for Arrays

C Code Interface for Statically Allocated Arrays

In generated code, MATLAB contains two pieces of information about statically allocated arrays: the maximum size of the array and its actual size.

For example, consider the MATLAB function `uniquetol`:

```
function B = uniquetol(A, tol) %#codegen
A = sort(A);
coder.varsize('B');
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
```

Generate code for `uniquetol` specifying that input `A` is a variable-size real double vector whose first dimension is fixed at 1 and second dimension can vary up to 100 elements.

In the generated code, the function declaration is:

There are two pieces of information about `A`:

- `real_T A_data[100]`: the maximum size of input `A` (where `100` is the maximum size specified using `coder.typeof`).
- `int32_T A_sizes[2]`: the actual size of the input.

Troubleshooting Issues with Variable-Size Data

In this section...

Diagnosing and Fixing Size Mismatch Errors

Check your code for these issues:

Assigning Variable-Size Matrices to Fixed-Size Matrices

You cannot assign variable-size matrices to fixed-size matrices in generated code. Consider this example:

```
function Y = example_mismatch1(n) %#codegen
assert(n<10);
B = ones(n,n);
A = magic(3);
A(1) = mean(A(:));
if (n == 3)
    A = B;
end
Y = A;
```

Compiling this function produces this error:

```
??? Dimension 1 is fixed on the left-hand side
but varies on the right ...
```

There are several ways to fix this error:

- Allow matrix `A` to grow by adding the `coder.varsize` construct:

  ```
  function Y = example_mismatch1_fix1(n) %#codegen
  coder.varsize('A');
  assert(n<10);
  B = ones(n,n);
  A = magic(3);
  ```

```
A(1) = mean(A(:));
if (n == 3)
    A = B;
end
Y = A;
```

- Explicitly restrict the size of matrix `B` to 3-by-3 by modifying the `assert` statement:

```
function Y = example_mismatch1_fix2(n) %#codegen
coder.varsize('A');
assert(n==3)
B = ones(n,n);
A = magic(3);
A(1) = mean(A(:));
if (n == 3)
    A = B;
end
Y = A;
```

- Use explicit indexing to make `B` the same size as `A`:

```
function Y = example_mismatch1_fix3(n) %#codegen
assert(n<10);
B = ones(n,n);
A = magic(3);
A(1) = mean(A(:));
if (n == 3)
   A = B(1:3, 1:3);
end
Y = A;
```

Empty Matrix Reshaped to Match Variable-Size Specification

If you assign an empty matrix `[]` to variable-size data, MATLAB might silently reshape the data in generated code to match a `coder.varsize` specification. For example:

```
function Y = test(u) %#codegen
Y = [];
coder.varsize(`Y', [1 10]);
```

```
If u < 0
   Y = [Y u];
end
```

In this example, `coder.varsize` defines `Y` as a column vector of up to 10 elements, so its first dimension is fixed at size 1. The statement `Y = []` designates the first dimension of `Y` as 0, creating a mismatch. The right hand side of the assignment is an empty matrix and the left hand side is a variable-size vector. In this case, MATLAB reshapes the empty matrix `Y = []` in generated code to `Y = zeros(1,0)` so it matches the `coder.varsize` specification.

Performing Binary Operations on Fixed and Variable-Size Operands

You cannot perform binary operations on operands of different sizes. Operands have different sizes if one has fixed dimensions and the other has variable dimensions. For example:

```
function z = mismatch_operands(n) %#codegen
 assert(n>=3 && n<10);
 x = ones(n,n);
 y = magic(3);
 z = x + y;
```

When you compile this function, you get an error because `y` has fixed dimensions (3 x 3), but `x` has variable dimensions. Fix this problem by using explicit indexing to make `x` the same size as `y`:

```
function z = mismatch_operands_fix(n) %#codegen
 assert(n>=3 && n<10);
 x = ones(n,n);
 y = magic(3);
 z = x(1:3,1:3) + y;
```

Diagnosing and Fixing Errors in Detecting Upper Bounds

Check your code for these issues:

Using Nonconstant Dimensions in a Matrix Constructor

You can define variable-size data by assigning a variable to a matrix with nonconstant dimensions. For example:

```
function y = dims_vary(u) %#codegen
if (u > 0)
   y = ones(3,u);
else
   y = zeros(3,1);
end
```

However, compiling this function generates an error because you did not specify an upper bound for `u`.

To fix the problem, add an `assert` statement before the first use of `u`:

```
function y = dims_vary_fix(u) %#codegen
assert (u < 20);
if (u > 0)
   y = ones(3,u);
else
   y = zeros(3,1);
end
```

Incompatibilities with MATLAB in Variable-Size Support for Code Generation

In this section...

Incompatibility with MATLAB for Scalar Expansion

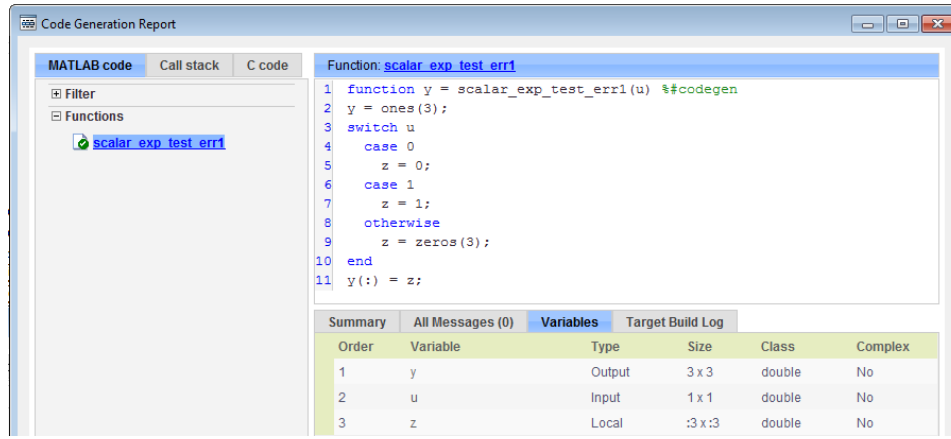
Scalar expansion is a method of converting scalar data to match the dimensions of vector or matrix data. Except for some matrix operators, MATLAB arithmetic operators work on corresponding elements of arrays with equal dimensions. For vectors and rectangular arrays, both operands must be the same size unless one is a scalar. If one operand is a scalar and the other is not, MATLAB applies the scalar to every element of the other operand—this property is known as *scalar expansion*.

During code generation, the standard MATLAB scalar expansion rules apply except when operating on two variable-size expressions. In this case, both operands must be the same size. The generated code does not perform scalar expansion even if one of the variable-size expressions turns out to be scalar at run time. Instead, it generates a size mismatch error at run time for MEX functions. For non-MEX builds, there is no run-time error checking; the generated code will have unspecified behavior.

For example, in the following function, `z` is scalar for the `switch` statement `case 0` and `case 1`. MATLAB applies scalar expansion when evaluating `y(:) = z;` for these two cases.

```
function y = scalar_exp_test_err1(u) %#codegen
for the otherwise case of the switch function.y = ones(3);
switch u
  case 0
    z = 0;
  case 1
    z = 1;
  otherwise
    z = zeros(3);
end
y(:) = z;
```

When you generate code for this function, the code generation software determines that `z` is variable size with an upper bound of 3.



If you run the MEX function with `u` equal to zero or one, even though `z` is scalar at run time, the generated code does not perform scalar expansion and a run-time error occurs.

```
scalar_exp_test_err1_mex(0)
Sizes mismatch: 9 ~= 1.

Error in scalar_exp_test_err1 (line 11)
y(:) = z;
```

Workaround

Use indexing to force `z` to be a scalar value:

```
function y = scalar_exp_test_err1(u) %#codegen
y = ones(3);
switch u
  case 0
    z = 0;
  case 1
    z = 1;
  otherwise
    z = zeros(3);
end
y(:) = z(1);
```

Incompatibility with MATLAB in Determining Size of Variable-Size N-D Arrays

For variable-size N-D arrays, the `size` function can return a different result in generated code than in MATLAB. In generated code, `size(A)` always returns a fixed-length output because it does not drop trailing singleton dimensions of variable-size N-D arrays. By contrast, `size(A)` in MATLAB returns a variable-length output because it drops trailing singleton dimensions.

For example, if the shape of array `A` is `:?x:?x:?` and `size(A,3)==1`, `size(A)` returns:

- Three-element vector in generated code
- Two-element vector in MATLAB code

Workarounds

If your application requires generated code to return the same size of variable-size N-D arrays as MATLAB code, consider one of these workarounds:

- Use the two-argument form of `size`.

  For example, `size(A,n)` always returns the same answer in generated code and MATLAB code.

- Rewrite `size(A)`:

  ```
  B = size(A);
  X = B(1:ndims(A));
  ```

  This version returns `X` with a variable-length output. However, you cannot pass a variable-size `X` to matrix constructors such as `zeros` that require a fixed-size argument.

Incompatibility with MATLAB in Determining Size of Empty Arrays

The size of an empty array in generated code might be different from its size in MATLAB source code. The size might be `1x0` or `0x1` in generated code, but `0x0` in MATLAB. Therefore, you should not write code that relies on the specific size of empty matrices.

For example, consider the following code:

```
function y = foo(n) %#codegen
x = [];
i=0;
   while (i<10)
     x = [5, x];
     i=i+1;
   end
if n > 0
  x = [];
end
y=size(x);
end
```

Concatenation requires its operands to match on the size of the dimension that is not being concatenated. In the preceding concatenation the scalar value has size `1x1` and `x` has size `0x0`. To support this use case, the code generation software determines the size for `x` as `[1 x :?]`. Because there is another assignment `x = []` after the concatenation, the size of `x` in the generated code is `1x0` instead of `0x0`.

Workaround

If your application checks whether a matrix is empty, use one of these workarounds:

- Rewrite your code to use the `isempty` function instead of the `size` function.
- Instead of using `x=[]` to create empty arrays, create empty arrays of a specific size using `zeros`. For example:

```
function y = test_empty(n) %#codegen
x = zeros(1,0);
i=0;
   while (i<10)
     x = [5, x];
     i=i+1;
   end
if n > 0
  x = zeros(1,0);
end
y=size(x);
end
```

Incompatibility with MATLAB in Vector-Vector Indexing

In vector-vector indexing, you use one vector as an index into another vector. When either vector is variable sized, you might get a run-time error during code generation. Consider the index expression `A(B)`. The general rule for indexing is that `size(A(B)) == size(B)`. However, when both `A` and `B` are vectors, MATLAB applies a special rule: use the orientation of A as the orientation of the output. For example, if `size(A) == [1 5]` and `size(B) == [3 1]`, then `size(A(B)) == [1 3]`.

In this situation, if the code generation software detects that both `A` and `B` are vectors at compile time, it applies the special rule and gives the same result as MATLAB. However, if either `A` or `B` is a variable-size matrix (has shape `?x?`) at compile time, the code generation software applies only the general indexing rule. Then, if both `A` and `B` become vectors at run time, the code generation software reports a run-time error when you run the MEX function. For non-MEX builds, there is no run-time error checking; the generated code

will have unspecified behavior. It is best practice to generate and test a MEX function before generating C code.

Workaround

Force your data to be a vector by using the colon operator for indexing: `A(B(:))`. For example, suppose your code intentionally toggles between vectors and regular matrices at run time. You can do an explicit check for vector-vector indexing:

```
...
if isvector(A) && isvector(B)
    C = A(:);
    D = C(B(:));
 else
    D = A(B);
 end
...
```

The indexing in the first branch specifies that `C` and `B(:)` are compile-time vectors. As a result, the code generation software applies the standard vector-vector indexing rule.

Incompatibility with MATLAB in Matrix Indexing Operations for Code Generation

The following limitations apply to matrix indexing operations for code generation:

- Initialization of the following style:

  ```
  for i = 1:10
    M(i) = 5;
  end
  ```

  In this case, the size of `M` changes as the loop is executed. Code generation does not support increasing the size of an array over time.

  For code generation, preallocate `M` as highlighted in the following code.

  ```
  M=zeros(1,10);
  ```

```
for i = 1:10
  M(i) = 5;
end
```

- `M(i:j)` where `i` and `j` change in a loop

  During code generation, memory is never dynamically allocated for the size of the expressions that change as the program executes. To implement this behavior, use `for`-loops as shown in the following example:

```
...
M = ones(10,10);
for i=1:10
 for j = i:10
  M(i,j) = 2 * M(i,j);
 end
end
...
```

Note The matrix `M` must be defined before entering the loop, as shown in the highlighted code.

Dynamic Memory Allocation Not Supported for MATLAB Function Blocks

You cannot use dynamic memory allocation for variable-size data in MATLAB Function blocks. Use bounded instead of unbounded variable-size data.

Restrictions on Variable Sizing in Toolbox Functions Supported for Code Generation

In this section...

Common Restrictions

The following common restrictions apply to multiple toolbox functions, but only for code generation. To determine which of these restrictions apply to specific library functions, see the table in "Toolbox Functions with Variable Sizing Restrictions" on page 35-32.

Variable-length vector restriction

Inputs to the library function must be variable-length vectors or fixed-size vectors. A variable-length vector is a variable-size array that has the shape `1x:n` or `:nx1` (one dimension is variable sized and the other is fixed at size 1). Other shapes are not permitted, even if they are vectors at run time.

Automatic dimension restriction

When the function selects the working dimension automatically, it bases the selection on the upper bounds for the dimension sizes. In the case of the `sum` function, `sum(X)` selects its working dimension automatically, while `sum(X, dim)` uses `dim` as the explicit working dimension.

For example, if `X` is a variable-size matrix with dimensions `1x:3x:5`, `sum(x)` behaves like `sum(X,2)` in generated code. In MATLAB, it behaves like `sum(X,2)` provided `size(X,2)` is not 1. In MATLAB, when `size(X,2)` is 1, `sum(X)` behaves like `sum(X,3)`. Consequently, you get a run-time error if an automatically selected working dimension assumes a length of 1 at run time.

To avoid the issue, specify the intended working dimension explicitly as a constant value.

Array-to-vector restriction

The function issues an error when a variable-size array that is not a variable-length vector assumes the shape of a vector at run time. To avoid the issue, specify the input explicitly as a variable-length vector instead of a variable-size array.

Array-to-scalar restriction

The function issues an error if a variable-size array assumes a scalar value at run time. To avoid this issue, specify all scalars as fixed size.

Toolbox Functions with Variable Sizing Restrictions

The following restrictions apply to specific toolbox functions, but only for code generation.

Function	Restrictions with Variable-Size Data
`all`	• See "Automatic dimension restriction" on page 35-31. • An error occurs if you pass the first argument a variable-size matrix that is 0-by-0 at run time.
`any`	• See "Automatic dimension restriction" on page 35-31. • An error occurs if you pass the first argument a variable-size matrix that is 0-by-0 at run time.
`bsxfun`	• Dimensions expand only where one input array or the other has a fixed length of 1.
`cat`	• Dimension argument must be a constant. • An error occurs if variable-size inputs are empty at run time.

Function	Restrictions with Variable-Size Data
`conv`	• See "Variable-length vector restriction" on page 35-31. • Input vectors must have the same orientation, either both row vectors or both column vectors.
`cov`	• For `cov(X)`, see"Array-to-vector restriction" on page 35-32.
`cross`	• Variable-size array inputs that become vectors at run time must have the same orientation.
`deconv`	• For both arguments, see"Variable-length vector restriction" on page 35-31.
`detrend`	• For first argument for row vectors only, see "Array-to-vector restriction" on page 35-32 .
`diag`	• See "Array-to-vector restriction" on page 35-32 .
`diff`	• See "Automatic dimension restriction" on page 35-31. • Length of the working dimension must be greater than the difference order input when the input is variable sized. For example, if the input is a variable-size matrix that is 3-by-5 at run time, `diff(x,2,1)` works but `diff(x,5,1)` generates a run-time error.
`fft`	• See "Automatic dimension restriction" on page 35-31.

Function	Restrictions with Variable-Size Data
`filter`	• For first and second arguments, see "Variable-length vector restriction" on page 35-31. • See "Automatic dimension restriction" on page 35-31.
`hist`	• For second argument, see "Variable-length vector restriction" on page 35-31. • For second input argument, see"Array-to-scalar restriction" on page 35-32.
`histc`	• See "Automatic dimension restriction" on page 35-31.
`ifft`	• See "Automatic dimension restriction" on page 35-31.
`ind2sub`	• First input (the size vector input) must be fixed size.
`interp1`	• For the `Y` input and `xi` input, see"Array-to-vector restriction" on page 35-32. • `Y` input can become a column vector dynamically. • A run-time error occurs if `Y` input is not a variable-length vector and becomes a row vector at run time.
`ipermute`	• Order input must be fixed size.
`issorted`	• For optional rows input, see "Variable-length vector restriction" on page 35-31.

Function	Restrictions with Variable-Size Data
`magic`	• Argument must be a constant. • Output can be fixed-size matrices only.
`max`	• See "Automatic dimension restriction" on page 35-31.
`mean`	• See "Automatic dimension restriction" on page 35-31. • An error occurs if you pass as the first argument a variable-size matrix that is 0-by-0 at run time.
`median`	• See "Automatic dimension restriction" on page 35-31. • An error occurs if you pass as the first argument a variable-size matrix that is 0-by-0 at run time.
`min`	• See "Automatic dimension restriction" on page 35-31.
`mode`	• See "Automatic dimension restriction" on page 35-31. • An error occurs if you pass as the first argument a variable-size matrix that is 0-by-0 at run time.

Function	Restrictions with Variable-Size Data
`mtimes`	• When an input is variable sized, MATLAB determines whether to generate code for a general matrix*matrix multiplication or a scalar*matrix multiplication, based on whether one of the arguments is a fixed-size scalar. If neither argument is a fixed-size scalar, the inner dimensions of the two arguments must agree even if a variable-size matrix input happens to be a scalar at run time.
`nchoosek`	• Inputs must be fixed sized. • Second input must be a constant for static allocation.. • You cannot create a variable-size array by passing in a variable `k` .
`permute`	• Order input must be fixed size.
`planerot`	• Input must be a fixed-size, two-element column vector. It cannot be a variable-size array that takes on the size 2-by-1 at run time.
`poly`	• See “Variable-length vector restriction” on page 35-31.
`polyfit`	• For first and second arguments, see “Variable-length vector restriction” on page 35-31.
`prod`	• See “Automatic dimension restriction” on page 35-31. • An error occurs if you pass as the first argument a variable-size matrix that is 0-by-0 at run time.

Function	Restrictions with Variable-Size Data
`rand`	• For an upper-bounded variable `N`, `rand(1,N)` produces a variable-length vector of `1x:M` where `M` is the upper bound on `N`. • For an upper-bounded variable `N`, `rand([1,N])` may produce a variable-length vector of `:1x:M` where `M` is the upper bound on `N`.
`randn`	• For an upper-bounded variable `N`, `randn(1,N)` produces a variable-length vector of `1x:M` where `M` is the upper bound on `N`. • For an upper-bounded variable `N`, `randn([1,N])` may produce a variable-length vector of `:1x:M` where `M` is the upper bound on `N`.
`reshape`	• When the input is a variable-size empty array, the maximum dimension size of the output array (also empty) cannot be larger than that of the input.
`roots`	• See "Variable-length vector restriction" on page 35-31.
`shiftdim`	• If you do not supply the second argument, the number of shifts is determined at compilation time by the upper bounds of the dimension sizes. Consequently, at run time the number of shifts is always constant. • An error occurs if the dimension that is shifted to the first dimension has length 1 at run time. To avoid the error, supply the number of shifts as the second input argument (must be a constant).

Function	Restrictions with Variable-Size Data
	• First input argument must always have the same number of dimensions when you supply a positive number of shifts.
`std`	• See "Automatic dimension restriction" on page 35-31. • An error occurs if you pass a variable-size matrix with 0-by-0 dimensions at run time.
`sub2ind`	• First input (the size vector input) must be fixed size.
`sum`	• See "Automatic dimension restriction" on page 35-31. • An error occurs if you pass as the first argument a variable-size matrix that is 0-by-0 at run time.
`trapz`	• See "Automatic dimension restriction" on page 35-31. • An error occurs if you pass as the first argument a variable-size matrix that is 0-by-0 at run time.
`typecast`	• See "Variable-length vector restriction" on page 35-31 on first argument.
`var`	• See "Automatic dimension restriction" on page 35-31. • An error occurs if you pass a variable-size matrix with 0-by-0 dimensions at run time.

36

Code Generation for MATLAB Structures

Structure Definition for Code Generation

To generate efficient standalone code for structures, you must define and use structures differently than you normally would when running your code in the MATLAB environment:

What's Different	More Information
Use a restricted set of operations.	"Structure Operations Allowed for Code Generation" on page 36-3
Observe restrictions on properties and values of scalar structures.	"Define Scalar Structures for Code Generation" on page 36-4
Make structures uniform in arrays.	"Define Arrays of Structures for Code Generation" on page 36-7
Reference structure fields individually during indexing.	"Index Substructures and Fields" on page 29-83
Avoid type mismatch when assigning values to structures and fields.	"Assign Values to Structures and Fields" on page 29-86

Structure Operations Allowed for Code Generation

To generate efficient standalone code for MATLAB structures, you are restricted to the following operations:

- Define structures as local and persistent variables by assignment and using the `struct` function
- Index structure fields using dot notation
- Define primary function inputs as structures
- Pass structures to local functions

Define Scalar Structures for Code Generation

In this section...

Restrictions When Using `struct`

When you use the `struct` function to create scalar structures for code generation, the following restrictions apply:

- Field arguments must be scalar values.
- You cannot create structures of cell arrays.

Restrictions When Defining Scalar Structures by Assignment

When you define a scalar structure by assigning a variable to a preexisting structure, you do not need to define the variable before the assignment. However, if you already defined that variable, it must have the same class, size, and complexity as the structure you assign to it. In the following example, `p` is defined as a structure that has the same properties as the predefined structure `S`:

```
...
S = struct('a',  0, 'b',  1, 'c',  2);
p = S;
...
```

Adding Fields in Consistent Order on Each Control Flow Path

When you create a structure, you must add fields in the same order on each control flow path. For example, the following code generates a compiler

error because it adds the fields of structure `x` in a different order in each `if` statement clause:

```
function y = fcn(u) %#codegen
if u > 0
   x.a = 10;
   x.b = 20;
else
   x.b = 30;  % Generates an error (on variable x)
   x.a = 40;
end
y = x.a + x.b;
```

In this example, the assignment to `x.a` comes before `x.b` in the first `if` statement clause, but the assignments appear in reverse order in the `else` clause. Here is the corrected code:

```
function y = fcn(u) %#codegen
if u > 0
   x.a = 10;
   x.b = 20;
else
   x.a = 40;
   x.b = 30;
end
y = x.a + x.b;
```

Restriction on Adding New Fields After First Use

You cannot add fields to a structure after you perform any of the following operations on the structure:

- Reading from the structure
- Indexing into the structure array
- Passing the structure to a function

For example, consider this code:

```
...
x.c = 10; % Defines structure and creates field c
```

```
y = x; % Reads from structure
x.d = 20; % Generates an error
...
```

In this example, the attempt to add a new field `d` after reading from structure `x` generates an error.

This restriction extends across the structure hierarchy. For example, you cannot add a field to a structure after operating on one of its fields or nested structures, as in this example:

```
function y = fcn(u) %#codegen

x.c = 10;
y = x.c;
x.d = 20; % Generates an error
```

In this example, the attempt to add a new field `d` to structure `x` after reading from the structure's field `c` generates an error.

Define Arrays of Structures for Code Generation

In this section...

Ensuring Consistency of Fields

When you create an array of MATLAB structures with the intent of generating code, you must be sure that each structure field in the array has the same size, type, and complexity.

Using `repmat` to Define an Array of Structures with Consistent Field Properties

You can create an array of structures from a scalar structure by using the MATLAB `repmat` function, which replicates and tiles an existing scalar structure:

1. Create a scalar structure, as described in "Define Scalar Structures for Code Generation" on page 36-4.
2. Call `repmat`, passing the scalar structure and the dimensions of the array.
3. Assign values to each structure using standard array indexing and structure dot notation.

For example, the following code creates `X`, a 1-by-3 array of scalar structures. Each element of the array is defined by the structure `s`, which has two fields, `a` and `b`:

```
...
s.a = 0;
s.b = 0;
X = repmat(s,1,3);
X(1).a = 1;
```

```
X(2).a = 2;
X(3).a = 3;
X(1).b = 4;
X(2).b = 5;
X(3).b = 6;
...
```

Defining an Array of Structures Using Concatenation

To create a small array of structures, you can use the concatenation operator, square brackets (`[ ]`), to join one or more structures into an array (see "Concatenating Matrices"). For code generation, all the structures that you concatenate must have the same size, class, and complexity.

For example, the following code uses concatenation and a local function to create the elements of a 1-by-3 structure array:

```
...
W = [ sab(1,2) sab(2,3) sab(4,5) ];

function s = sab(a,b)
  s.a = a;
  s.b = b;
...
```

Make Structures Persistent

To make structures persist, you define them to be persistent variables and initialize them with the `isempty` statement, as described in "Define and Initialize Persistent Variables" on page 33-10.

For example, the following function defines structure `X` to be persistent and initializes its fields `a` and `b`:

```
function f(u)  %#codegen
persistent X

if isempty(X)
   X.a = 1;
   X.b = 2;
end
```

Index Substructures and Fields

Use these guidelines when indexing substructures and fields for code generation:

Reference substructure field values individually using dot notation

For example, the following MATLAB code uses dot notation to index fields and substructures:

```
...
substruct1.a1 = 15.2;
substruct1.a2 = int8([1 2;3 4]);

mystruct = struct('ele1',20.5,'ele2',single(100),
                  'ele3',substruct1);

substruct2 = mystruct;
substruct2.ele3.a2 = 2*(substruct1.a2);
...
```

The generated code indexes elements of the structures in this example by resolving symbols as follows:

Dot Notation	Symbol Resolution
`substruct1.a1`	Field `a1` of local structure `substruct1`
`substruct2.ele3.a1`	Value of field `a1` of field `ele3`, a substructure of local structure `substruct2`
`substruct2.ele3.a2(1,1)`	Value in row 1, column 1 of field `a2` of field `ele3`, a substructure of local structure `substruct2`

Reference field values individually in structure arrays

To reference the value of a field in a structure array, you must index into the array to the structure of interest and then reference that structure's field individually using dot notation, as in this example:

```
...
```

```
y = X(1).a % Extracts the value of field a
           % of the first structure in array X
...
```

To reference all the values of a particular field for each structure in an array, use this notation in a `for` loop, as in this example:

```
...
s.a = 0;
s.b = 0;
X = repmat(s,1,5);
for i = 1:5
    X(i).a = i;
    X(i).b = i+1;
end
```

This example uses the `repmat` function to define an array of structures, each with two fields `a` and `b` as defined by `s`. See "Define Arrays of Structures for Code Generation" on page 36-7 for more information.

Do not reference fields dynamically

You cannot reference fields in a structure by using dynamic names, which express the field as a variable expression that MATLAB evaluates at run time (see "Generate Field Names from Variables").

Assign Values to Structures and Fields

Use these guidelines when assigning values to a structure, substructure, or field for code generation:

Field properties must be consistent across structure-to-structure assignments

If:	Then:
Assigning one structure to another structure.	Define each structure with the same number, type, and size of fields.
Assigning one structure to a substructure of a different structure and vice versa.	Define the structure with the same number, type, and size of fields as the substructure.
Assigning an element of one structure to an element of another structure.	The elements must have the same type and size.

Do not use field values as constants

The values stored in the fields of a structure are not treated as constant values in generated code. Therefore, you cannot use field values to set the size or class of other data. For example, the following code generates a compiler error:

```
...
Y.a = 3;
X = zeros(Y.a); % Generates an error
```

In this example, even though you set field `a` of structure `Y` to the value 3, `Y.a` is not a constant in generated code and, therefore, it is not a valid argument to pass to the function `zeros`.

Do not assign mxArrays to structures

You cannot assign `mxArrays` to structure elements; convert `mxArrays` to known types before code generation (see “Working with mxArrays” on page 41-17).

Pass Large Structures as Input Parameters

If you generate a MEX function for a MATLAB function that takes a large structure as an input parameter, for example, a structure containing fields that are matrices, the MEX function might fail to load. This load failure occurs because, when you generate a MEX function from a MATLAB function that has input parameters, the code generation software allocates memory for these input parameters on the stack. To avoid this issue, pass the structure by reference to the MATLAB function. For example, if the original function signature is:

```
y = foo(a, S)
```

where `S` is the structure input, rewrite the function to:

```
[y, S] = foo(a, S)
```

37

Code Generation for Enumerated Data

Enumerated Data Definition for Code Generation

To generate efficient standalone code for enumerated data, you must define and use enumerated types differently than you normally would when running your code in the MATLAB environment:

What's Different	More Information
Supports integer-based enumerated types only	"Enumerated Types Supported in MATLAB Function Blocks" on page 29-105
Each enumerated data type must be defined in a separate file on the MATLAB path	"Define Enumerated Data Types for MATLAB Function Blocks" on page 29-106
Restricted set of operations	"Operations on Enumerated Data" on page 29-115
Restricted use in `for`-loops	"Restrictions on Use of Enumerated Data in `for`-Loops" on page 37-22

Enumerated Types Supported for Code Generation

Enumerated Type Based on Simulink.IntEnumType

This enumerated data type is based on the built-in type `Simulink.IntEnumType`, which is available with a Simulink license. Use this enumerated type when exchanging enumerated data with Simulink blocks and Stateflow charts.

Syntax

```
classdef(Enumeration) type_name < Simulink.IntEnumType
```

Example

```
classdef(Enumeration) myMode < Simulink.IntEnumType
  enumeration
    OFF(0)
    ON(1)
  end
end
```

How to Use

Here are the basic guidelines for using enumerated data based on `Simulink.IntEnumType`:

Application	What to Do
When exchanging enumerated data with Simulink blocks	Define enumerated data in MATLAB Function blocks in Simulink models. Requires Simulink software.
When exchanging enumerated data with Stateflow charts	Define enumerated data in MATLAB functions in Stateflow charts. Requires Simulink and Stateflow software.

See “About Simulink Enumerations” on page 44-2 for more information about enumerated types based on `Simulink.IntEnumType`

When to Use Enumerated Data for Code Generation

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, you get a compile-time error 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.

Generate Code for Enumerated Data from MATLAB Function Blocks

Step	Action	How?
1	Define an enumerated data type that inherits from `Simulink.IntEnumType`.	See "Define Enumerated Data Types for MATLAB Function Blocks" on page 29-106
2	Add the enumerated data to your MATLAB Function block.	See "Add Inputs, Outputs, and Parameters as Enumerated Data" on page 29-107
3	Instantiate the enumerated type in your MATLAB Function block.	See "Instantiate Enumerated Data in MATLAB Function Blocks" on page 29-110
4	Simulate and/or generate code.	See "Enumerations"

This workflow requires the following licenses:

- Simulink (for simulation)
- MATLAB Coder and Simulink Coder (for code generation)

Define Enumerated Data for Code Generation

Follow these steps to define enumerated data for code generation from MATLAB algorithms:

1. Create a class definition file.

   In the MATLAB Command Window, select **File > New > Class**.

2. Enter the class definition as follows:

   ```
   classdef(Enumeration) EnumTypeName < int32
   ```

   For example, the following code defines an enumerated type called `sysMode`:

   ```
   classdef(Enumeration) sysMode < int32
       ...
   end
   ```

   `EnumTypeName` is a case-sensitive string that must be unique among data type names and workspace variable names. It must inherit from the built-in type `int32`.

3. Define enumerated values in an `enumeration` section as follows:

   ```
   classdef(Enumeration) EnumTypeName < int32
     enumeration
       EnumName(N)
       ...
     end
   end
   ```

   For example, the following code defines a set of two values for enumerated type `sysMode`:

   ```
   classdef(Enumeration) sysMode < int32
       enumeration
            OFF(0)
            ON(1)
       end

   end
   ```

An enumerated type can define any number of values. Each enumerated value consists of a string *`EnumName`* and an underlying integer *`N`*. Each *`EnumName`* must be unique within its type, but can also appear in other enumerated types. The underlying integers need not be either consecutive or ordered, nor must they be unique within the type or across types.

4 Save the file on the MATLAB path.

The name of the file must match the name of the enumerated data type. The match is case sensitive.

To add a 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`.

For examples of enumerated data type definitions, see "Define Enumerated Data for Code Generation" on page 37-6.

Naming Enumerated Types for Code Generation

You must use a unique name for each enumerated data type. The name of an enumerated data type cannot match the name of a toolbox function supported for code generation, or another data type or a variable in the MATLAB base workspace. Otherwise, a name conflict occurs.

For example, you cannot name an enumerated data type `mode` because MATLAB for code generation provides a toolbox function of the same name.

For a list of toolbox functions supported for code generation, see "Functions Supported for Code Generation — Alphabetical List" on page 31-2.

Instantiate Enumerated Types for Code Generation

To instantiate an enumerated type for code generation from MATLAB algorithms, use dot notation to specify `ClassName.EnumName`. For an example, see "Include Enumerated Data in Control Flow Statements" on page 37-12.

Operations on Enumerated Data Allowed for Code Generation

To generate efficient standalone code for enumerated data, you are restricted to the following operations. The examples are based on the definitions of the enumeration type `LEDcolor` described in .

Assignment Operator, =

Example	Result

`xon = LEDcolor.GREEN`
`xoff = LEDcolor.RED`
	`xon =`
	
	`GREEN`
	`xoff =`
	
	`RED`

Relational Operators, < > <= >= == ~=

Example	Result

`xon == xoff`	`ans =`
	
	`0`

`xon <= xoff`	`ans =`
	
	`1`

`xon > xoff`	`ans =`
	
	`0`

Cast Operation

Example	Result

`double(LEDcolor.RED)`	`ans =`
	
	`2`

`z = 2`
`y = LEDcolor(z)`
	`z =`
	
	`2`
	
	`y =`
	
	`RED`

Indexing Operation

Example	Result

`m = [1 2]`
`n = LEDcolor(m)`
`p = n(LEDcolor.GREEN)`
	`m =`
	
	`1 2`
	
	`n =`
	
	`GREEN RED`
	
	`p =`
	
	`GREEN`

Control Flow Statements: if, switch, while

Statement	Example	Executable Example

`if`	`if state == sysMode.ON`
	`  led = LEDcolor.GREEN;`
	`else`
	`  led = LEDcolor.RED;`
	`end`
		"`if` Statement with Enumerated Data Types" on page 37-12

`switch`	`switch button`
	`  case VCRButton.Stop`
	`  state = VCRState.Stop;`
	`  case VCRButton.PlayOrPause`
	`  state = VCRState.Play;`
	`  case VCRButton.Next`
	`  state = VCRState.Forward;`
	`  case VCRButton.Previous`
	`  state = VCRState.Rewind;`
	`  otherwise`
	`  state = VCRState.Stop;`
	`end`
		"`switch` Statement with Enumerated Data Types" on page 37-13

`while`	`while state ~= State.Ready`
	`  switch state`
	`  case State.Standby`
	`  initialize();`
	`  state = State.Boot;`
	`  case State.Boot`
	`  boot();`
	`  state = State.Ready;`
	`  end`
	`end`
		"`while` Statement with Enumerated Data Types" on page 37-16

Include Enumerated Data in Control Flow Statements

The following control statements work with enumerated operands in generated code. However, there are restrictions (see "Restrictions on Use of Enumerated Data in `for`-Loops" on page 37-22).

`if` Statement with Enumerated Data Types

This example is based on the definition of the enumeration types `LEDcolor` and `sysMode`. The function `displayState` uses these enumerated data types to activate an LED display.

Class Definition: sysMode

```
classdef(Enumeration) sysMode < int32
  enumeration
    OFF(0)
    ON(1)
  end
end
```

This definition must reside on the MATLAB path in a file with the same name as the class, `sysMode.m`.

Class Definition: LEDcolor

```
classdef(Enumeration) LEDcolor < int32
    enumeration
        GREEN(1),
        RED(2),
    end
end
```

This definition must reside on the MATLAB path in a file called `LEDcolor.m`.

MATLAB Function: displayState

This function 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 = displayState(state)
%#codegen

if state == sysMode.ON
    led = LEDcolor.GREEN;
else
    led = LEDcolor.RED;
end
```

Build and Test a MEX Function for `displayState`

1. Generate a MEX function for `displayState`. Use the `-args` option to pass one of the allowable values for the enumerated data input as a sample value.

   ```
   codegen displayState -args {sysMode.ON}
   ```

2. Test the function. For example,

   ```
   displayState(sysMode.OFF)
   ```

   You should get the following result:

   ```
   ans =

       RED
   ```

`switch` Statement with Enumerated Data Types

This example is based on the definition of the enumeration types `VCRState` and `VCRButton`. The function `VCR` uses these enumerated data types to set the state of the VCR.

Class Definition: VCRState

```
classdef(Enumeration) VCRState < int32
    enumeration
        Stop(0),
        Pause(1),
        Play(2),
        Forward(3),
```

```
        Rewind(4)
    end
end
```

This definition must reside on the MATLAB path in a file with the same name as the class, `VCRState.m`.

Class Definition: VCRButton

```
classdef(Enumeration) VCRButton < int32
    enumeration
        Stop(1),
        PlayOrPause(2),
        Next(3),
        Previous(4)
    end
end
```

This definition must reside on the MATLAB path in a file with the same name as the class, `VCRButton.m`.

MATLAB Function: VCR

This function uses enumerated data to set the state of a VCR, based on the initial state of the VCR and the state of the VCR button.

```
function s = VCR(button)
%#codegen

persistent state

if isempty(state)
    state = VCRState.Stop;
end

switch state
    case {VCRState.Stop, VCRState.Forward, VCRState.Rewind}
        state = handleDefault(button);
    case VCRState.Play
        switch button
```

```
            case VCRButton.PlayOrPause, state = VCRState.Pause;
            otherwise, state = handleDefault(button);
        end
    case VCRState.Pause
        switch button
            case VCRButton.PlayOrPause, state = VCRState.Play;
            otherwise, state = handleDefault(button);
        end
end
s = state;

function state = handleDefault(button)
switch button
    case VCRButton.Stop, state = VCRState.Stop;
    case VCRButton.PlayOrPause, state = VCRState.Play;
    case VCRButton.Next, state = VCRState.Forward;
    case VCRButton.Previous, state = VCRState.Rewind;
    otherwise, state = VCRState.Stop;
end
```

Build and Test a MEX Function for `VCR`

1 Generate a MEX function for `VCR`. Use the `-args` option to pass one of the allowable values for the enumerated data input as a sample value.

```
codegen -args {VCRButton.Stop}  VCR
```

2 Test the function. For example,

```
s = VCR(VCRButton.Stop)
```

You should get the following result:

```
s =

    Stop
```

`while` Statement with Enumerated Data Types

This example is based on the definition of the enumeration type `State`. The function `Setup` uses this enumerated data type to set the state of a device.

Class Definition: State

```
classdef(Enumeration) State < int32
    enumeration
        Standby(0),
        Boot(1),
        Ready(2)
     end
end
```

This definition must reside on the MATLAB path in a file with the same name as the class, `State.m`.

MATLAB Function: Setup

The following function `Setup` uses enumerated data to set the state of a device.

```
function s = Setup(initState)
%#codegen

state = initState;

if isempty(state)
    state = State.Standby;
end

while state ~= State.Ready
    switch state
        case State.Standby
            initialize();
            state = State.Boot;
        case State.Boot
            boot();
            state = State.Ready;
    end
end
```

```
s = state;

function initialize()
% Perform initialization.

function boot()
% Boot the device.
```

Build and Test a MEX Executable for `Setup`

1. Generate a MEX executable for `Setup`. Use the `-args` option to pass one of the allowable values for the enumerated data input as a sample value.

   ```
   codegen Setup -args {State.Standby}
   ```

2. Test the function. For example,

   ```
   s = Setup(State.Standby)
   ```

   You should get the following result:

   ```
   s =

       Ready
   ```

Customize Enumerated Types Based on Simulink.IntEnumType

You can customize a Simulink enumerated type by using the same techniques that work with MATLAB classes, as described in Modifying Superclass Methods and Properties. For more information, see “Customize Simulink Enumeration” on page 44-4.

Control Names of Enumerated Type Values in Generated Code

This example shows how to control the name of enumerated type values in code generated by MATLAB Coder. (Requires a MATLAB Coder license.) The example uses the enumerated data type definitions and function `displayState` described in "Include Enumerated Data in Control Flow Statements" on page 37-12.

1. Generate a library for the function `displayState` that takes one input of enumerated data type `sysMode`.

   ```
   codegen -config:lib -report  displayState -args {sysMode.ON}
   ```

   `codegen` generates a C static library with the default name, `displayState`, and supporting files in the default folder, `codegen/lib/displayState`.

2. Click the *View Report* link.

3. In the report, on the **C Code** tab, click the link to the `displayState_types.h` file.

   The report displays the header file containing the enumerated data type definition.

   ```
   typedef enum LEDcolor
   {
     LEDcolor_GREEN = 1,
     LEDcolor_RED
   } LEDcolor;
   ```

   The enumerated value names include the class name prefix `LEDcolor_`.

4. Modify the definition of `LEDcolor` to override the `addClassNameToEnumNames` method. Set the return value to `false` instead of `true` so that the enumerated value names in the generated code do not contain the class prefix.

   ```
   classdef(Enumeration) LEDcolor < int32
       enumeration
           GREEN(1),
   ```

```
        RED(2),
    end

    methods(Static)
      function y=addClassNameToEnumNames()
        y=false;
      end
    end
end
```

5 Clear existing class instances:

```
clear classes
```

6 Generate code again.

```
codegen -config:lib -report  displayState -args {sysMode.ON}
```

7 Open the code generation report and look at the enumerated type definition in `displayState_types.h`.

```
typedef enum LEDcolor
{
  GREEN = 1,
  RED
} LEDcolor;
```

This time the enumerated value names do not include the class name prefix.

For more information, see:

- `codegen`
- "Include Enumerated Data in Control Flow Statements" on page 37-12 for a description of the example function `displayState` and its enumerated type definitions

Change and Reload Enumerated Data Types

You can change the definition of an enumerated data type 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 enumerated data type 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 the classes from the workspace by using the `clear classes` command. For more information, see `clear`.	• Clear MEX functions that are caching instances of the class.

Restrictions on Use of Enumerated Data in `for`-Loops

Do not use enumerated data as the loop counter variable in `for`-loops

To iterate over a range of enumerated data with consecutive values, you can cast the enumerated data to `int32` in the loop counter.

For example, suppose you define an enumerated type `ColorCodes` as follows:

```
classdef(Enumeration) ColorCodes < int32
    enumeration
        Red(1),
        Blue(2),
        Green(3)
        Yellow(4)
        Purple(5)
    end
end
```

Because the enumerated values are consecutive, you can use `ColorCodes` data in a `for`-loop like this:

```
...
for i = int32(ColorCodes.Red):int32(ColorCodes.Purple)
     c = ColorCodes(i);
     ...
end
```

Toolbox Functions That Support Enumerated Types for Code Generation

The following MATLAB toolbox functions support enumerated types for code generation:

- `cast`
- `cat`
- `circshift`
- `flipdim`
- `fliplr`
- `flipud`
- `histc`
- `ipermute`
- `isequal`
- `isequaln`
- `isfinite`
- `isinf`
- `isnan`
- `issorted`
- `length`
- `permute`
- `repmat`
- `reshape`
- `rot90`
- `shiftdim`
- `sort`
- `sortrows`

- `squeeze`

38

Code Generation for MATLAB Classes

MATLAB Classes Definition for Code Generation

To generate efficient standalone code for MATLAB classes, you must use classes differently than you normally would when running your code in the MATLAB environment.

What's Different	More Information
Class must be in a single file. Because of this limitation, there is no code generation support for a class definition that uses an `@`-folder.	"Creating a Single, Self-Contained Class Definition File"
Restricted set of language features.	"Language Limitations" on page 38-2
Restricted set of code generation features.	"Code Generation Features Not Compatible with Classes" on page 38-4
Definition of class properties.	"Defining Class Properties for Code Generation" on page 38-5
Use of handle classes.	"Generate Code for MATLAB Handle Classes and System Objects" on page 38-16
Calls to base class constructor.	"Calls to Base Class Constructor" on page 38-6

Language Limitations

Although code generation support is provided for common features of classes such as properties and methods, there are a number of advanced features which are not supported, such as:

- Events
- Listeners
- Arrays of objects
- Recursive data structures
  - Linked lists

  - Trees
  - Graphs
- Overloadable operators `subsref`, `subsassign`, and `subsindex`

  In MATLAB, classes can define their own versions of the `subsref`, `subsassign`, and `subsindex` methods. Code generation does not support classes that have their own definitions of these methods.
- The `empty` method

  In MATLAB, all classes have a built-in static method, `empty`, which creates an empty array of the class. Code generation does not support this method.
- The following MATLAB handle class methods:
  - `addlistener`
  - `delete`
  - `eq`
  - `findobj`
  - `findprop`
  - `ge`
  - `gt`
  - `isvalid`
  - `le`
  - `lt`
  - `ne`
  - `notify`
- Diamond inheritance. If classes `B` and `C` both inherit from the same class and class `D` inherits from both class `B` and `C`, you cannot generate code for class `D`.

Code Generation Features Not Compatible with Classes

- You can generate code for entry-point MATLAB functions that use classes, but you cannot generate code directly for a MATLAB class.

  For example, if `ClassNameA` is a class definition, you cannot generate code by executing:

  ```
  codegen ClassNameA
  ```

- If an entry-point MATLAB function has an input or output that is a MATLAB class, you cannot generate code for this function.

  For example, if function `foo` takes one input, `a`, that is a MATLAB object, you cannot generate code for `foo` by executing:

  ```
  codegen foo -args {a}
  ```

- You cannot generate code for a value class that has a `set.prop` method. For example, you cannot generate code for the following `Square` class because of the `set.side` method.

  ```
  classdef Square < Shape  %#codegen
      properties
          side;
      end
      methods
          function obj = Square(side)
              obj = obj@Shape(side^2);
              obj.side = side;
          end
          function set.side(obj,value)
              obj.side = value;
              obj.area = value^2;
          end
      end
  end
  ```

  To generate code for this class, modify the class definition to remove the `set.side` method.

- You cannot use to declare a class or method as extrinsic.
- You cannot pass a MATLAB class to the function.
- If you use classes in code in the MATLAB Function block, you cannot use the debugger to view class information.

Defining Class Properties for Code Generation

For code generation, you must define class properties differently than you normally would when running your code in the MATLAB environment:

- If a class has a property of handle type, set the property in the class constructor. For System objects, you can also use the `setupImpl` method.
- After defining a property, do not assign it an incompatible type. Do not use a property before attempting to grow it.

  When you define class properties for code generation, consider the same factors that you take into account when defining variables. In the MATLAB language, variables can change their class, size, or complexity dynamically at run time so you can use the same variable to hold a value of any class, size, or complexity. C and C++ use static typing. Before using variables, to determine their type, the code generation software requires a complete assignment to each variable. Similarly, before using any properties, you must explicitly define the class, size, and complexity of all properties.
- Initial values:
  - If the property has no explicit initial value, the code generation software assumes that it is undefined at the beginning of the constructor. The code generation software does not assign an empty matrix as the default.
  - If the property has no initial value and the code generation software cannot determine that the property is assigned on all paths prior to first use, the software generates a compilation error.
  - For System objects, if a nontunable property is a structure, you must completely assign the structure. You cannot do partial assignment using subscripting.

    For example, for a nontunable property, you can use the following assignment:

    ```
    mySystemObject.nonTunableProperty=struct('fieldA','a','fieldB','b');
    ```

You cannot use the following partial assignments:

```
mySystemObject.nonTunableProperty.fieldA = a;
mySystemObject.nonTunableProperty.fieldB = b;
```

  - If dynamic memory allocation is enabled, code generation supports variable-size properties for handle classes. Without dynamic memory allocation, you cannot generate code for handle classes that have variable-size properties.
  - `coder.varsize` is not supported for any class properties.
- MATLAB computes class initial values at class loading time before code generation. If you use persistent variables in MATLAB class property initialization, the value of the persistent variable computed when the class loads belongs to MATLAB; it is not the value used at code generation time. If you use `coder.target` in MATLAB class property initialization, `coder.target` is always `''`.

Calls to Base Class Constructor

If a class constructor contains a call to the constructor of the base class, the call to the base class constructor must be before any `for`, `if`, `return`, `switch` or `while` statements.

For example, if you define a class `B` based on class `A`:

```
classdef B < A
    methods
        function obj = B(varargin)
            if nargin == 0
                a = 1;
                b = 2;
            elseif nargin == 1
                a = varargin{1};
                b = 1;
            elseif nargin == 2
                a = varargin{1};
                b = varargin{2};
            end
            obj = obj@A(a,b);
```

```
        end

    end
end
```

Because the class definition for `B` uses an `if` statement before calling the base class constructor for `A`, you cannot generate code for function `callB`:

```
function [y1,y2] = callB
x = B;
y1 = x.p1;
y2 = x.p2;
end
```

However, you can generate code for `callB` if you define class `B` as:

```
classdef B < A
    methods
        function obj = NewB(varargin)
            [a,b] = getaandb(varargin{:});
            obj = obj@A(a,b);
        end

    end
end

function [a,b] = getaandb(varargin)
if nargin == 0
    a = 1;
    b = 2;
elseif nargin == 1
    a = varargin{1};
    b = 1;
elseif nargin == 2
    a = varargin{1};
    b = varargin{2};
end
end
```

Classes That Support Code Generation

You can generate code for MATLAB value and handle classes and user-defined System objects. Your class can have multiple methods and properties and can inherit from multiple classes.

To generate code for:	Example:
Value classes	"Generate Code for MATLAB Value Classes" on page 38-10
Handle classes including user-defined System objects	"Generate Code for MATLAB Handle Classes and System Objects" on page 38-16

For more information, see:

- "Classes in the MATLAB Language"
- "MATLAB Classes Definition for Code Generation" on page 38-2

Memory Allocation Requirements

When you create a handle object, you must assign the object to a persistent variable or to a property of another MATLAB object that must also be a persistent variable. The assignment must be in an `if-isempty` clause. After assignment, you can copy the object to a local variable, pass it to or return it from another function. For more information, see “Generate Code for MATLAB Handle Classes and System Objects” on page 38-16.

Generate Code for MATLAB Value Classes

This example shows how to generate code for a MATLAB value class and then view the generated code in the code generation report.

1 In a writable folder, create a MATLAB value class, `Shape`. Save the code as `Shape.m`.

```
classdef Shape
% SHAPE Create a shape at coordinates
% centerX and centerY
    properties
        centerX;
        centerY;
    end
    properties (Dependent = true)
        area;
    end
    methods
        function out = get.area(obj)
            out =  obj.getarea();
        end
        function obj = Shape(centerX,centerY)
            obj.centerX = centerX;
            obj.centerY = centerY;
        end
    end
    methods(Abstract = true)
        getarea(obj);
    end
    methods(Static)
        function d = distanceBetweenShapes(shape1,shape2)
            xDist = abs(shape1.centerX - shape2.centerX);
            yDist = abs(shape1.centerY - shape2.centerY);
            d = sqrt(xDist^2 + yDist^2);
        end
    end
end
```

2 In the same folder, create a class, `Square`, that is a subclass of `Shape`. Save the code as `Square.m`.

```
classdef Square < Shape
% Create a Square at coordinates center X and center Y
% with sides of length of side
    properties
        side;
    end
    methods
        function obj = Square(side,centerX,centerY)
            obj@Shape(centerX,centerY);
            obj.side = side;
        end
        function Area = getarea(obj)
            Area = obj.side^2;
        end
    end
end
```

3 In the same folder, create a class, `Rhombus`, that is a subclass of `Shape`. Save the code as `Rhombus.m`.

```
classdef Rhombus < Shape
    properties
        diag1;
        diag2;
    end
    methods
        function obj = Rhombus(diag1,diag2,centerX,centerY)
            obj@Shape(centerX,centerY);
            obj.diag1 = diag1;
            obj.diag2 = diag2;
        end
        function Area = getarea(obj)
            Area = 0.5*obj.diag1*obj.diag2;
        end
    end
end
```

4 Write a function that uses this class.

```
function [TotalArea, Distance] =   use_shape
%#codegen
s = Square(2,1,2);
r = Rhombus(3,4,7,10);
TotalArea  = s.area + r.area;
Distance = Shape.distanceBetweenShapes(s,r);
```

5. Generate a static library for `use_shape` and generate a code generation report.

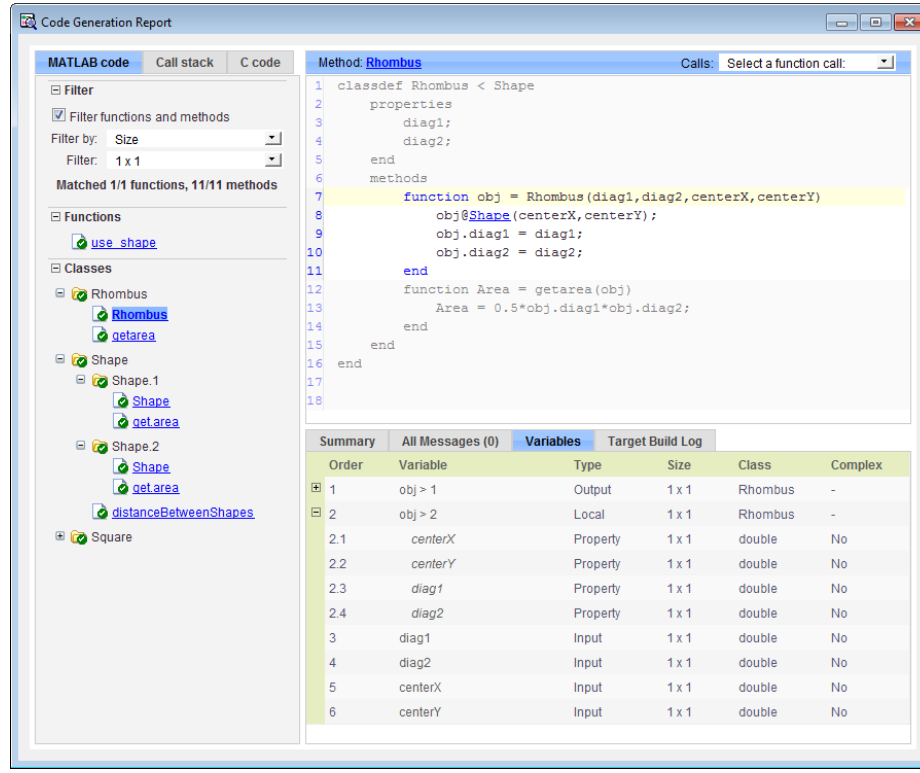
   ```
   codegen -config:lib -report use_shape
   ```

   `codegen` generates a C static library with the default name, `use_shape`, and supporting files in the default folder, `codegen/lib/use_shape`.

6. Click the *View report* link.

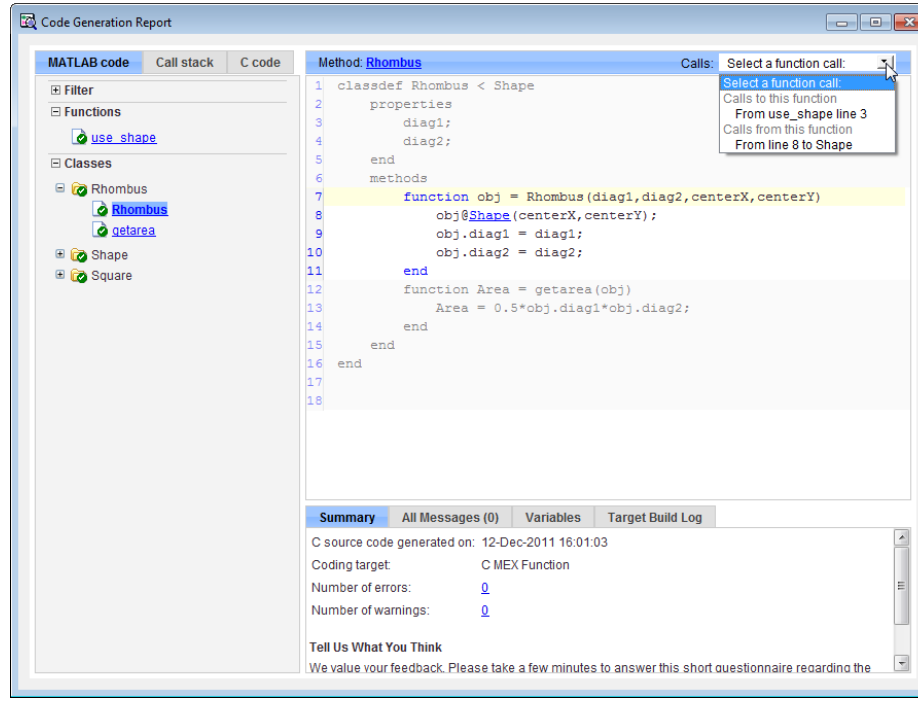
7. In the report, on the **MATLAB code** tab, click the link to the `Rhombus` class.

   The report displays the class definition of the `Rhombus` class and highlights the class constructor. On the **Variables** tab, it provides details of all the variables used in the class. If a variable is a MATLAB object, by default, the report displays the object without displaying its properties, as shown for `obj>1`. To view the complete list of properties, expand the list as shown for `obj>2`.

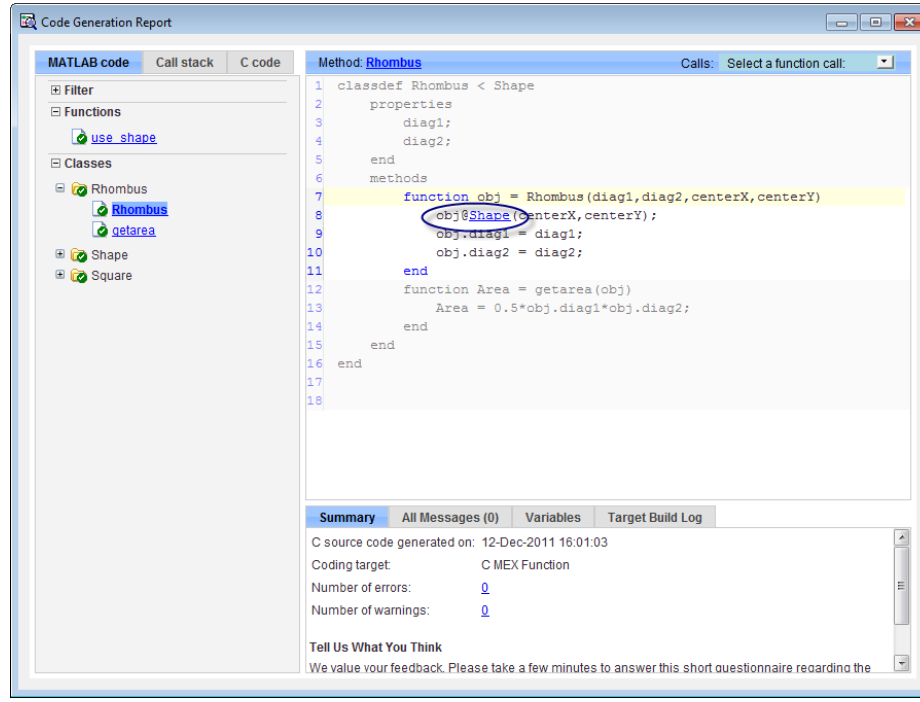


8 At the top right side of the report, expand the **Calls** list.

The **Calls** list shows that there is a call to the `Rhombus` constructor from `use_shape` and that this constructor calls the `Shape` constructor.



9 The constructor for the `Rhombus` class calls the `Shape` method of the base `Shape` class: `obj@Shape`. In the report, click the `Shape` link in this call.



The link takes you to the `Shape` method in the `Shape` class definition.

Generate Code for MATLAB Handle Classes and System Objects

This example shows how to generate code for a user-defined System object and then view the generated code in the code generation report. When you create a System or handle object, you must assign the object to a persistent variable or to a property of another MATLAB object that must also be a persistent variable. The assignment must be in an `if-isempty` clause. After assignment, you can copy the object to a local variable, pass it to or return it from another function.

1. In a writable folder, create a System object, `AddOne`, which subclasses from `matlab.System`. Save the code as `AddOne.m`.

```
classdef AddOne < matlab.System
% ADDONE Compute an output value that increments the input by one

  methods (Access=protected)
    % stepImpl method is called by the step method
    function y = stepImpl(~,x)
      y = x+1;
    end
  end
end
```

2. Write a function that uses this System object.

```
function y = testAddOne(x)
%#codegen
  persistent p;
  if isempty(p)
    p = AddOne();
  end
  y = p.step(x);
end
```

   For code generation, you must immediately assign a System object to a persistent variable in an `if isempty` clause as in this example.

3. Generate a MEX function for this code.

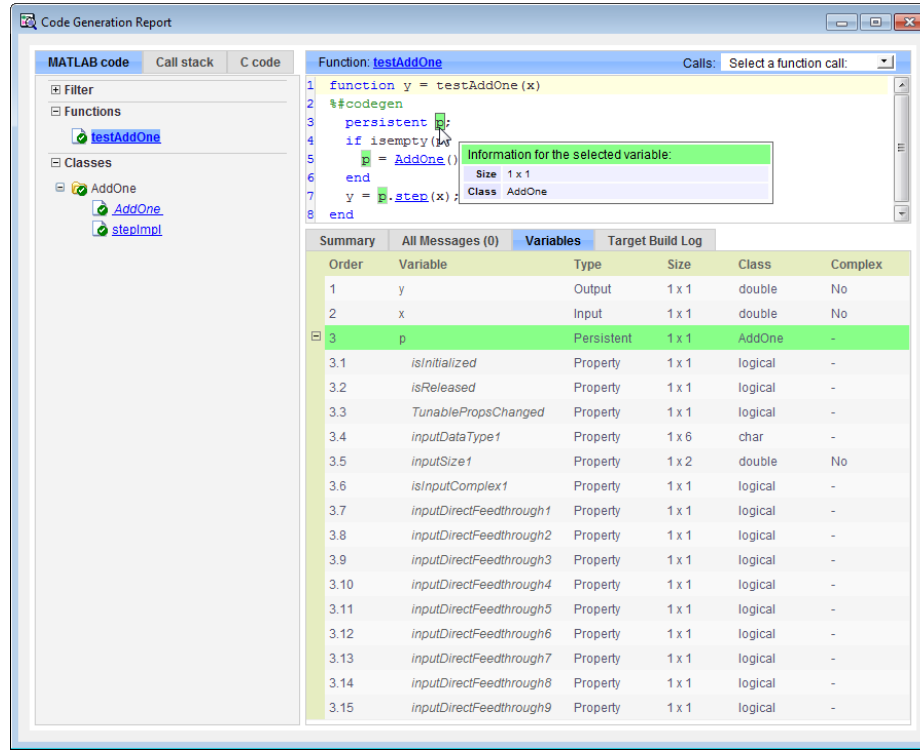
```
codegen -report testAddOne -args {0}
```

The `-report` option instructs `codegen` to generate a code generation report, even if no errors or warnings occur. The `-args` option specifies that the `testAddOne` function takes one scalar double input.

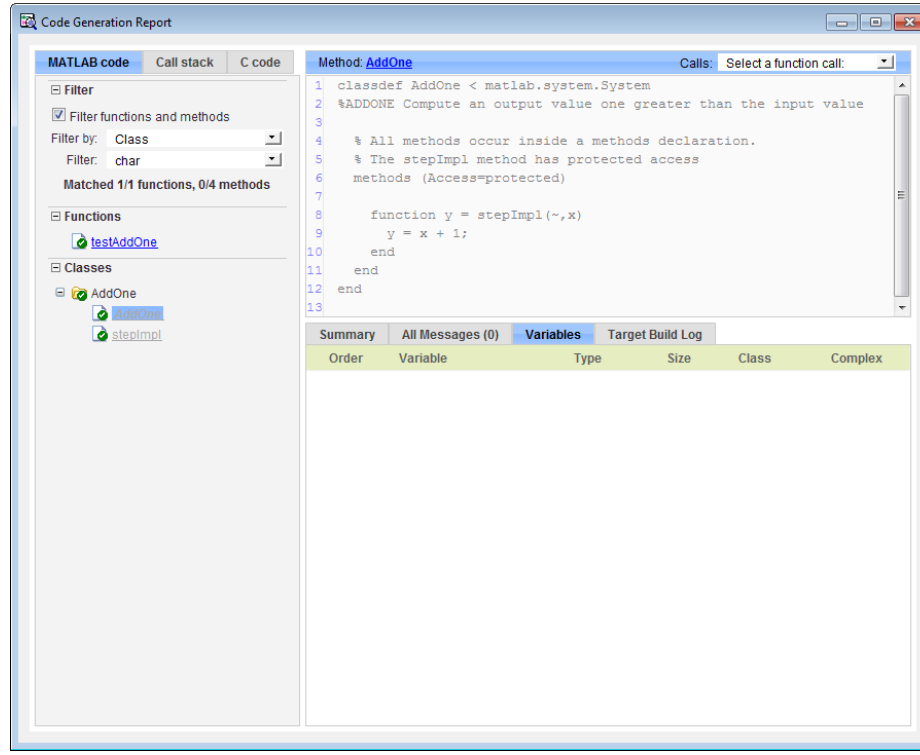
```
>> codegen -report testAddOne -args {0}
Code generation successful: View report
```

4 Click the *View report* link.

5 In the report, on the **MATLAB Code** tab **Functions** panel, click `testAddOne`, then click the **Variables** tab. You can view information about the variable `p` on this tab.



6 To view the class definition, on the **Classes** panel, click `AddOne`.


Code Generation Report
MATLAB code
Call stack
C code
Filter
Filter functions and methods
Filter by: Class
Filter: char
Matched 1/1 functions, 0/4 methods
Functions
testAddOne
Classes
AddOne
AddOne
stepImpl
Method: AddOne
Calls: Select a function call:
1 classdef AddOne < matlab.system.System
2 %ADDONE Compute an output value one greater than the input value
3
4 % All methods occur inside a methods declaration.
5 % The stepImpl method has protected access
6 methods (Access=protected)
7
8 function y = stepImpl(~,x)
9 y = x + 1;
10 end
11 end
12 end
13
Summary
All Messages (0)
Variables
Target Build Log
Order
Variable
Type
Size
Class
Complex

MATLAB Classes in Code Generation Reports

What Reports Tell You About Classes

Code generation reports:

- Provide a hierarchical tree of the classes used in your MATLAB code.
- Display a list of methods for each class in the MATLAB code tab.
- Display the objects used in your MATLAB code together with their properties on the **Variables** tab.
- Provide a filter so that you can sort methods by class, size, and complexity.
- List the set of calls from and to the selected method in the **Calls** list.

How Classes Appear in Code Generation Reports

In the MATLAB Code Tab

The report displays an alphabetical hierarchical list of the classes used in the your MATLAB code. For each class, you can:

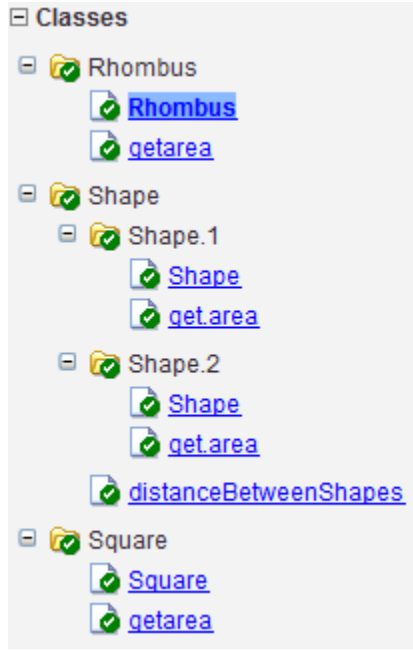
- Expand the class information to view the class methods.
- View a class method by clicking its name. The report displays the methods in the context of the full class definition.
- Filter the methods by size, complexity, and class by using the **Filter functions and methods** option.

Default Constructors. If a class has a default constructor, the report displays the constructor in italics.

Specializations. If the same class is specialized into multiple different classes, the report differentiates the specializations by grouping each one under a single node in the tree. The report associates the class definition functions and static methods with the primary node. It associates the instance-specific methods with the corresponding specialized node.

For example, consider a base class, `Shape` that has two specialized subclasses, `Rhombus` and `Square`. The `Shape` class has an abstract method, `getarea`,

and a static method, `distanceBetweenShapes`. The code generation report, displays a node for the specialized `Rhombus` and `Square` classes with their constructors and `getarea` method. It displays a node for the Shape class and its associated static method, `distanceBetweenShapes`, and two instances of the `Shape` class, `Shape1` and `Shape2`.



Packages. If you define classes as part of a package, the report displays the package in the list of classes. You can expand the package to view the classes that it contains. For more information about packages, see "Packages Create Namespaces".

In the Variables Tab

The report displays all the objects in the selected function or class. By default, for classes that have properties, the list of properties is collapsed. Click the + symbol next to the object name to open the list.

The report displays the properties using just the base property name, not the fully qualified name. For example, if your code uses variable `obj1` that is a

MATLAB object with property `prop1`, then the report displays the property as `prop1` not `obj1.prop1`. When you sort the **Variables** column, the sort order is based on the fully qualified property name.

In the Call Stack

The call stack lists the functions and methods in the order that the top-level function calls them. It also lists the local functions that each function calls.

How to Generate a Code Generation Report

Add the `-report` option to your `codegen` command (requires a MATLAB Coder license)

Troubleshooting Issues with MATLAB Classes

Class *`class`* does not have a property with name *`name`*

If a MATLAB class has a method, `mymethod`, that returns a handle class with a property, `myprop`, you cannot generate code for the following type of assignment:

```
obj.mymethod().myprop=...
```

For example, consider the following classes:

```
classdef MyClass < handle
  properties
    myprop
  end
  methods
    function this = MyClass
      this.myprop = MyClass2;
    end
    function y = mymethod(this)
      y = this.myprop;
    end
  end
end

classdef MyClass2 < handle
  properties
    aa
  end
end
```

You cannot generate code for function `foo`.

```
function foo

persistent h
if isempty(h)
  h = MyClass;
end
```

```
h.mymethod().aa = 12;
```

In this function, `h.mymethod()` returns a handle object of type `MyClass2`. In MATLAB, the assignment `h.mymethod().aa = 12;` changes the property of that object. Code generation does not support this assignment.

Workaround

Rewrite the code to return the object and then assign a value to a property of the object.

```
function foo

persistent h
if isempty(h)
  h = MyClass;
end

b=h.mymethod();
b.aa=12;
```

39

Code Generation for Function Handles

Function Handles Definition for Code Generation

You can use function handles to invoke functions indirectly and parameterize operations that you repeat frequently. You can perform the following operations with function handles:

- Define handles that reference user-defined functions and built-in functions supported for code generation (see "Functions Supported for Code Generation — Alphabetical List" on page 31-2)

  Note You cannot define handles that reference extrinsic MATLAB functions.

- Define function handles as scalar values
- Pass function handles as arguments to other functions (excluding extrinsic functions)

To generate efficient standalone code for enumerated data, you are restricted to using a subset of the operations you can perform with function handles in MATLAB, as described in "Function Handle Limitations for Code Generation" on page 39-5

Define and Pass Function Handles for Code Generation

The following code example shows how to define and call function handles for code generation. You can copy the example to a MATLAB Function block in Simulink or MATLAB function in Stateflow. To convert this function to a MEX function using `codegen`, uncomment the two calls to the `assert` function, highlighted below:

```
function addval(m)
%#codegen

  % Define class and size of primary input m
  % Uncomment next two lines to build MEX function with codegen
  % assert(isa(m,'double'));
  % assert(all (size(m) == [3 3]));

  % Pass function handle to addone
  %  to add one to each element of m
  m = map(@addone, m);
  disp(m);

  % Pass function handle to addtwo
  %  to add two to each element of m
  m = map(@addtwo, m);
  disp(m);

  function y = map(f,m)
    y = m;
    for i = 1:numel(y)
       y(i) = f(y(i));
    end

  function y = addone(u)
  y = u + 1;

  function y = addtwo(u)
  y = u + 2;
```

This code passes function handles `@addone` and `@addtwo` to the function `map` which increments each element of the matrix `m` by the amount prescribed

by the referenced function. Note that `map` stores the function handle in the input variable `f` and then uses `f` to invoke the function — in this case `addone` first and then `addtwo`.

If you have MATLAB Coder, you can use the function `codegen` to convert the function `addval` to a MEX executable that you can run in MATLAB. Follow these steps:

1. At the MATLAB command prompt, issue this command:

   ```
   codegen addval
   ```

2. Define and initialize a 3-by-3 matrix by typing a command like this at the MATLAB prompt:

   ```
   m = zeros(3)
   ```

3. Execute the function by typing this command:

   ```
   addval(m)
   ```

   You should see the following result:

   ```
   0     0     0
   0     0     0
   0     0     0

   1     1     1
   1     1     1
   1     1     1

   3     3     3
   3     3     3
   3     3     3
   ```

For more information, see “MEX Function Generation at the Command Line”.

Function Handle Limitations for Code Generation

Function handles must be scalar values.

You cannot store function handles in matrices or structures.

You cannot use the same bound variable to reference different function handles.

After you bind a variable to a specific function, you cannot use the same variable to reference two different function handles, as in this example

```
%Incorrect code
...
x = @plus;
x = @minus;
...
```

This code produces a compilation error.

You cannot pass function handles to or from extrinsic functions.

You cannot pass function handles to or from `feval` and other extrinsic MATLAB functions. For more information, see “Declaring MATLAB Functions as Extrinsic Functions” on page 41-12

You cannot pass function handles to or from primary functions.

You cannot pass function handles as inputs to or outputs from primary functions. For example, consider this function:

```
function x = plotFcn(fhandle, data)

assert(isa(fhandle,'function_handle') && isa(data,'double'));

plot(data, fhandle(data));
x = fhandle(data);
```

In this example, the function `plotFcn` receives a function handle and its data as primary inputs. `plotFcn` attempts to call the function referenced by

the `fhandle` with the input `data` and plot the results. However, this code generates a compilation error, indicating that the function `isa` does not recognize `'function_handle'` as a class name when called inside a MATLAB function to specify properties of primary inputs.

You cannot view function handles from the debugger

You cannot display or watch function handles from the debugger. They appear as empty matrices.

40

Defining Functions for Code Generation

Specify Variable Numbers of Arguments

You can use `varargin` and `varargout` for passing and returning variable numbers of parameters to MATLAB functions called from a top-level function.

Common applications of `varargin` and `varargout` for code generation are to:

- "Apply Operations to a Variable Number of Arguments" on page 40-4
- "Implement Wrapper Functions" on page 40-7
- "Pass Property/Value Pairs" on page 40-8

Code generation relies on loop unrolling to produce simple and efficient code for `varargin` and `varargout`. This technique permits most common uses of `varargin` and `varargout`, but not all (see "Variable Length Argument Lists for Code Generation" on page 40-10). This following sections explain how to code effectively using these constructs.

For more information about using `varargin` and `varargout` in MATLAB functions, see Passing Variable Numbers of Arguments.

Supported Index Expressions

In MATLAB, `varargin` and `varargout` are cell arrays. Generated code does not support cell arrays, but does allow you to use the most common syntax — curly braces `{}` — for indexing into `varargin` and `varargout` arrays, as in this example:

```
%#codegen
function [x,y,z] = fcn(a,b,c)
[x,y,z] = subfcn(a,b,c);

function varargout = subfcn(varargin)
for i = 1:length(varargin)
   varargout{i} = varargin{i};
end
```

You can use the following index expressions. The *exp* arguments must be constant expressions or depend on a loop index variable.

Expression		Description
`varargin` *(read only)*	`varargin{`*exp*`}`	Read the value of element *exp*
	`varargin{`*exp1*`:` *exp2*`}`	Read the values of elements *exp1* through *exp2*
	`varargin{:}`	Read the values of all elements
`varargout` *(read and write)*	`varargout{`*exp*`}`	Read or write the value of element *exp*

Note The use of `()` is not supported for indexing into `varargin` and `varargout` arrays.

Apply Operations to a Variable Number of Arguments

You can use `varargin` and `varargout` in `for`-loops to apply operations to a variable number of arguments. To index into `varargin` and `varargout` arrays in generated code, the value of the loop index variable must be known at compile time. Therefore, during code generation, the compiler attempts to automatically unroll these `for`-loops. Unrolling eliminates the loop logic by creating a separate copy of the loop body in the generated code for each iteration. Within each iteration, the loop index variable becomes a constant. For example, the following function automatically unrolls its `for`-loop in the generated code:

```
%#codegen
function [cmlen,cmwth,cmhgt] = conv_2_metric(inlen,inwth,inhgt)

[cmlen,cmwth,cmhgt] = inch_2_cm(inlen,inwth,inhgt);

function varargout = inch_2_cm(varargin)
for i = 1:length(varargin)
   varargout{i} = varargin{i} * 2.54;
end
```

When to Force Loop Unrolling

To automatically unroll `for`-loops containing `varargin` and `varargout` expressions, the relationship between the loop index expression and the index variable must be determined at compile time.

In the following example, the function `fcn` cannot detect a logical relationship between the index expression `j` and the index variable `i`:

```
%#codegen
function [x,y,z] = fcn(a,b,c)

[x,y,z] = subfcn(a,b,c);

function varargout = subfcn(varargin)
j = 0;
for i = 1:length(varargin)
    j = j+1;
    varargout{j} = varargin{j};
```

```
end
```

As a result, the function does not unroll the loop and generates a compilation error:

```
Nonconstant expression or empty matrix.
This expression must be constant because
its value determines the size or class of some expression.
```

To fix the problem, you can force loop unrolling by wrapping the loop header in the function `coder.unroll`, as follows:

```
%#codegen
function [x,y,z] = fcn(a,b,c)
  [x,y,z] = subfcn(a,b,c);

function varargout = subfcn(varargin)
  j = 0;
  for i = coder.unroll(1:length(varargin))
      j = j + 1;
      varargout{j} = varargin{j};
  end;
```

Using Variable Numbers of Arguments in a for-Loop

The following example multiplies a variable number of input dimensions in inches by 2.54 to convert them to centimeters:

```
%#codegen
function [cmlen,cmwth,cmhgt] = conv_2_metric(inlen,inwth,inhgt)

[cmlen,cmwth,cmhgt] = inch_2_cm(inlen,inwth,inhgt);

function varargout = inch_2_cm(varargin)
for i = 1:length(varargin)
   varargout{i} = varargin{i} * 2.54;
end
```

Key Points About the Example

- `varargin` and `varargout` appear in the local function `inch_2_cm`, not in the top-level function `conv_2_metric`.
- The index into `varargin` and `varargout` is a for-loop variable

For more information, see "Variable Length Argument Lists for Code Generation" on page 40-10.

Implement Wrapper Functions

You can use `varargin` and `varargout` to write wrapper functions that accept any number of inputs and pass them directly to another function.

Passing Variable Numbers of Arguments from One Function to Another

The following example passes a variable number of inputs to different optimization functions, based on a specified input method:

```
%#codegen
function answer = fcn(method,a,b,c)
answer = optimize(method,a,b,c);

function answer = optimize(method,varargin)
  if strcmp(method,'simple')
    answer = simple_optimization(varargin{:});
  else
    answer = complex_optimization(varargin{:});
  end
...
```

Key Points About the Example

- You can use `{:}` to read all elements of `varargin` and pass them to another function.
- You can mix variable and fixed numbers of arguments.

For more information, see “Variable Length Argument Lists for Code Generation” on page 40-10.

Pass Property/Value Pairs

You can use `varargin` to pass property/value pairs in functions. However, for code generation, you must take precautions to avoid type mismatch errors when evaluating `varargin` array elements in a `for`-loop:

If	Do This:
You assign `varargin` array elements to local variables in the for-loop	Verify that for all pairs, the size, type, and complexity are the same for each property and the same for each value
Properties or values have different sizes, types, or complexity	Do not assign `varargin` array elements to local variables in a for-loop; reference the elements directly

For example, in the following function `test1`, the sizes of the property strings and numeric values are not the same in each pair:

```
%#codegen
function test1
    v = create_value('size', 18, 'rgb', [240 9 44]);
end

function v = create_value(varargin)
    v = new_value();
    for i = 1 : 2 : length(varargin)
        name = varargin{i};
        value = varargin{i+1};
        switch name
            case 'size'
                v = set_size(v, value);
            case 'rgb'
                v = set_color(v, value);
            otherwise
        end
    end
end
```

```
...
```

Generated code determines the size, type, and complexity of a local variable based on its first assignment. In this example, the first assignments occur in the first iteration of the for-loop:

- Defines local variable `name` with size equal to 4
- Defines local variable `value` with a size of scalar

However, in the second iteration, the size of the property string changes to 3 and the size of the numeric value changes to a vector, resulting in a type mismatch error. To avoid such errors, reference `varargin` array values directly, not through local variables, as highlighted in this code:

```
%#codegen
function test1
    v = create_value('size', 18, 'rgb', [240 9 44]);
end

function v = create_value(varargin)
    v = new_value();
    for i = 1 : 2 : length(varargin)
            switch varargin{i}
            case 'size'
                v = set_size(v, varargin{i+1});
            case 'rgb'
                v = set_color(v, varargin{i+1});
            otherwise
        end
    end
end
...
```

Variable Length Argument Lists for Code Generation

Do not use varargin or varargout in top-level functions

You **cannot** use `varargin` or `varargout` as arguments to top-level functions. A *top-level function* is:

- The function called by Simulink in a MATLAB Function block or by Stateflow in a MATLAB function.
- The function that you provide on the command line to `codegen`

For example, the following code generates compilation errors:

```
%#codegen
function varargout = inch_2_cm(varargin)
for i = 1:length(varargin)
   varargout{i} = varargin{i} * 2.54;
end
```

To fix the problem, write a top-level function that specifies a fixed number of inputs and outputs and then call `inch_2_cm` as an external function or local function, as in this example:

```
%#codegen
function [cmL, cmW, cmH] = conv_2_metric(inL, inW, inH)
[cmL, cmW, cmH] = inch_2_cm(inL, inW, inH);

function varargout = inch_2_cm(varargin)
for i = 1:length(varargin)
   varargout{i} = varargin{i} * 2.54;
end
```

Use curly braces {} to index into the argument list

For code generation, you can use curly braces `{}`, but not parentheses `()`, to index into `varargin` and `varargout` arrays. For more information, see "Supported Index Expressions" on page 40-3.

Verify that indices can be computed at compile time

If you use an expression to index into `varargin` or `varargout`, make sure that the value of the expression can be computed at compile time. For examples, see "Apply Operations to a Variable Number of Arguments" on page 40-4.

Do not write to varargin

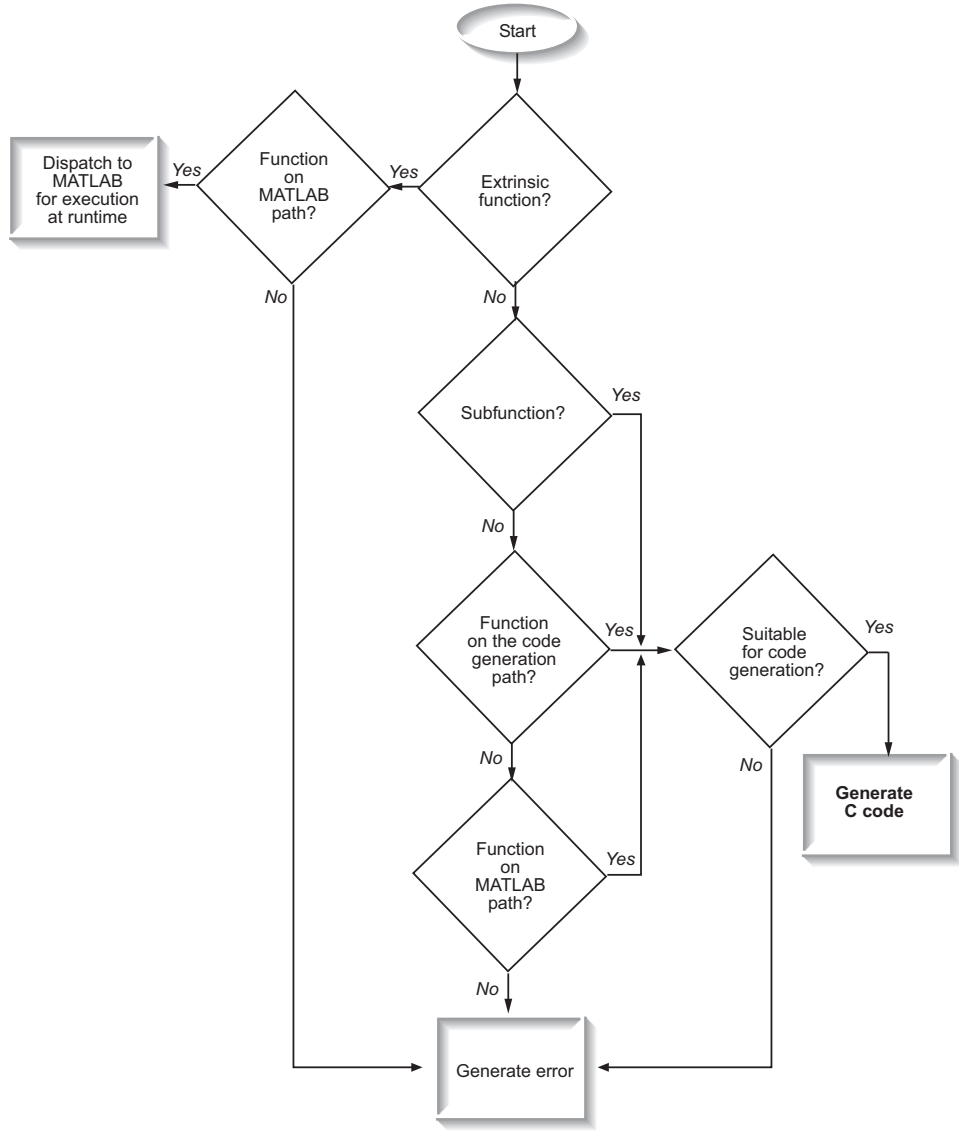
Generated code treats `varargin` as a read-only variable. If you want to write to any of the input arguments, copy the values into a local variable.

41

Calling Functions for Code Generation

Resolution of Function Calls in MATLAB Generated Code

From a MATLAB function, you can call local functions, supported toolbox functions, and other MATLAB functions. MATLAB resolves function names for code generation as follows:


Start
Extrinsic function?
Yes
Function on MATLAB path?
Yes
Dispatch to MATLAB for execution at runtime
No
No
Subfunction?
Yes
No
Function on the code generation path?
Yes
Suitable for code generation?
Yes
No
Generate C code
No
Function on MATLAB path?
Yes
No
Generate error

Key Points About Resolving Function Calls

The diagram illustrates key points about how MATLAB resolves function calls for code generation:

- Searches two paths, the code generation path and the MATLAB path

  See "Compile Path Search Order" on page 41-4.

- Attempts to compile all functions unless the code generation software determines that it should not compile them or you explicitly declare them to be extrinsic.

  An extrinsic function is a function on the MATLAB path that the compiler dispatches to MATLAB software for execution because the target language does not support the function. MATLAB does not generate code for extrinsic functions. You declare functions to be extrinsic by using the construct `coder.extrinsic`, as described in "Declaring MATLAB Functions as Extrinsic Functions" on page 41-12.

  The code generation software detects calls to many common visualization functions, such as `plot`, `disp`, and `figure`. For MEX code generation, it automatically calls out to MATLAB for these functions. For standalone code generation, it does not generate code for these visualization functions. This capability removes the requirement to declare these functions extrinsic using the `coder.extrinsic` function.

- Resolves file type based on precedence rules described in "Resolution of Files Types on Code Generation Path" on page 41-6

Compile Path Search Order

During code generation, function calls are resolved on two paths:

1. Code generation path

   MATLAB searches this path first during code generation. The code generation path contains the toolbox functions supported for code generation.

2. MATLAB path

   If the function is not on the code generation path, MATLAB searches this path.

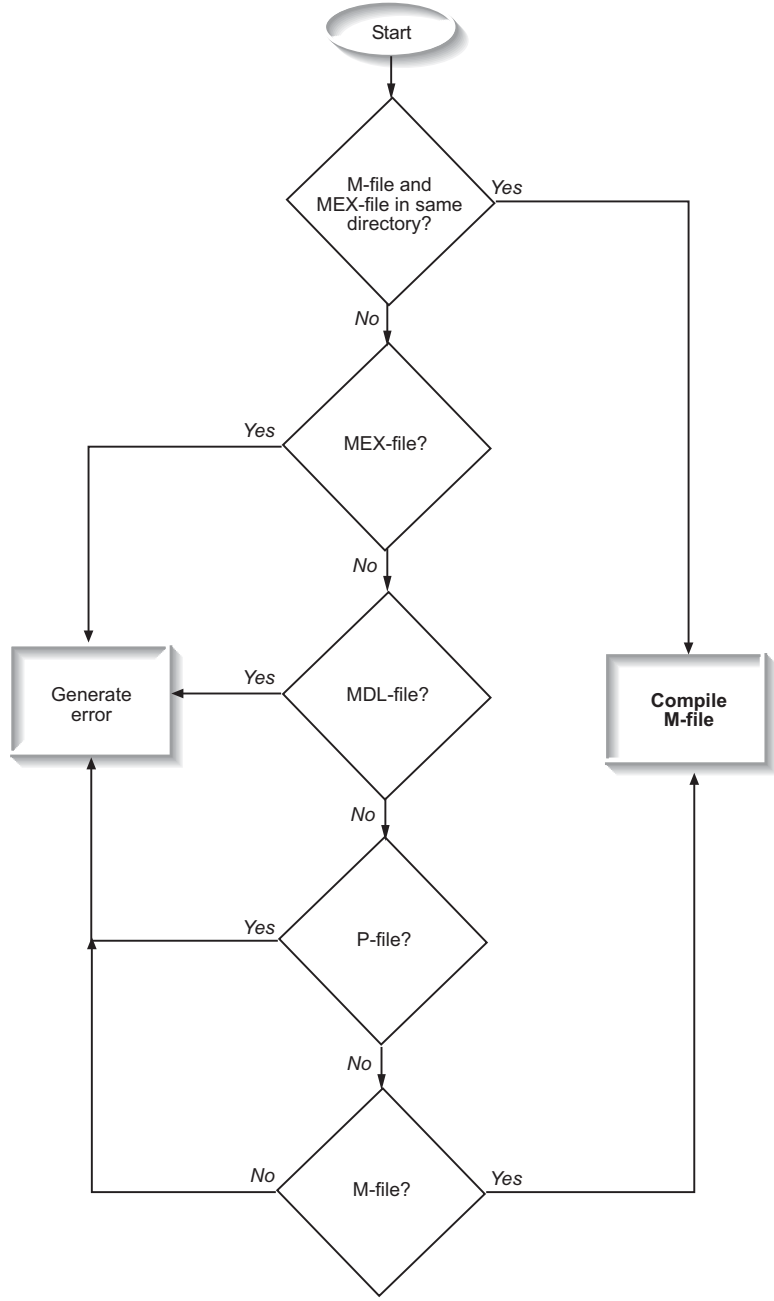
MATLAB applies the same dispatcher rules when searching each path (see "Function Precedence Order").

When to Use the Code Generation Path

Use the code generation path to override a MATLAB function with a customized version. A file on the code generation path always shadows a file of the same name on the MATLAB path.

Resolution of Files Types on Code Generation Path

MATLAB uses the following precedence rules for code generation:


Start
M-file and MEX-file in same directory?
Yes
No
MEX-file?
Yes
No
MDL-file?
Yes
Generate error
No
P-file?
Yes
No
M-file?
No
Yes
Compile M-file

Compilation Directive %#codegen

Add the `%#codegen` directive (or pragma) to your function to indicate that you intend to generate code for the MATLAB algorithm. Adding this directive instructs the MATLAB code analyzer to help you diagnose and fix violations that would result in errors during code generation.

Call Local Functions

Local functions are functions defined in the body of MATLAB function. They work the same way for code generation as they do when executing your algorithm in the MATLAB environment.

The following example illustrates how to define and call a local function `mean`:

```
function [mean, stdev] = stats(vals)
%#codegen

% Calculates a statistical mean and a standard
% deviation for the values in vals.

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;
```

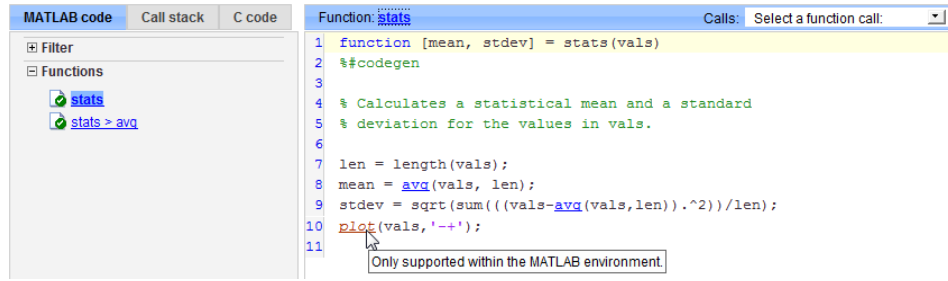
Call Supported Toolbox Functions

You can call toolbox functions directly if they are supported for code generation. For a list of supported functions, see “Functions Supported for Code Generation — Alphabetical List” on page 31-2.

Call MATLAB Functions

The code generation software attempts to generate code for all functions, even if they are not supported for C code generation. The software detects calls to many common visualization functions, such as `plot`, `disp`, and `figure`. For MEX code generation, it automatically calls out to MATLAB for these functions. For standalone code generation, it does not generate code for them.

For example, you might want to call `plot` to visualize your results in the MATLAB environment. If you generate a MEX function from a function that calls `plot` and then run the generated MEX function, the code generation software dispatches calls to the `plot` function to MATLAB. If you generate a library or executable, the generated code does not contain calls to the `plot` function. The code generation report highlights calls from your MATLAB code to extrinsic functions so that it is easy to determine which functions are supported only in the MATLAB environment.



For unsupported functions other than common visualization functions, you must declare the functions (like `pause`) to be extrinsic (see "Resolution of Function Calls in MATLAB Generated Code" on page 41-2). Extrinsic functions are not compiled, but instead executed in MATLAB during simulation (see "How MATLAB Resolves Extrinsic Functions During Simulation" on page 41-16).

There are two ways to declare a function to be extrinsic:

- Use the `coder.extrinsic` construct in main functions or local functions (see "Declaring MATLAB Functions as Extrinsic Functions" on page 41-12).

- Call the function indirectly using `feval` (see "Calling MATLAB Functions Using feval" on page 41-16).

Declaring MATLAB Functions as Extrinsic Functions

To declare a MATLAB function to be extrinsic, add the `coder.extrinsic` construct at the top of the main function or a local function:

```
coder.extrinsic('function_name_1', ... , 'function_name_n');
```

Declaring Extrinsic Functions

The following code declares the MATLAB `patch` function extrinsic in the local function `create_plot`:

```
function c = pythagoras(a,b,color) %#codegen
% Calculates the hypotenuse of a right triangle
%  and displays the triangle.

c = sqrt(a^2 + b^2);
create_plot(a, b, color);


function create_plot(a, b, color)
%Declare patch and axis as extrinsic

coder.extrinsic('patch');

x = [0;a;a];
y = [0;0;b];
patch(x, y, color);
axis('equal');
```

The code generation software detects that `axis` is not supported for code generation and automatically treats it as an extrinsic function. The compiler does not generate code for `patch` and `axis`, but instead dispatches them to MATLAB for execution.

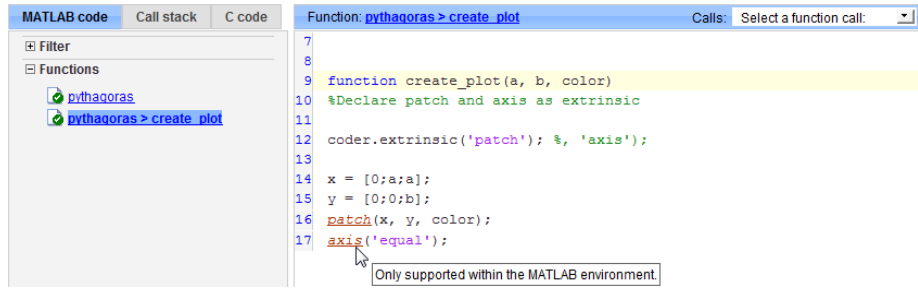
To test the function, follow these steps:

1. Convert `pythagoras` to a MEX function by executing this command at the MATLAB prompt:

   ```
   codegen -report pythagoras -args {1, 1, [.3 .3 .3]}
   ```

2. Click the link to the code generation report and then, in the report, view the MATLAB code for `create_plot`.

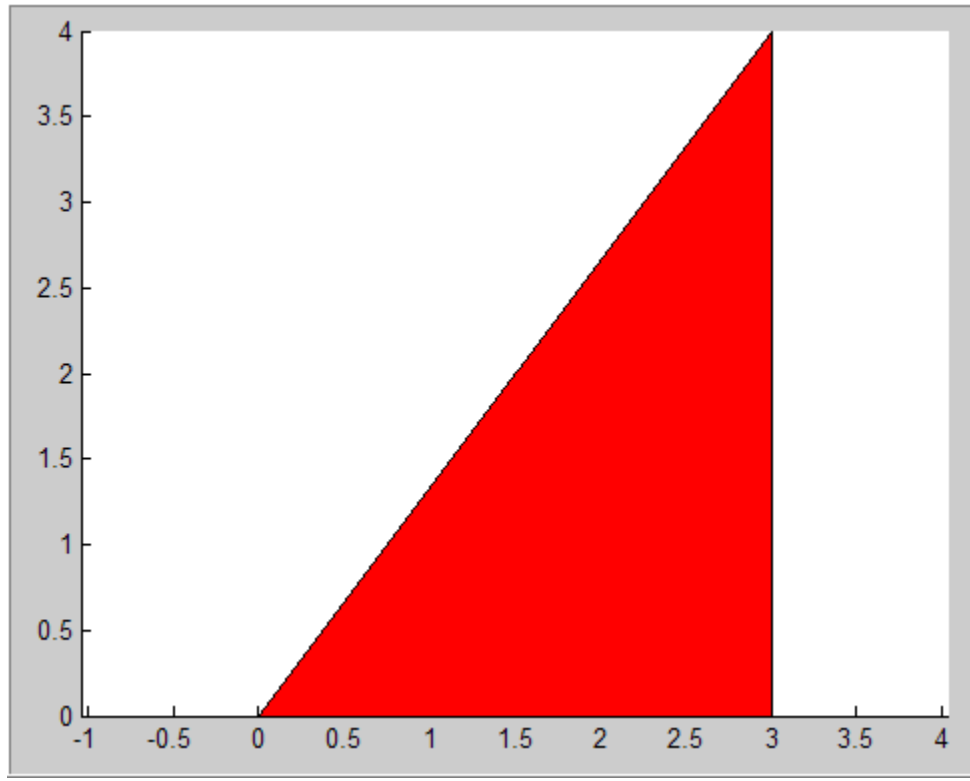
   The report highlights the `patch` and `axis` functions to indicate that they are supported only within the MATLAB environment.



3. Run the MEX function by executing this command:

   ```
   pythagoras_mex(3, 4, [1.0 0.0 0.0]);
   ```

   MATLAB displays a plot of the right triangle as a red patch object:



When to Use the coder.extrinsic Construct

Use the `coder.extrinsic` construct to:

- Call MATLAB functions that produce no output — such as `pause` — during simulation, without generating unnecessary code (see "How MATLAB Resolves Extrinsic Functions During Simulation" on page 41-16).
- Make your code self-documenting and easier to debug. You can scan the source code for `coder.extrinsic` statements to isolate calls to MATLAB functions, which can potentially create and propagate `mxArrays` (see "Working with mxArrays" on page 41-17).
- Save typing. With one `coder.extrinsic` statement, each subsequent function call is extrinsic, as long as the call and the statement are in the same scope (see "Scope of Extrinsic Function Declarations" on page 41-15).

- Declare the MATLAB function(s) extrinsic throughout the calling function scope (see "Scope of Extrinsic Function Declarations" on page 41-15). To narrow the scope, use `feval` (see "Calling MATLAB Functions Using feval" on page 41-16).

Rules for Extrinsic Function Declarations

Observe the following rules when declaring functions extrinsic for code generation:

- Declare the function extrinsic before you call it.
- Do not use the extrinsic declaration in conditional statements.

Scope of Extrinsic Function Declarations

The `coder.extrinsic` construct has function scope. For example, consider the following code:

```
function y = foo %#codegen
coder.extrinsic('rat','min');
[N D] = rat(pi);
y = 0;
y = min(N, D);
```

In this example, `rat` and `min` as treated as extrinsic every time they are called in the main function `foo`. There are two ways to narrow the scope of an extrinsic declaration inside the main function:

- Declare the MATLAB function extrinsic in a local function, as in this example:

  ```
  function y = foo %#codegen
  coder.extrinsic('rat');
  [N D] = rat(pi);
  y = 0;
  y = mymin(N, D);

  function y = mymin(a,b)
  coder.extrinsic('min');
  y = min(a,b);
  ```

Here, the function `rat` is extrinsic every time it is called inside the main function `foo`, but the function `min` is extrinsic only when called inside the local function `mymin`.

- Call the MATLAB function using `feval`, as described in "Calling MATLAB Functions Using feval" on page 41-16.

Calling MATLAB Functions Using feval

The function `feval` is automatically interpreted as an extrinsic function during code generation. Therefore, you can use `feval` to conveniently call functions that you want to execute in the MATLAB environment, rather than compiled to generated code.

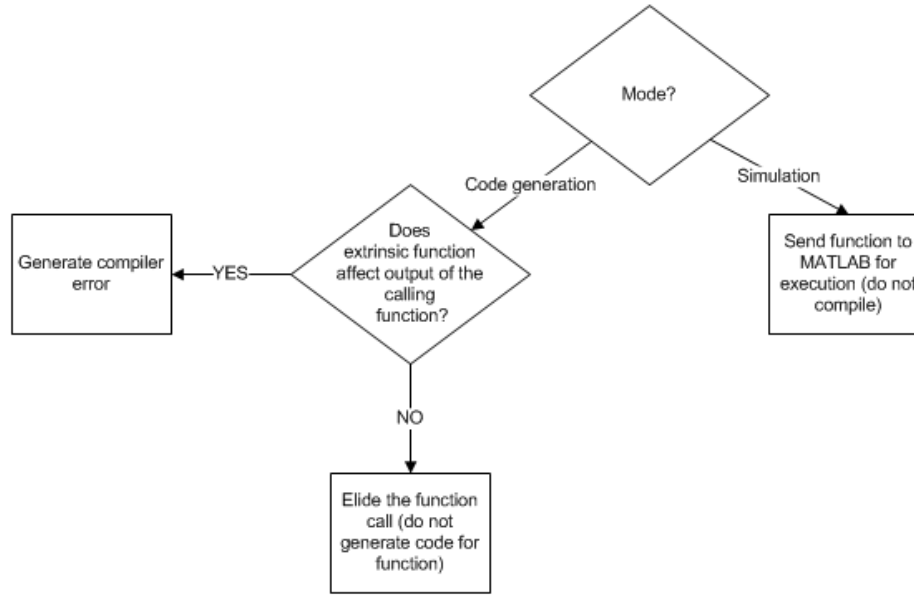
Consider the following example:

```
function y = foo
coder.extrinsic('rat');
[N D] = rat(pi);
y = 0;
y = feval('min', N, D);
```

Because `feval` is extrinsic, the statement `feval('min', N, D)` is evaluated by MATLAB — not compiled — which has the same effect as declaring the function `min` extrinsic for just this one call. By contrast, the function `rat` is extrinsic throughout the function `foo`.

How MATLAB Resolves Extrinsic Functions During Simulation

MATLAB resolves calls to extrinsic functions — functions that do not support code generation — as follows:



During simulation, MATLAB generates code for the call to an extrinsic function, but does not generate the function's internal code. Therefore, you can run the simulation only on platforms where you install MATLAB software.

During code generation, MATLAB attempts to determine whether the extrinsic function affects the output of the function in which it is called — for example by returning `mxArrays` to an output variable (see "Working with mxArrays" on page 41-17). Provided that there is no change to the output, MATLAB proceeds with code generation, but excludes the extrinsic function from the generated code. Otherwise, MATLAB issues a compiler error.

Working with mxArrays

The output of an extrinsic function is an `mxArray` — also called a MATLAB array. The only valid operations for `mxArrays` are:

- Storing `mxArrays` in variables
- Passing `mxArrays` to functions and returning them from functions
- Converting `mxArrays` to known types at run time

To use `mxArrays` returned by extrinsic functions in other operations, you must first convert them to known types, as described in "Converting mxArrays to Known Types" on page 41-18.

Converting mxArrays to Known Types

To convert an`mxArray` to a known type, assign the `mxArray` to a variable whose type is defined. At run time, the `mxArray` is converted to the type of the variable assigned to it. However, if the data in the `mxArray` is not consistent with the type of the variable, you get a run-time error.

For example, consider this code:

```
function y = foo %#codegen
coder.extrinsic('rat');
[N D] = rat(pi);
y = min(N, D);
```

Here, the top-level function `foo` calls the extrinsic MATLAB function `rat`, which returns two `mxArrays` representing the numerator `N` and denominator `D` of the rational fraction approximation of `pi`. Although you can pass these `mxArrays` to another MATLAB function — in this case, `min` — you cannot assign the `mxArray` returned by `min` to the output `y`.

If you run this function `foo` in a MATLAB Function block in a Simulink model, the code generates the following error during simulation:

```
Function output 'y' cannot be of MATLAB type.
```

To fix this problem, define `y` to be the type and size of the value that you expect `min` to return — in this case, a scalar double — as follows:

```
function y = foo %#codegen
coder.extrinsic('rat');
[N D] = rat(pi);
y = 0; % Define y as a scalar of type double
y = min(N,D);
```

Restrictions on Extrinsic Functions for Code Generation

The full MATLAB run-time environment is not supported during code generation. Therefore, the following restrictions apply when calling MATLAB functions extrinsically:

- MATLAB functions that inspect the caller or write to the caller's workspace do not work during code generation. Such functions include:
  - `dbstack`
  - `evalin`
  - `assignin`
- The MATLAB debugger cannot inspect variables defined in extrinsic functions.
- Functions in generated code may produce unpredictable results if your extrinsic function performs any of the following actions at run time:
  - Change folders
  - Change the MATLAB path
  - Delete or add MATLAB files
  - Change warning states
  - Change MATLAB preferences
  - Change Simulink parameters

Limit on Function Arguments

You can call functions with up to 64 inputs and 64 outputs.

42

Generating Efficient and Reusable Code

Unroll for-Loops

Unrolling for-loops eliminates the loop logic by creating a separate copy of the loop body in the generated code for each iteration. Within each iteration, the loop index variable becomes a constant. By unrolling short loops with known bounds at compile time, MATLAB generates highly optimized code with no branches.

You can also force loop unrolling for individual functions by wrapping the loop header in a `coder.unroll` function. For more information, see `coder.unroll`.

Inline Functions

MATLAB uses internal heuristics to determine whether or not to inline functions in the generated code. You can use the `coder.inline` directive to fine-tune these heuristics for individual functions. See `coder.inline`.

Eliminate Redundant Copies of Function Inputs

You can reduce the number of copies in your generated code by writing functions that use the same variable as both an input and an output. For example:

```
function A = foo( A, B ) %#codegen
A = A * B;
end
```

This coding practice uses a reference parameter optimization. When a variable acts as both input and output, MATLAB passes the variable by reference in the generated code instead of redundantly copying the input to a temporary variable. For example, input `A` above is passed by reference in the generated code because it also acts as an output for function `foo`:

```
...
/* Function Definitions */
void foo(real_T *A, real_T B)
{
  *A *= B;
}
...
```

The reference parameter optimization reduces memory usage and improves run-time performance, especially when the variable passed by reference is a large data structure. To achieve these benefits at the call site, call the function with the same variable as both input and output.

By contrast, suppose you rewrite function `foo` without using this optimization:

```
function y = foo2( A, B ) %#codegen
y = A * B;
end
```

In this case, MATLAB generates code that passes the inputs by value and returns the value of the output:

```
...
/* Function Definitions */
real_T foo2(real_T A, real_T B)
```

```
{
   return A * B;
}
...
```

Generate Reusable Code

With MATLAB, you can generate reusable code in the following ways:

- Write reusable functions using standard MATLAB function file names which you can call from different locations, for example, in a Simulink model or MATLAB function library.
- Compile external functions on the MATLAB path and integrate them into generated C code for embedded targets.

See “Resolution of Function Calls in MATLAB Generated Code” on page 41-2.

Common applications include:

- Overriding generated library function with a custom implementation
- Implementing a reusable library on top of standard library functions that can be used with Simulink
- Swapping between different implementations of the same function

Managing Data

Working with Data

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 Simulink Coder 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 43-28). 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 43-6.

Many Simulink blocks also support fixed-point data types. For more information on the data types supported by a specific block for parameter and input and output values, in the Simulink documentation see the **Data Type Support** section of the reference page for that bock. 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 43-5 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 43-19.

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.

To simulate a model without using Simulink Fixed Point:

1. In the **Model Hierarchy** pane, select the root model.
2. In the Simulink Editor, select **Analysis > Fixed-Point Tool**.

The Fixed-Point Tool opens.

3. In the section **Settings for selected system**:
   - Set **Fixed-point instrumentation mode** to `Force off`.
   - Set **Data type override** to `Double` or `Single`.
   - Set **Data type override applies to** `All numeric types`.
4. If you use `fi` objects or embedded numeric data types in your model, set the `fipref` `DataTypeOverride` property to `TrueDoubles` or `TrueSingles` (to be consistent with the model-wide data type override setting) and the `DataTypeOverrideAppliesTo` property to `All numeric types`.

   For example, 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 "Data Types". Do not confuse enumerations with enumerated property types (see "Enumerated Property Types" on page 43-76).

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
- Data Store Memory

- 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 “Specify a Bus Object Data Type” on page 43-26 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. For more information on the data types supported by a specific block for parameter and input and output values, in the Simulink documentation see the **Data Type Support** section of the reference page for that bock. If the documentation for a block does not specify a data type, the block inputs or outputs only data of type `double`.

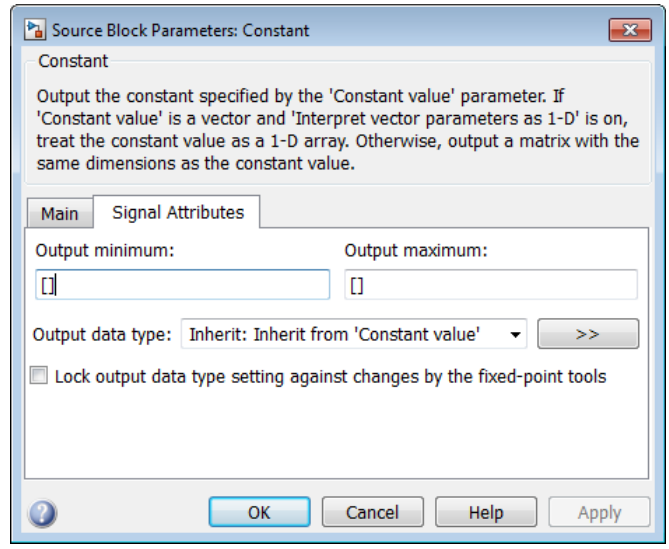
Create Signals of a Specific Data Type

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.

Specify 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:

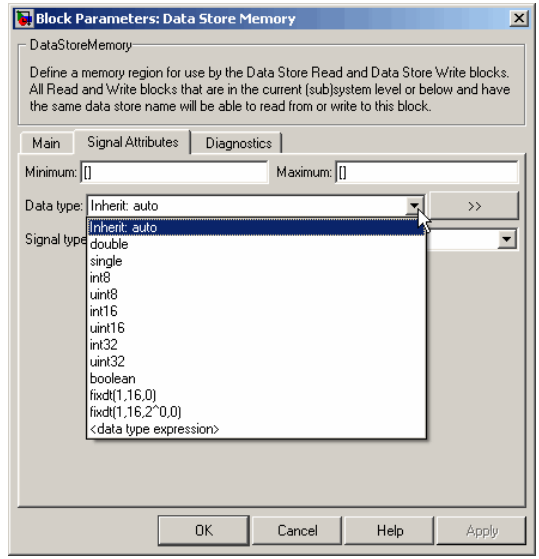
For Information About...	See...
Valid data type values that you can specify	"Entering Valid Data Type Values" on page 43-9
An assistant that helps you specify valid data type values	"Specify Data Types Using Data Type Assistant" on page 43-15
Specifying valid data type values for multiple blocks simultaneously	"Using the Model Explorer for Batch Editing" on page 43-12

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 43-10)
- The name of a built-in data type (see "Built-In Data Types" on page 43-11)
- An expression that evaluates to a data type (see "Data Type Expressions" on page 43-11)

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 documentation.

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 43-28). 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 43-3 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 for more information.

- **Data Type Object Name**

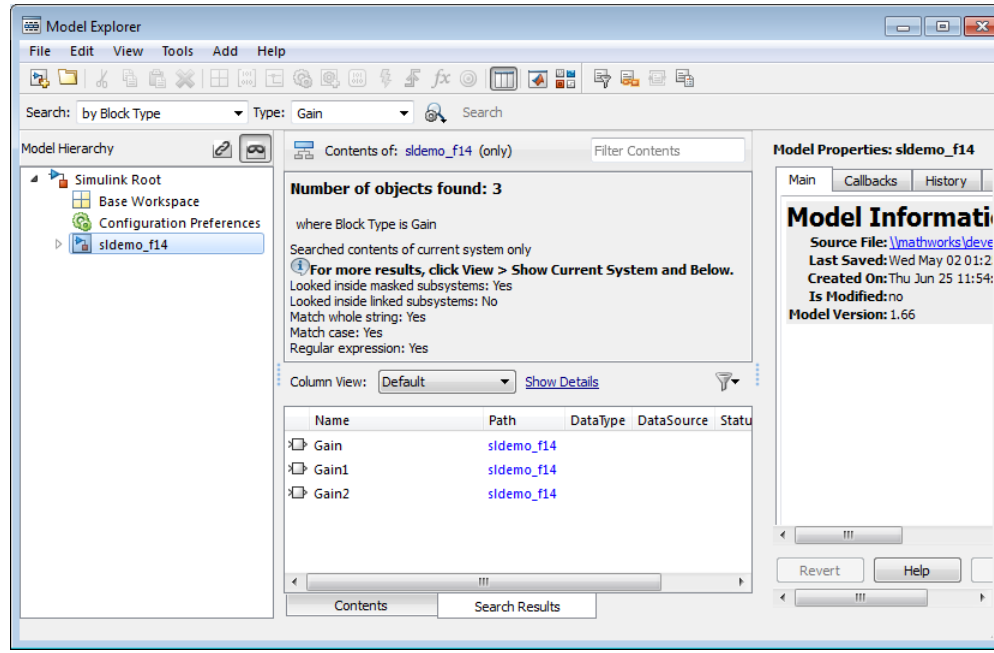
  Specify the value of a data type parameter as the name of a data object that represents a data type. Simulink data objects that you instantiate from classes, such as `Simulink.NumericType` and `Simulink.AliasType`, simplify the task of making model-wide changes to output data types and allow you to use custom aliases for data types. See "Data Objects" on page 43-37 for more information about Simulink data objects.

Using the Model Explorer for Batch Editing

Using the Model Explorer (see "Model Explorer Overview" on page 9-2), 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:

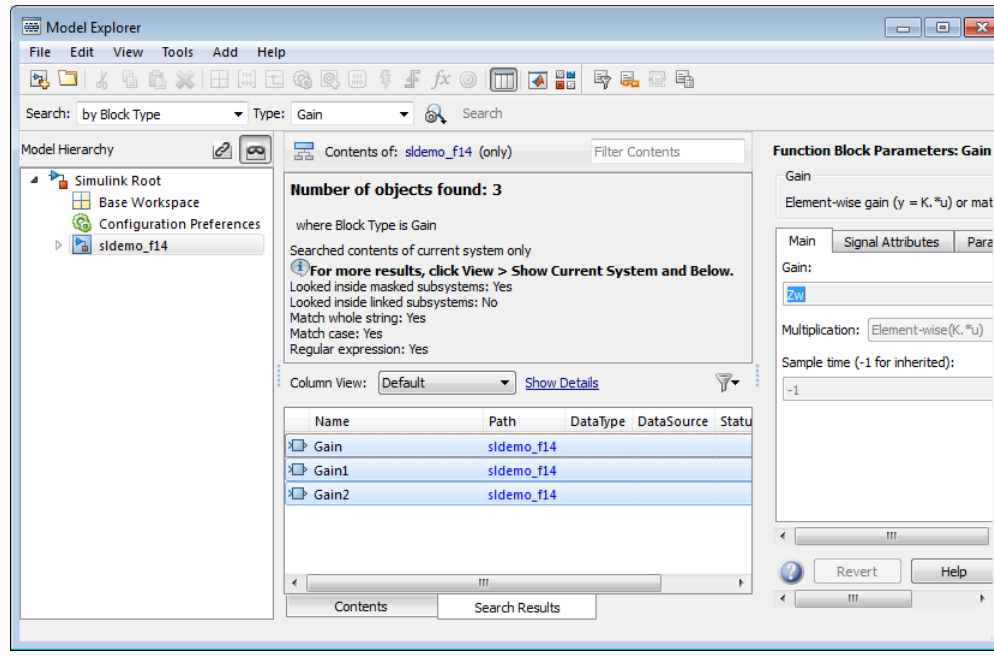
1 Use the Model Explorer search bar (see "Search Using Model Explorer" on page 9-63) to identify all blocks in the `sldemo_f14` model of type `Gain`.

The Model Explorer **Contents** pane lists all Gain blocks in the model.



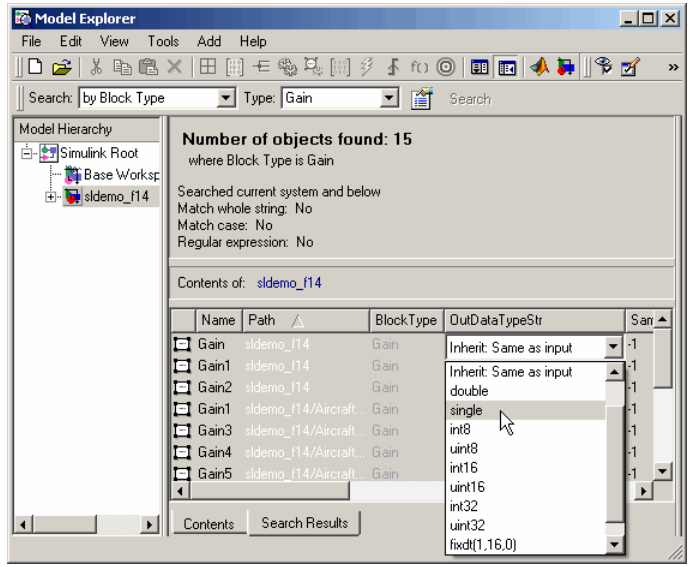
2 In the Model Explorer **Contents** pane, select all the Gain blocks whose **Output data type** parameter you want to specify.

Model Explorer highlights the rows corresponding to your selections.



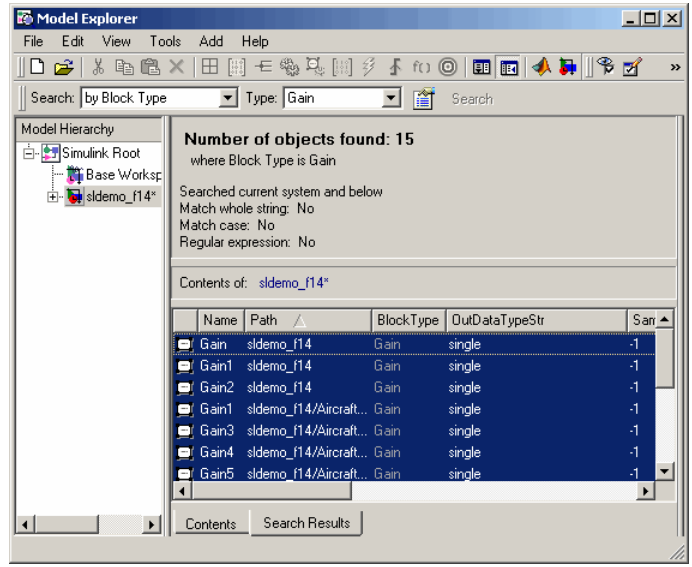
3 In the Model Explorer **Contents** pane, click the data type associated with one of the selected Gain blocks.

Model Explorer displays a pull-down menu with valid data type options.



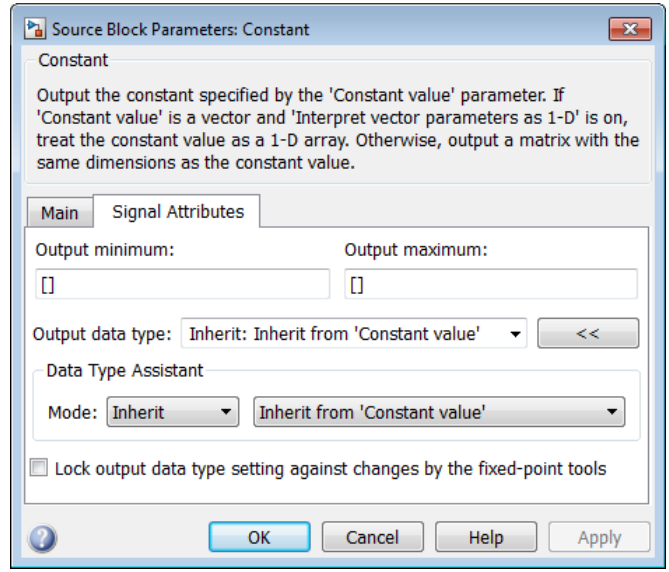
4 In the pull-down menu, enter or select the desired data type, for example, `single`.

Model Explorer specifies the data type of all selected items as `single`.

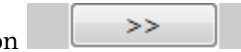
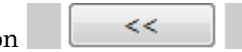


Specify Data Types Using Data Type Assistant

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.

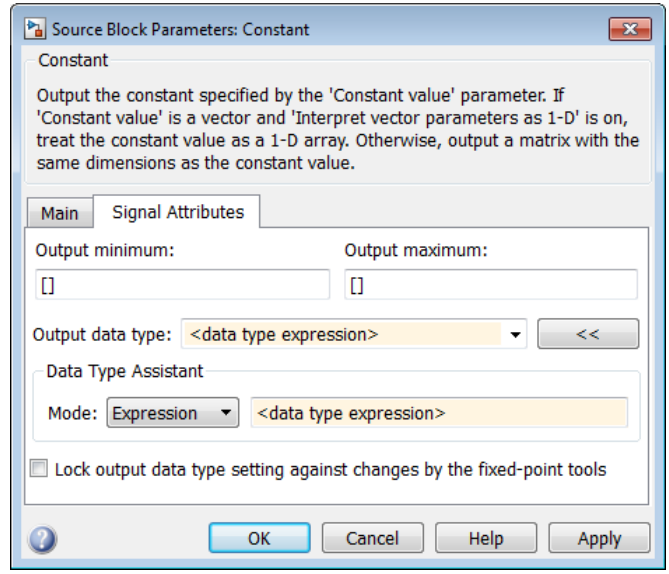
Use the **Data Type Assistant** to specify a data type as follows:

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

Mode	Description
`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.

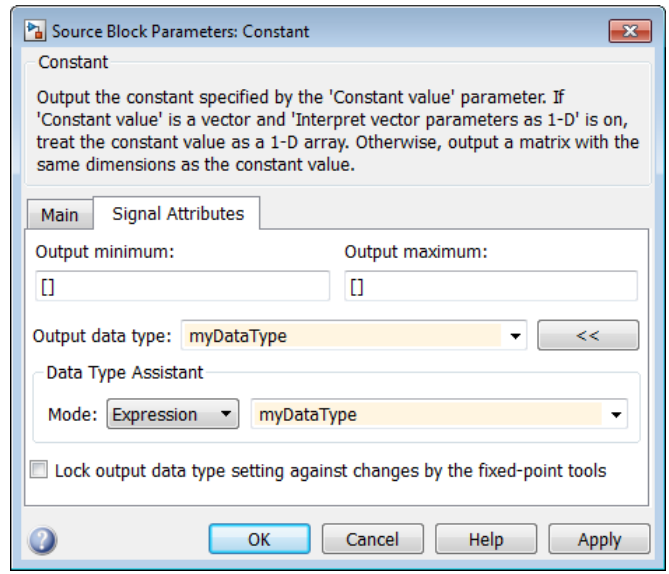


2 In the field that is to the right of the **Mode** field, select or enter a data type.

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:

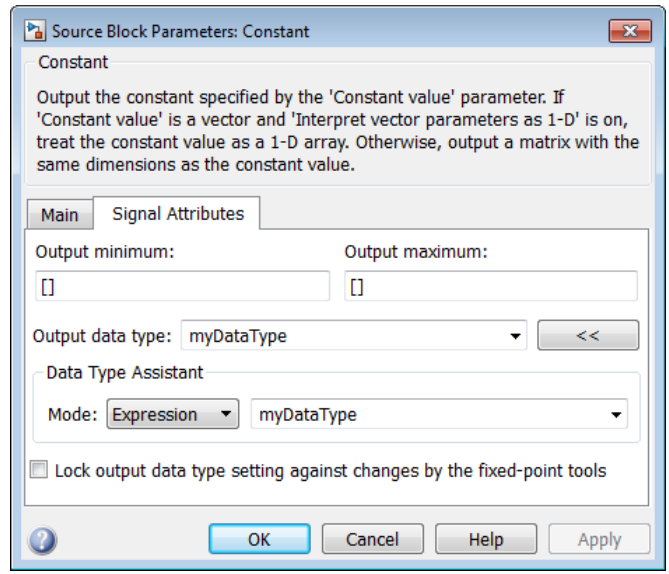
```
myDataType = Simulink.AliasType
myDataType.BaseType = 'single'
```

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.

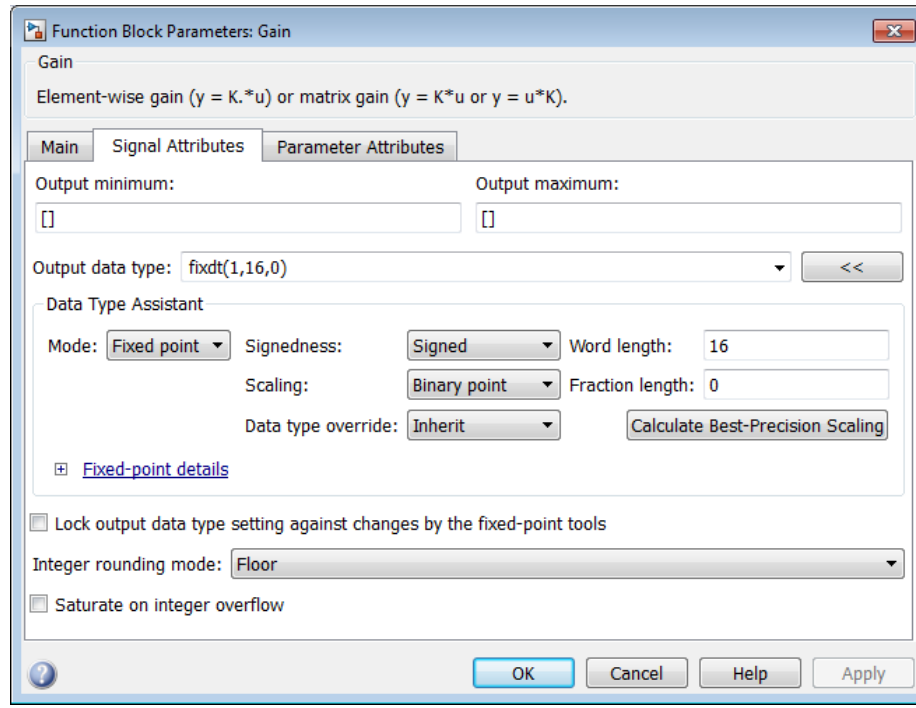
The assistant uses the data type that you specified to populate the associated data type parameter in the block or object dialog box. In the following example, the **Output data type** parameter of the Constant block specifies the same expression that you entered using the assistant.



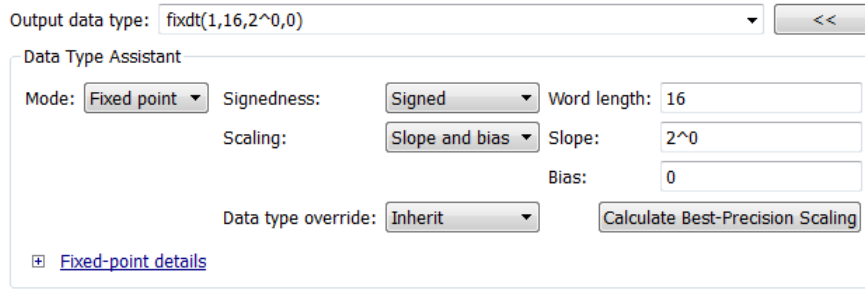
For more information about the data types that you can specify using the **Data Type Assistant**, see “Entering Valid Data Type Values” on page 43-9. For details about specifying fixed-point data types, see “Specifying Fixed-Point Data Types with the Data Type Assistant”.

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 Basics”. 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:

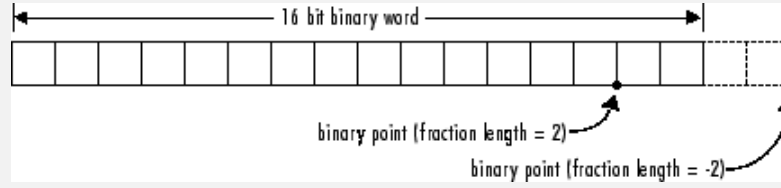


You can use the Data Type Assistant to set these fixed-point properties:

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".

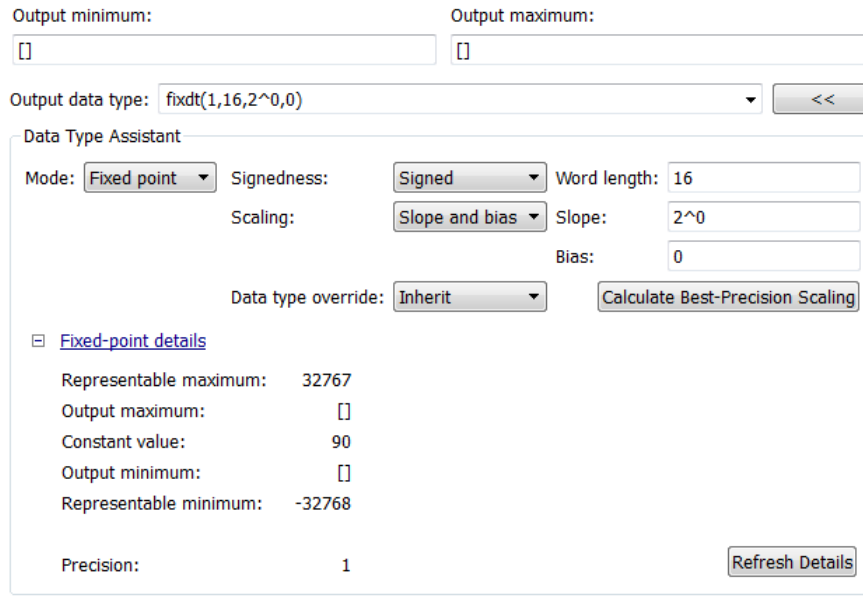
Data type override. When the **Mode** is `Built in` or `Fixed point`, you can use the **Data type override** option to specify whether you want this data type to inherit or ignore the data type override setting specified for its context, that is, for the block, `Simulink.Signal` object or Stateflow chart 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".

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 "Signal Ranges" on page 47-44 and "Check Parameter Values" on page 24-9 for more information.

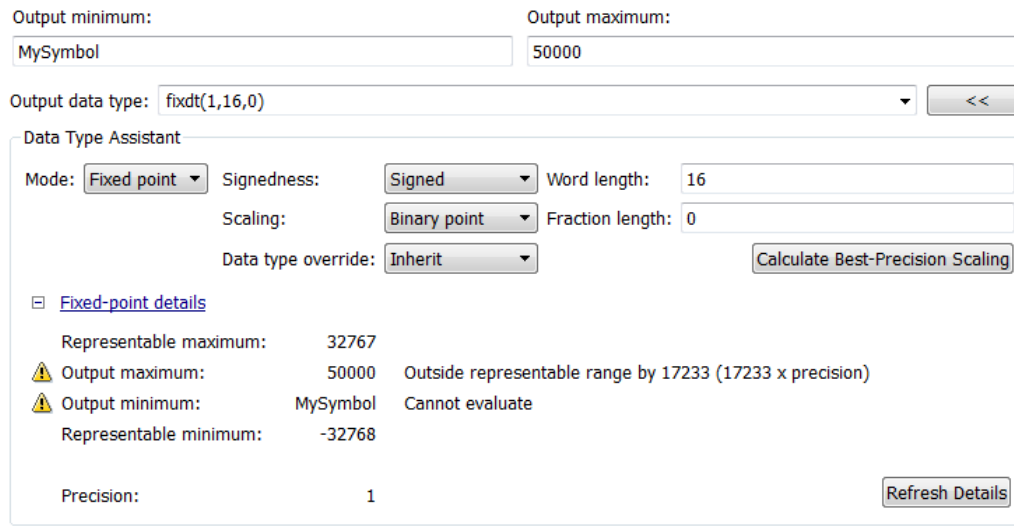
The rows labeled `Representable minimum`, `Representable maximum`, and `Precision` always appear. These rows show the minimum value, maximum value, and precision that can be represented by the fixed-point data type

currently displayed in the Data Type Assistant. For information about these three quantities, see “Fixed-Point Basics”.

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:



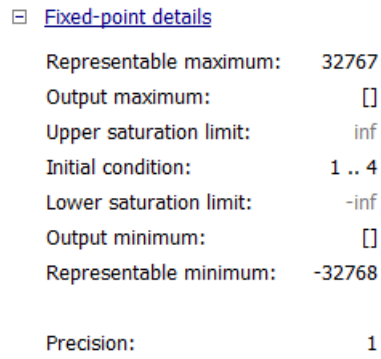
The row labeled `Output minimum` shows the error `Cannot evaluate` because evaluating the expression `MySymbol`, specified in the **Output minimum** field, did not return an appropriate numeric value. When an expression does not evaluate successfully, the **Fixed-point details** subpane displays the

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.

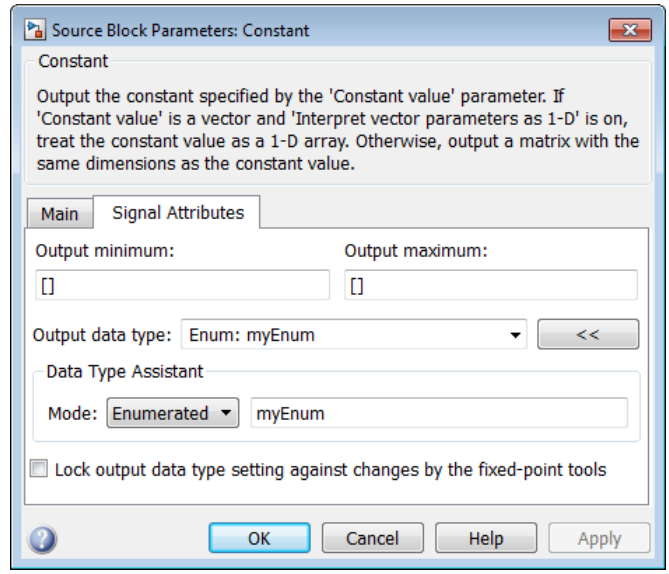
Note also that `Initial condition` displays the value `1..4`. The actual value is a vector or matrix whose smallest element is `1` and largest element is `4`. To conserve space, the **Fixed-point details** subpane shows only the smallest and largest element of a vector or matrix. An ellipsis (`..`) replaces 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. For instructions on autoscaling fixed-point data, see "Scaling".

Specify 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.



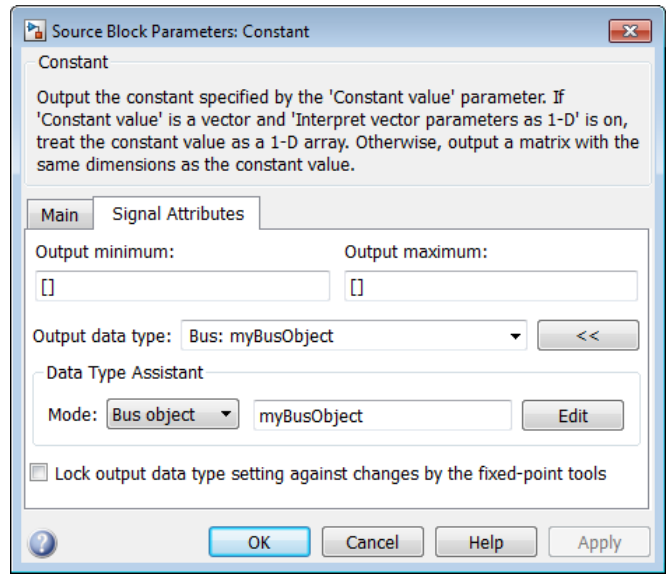
For details about enumerated data types, see "Data Types".

Specify a Bus Object Data Type

The blocks listed in the section called "Bus Objects" on page 43-6 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.

For more information on specifying a bus object data type, see "Associating Bus Objects with Simulink Blocks" on page 48-21

Display Port Data Types

In the Simulink Editor, select **Display > Signals & Ports > 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 "Typecast Signals" on page 43-29 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.

Typecast 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.

Validate 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.

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. In the Simulink Editor, select **Analysis > Fixed-Point Tool**.

   The Fixed-Point Tool opens.

2. Select **View > Show Settings for Selected System**.

3. In the Fixed-Point Tool right pane, under **Settings for selected system**:

   a. Set **Data type override** to `Single`.

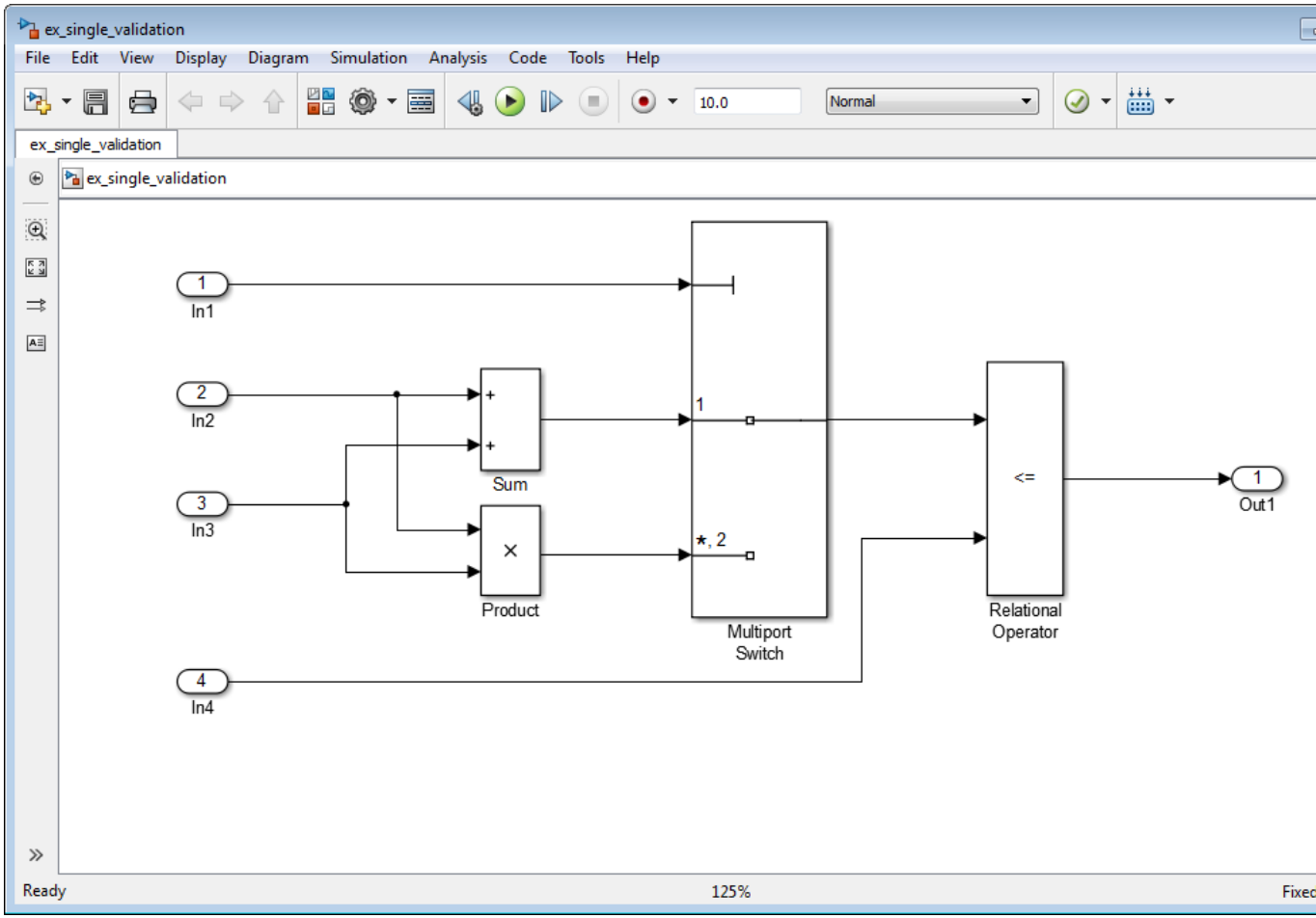
   b. Set **Data type override applies** to `Floating-point`.

For more information on data type override settings, see `fxptdlg`.

Validate 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 43-33

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 43-34

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 43-35

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:

```
addpath(fullfile(docroot,'toolbox','simulink','examples'))
ex_single_validation
```

Generate Code for the Double-Precision Model.

1. In the Simulink Editor, select **Simulation > Model Configuration Parameters**.

   The Configuration Parameters dialog box opens.

2. From the **Code Generation** node, select **Report**.

   On the **Report** pane, verify that **Create code generation report** and **Launch report automatically** are selected so that the Simulink Coder software creates a code generation report.

3. In the Simulink Editor, select **Code > C/C++ Code > Build Model**.

   Simulink Coder 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 In the Simulink Editor, select **Analysis > Fixed-Point Tool**.

The Fixed-Point Tool opens.

2 Select **View > Show Settings for Selected System**.

3 In the Fixed-Point Tool right pane, under **Settings for selected system**:

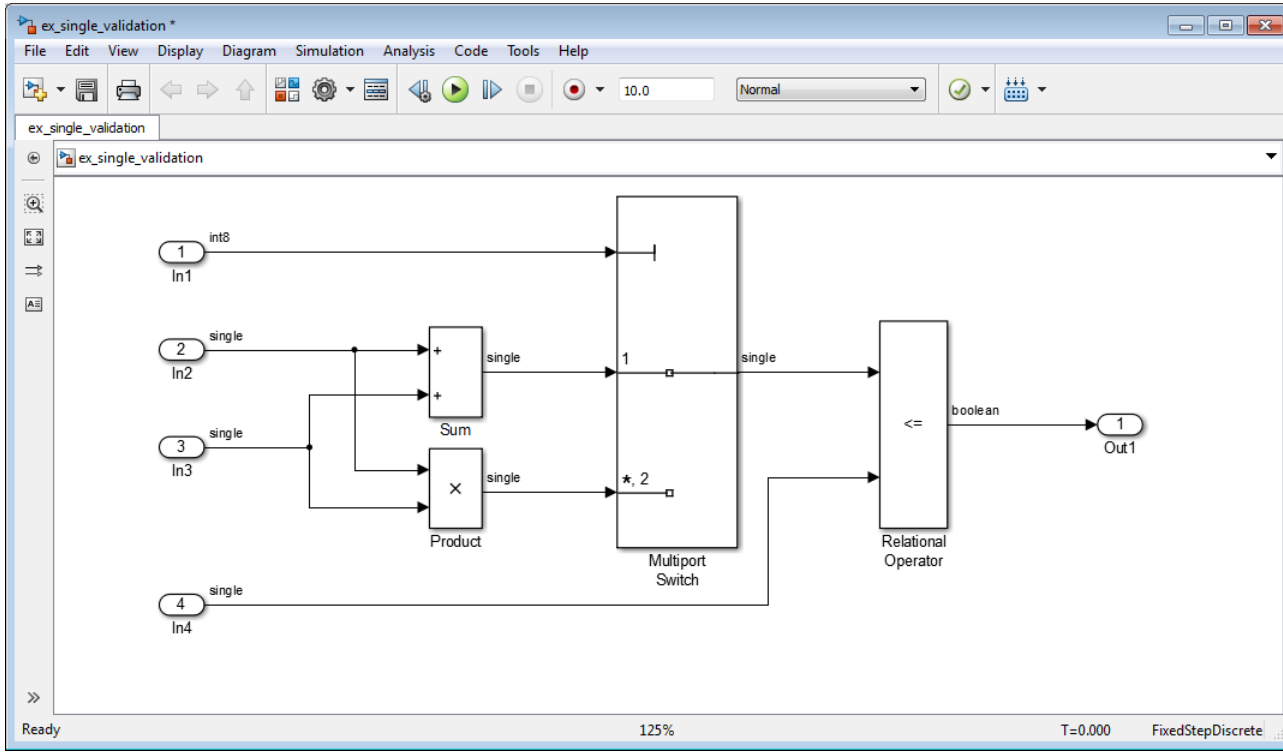
a Set **Data type override** to `Single`.

b Set **Data type override applies to** `Floating-point`.

c Click **Apply**.

4 From the Fixed-Point Tool menu, select **Collect > Start Simulation**.

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. In the Simulink Editor, select **Code > C/C++ Code > Build Model**.

   Simulink Coder 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.

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.

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. Some MathWorks products based on Simulink, such as the Simulink Coder 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 "Define Level-1 Data Classes" on page 43-63).

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 43-44).

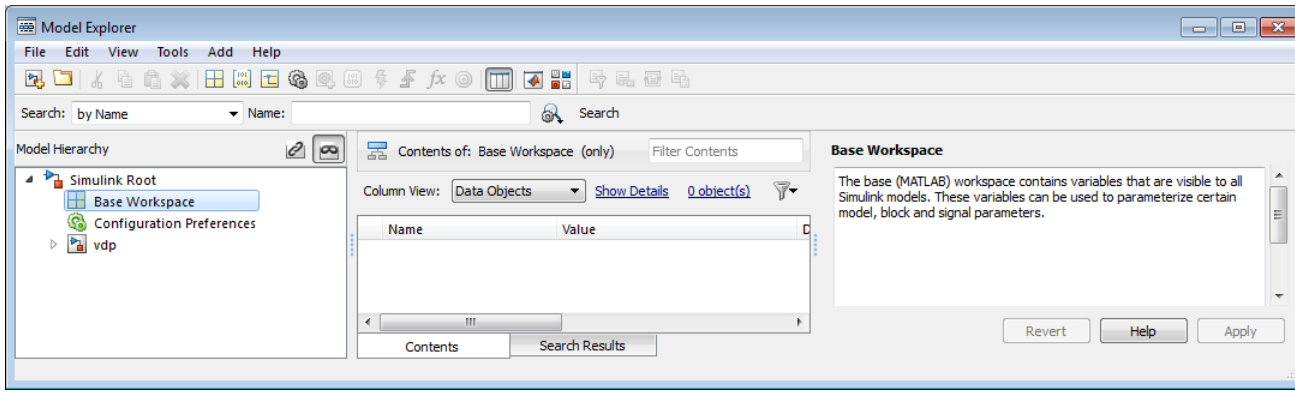
Using the Model Explorer to Create Data Objects

You can use the Model Explorer (see "Model Explorer Overview" on page 9-2) as well as MATLAB commands to create data objects. To use the Model Explorer,

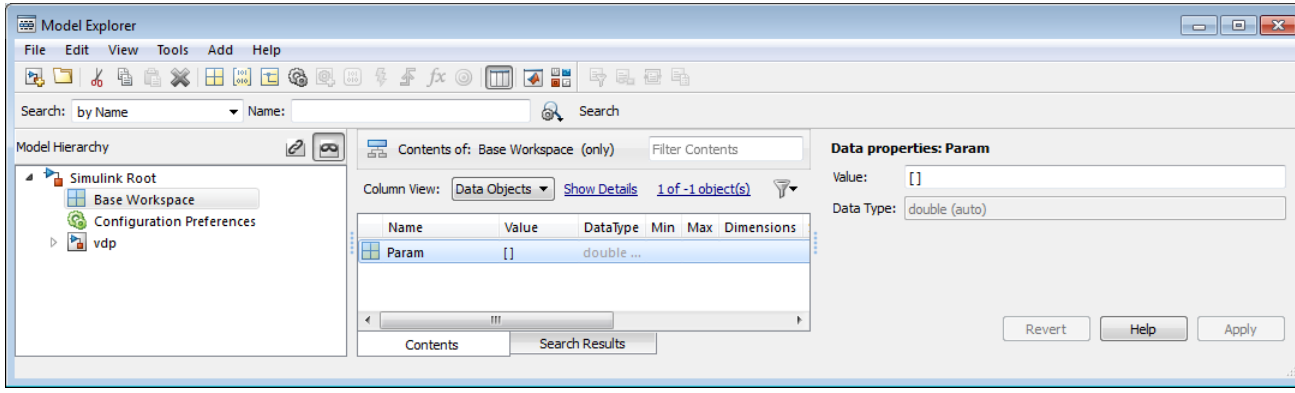
1. Select the workspace in which you want to create the object in the Model Explorer **Model Hierarchy** pane.

   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.

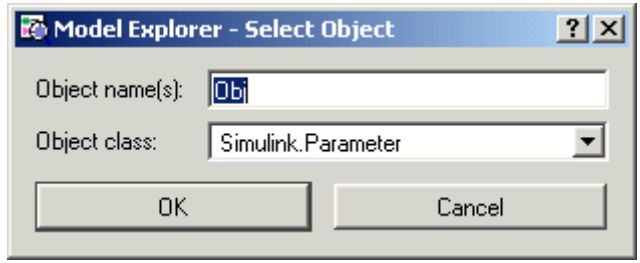
Note Subclasses of `Simulink.Parameter` and `Simulink.Signal` classes, including `mpt.Parameter` and `mpt.Signal` objects (Embedded Coder license required), can reside in a model workspace only if their storage class is set to `Auto`.



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.

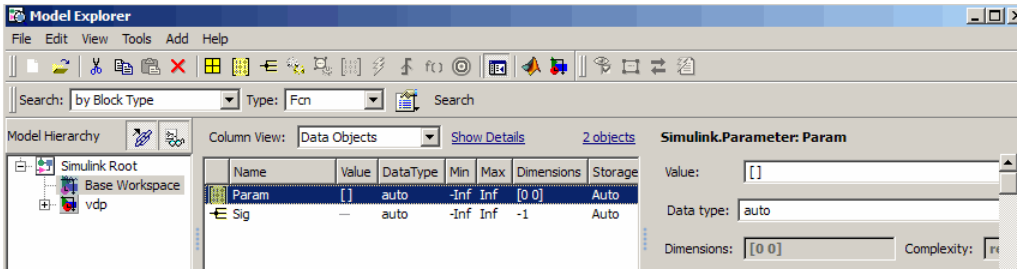
Changing Object Properties

You can use either the Model Explorer (see "Using the Model Explorer to Change an Object's Properties" on page 43-42) or MATLAB commands to change a data object's properties (see "Use MATLAB Commands to Change Workspace Data" on page 4-71).

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 "Model Explorer: Contents Pane" on page 9-19). 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 43-44), `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.CoderInfo.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 43-39) 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: []
        CoderInfo: [1x1 Simulink.ParamCoderInfo]
    Description: ''
       DataType: 'auto'
            Min: []
            Max: []
       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 objects (see "Define Level-2 Data Classes" on page 43-53) or at the command line and save them in a MAT-file (see "Saving and Loading Data Objects" on page 43-46). 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.

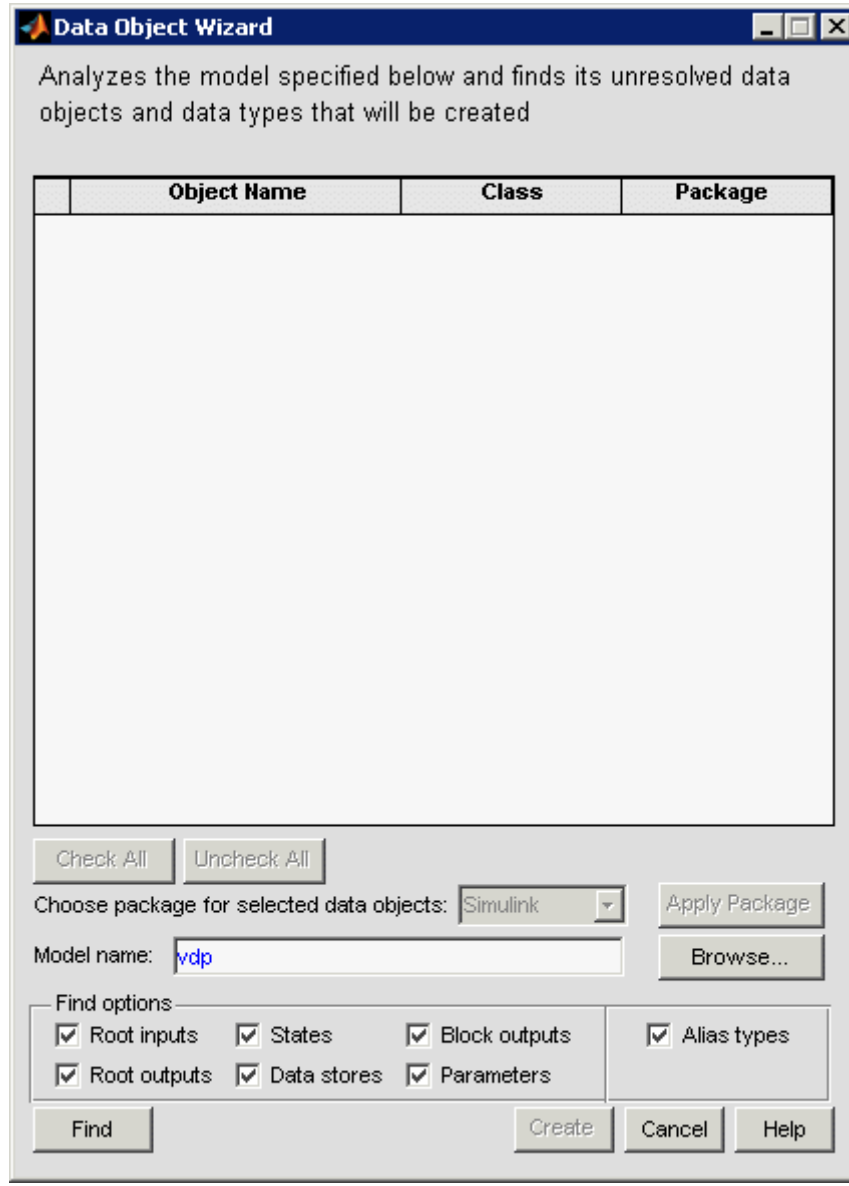
Data Object Wizard

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. In the Simulink Editor, select **Code > DataObjects > Data Object Wizard**.

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.

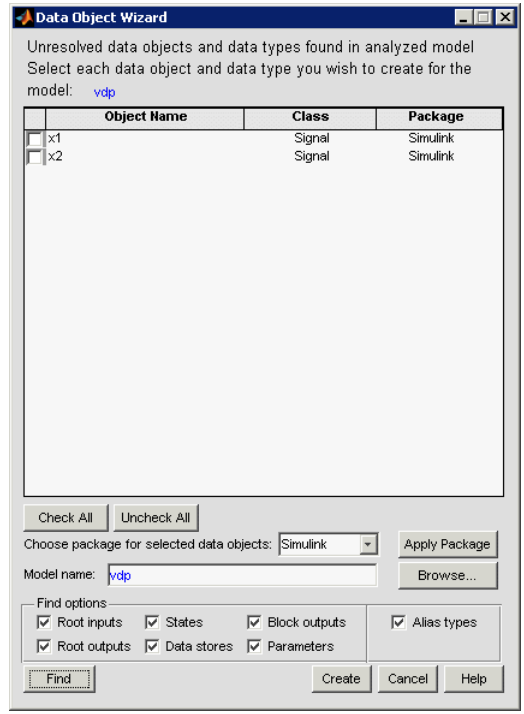
The search options include:

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 PID Controller PID Controller (2DOF) Unit Delay
Data stores	Data stores (see "About Data Stores" on page 46-2)
Block outputs	Named signals emitted by non-root-level blocks.

Option	Description
Parameters	• Parameters of any instances of the following block types: Constant Gain Relay • Stateflow data with a **Scope** of `Parameter`. For more information, see "Sharing Simulink Parameters with Charts" in the Stateflow documentation.
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 "Create Data Objects with Data Object Wizard" in the 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.

Note User-defined packages that you add to the Data Object Wizard must contain a `Simulink.Signal` subclass named `Signal` and a `Simulink.Parameter` subclass named `Parameter`.

---

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.

Define Level-2 Data Classes

Note The Data Class Designer, which is used to define level-1 data classes, is disabled by default. To learn why you should switch to level-2 data classes, see "Infrastructure for Extending Simulink Data Classes" on page 43-61

To use the Data Class Designer, see "Define Level-1 Data Classes" on page 43-63.

This example shows how to use level-2 data class infrastructure to create subclasses of Simulink data classes.

Use MATLAB class syntax to create a data class in a package, and, optionally, assign properties to the data class and define custom storage classes.

Define data class

1. Create a package folder `+mypkg` and add its parent folder to the MATLAB path.
2. Create class folders `@Parameter` and `@Signal` inside `+mypkg`.

   Note Simulink requires data classes to be defined inside `+Package/@Class` folders.

3. In the `@Parameter` folder, create a MATLAB file `Parameter.m` and open it for editing.
4. Define a data class that is a subclass of `Simulink.Parameter` using MATLAB class syntax.

   ```
   classdef Parameter < Simulink.Parameter

   end % classdef
   ```

Optional: Add properties to data class

The `properties` and `end` keywords enclose a property definition block.

See "Supported Property Types" on page 43-58.

```
classdef Parameter < Simulink.Parameter
 properties % Unconstrained property type
  Prop1 = [];
 end

 properties(PropertyType = 'logical scalar')
  Prop2 = false;
 end

 properties(PropertyType = 'char')
  Prop3 = '';
 end

 properties(PropertyType = 'char', AllowedValues = {'red'; 'green'; 'blue'}
  Prop4 = 'red';
 end
end % classdef
```

Note The MATLAB editor will not recognize the attributes `PropertyType` and `AllowedValues`, because they are only defined for Simulink data classes. You can suppress `mlint` warnings about these unrecognized attributes by right-clicking the attribute in the MATLAB editor and selecting **Suppress**.

Optional: Add initialization code to data class

You can add a constructor within your data class to perform initialization activities when the class is instantiated.

In this example, the constructor initializes the value of object `obj` based on an optional input argument.

```
classdef Parameter < Simulink.Parameter
 methods
  function obj = Parameter(optionalValue)
```

```
   if (nargin == 1)
    obj.Value = optionalValue;
   end
  end
 end % methods
end % classdef
```

Optional: Define custom storage classes

Use the `setupCoderInfo` method to configure the `CoderInfo` object of your class. Then, create a call to the `useLocalCustomStorageClasses` method and launch the Custom Storage Class Designer.

1. In the constructor within your data class, call the `useLocalCustomStorageClasses` method.

   ```
   classdef Parameter < Simulink.Parameter
    methods
     function setupCoderInfo(obj)
      useLocalCustomStorageClasses(obj, 'mypkg');

      obj.CoderInfo.StorageClass = 'Custom';
     end
    end % methods
   end % classdef
   ```

2. Launch the Custom Storage Class Designer for your package.

   ```
   cscdesigner('mypkg')
   ```

3. Define custom storage classes. “Use Custom Storage Class Designer”.

Optional: Define custom attributes for custom storage classes

1. Create a MATLAB file `myCustomAttribs.m` and open it for editing.

2. Define a subclass of `Simulink.CustomStorageClassAttributes` MATLAB class syntax.

   ```
   classdef CSCAttributes < Simulink.CustomStorageClassAttributes
    properties(PropertyType = 'char')
   ```

```
    AlternateName = '';
   end
  end % classdef
```

3 Override the default implementation of the `getInstanceSpecificProps` method.

Note This is an optional step. By default, you can set all custom attributes to be instance-specific in the Custom Storage Class designer so that they are modifiable for each data object. However, you can limit which properties are allowed to be instance-specific.

```
classdef CSCAttributes < Simulink.CustomStorageClassAttributes
 properties(PropertyType = 'char')
  AlternateName = '';
 end % properties

 properties(PropertyType = 'logical scalar')
  IsAlternateNameInstanceSpecific = true;
 end

 methods
  function props = getInstanceSpecificProps(obj)
   if obj.IsAlternateNameInstanceSpecific
    props = findprop(obj, 'AlternateName');
   end
  end
 end % methods
end % classdef
```

Alternate way of defining level-2 data classes

1 Locate the `+SimulinkDemos` data class package on the MATLAB path.

Note The `+SimulinkDemos` folder is at `matlabroot/toolbox/simulink/simdemos/dataclasses`

This package contains predefined data classes.

2. Copy the folder to the location where you want to define your data classes.
3. Rename the folder `+mypkg` and add its parent folder to the MATLAB path.
4. Modify the data class definitions as desired.

Supported Property Types

If you add properties to a subclass of `Simulink.Parameter`, `Simulink.Signal`, or `Simulink.CustomStorageClassAttributes`, you can specify the following property types.

Property Type	Syntax
Double number	`properties(PropertyType = 'double scalar')`
int32 number	`properties(PropertyType = 'int32 scalar')`
Logical number	`properties(PropertyType = 'logical scalar')`
String (char)	`properties(PropertyType = 'char')`
String with limited set of allowed values	`properties(PropertyType = 'char', AllowedValues = {'a', 'b', 'c'})`

Upgrade Level-1 Data Classes

Run the following utility function while specifying the destination folder for the upgraded classes.

Note Property types defined in level-1 data classes that are not subclasses of `Simulink.Parameter`, `Simulink.Signal`, or `Simulink.CustomStorageClassAttributes` are not preserved during an upgrade. Only subclasses of these three classes will preserve attributes `PropertyType` and `AllowedValues`.

---

1 This command upgrades all your level-1 data class packages. You cannot upgrade selected data packages.

```
Simulink.data.upgradeClasses('C:\myLevel2Classes')
```

Here, `C:\myLevel2Classes` is the destination folder for your level-2 data classes.

Note Do not place your upgraded level-2 classes and their equivalent level-1 classes in the same folder.

`Simulink.data.upgradeClasses` uses the `packagedefn.mat` file in your level-1 class packages for the upgrade and creates level-2 classes in the specified destination folder. Then, `Simulink.data.upgradeClasses` adds the folder to top of the MATLAB path and saves the path.

Note If `Simulink.data.upgradeClasses` cannot save the MATLAB path because of restricted access, a warning appears. In this case, manually add the folder to the top of the MATLAB path and save the path using `savepath`.

---

2 You can change the location of the level-2 package folders after they have been generated. However, you will need to update your MATLAB path so that MATLAB can find these package folders.

3 Retain your level-1 classes on the MATLAB path until you have resaved all of your models and MAT-files that contain level-1 data class objects. Any models or MAT-files that contain level-1 data classes will continue to work while your level-1 data classes are on the MATLAB path.

Note You cannot use both level-1 and level-2 data classes at the same time. Level-2 classes need to be above the level-1 classes on the MATLAB path so that they are found by MATLAB.

Infrastructure for Extending Simulink Data Classes

In this section...

Previously, you could only use the Data Class Designer to create user-defined subclasses of Simulink data classes such as `Simulink.Parameter` or `Simulink.Signal`.

The Data Class Designer, which is based on *level-1 data class infrastructure*, allows you to create, modify, or delete user-defined packages containing user-defined subclasses.

In a future release, support for level-1 data class infrastructure is being removed.

In R2012a, a replacement called *level-2 data class infrastructure* is being introduced. This infrastructure will allow you to extend Simulink data classes using MATLAB class syntax.

Disadvantages of Level-1 Data Class Infrastructure

- The syntax for defining data classes using this infrastructure is not documented.
- The infrastructure offers limited capability for defining data classes:
  - You cannot add methods to your data classes.
  - You cannot add private or protected properties to your data classes.
- The data classes are only defined in P-code.

Features of Level-2 Data Class Infrastructure

- Ability to upgrade data classes you defined using level-1 data class infrastructure. See "Upgrade Level-1 Data Classes" on page 43-59.

- Complete flexibility in defining your data classes, which can now have their own methods and private properties.
- Simplified mechanism for defining custom storage classes for your data classes.
- Ability to define data classes as readable MATLAB code, not P-code. With class definitions in MATLAB code, it is easier to understand how these classes work, to integrate code using configuration management, and to perform peer code reviews.
- Strict matching for properties, methods, and enumeration property values.

See the detailed example “Define Level-2 Data Classes” on page 43-53.

Other Differences between Level-1 and Level-2 Data Classes

Level-1 data class infrastructure offers the following capabilities, which are not supported in the level-2 infrastructure.

- The infrastructure permits partial property matching and does not enforce case sensitivity. For example, after creating a `Simulink.Parameter` data object

  ```
  a = Simulink.Parameter;
  ```

  you could set the property `Value` of the data object by using the following command.

  ```
  a.value = 5;
  ```

- You can add a data class property that is already included in the superclass.
- You can add a data class property with the same name as the class.

Define Level-1 Data Classes

Support for level-1 data class infrastructure will be removed in a future release. Use level-2 data classes instead. See “Define Level-2 Data Classes” on page 43-53.

Note The Data Class Designer, which is used to define level-1 data classes, is disabled by default.

To use the Data Class Designer, run the following commands to enable level-1 data class infrastructure.

```
sldataclasssetup (1)
savepath
```

In this section...

About Packages and Data Classes

Simulink packages and data classes are introduced in “About Data Object Classes” on page 43-37 and, if you have a Simulink Coder license, in“Data Representation”. 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 43-79.

Custom storage classes are defined and stored in different files than packages and data classes use, and different rules apply to changing them. See "Apply Custom Storage Classes" in the Embedded Coder documentation for complete information about custom storage classes.

Define Level-1 Data Classes

This example shows how to use level-1 data class infrastructure to create subclasses of Simulink data classes.

Note The Data Class Designer is disabled by default.

To use the Data Class Designer, run the following commands to enable level-1 data class infrastructure.

```
sldataclasssetup (1)
savepath
```

Use the Data Class Designer to create a data class in a package, and, optionally, define custom storage classes.

Create a package

1. Open the Simulink Data Class Designer.

   ```
   sldataclassdesigner
   ```

   The Data Class Designer loads all packages that exist on the MATLAB path.

2. Click **New** next to the **Package name** field, name your package, and click **OK**.

3. In the **Parent directory** field, enter the path to the directory for storing 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.

4. Add the parent directory to the MATLAB path.

Define a data class

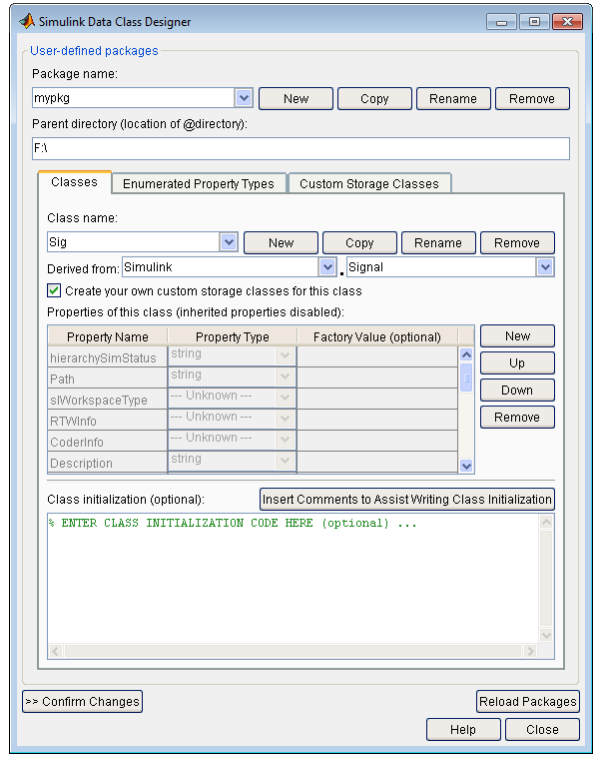
1. In the **Classes** tab, click **New** next to the **Class name** field, name your class, and click **OK**.

2 Specify the parent class using the **Derived from** menus. Select `Simulink.Signal` or `Simulink.Parameter`.

3 Select the option to **Create your own custom storage classes for this class**.

At least one class in your package must have this option selected.

Note If you do not select this option, your new class inherits the CSCs of the parent class.



In the figure above, a new package `mypkg` contains a new class called `sig` derived from `Simulink.Signal`. The option to **Create your own custom storage classes for this class** is selected.

4 Add other derived classes to your package and associate CSCs with them.

Register the package

1 Click **Confirm Changes**.

2 In the **Confirm changes** pane, select the package you created.

Note User-defined packages that you plan to add to the Data Object Wizard must contain a `Simulink.Signal` subclass named `Signal` and a `Simulink.Parameter` subclass named `Parameter`.

---

3 Click **Write Selected**.

The package directories and files, including the CSC registration file, are written out to the parent directory.

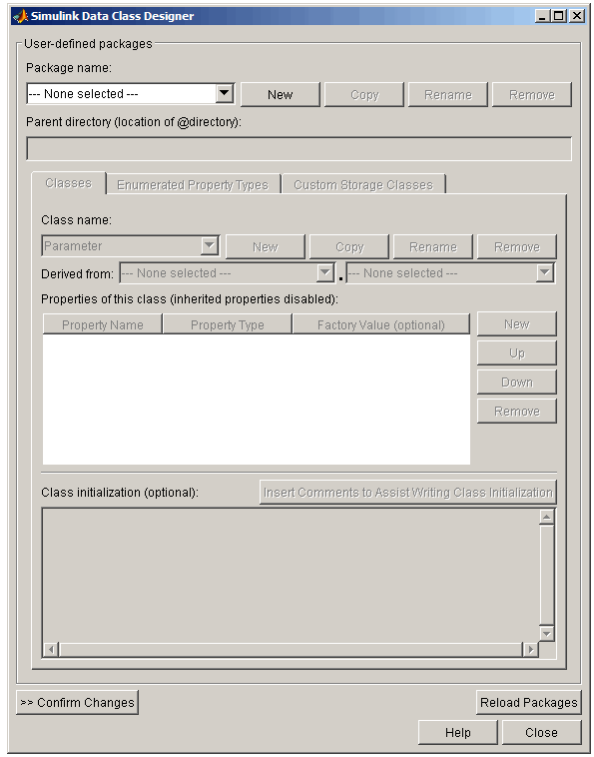
4 Click **Close**.

Optional: Define custom storage classes

Define custom storage classes. See "Use Custom Storage Class Designer".

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 43-67.

Creating a Data Object Class

To create a class within the currently selected package:

1. In the Simulink Editor, select **Code > DataObjects > Design Data Classes**.

   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`*.

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 43-71).

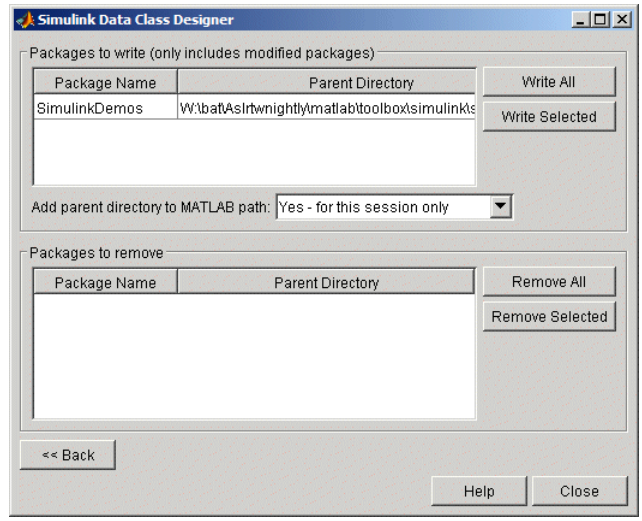
7. Optionally enable custom storage classes for the class (see "Enabling Custom Storage Classes" on page 43-79).

8. Define the properties of the new class (see "Defining Class Properties" on page 43-72).

9. If necessary, create initialization code for the new class (see "Creating Initialization Code" on page 43-74).

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.

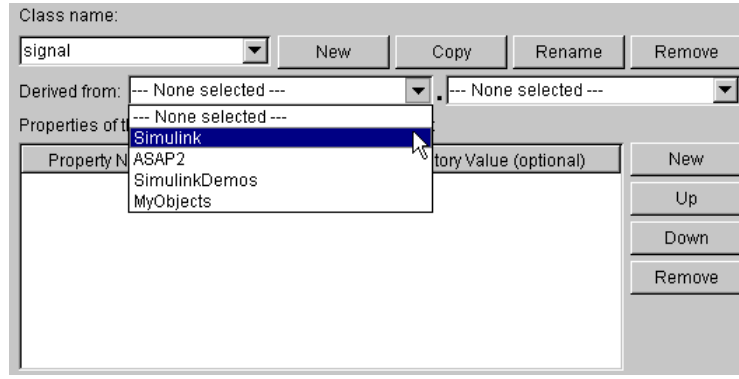
Removing a class from a package

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.

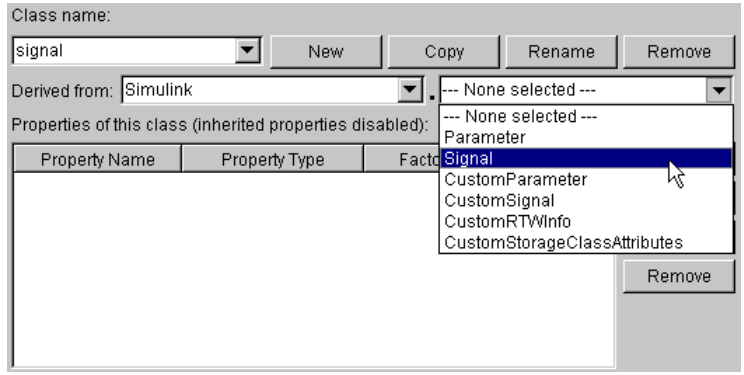
Specifying a Parent for a Class

To specify a parent for a class:

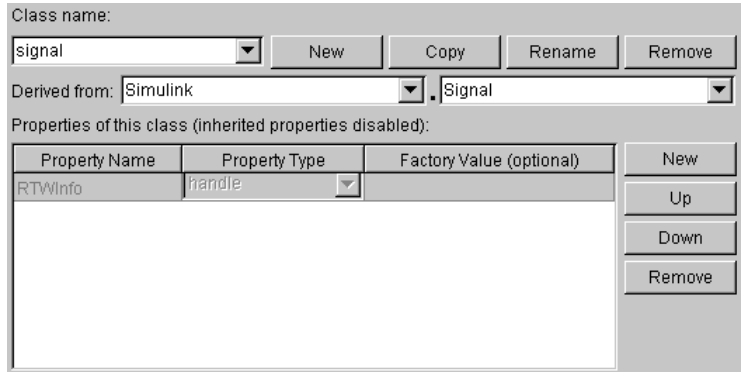
1. Select the name of the class from the **Class name** field on the **Classes** pane.
2. Select the package name of the parent class from the left-hand **Derived from** list box.



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:

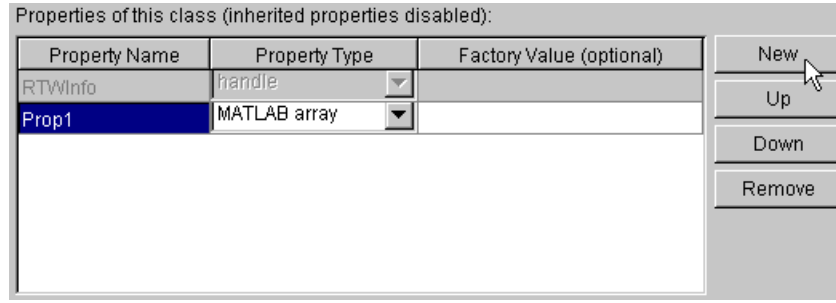
1 Select the name of the class from the **Class name** field on the **Classes** pane.

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 43-76).

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 43-74 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.

Note Do not include function definitions of the form shown below in the initialization code. The following example only illustrates how the **Data Class Designer** considers a class instantiation function.

```
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
```

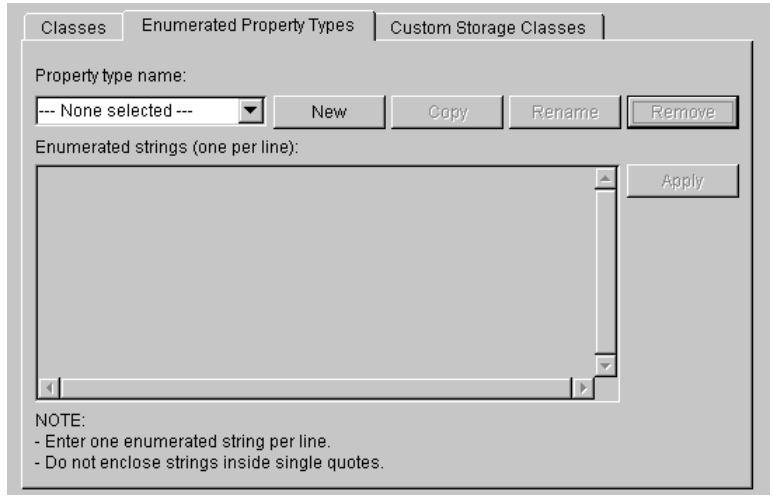
Enumerated Property Types

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 "Use Enumerated Data in Simulink Models" on page 44-10. 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.

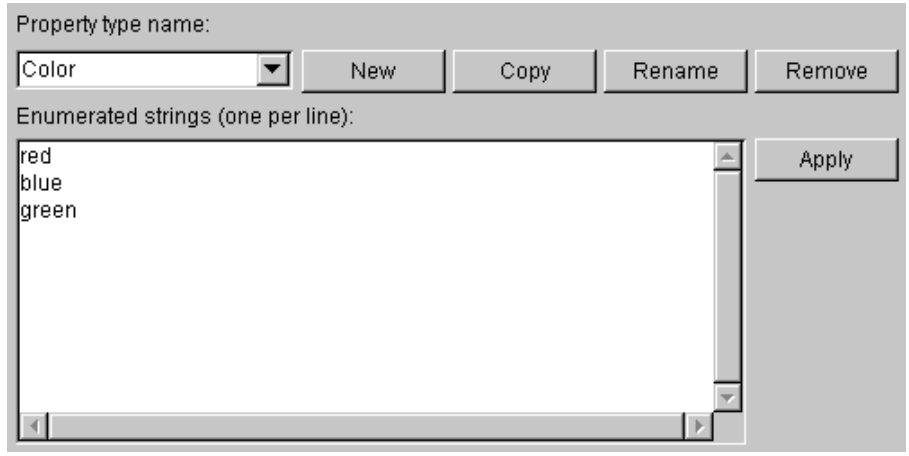
The currently selected package defines an enumerated property type and the type can be referenced only in the package that defines it. However, the name of the enumerated property type must be globally unique. There cannot be any other built-in or user-defined enumerated property type with the same name. 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 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. 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.

Design Minimum and Maximum

In this section...

Use of Design Minimum and Maximum

You can specify the design minimum and maximum for model data such as blocks and data objects. Simulink uses the design minimum and maximum as follows.

- To define a valid range for Simulink parameters and signals and use it in range-checking
- To calculate best-precision scaling for fixed-point data types
- To calculate derived minimum and maximum for model data for which design minimum and maximum are not specified

Valid Values for Design Minimum and Maximum

Simulink no longer allows you to specify the design minimum and maximum as `-Inf/Inf`. The default design minimum or maximum is `[]`.

Previously, you could specify the design minimum and maximum as `-Inf/Inf`. However, this specification is ambiguous.

It may imply that the design minimum and maximum are explicitly specified; in other words, it may imply that the parameter or signal can have any value. It may also imply that the design minimum and maximum are unspecified. While this ambiguity may not have a significant effect on range-checking, it could affect the calculation of derived minimum and maximum or the checking of data type validity.

Note Simulink generates an error or warning when you specify the design minimum and maximum as `-Inf/Inf`.

Avoiding Specifying Infinite Design Minimum or Maximum

There are three sources for the warning Simulink generates if the design minimum and/or maximum are set to `-Inf/Inf`. Each source requires a different solution.

1. MATLAB code
   a. Use error handling tools such as `dbstop` and `lastwarn` to locate the MATLAB code that is setting the design minimum and maximum to `-Inf/Inf`.
   b. Either remove these lines of code from the MATLAB file or replace instances of `-Inf` and `Inf` with `[]`.
2. MAT-file: Resave the MAT-file
3. SLX file: Resave the SLX file

44

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 examples show how to use enumerations in Simulink and Stateflow:

Example	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 "Enumerated Data".

Define Simulink Enumerations

In this section...

Workflow to Define a Simulink Enumeration

1. Create a class definition.
2. Optionally, customize the enumeration.
3. Optionally, save the enumeration in a MATLAB file.

Create 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 "Target" and "Hardware Implementation Pane" for more information.

For more information on superclasses, see "Converting to Superclass Value".

Customize 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 the following static methods from the superclass `Simulink.IntEnumType`. For more information about these methods, see `Simulink.defineIntEnumType`.

Default Method	Description	Default Value Returned or Specified	Usage Context
`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

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 "Type Casting for Enumerations" in the Simulink Coder 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 "Instantiate Enumerations" on page 44-15 for more information.

Save 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.

Change and Reload 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".

Import 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 in which the enumeration is defined for generated code.
- 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 = true)
  function retVal = getDescription()
   retVal = 'Basic colors...';
  end
  function retVal = getDefaultValue()
   retVal = BasicColors.Blue;
  end
  function retVal = getHeaderFile()
   retVal = 'mybasiccolors.h';
  end
  function retVal = addClassNameToEnumNames()
   retVal = true;
  end
 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', ...
     'DataScope', 'Imported', ...
     'AddClassNameToEnumNames', true);
```

Use Enumerated Data in Simulink Models

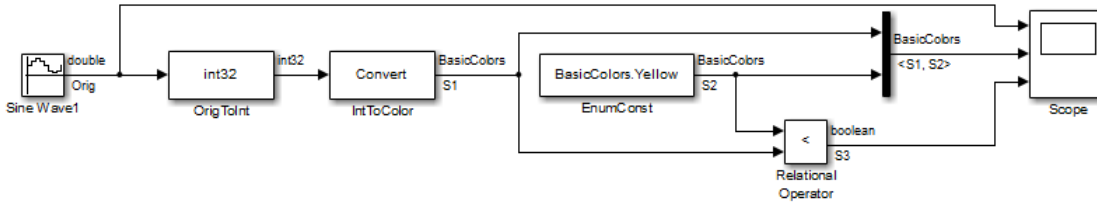
In this section...

Simulate with Enumerations

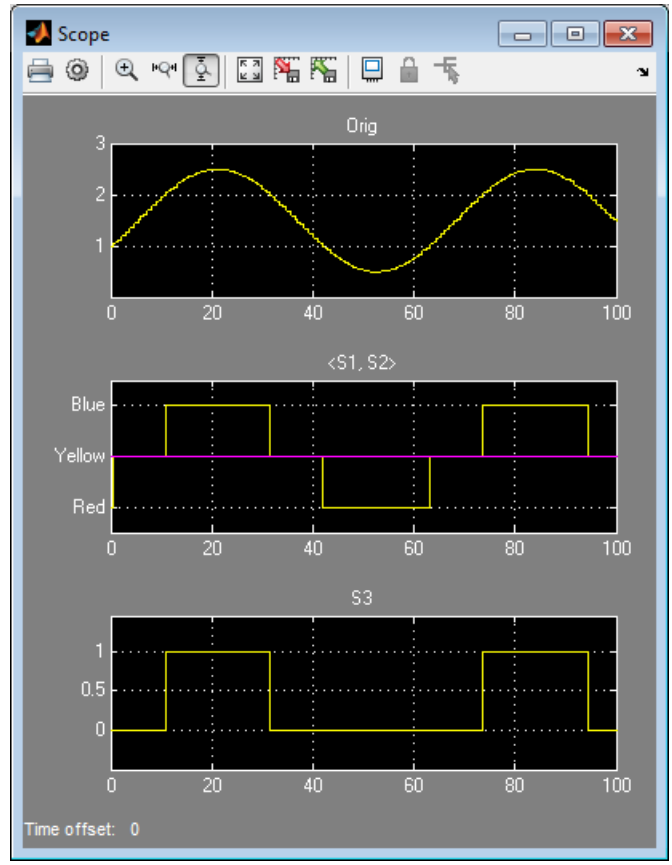
Consider the following enumeration class definition—`BasicColors` with enumerated values `Red`, `Yellow`, and `Blue`, with `Blue` as the default value:

```
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 "Enumerated Data". 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.

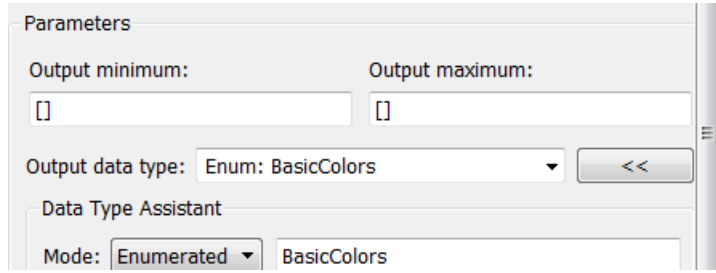
The sort order used by the comparison is the numeric order of the underlying integers of the compared values, *not* the lexical order in which the enumerated values appear in the enumerated class definition. In this example the two orders are the same, but they need not be. See "Specify Enumerations as Data Types" on page 44-12 and "Enumerated Values in Computation" on page 44-19 for more information.

Specify 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. 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 44-19 for more information.

Get 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

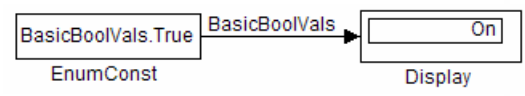
Wherever possible, Simulink software displays enumeration values by name, not by the underlying integer value. However, the underlying integers can affect value display in Scope and Floating Scope blocks.

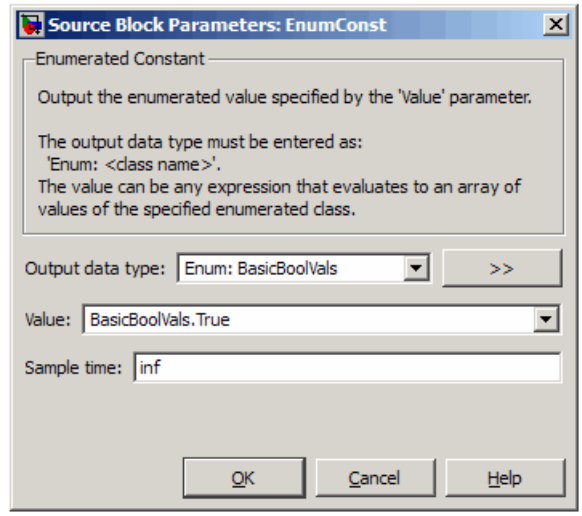
Block...	Affect on Value Display...
Scope	When displaying an enumerated signal, the names of the enumerated values appear as labels on the Y axis. The names appear in the order given by their underlying integers, with the lowest value at the bottom.
Floating Scope	When displaying signals that are of 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 "Specify Enumerations as Data Types" on page 44-12. 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.

Instantiate 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

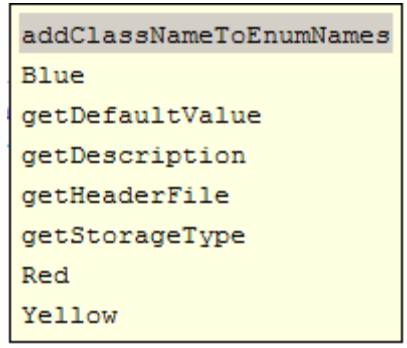
To instantiate an enumeration in MATLAB, enter *`ClassName.EnumName`* in the MATLAB Command Window. The instance is created in the base workspace. For example, if `BasicColors` is defined as in "Create Simulink Enumeration Class" on page 44-3, you can type:

```
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 "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:

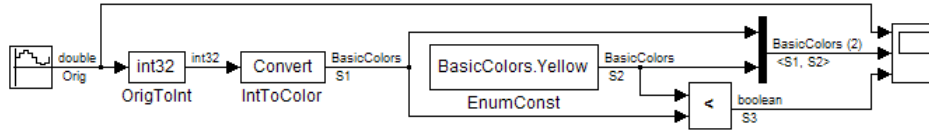
```
>> bci = int32(bcb)

bci =

    2
```

In either case, MATLAB returns the result of the cast in a 1x1 array of the relevant data type.

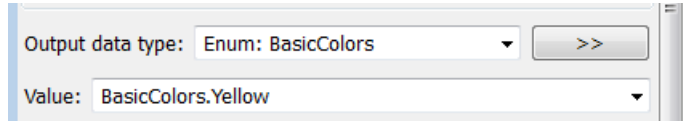
Although casting is possible, use of enumeration values is not robust in cases where enumeration values and the integer equivalents defined for an enumeration class might change.

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:

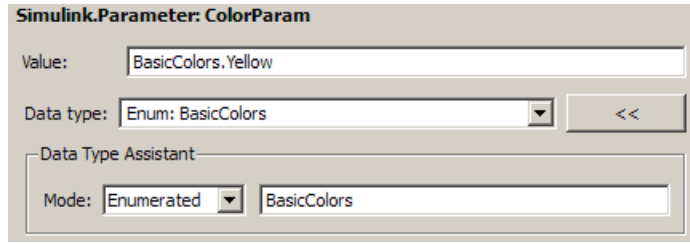


You can enter any valid MATLAB expression that evaluates to an enumerated value, including arrays and workspace variables. For example, you could enter `BasicColors(1)`, or if you had previously executed

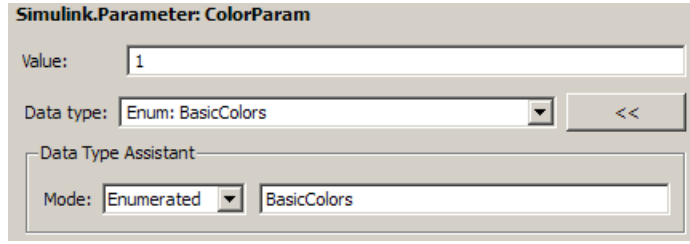
`bcy = BasicColors.Yellow` in the MATLAB Command Window, you could enter `bcy`. As another example, you could enter an array, such as`[BasicColors.Red, BasicColors.Yellow, BasicColors.Blue]` .

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 "Specify Enumerations as Data Types" on page 44-12.



You *cannot* specify the integer value of an enumeration member for the **Value** parameter. See "Enumerated Values in Computation" on page 44-19 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 "Enumerated Data" 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 44-19 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.

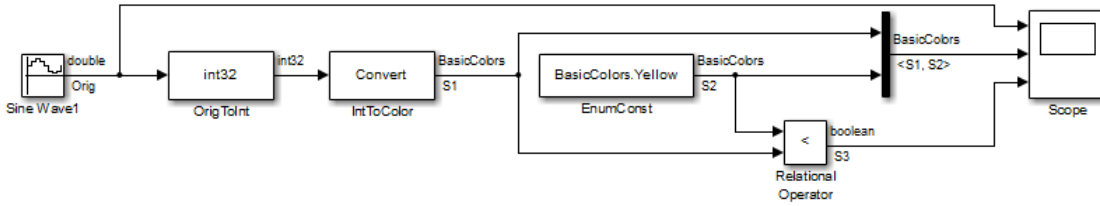
When a block like the Switch block or Multiport Switch block selects among multiple data signals, and any data signal is of an enumerated type, all the data signals must be of that same enumerated type. When a block inputs both control and data signals, as Switch and Multiport Switch do, the control 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.

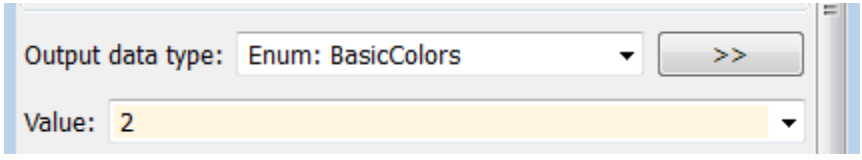
You cannot use a Data Type Conversion block to cast a numeric signal of any non-integer data type to an enumerated type. For example, the model used in "Simulate with Enumerations" on page 44-10 needed two Data Conversion blocks to convert a sine wave to enumerated values.



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.

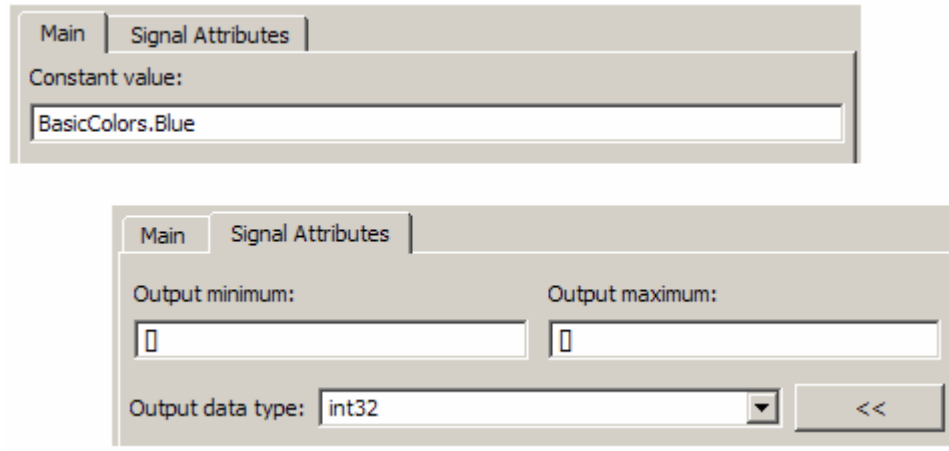
Casting Enumerated Block Parameters

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 44-19 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 44-25 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
- 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
- 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 48-19)
- 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`

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 "Export Runtime Information" 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 "Import 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.
- HDL Coder does not support enumerations.

Importing and Exporting Simulation Data

Using Simulation Data

Working with Simulation Data

During simulation, you can:

- Import input signal and initial state data from a workspace or file.
- Export output signal and state data to a workspace or file.

Exporting (logging) simulation data provides a baseline for analyzing and debugging a model. Use standard or custom MATLAB functions to generate simulated system input signals and to graph, analyze, or otherwise postprocess the system outputs.

Also, import data into a model for testing and analysis.

Export Simulation Data

In this section...

Simulation Data

Simulation data can include any combination of signal, time, output, state, and data store logging data.

Exporting simulation data involves saving signal values to the MATLAB workspace during simulation for later retrieval and postprocessing. Exporting data is also known as "data logging" or "saving simulation data."

You can also import the exported data to use as input for simulating a model.

Approaches for Exporting Signal Data

Exporting simulation data very often involves exporting signal data. You can use a variety of approaches for exporting signal data.

Export Approach	Usage	Documentation
Connect a signal to a Scope block or viewer.	If you use a Scope block for viewing results during simulation, consider also using the Scope block to export data. Document in the diagram the workspace variables used to store signal data. Save output at a sample rate other than the base sample rate.	Scope

Export Approach	Usage	Documentation
	Scopes store data and can be memory intensive.	
Connect a signal to a To File block.	Consider using a To File block for exporting large amounts of data. Document in the diagram the workspace variables used to store signal data. Save output at a sample rate other than the base sample rate. Use the MAT-file only after the simulation has completed.	To File
Connect a signal to a To Workspace block.	Document in the diagram the workspace variables used to store signal data. Save output at a sample rate other than the base sample rate.	To Workspace
Connect a signal to a root-level Outport block.	Consider using this approach for logging data in a top-level model, if the model already includes an Outport block.	Outport
Set the signal logging properties for a signal.	Use signal logging to avoid adding blocks. Log signals based on individual signal rates. Data is available only when simulation is paused or completed.	"Export Signal Data Using Signal Logging" on page 45-19

Export Approach	Usage	Documentation
Configure Simulink to export time, state, and output data.	Consider exporting this data to capture information about the simulation as a whole. Outputs and states are logged at the base sample rate of the model.	"Data Format for Exported Simulation Data" on page 45-8 "Limit Amount of Exported Data" on page 45-14 "Control Samples to Export for Variable-Step Solvers" on page 45-16
Log a data store.	Log a data store to share data throughout a model hierarchy, capturing the order of all data store writes.	"Log Data Stores" on page 46-26
Use the `sim` command to log simulation data programmatically.	Use `sim` to export to one data object the time, states, and signal simulation data. Select the **Return as single object** parameter when simulating the model using the `sim` command inside a function or a `parfor` loop.	`sim`

Enable Simulation Data Export

To export the states and root-level outputs of a model to the MATLAB base workspace during simulation of the model, use one of these interfaces:

- **Configuration Parameters > Data Import/Export** pane (for details, see "Data Import/Export Pane")
- `sim` command

In both approaches, specify:

- The kinds of simulation data that you want to export:
  - Signal logging
  - Time

  - Output
  - State or final state
  - Data store

  Each kind of simulation data export has an associated default variable. You can specify your own variables for the exported data.

- The characteristics of the logged data, including:
  - "Data Format for Exported Simulation Data" on page 45-8
  - "Limit Amount of Exported Data" on page 45-14
  - "Control Samples to Export for Variable-Step Solvers" on page 45-16

View Logged Simulation Data With the Simulation Data Inspector

To inspect exported simulation data interactively, consider using the Simulation Data Inspector tool.

The Simulation Data Inspector has some limitations on the kinds of logged data that it displays. See "Limitations of the Simulation Data Inspector Tool" on page 17-54.

Data Format for Exported Simulation Data

In this section...

Data Format for Block-Based Exported Data

You can use the Scope, To File, or To Workspace blocks to export simulation data. Each of these blocks has a parameter that you use to specify the data format.

Data Format for Model-Based Exported Data

The data format for model-based exporting of simulation data specifies how Simulink stores the exported data.

Simulink uses different data formats, depending on the kind of data that you export. For details, see:

- "Signal Logging Format" on page 45-8
- "Logged Data Store Format" on page 45-9
- "State and Output Data Format" on page 45-9

Signal Logging Format

Use the `Dataset` format for signal logging data in new models. Select the format using the **Configuration Parameters > Data Import/Export > Signal logging format** parameter.

For details, see "Specify the Signal Logging Data Format" on page 45-34.

For backwards compatibility, Simulink supports the `ModelDataLogs` format for signal logging. The `ModelDataLogs` format will be removed in a future release. For details, see " Migrate from ModelDataLogs to Dataset Format" on page 45-35.

Logged Data Store Format

When you log data store data, Simulink uses a `Simulink.SimulationData.Dataset` object.

For details, see "Accessing Data Store Logging Data" on page 46-29.

State and Output Data Format

For exported state, final state, and output data, use one of the following formats:

Array

If you select this `Array` option, Simulink saves the states and outputs of a model 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 states of a model. 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, and each row to the outputs at a specific time.

Note Use array format to save your model outputs and states only if the outputs are:

- Either all scalars or all vectors (or all matrices for states)
- Either all real or all complex
- All of the same data type

Use the `Structure` or `Structure with time` output formats (see "Structure with Time" on page 45-10) if your model outputs and states do not meet these conditions.

Structure with Time

If you select this format, Simulink saves the model states and outputs in structures that have their names specified in the **Save to workspace** area. By default, the structures are `xout` for states and `yout` for output.

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 example shows 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 states of the model.

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. Each row corresponds to a time sample of the state, and the first two elements of each row correspond to the first column of the sample. The last two elements correspond to the second column of the sample.

Note Simulink can read back simulation data saved to the MATLAB workspace in the `Structure with time` output format. See "Examples of Specifying Signal and Time Data" on page 45-111 for more information.

Structure

This format is the same as for `Structure with time` output format, except that Simulink does not store simulation times in the `time` field of the saved structure.

Per-Port Structure

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.

Limit Amount of Exported Data

In this section...

Decimation

To skip samples when exporting data, apply a decimation factor. For example, a decimation factor of 2 saves every other sample.

The approach you use to specify a decimation factor depends on the kind of logging data.

Kind of Data	How to Specify
Signal logging	Right-click the signal. In the Signal Properties dialog box, select the **Decimation** parameter.
Data store logging	From the block parameters dialog box for that block, open the **Logging** tab. Apply a decimation factor using the **Decimation** parameter.
State and output	Enter a value in the field to the right of the **Decimation** label.

Limit Data Points to Last

To limit the number of samples saved to be only the most recent samples, set the **Limit Data Points to Last** parameter.

The approach you use depends on the kind of logging data.

Kind of Data	How to Specify
Signal logging	Right-click the signal. In the Signal Properties dialog box, select the **Limit Data Points to Last** parameter.
Data store logging	From the block parameters dialog box for that block, open the **Logging** tab. Select the **Limit Data Points to Last** parameter.
State and output	Enter a value in the field to the right of the **Limit Data Points to Last** label.

Control Samples to Export for Variable-Step Solvers

In this section...

Output Options

Use the **Output options** list on the **Data Import/Export** configuration pane to control how much output the simulation generates when your model uses a variable-step solver. Consider using one or more of these options:

- `Refine output`
- `Produce additional output`
- `Produce specified output only`

For details, see "Data Import/Export Pane".

Refine Output

The `Refine output` option 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.

Suppose that 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
```

To get smoother output more efficiently, 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. However, when you graph simulation output, the output from this solver sometimes is not sufficiently smooth. In such cases, 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, although it does not ensure that Simulink detects all zero crossings (see "Zero-Crossing Detection" on page 3-23).

Produce 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. In this field, enter a MATLAB expression that evaluates to an additional time or a vector of additional times. The solver produces hit times at the output times you have specified, in addition to the times it needs to accurately simulate the model.

Suppose that a sample simulation generates output at these times:

```
0, 2.5, 5, 8.5, 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.

Note This option helps the solver locate zero crossings, although it does not ensure that Simulink detects all zero crossings (see "Zero-Crossing Detection" on page 3-23).

Produce 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.

Suppose that a sample simulation generates output at these times:

```
0, 2.5, 5, 8.5, 10
```

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
```

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 option 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, although it does not ensure that Simulink detects all zero crossings (see "Zero-Crossing Detection" on page 3-23).

Export Signal Data Using Signal Logging

In this section...

Signal Logging

Use signal logging to capture signal data from a simulation. To enable signal logging, set the signal logging property for individual signals and enable signal logging for a model. For details, see "Configure a Signal for Signal Logging" on page 45-21 and "Enable Signal Logging for a Model" on page 45-34.

For a summary of other approaches to capture signal data, see "Export Simulation Data" on page 45-4.

Signal Logging Workflow

Signal logging involves this general workflow:

1. Configure individual signals for signal logging, including controlling how much output the simulation generates. See "Configure a Signal for Signal Logging" on page 45-21.
2. (Optional) Review the signal logging configuration for a model. See "View Signal Logging Configuration" on page 45-27.
3. Enable signal logging globally for a model. See "Enable Signal Logging for a Model" on page 45-34.
4. Specify the format for the logged signal data. See "Specify the Signal Logging Data Format" on page 45-34.
5. (Optional) Specify a name for the signal logging data. See "Specify Logging Name" on page 45-23.
6. (Optional) Specify which samples to export for models with variable-step solvers. See "Limit the Data Logged for a Signal" on page 45-25.

7 (Optional) Configure the model to display signal logging data in the Simulation Data Inspector. See “View Logged Signal Data with the Simulation Data Inspector” on page 45-54.

8 (Optional) Override the signal logging property settings in the model or referenced models. See “Override Signal Logging Settings” on page 45-41.

9 Simulate the model.

10 Access the signal logging data. See “Access Signal Logging Data” on page 45-53.

Signal Logging Limitations

- Rapid Accelerator mode does not support signal logging. For more information, see “Behavior of Scopes and Viewers with Rapid Accelerator Mode” on page 22-18.

  Top-model software-in-the-loop (SIL) and processor-in-the-loop (PIL) simulation modes support signal logging. For a description of limitations of signal logging using SIL and PIL modes, see “Internal Signal Logging Support” in the Embedded Coder documentation.

- You cannot log local data in Stateflow Truth Table blocks.

Configure a Signal for Signal Logging

In this section...

Enable Logging for a Signal

Enable logging for a signal with *one* of the following techniques:

- "Signal Properties Dialog Box" on page 45-21
- "Model Explorer" on page 45-22
- "Programmatic Interface" on page 45-22

You can use the Model Explorer to enable signal logging for several signals at once, compared to opening the Signal Properties dialog box repeatedly for each signal that you want to log. However, the Model Explorer:

- Does not display unnamed signals
- Might need to be reconfigured to display the `DataLogging` property (which sets up logging for a signal)

A signal for which you enable signal logging is a *logged signal*. By default, Simulink displays a logged signal indicator () for each logged signal.

Signal Properties Dialog Box

1. In the Simulink Editor, right-click the signal.
2. From the context menu, select **Signal Properties**.
3. In the Signal Properties dialog box, in the **Logging and accessibility** tab, select **Log signal**.

Model Explorer

Note The only signals that Model Explorer displays are named signals. See "Signal Names" on page 47-19.

1. In the Model Explorer **Model Hierarchy** pane, select the node that contains the signal for which you want to enable signal logging.
2. If the **Contents** pane does not display the `DataLogging` property, set the **Column view** to `Signals` or add the `DataLogging` property to the current view. For details about column views, see "Control Model Explorer Contents Using Views" on page 9-26.
3. Enable the `DataLogging` property for one or more signals.

Programmatic Interface

To enable signal logging programmatically for selected blocks, use the outport `DataLogging` property. Set this property using the `set_param` command. For example:

1. At the MATLAB Command Window, open a model. Type

   ```
   vdp
   ```

2. Get the port handles of the signal to log. For example, for the Mu block outport signal.

   ```
   ph = get_param('vdp/Mu','PortHandles')
   ```

3. Enable signal logging for the desired outport signal.

   ```
   set_param(ph.Outport(1),'DataLogging','on')
   ```

   The logged signal indicator appears.

Logging Referenced Model Signals

You can log any logged signal in a referenced model. Use the Signal Logging Selector to configure signal logging for a model reference hierarchy. For

details, see "Models with Model Referencing: Overriding Signal Logging Settings" on page 45-45.

If you use the `ModelDataLogs` signal logging format, then you can also use test points to log data in referenced models (but not for a top-level model). For information about test points, see "Designating a Signal as a Test Point" on page 47-58. However, MathWorks recommends using the `Dataset` format for signal logging. For a description of the benefits of using the `Dataset` format, see "Signal logging format". The `Dataset` format supports using test points for logging in referenced models for signals that you configure for signal logging.

Specify Logging Name

You can specify a name, called the logging name, to the object that Simulink uses to store logging data for a signal. Specifying a logging name can be useful for signals that are unnamed or that share a duplicate name with another signal in the model hierarchy. Specifying logging names, rather than using the logging names that Simulink generates, can make the logged data easier to analyze.

Note The logging name is for a specific signal. The logging name is distinct from the signal logging name, which is the name for the object containing all the logged signal data for a model. The default signal logging name is `logsout`. For details about the signal logging name, see "Specify a Name for the Signal Logging Data" on page 45-40.

To specify a logging name, use *one* of the following approaches:

- "Using the Signal Properties Dialog Box to Specify a Logging Name" on page 45-24
- "Using the Model Explorer to Specify a Logging Name" on page 45-24
- "Programmatically Specifying a Logging Name" on page 45-24

If you do not specify a custom logging name, Simulink uses the signal name. If the signal does not have a name, the action Simulink takes depends on the signal logging format:

- `Dataset` — Uses a blank name
- `ModelDataLogs` — 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 name `SL_MyBlock1`.

Using the Signal Properties Dialog Box to Specify a Logging Name

1. In the Simulink Editor, right-click the signal.
2. From the context menu, select **Signal Properties**.
3. Specify the logging name:
   a. In the Signal Properties dialog box, select the **Logging and accessibility** tab.
   b. From the **Logging name** list, select `Custom`.
   c. Enter the logging name in the adjacent text field.

Using the Model Explorer to Specify a Logging Name

1. In the Model Explorer **Model Hierarchy** pane, select the node that contains the signal for which you want to specify a logging name.
2. If the **Contents** pane does not display the `LoggingName` property, add the `LoggingName` property to the current view. For details about column views, see "Control Model Explorer Contents Using Views" on page 9-26.
3. Enter a logging name for one or more signals using the `LoggingName` column.

Programmatically Specifying a Logging Name

Enable signal logging programmatically for selected blocks with the outport `DataLogging` property. Set this property using the `set_param` command.

1. At the MATLAB Command Window, open a model. For example, type:

```
vdp
```

2. Get the port handles of the signal to log. For example, for the Mu block outport signal:

```
ph = get_param('vdp/Mu','PortHandles');
```

3. Enable signal logging for the desired outport signal:

```
set_param(ph.Outport(1),'DataLogging','on');
```

The logged signal indicator appears.

4. Issue commands that use the `DataLoggingNameMode` and `DataLoggingName` parameters. For example:

```
set_param(ph.Outport(1),'DataLoggingNameMode','Custom');
set_param(ph.Outport(1),'DataLoggingName','x2_log');
```

Limit the Data Logged for a Signal

You can limit the amount of data logged for a signal by:

- Specifying a decimation factor
- Limiting the number of samples saved to be only the most recent samples

For details, see "Limit Amount of Exported Data" on page 45-14.

To limit data logged for a signal, use either the Signal Properties dialog box or the Model Explorer. The following two sections describe how to use each of these interfaces.

Using the Signal Properties Dialog Box to Limit the Amount of Data Logged

1. In the Simulink Editor, right-click the signal.
2. From the context menu, select **Signal Properties**.
3. In the Signal Properties dialog box, click the **Logging and accessibility** tab. Then select one or both of these options:

- **Limit data points to last**
- **Decimation**

Using the Model Explorer to Limit Data Logged

1. In the Model Explorer **Model Hierarchy** pane, select the node that contains the signal for which you want to limit the amount of data logged.
2. If the **Contents** pane does not display the `DataLoggingDecimation` property or the `DataLoggingLimitDataPoints` property, add one or both of those properties to the current view. For details about column views, see "Control Model Explorer Contents Using Views" on page 9-26.
3. To specify a decimation factor, edit the `Decimation` and `DecimateData` properties. To limit the number of samples logged, edit the `LimitDataPoints` property.

View Signal Logging Configuration

In this section...

Approaches for Viewing the Signal Logging Configuration

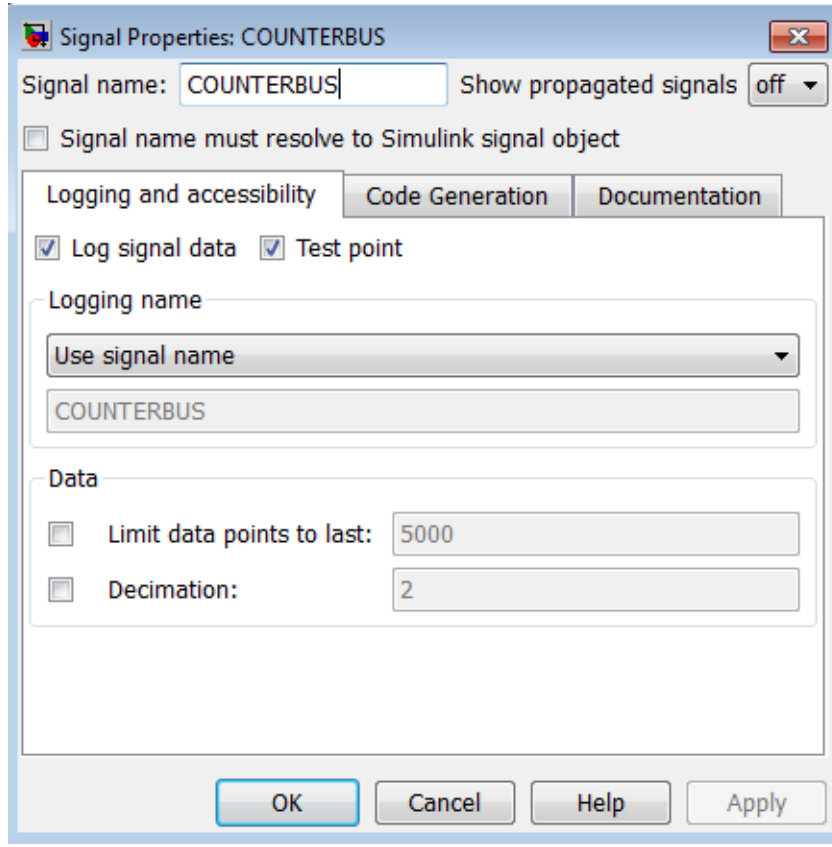
Signal Logging Configuration Viewing Approach	Usage	Documentation
In the Simulink Editor, view signal logging indicators.	Consider using this approach for models with few signals configured for signal logging and the model hierarchy is shallow. This approach avoids leaving the Simulink Editor. You need to open the Signal Properties dialog box for each signal.	"Use Simulink Editor to View Signal Logging Configuration" on page 45-28
Use the Signal Logging Selector.	Consider using for models with deep hierarchies. View a model that has signal logging override settings for some signals. View the configuration as part of specifying a subset of	"Use Signal Logging Selector to View Signal Logging Configuration" on page 45-30

Signal Logging Configuration Viewing Approach	Usage	Documentation
	signals to log from all signals configured for signal logging. View signal logging configuration without displaying the signal logging indicators in the model. View signal logging configuration information such as decimation and output options in one window.	
Use the Model Explorer.	View signal logging configuration in the context of other model component properties. You may need to adjust the column view to display signal logging properties.	"Use Model Explorer to View Signal Logging Configuration" on page 45-32

Use Simulink Editor to View Signal Logging Configuration

By default, Simulink Editor displays an indicator on each signal that is set up to log signal data. To view the signal logging setting for a signal:

1. Right-click the signal, and from the context menu, select **Signal Properties**.
2. Select the **Logging and accessibility** tab.



For example, in the following model the output of the Sine Wave block is logged:

If you use the command-line interface to override logging for a signal, the Simulink Editor continues to display the sign logging indicator for that signal in the Simulink Editor. When you simulate the model, Simulink displays a red signal logging indicator for all signals configured to be logged,

reflecting any overrides. For details about configuring a signal for logging, see "Configure a Signal for Signal Logging" on page 45-21.

A logged signal can also be a test point. See "Test Points" on page 47-58 for information about test points.

To turn the display of logging indicators off, clear **Display > Signals & Ports > Testpoint & Logging Indicators**.

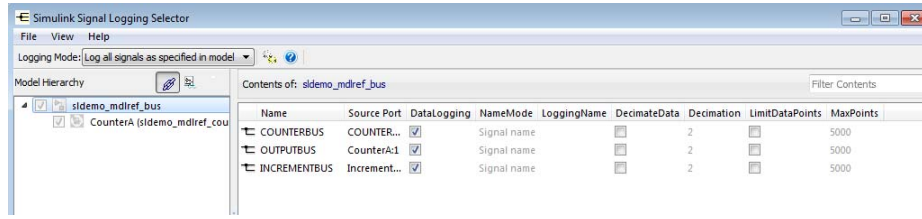
Use Signal Logging Selector to View Signal Logging Configuration

1. Open the model for which you want to view the signal logging configuration.
2. Open the Signal Logging Selector, using one of the following approaches:
   - In the **Configuration Parameters > Data Import/Export** pane, in the **Signals** area, select the **Configure Signals to Log** button.

     If necessary, select **Signal logging** to enable the **Configure Signals to Log** button.
   - For a model that includes a Model block, you can also use the following approach:

     a. In the Simulink Editor, right-click a Model block.

     b. In the context-menu, select **Log Referenced Signals**.
3. In the **Model Hierarchy** pane, select the model node for which you want to view the signal logging configuration. For example:



To expand a node in the **Model Hierarchy** pane, right-click that the arrow to the left of the node.

If there are no logged signals for a node, the **Contents** pane is empty.

If you open the Signal Logging Selector for a model that uses model referencing, then in the **Model Hierarchy** pane, the check box to the left of a model node indicates the override configuration of the node.

Check Box	Signal Logging Configuration
	For the top-level model node, logs all logged signals in the top model. For a Model block node, logs all logged signals in the model reference hierarchy for that block.
	For the top-level model node, disables logging for all logged signals in the top model. For a Model block node, logs disables logging for all signals in the model reference hierarchy for that block.
	For the top-level model node, logs all logged signals that have the `DataLogging` setting enabled. For a Model block node, logs all logged signals in the model reference hierarchy for that block that have the `DataLogging` setting enabled.

Viewing the Signal Logging Configuration for Subsystems, Masked Subsystems, and Linked Libraries

The following table describes default **Model Hierarchy** pane display of subsystems, masked subsystems, and linked library nodes.

Node	Display Default
Subsystem	Displays all that include logged signals
Masked subsystem	Does not display
Linked library	Displays all that include logged signals

You can control how the **Model Hierarchy** pane displays subsystems, masked subsystems, and linked libraries. To do control how , use icons at the top of the **Model Hierarchy** pane or use the **View** menu, using the same approach as you use in the Model Explorer. For details, see "Displaying Linked Library Subsystems" on page 9-13 and "Displaying Masked Subsystems" on page 9-14.

- To display all subsystems, including subsystems that do not include logged signals, select the icon or **View > Show All Subsystems**. This subsystem setting also applies to masked subsystems, if you specify to display masked subsystems.
- To display masked subsystems with logged signals, use the icon or **View > Show Masked Subsystems**
- To display linked libraries, use the icon or **View > Show Library Links**

Filtering Signal Logging Selector Contents

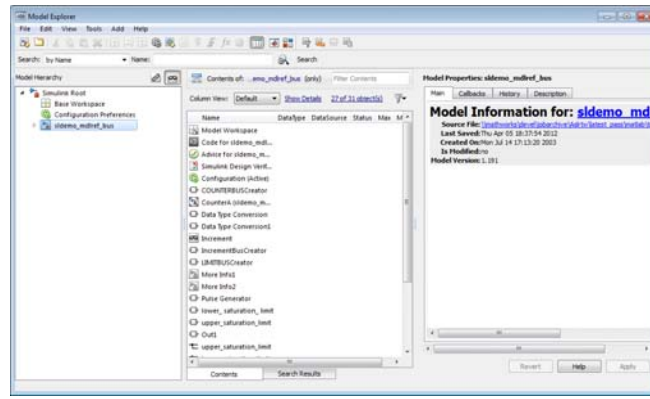
To find a specific signal or property value for a signal, use the **Filter Contents** edit box. Use the same approach as you use in the Model Explorer; for details, see "Filtering Contents" on page 9-48.

Highlighting a Block in a Model

To use the Model Hierarchy pane to highlight a block in model, right-click the block or signal and select **Highlight block in model**.

Use Model Explorer to View Signal Logging Configuration

1. Open the model for which you want to view the signal logging configuration. Select the top-level model in a model reference hierarchy gives you to access to logging configuration information for referenced models.
2. In the **Contents** pane, set **Column View** to the `Signals` view.



For further information, see “Model Explorer: Model Hierarchy Pane” on page 9-9 and “Model Explorer: Contents Pane” on page 9-19.

Enable Signal Logging for a Model

In this section...

Enable and Disable Logging Globally for a Model

You enable or disable logging globally for logged signals in a model. By default, signal logging is enabled. Simulink logs signals only if the **Signal logging** parameter is checked. If the option is not checked, Simulink ignores the signal logging settings for individual signals.

To disable signal logging, use *one* of these approaches:

- Clear the **Configuration Parameters > Data Import/Export > Signal logging** parameter.
- Use the `SignalLogging` parameter. For example:

```
set_param(bdroot, 'SignalLogging', 'off')
```

Selecting a Subset of Signals to Log

You can select a subset of signals to log for a model that has:

- Signal logging enabled
- Logged signals

For details, see "Override Signal Logging Settings" on page 45-41.

Specify the Signal Logging Data Format

The signal logging format determines how Simulink stores the logged signal data. You can store the data using either the `Dataset` or `ModelDataLogs` format.

Set the Signal Logging Format

To set the signal logging format, use either of these approaches:

- Set the **Configuration Parameters > Data Import/Export > Signal logging format** parameter to either `Dataset` (default) or `ModelDataLogs`.
- Use the `SignalLoggingSaveFormat` parameter, with a value of `Dataset` or `ModelDataLogs`. For example:

```
set_param(bdroot, 'SignalLoggingSaveFormat', 'Dataset')
```

Use the Dataset Format for Signal Logging in New Models

Use the `Dataset` format for signal logging for new models. The `ModelDataLogs` format is supported for backwards compatibility. The `ModelDataLogs` format will be removed in a future release.

The `Dataset` format:

- Uses MATLAB `timeseries` objects to store logged data , which allows you to work with logging data in MATLAB without a Simulink license. For example, to manipulate the logged data, you can use MATLAB timeseries methods such as `filter`, `detrend`, and `resample`.
- Supports logging multiple data values for a given time step, which can be important for Iterator subsystem and Stateflow signal logging.
- Provides an easy to analyze format for logged signal data for models with deep hierarchies, bus signals, and signals with duplicate or invalid names.
- Avoids the limitations of the `ModelDataLogs` format, which Bug Report 495436 describes.

When you specify the `Dataset` format, Simulink stores the data using a `Simulink.SimulationData.Dataset` object.

Migrate from ModelDataLogs to Dataset Format

The `ModelDataLogs` logging format is supported for backwards compatibility. The `ModelDataLogs` format will be removed in a future release. To enable existing models that use `ModelDataLogs` format to continue to work in future releases, migrate those models to use `Dataset` format.

Use the Upgrade Advisor to upgrade a model to use `Dataset` format, using *one* of these approaches:

- In the Simulink Editor, select **Analysis > Model Advisor > Upgrade Advisor**
- From the MATLAB command line, use the `upgradeadvisor` function.

If you have already logged signal data in the `ModelDataLogs` format, you can use the `Simulink.ModelDataLogs.convertToDataset` function to update the `ModelDataLogs` signal logging dataset to use `Dataset` format. For example, to update the `older_model_dataset` from `ModelDataLogs` format to `Dataset` format:

```
new_dataset = logsout.convertToDataset('older_model_dataset')
```

Depending upon your particular circumstances, converting a model from using `ModelDataLogs` format to using `Dataset` format may require that you make some modifications to your existing models and to code in callbacks, functions, scripts, or tests. The following table identifies possible issues that you may need to address after converting to `Dataset` format. The table provides solutions for each issue.

Possible Issue After Conversion to Dataset Format	Solution

Code in existing callbacks, functions, scripts, or tests that used the `ModelDataLogs` programmatic interface to access data may result in an error.	Check for code that uses `ModelDataLogs` format access methods. Update that code to use `Dataset` format access methods.
	For example, suppose existing code includes the following line:
	`logsout.('Subsystem Name').X.data`
	Replace that code with a `Dataset` access method:
	`logsout.get('x').Values.Data`
	or

Possible Issue After Conversion to Dataset Format	Solution
	`logsout.getElement('x').Values.Data`
Logging bus signals requires a configuration parameter change.	Logging buses in `Dataset` format requires that **Configuration Parameters > Diagnostics > Connectivity > Mux blocks used to create bus signals** be set to `error`. To configure a model for proper bus usage, run the Upgrade Advisor with the **Check for proper bus usage** check.
Mux block signal names are lost.	The `Dataset` format treats Mux block signals as a vector. If you need to identify signals by signal names, replace Mux blocks with a Bus Creator blocks. Set **Configuration Parameters > Diagnostics > Connectivity > Mux blocks used to create bus signals** to `error`.
Signal Viewer cannot be used for signal logging.	If you use the `Dataset` format for signal logging, then Simulink does not log the signals configured to be logged in the Signal Viewer. Explicitly mark the signal for signal logging by using the Signal Properties dialog box. To access the Signal Properties dialog box, right-click a signal and from the context menu, select **Properties**.

Possible Issue After Conversion to Dataset Format	Solution
The `unpack` method generates an error.	The unpack method, which is supported for `Simulink.ModelDataLogs` and `Simulink.SubsysDataLogs` objects, is *not* supported for `Simulink.SimulationData.Dataset` objects. For example, if the logged data has three fields: `x`, `y`, and `z`, then: • For `ModelDataLogs` format data, the `mlog.unpack` method creates three variables in the base workspace. • For `Dataset` format data, access methods by names. For example: `x = logsout.get('x').Values`
The `ModelDataLogs` and `Dataset` formats have different naming rules for unnamed signals.	If necessary, add signal names. • In `ModelDataLogs` format, for an unnamed signal coming from a block, Simulink assigns a name in this form: `SL_BlockName+<portIndex>` For example, `SL_Gain1`. • In `Dataset` format, elements do not need a name, so Simulink leaves the signal name empty. • For both `ModelDataLogs` and `Dataset` formats, Simulink assigns the same name to unnamed signals that come from Bus Selector blocks.

Possible Issue After Conversion to Dataset Format	Solution
Test points in referenced models are not logged.	Consider enabling signal logging for test points in a referenced model.
Running or updating a model that uses model referencing might return a signal logging format inconsistency error.	Follow the approach described in "Model Reference Signal Logging Format Consistency" on page 45-39.

Model Reference Signal Logging Format Consistency

If signal logging is enabled for a top model, then the signal logging format for the non-protected referenced models must be the same as the signal logging format for the top model.

Simulink performs signal logging format consistency checking during model update or when you run a simulation. Simulink does not report inconsistencies during code generation for model reference simulation target code.

If Simulink reports a signal logging format inconsistency, then use *one* of the following approaches:

- Use the Upgrade Advisor (with the `upgradeadvisor` function) to upgrade a model to use `Dataset` format.
- Use the `Simulink.SimulationData.updateDatasetFormatLogging` function to convert a model and its referenced models to use `Dataset` format for signal logging.
- Turn off signal logging for the model, including for all referenced models, by clearing the **Configuration Parameters > Data Import/Export > Signal logging** parameter check box.
- Disable logging for all signals in this top-level Model block.

  1 Select the **Configuration Parameters > Data Import/Export > Configure Signals to Log** button.

2 In the Signal Logging Selector dialog box, in the **Model Hierarchy** pane, clear the check box for the top Model block in the model reference hierarchy that generated the error.

Specify a Name for the Signal Logging Data

You use the signal logging name to access the signal logging data. The default name for the signal logging data is `logsout`. Specifying a signal logging name can make it easier to identify the source of the logged data. For example, you could specify the signal logging name `car_logsout` to identify the data as being the signal logging data for the `car` model.

To specify a different signal logging name, use either of these approaches:

- In the edit box next to the **Configuration Parameters > Data Import/Export > Signal logging** parameter, enter the signal logging name.
- Use the `SignalLoggingName` parameter, specifying a signal logging name. For example:

```
set_param(bdroot, 'SignalLoggingName', 'heater_model_signals')
```

Override Signal Logging Settings

In this section...

Benefits of Overriding Signal Logging Settings

As you develop a model, you may want to override the signal logging settings for a specific simulation run. You can override signal logging properties without changing the model in the Simulink Editor. Override signal logging properties to reduce memory overhead and to facilitate the analysis of simulation logging results.

Overriding signal logging properties is useful when you want to:

- Focus on only a few logged signals by disabling logging for most of the logged signals
- Exclude a few signals from the signal logging output
- Override specific signal logging properties, such as decimation, for a signal
- Collect only what you need when running multiple test vectors

Two Interfaces for Overriding Signal Logging Settings

Use either of two interfaces to override signal logging settings:

- "Signal Logging Selector" on page 45-42
- "Command-Line Interface for Overriding Signal Logging Settings" on page 45-48

You can use a combination of the two interfaces. The Signal Logging Selector creates `Simulink.SimulationData.ModelLoggingInfo` objects when saving the override settings. The command-line interface has properties whose names correspond to the Signal Logging Selector interface. For example, the `Simulink.SimulationData.ModelDataLoggingInfo` class has a `LoggingMode` property, which corresponds to the **Logging Mode** parameter in the Signal Logging Selector.

Scope of Signal Logging Setting Overrides

When you override signal logging settings, Simulink uses those override settings when you simulate the model.

Simulink saves in the model the signal logging override configuration that you specify. However, Simulink does not change the signal logging settings in the Signal Properties dialog box for each signal in the model.

In the Signal Logging Selector, if you override some signal logging settings, and then set the **Logging Mode** to `Log all signals as specified in model`, the logging settings defined in the model appear in the Signal Logging Selector. The override settings are greyed out, indicating that you cannot override these settings. To reactivate the override settings, set **Logging Mode** to `Override signals`.

If you close and reopen the model, the logging setting overrides that you made are in effect, if logging mode is set to override signals for that model. When the model displays the signal logging indicators, it displays the indicators for all logged signals, including logged signals that you have overridden.

To use the signal logging settings that the model defines, set the logging mode to use the logging settings defined in the model. That setting causes all logged signals to be included in the signal logging data, ignoring any overrides. Using the Signal Logging Selector to override logging for a specific signal does not affect the signal logging indicator for that signal.

Signal Logging Selector

1 Open the Signal Logging Selector, using one of the following approaches:

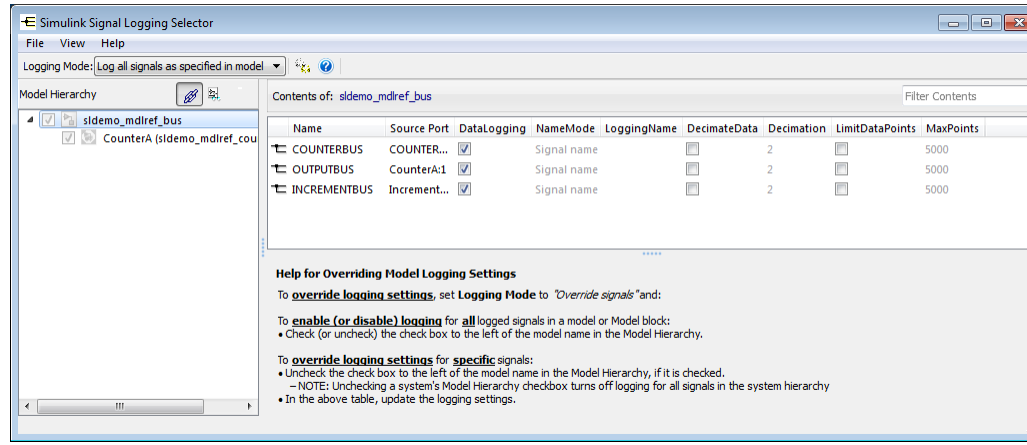
- In the **Configuration Parameters > Data Import/Export** pane, in the **Signals** area, select the **Configure Signals to Log** button.

  If necessary, select **Signal logging** to enable the **Configure Signals to Log** button.

- For a model that includes a Model block, you can also use the following approach:

  a In the Simulink Editor, right-click a Model block.

  b In the context-menu, select **Log Referenced Signals**.



2 Set **Logging Mode** to `Override signals`.

Note The `Override signals` setting affects all levels of the model hierarchy. This setting can result in turning off logging for any signal throughout the hierarchy, based on existing settings. To review settings, select the appropriate node in the **Model Hierarchy** pane.

---

3 View the node containing the logged signals that you want to override. If necessary, expand nodes or configure the Model Hierarchy pane to display masked subsystems. See “Use Signal Logging Selector to View Signal Logging Configuration” on page 45-30.

4 Override signal logging settings. Use one of the following approaches, depending on whether or not your model uses model referencing:

- "Models Without Model Referencing: Overriding Signal Logging Settings" on page 45-44
- "Models with Model Referencing: Overriding Signal Logging Settings" on page 45-45

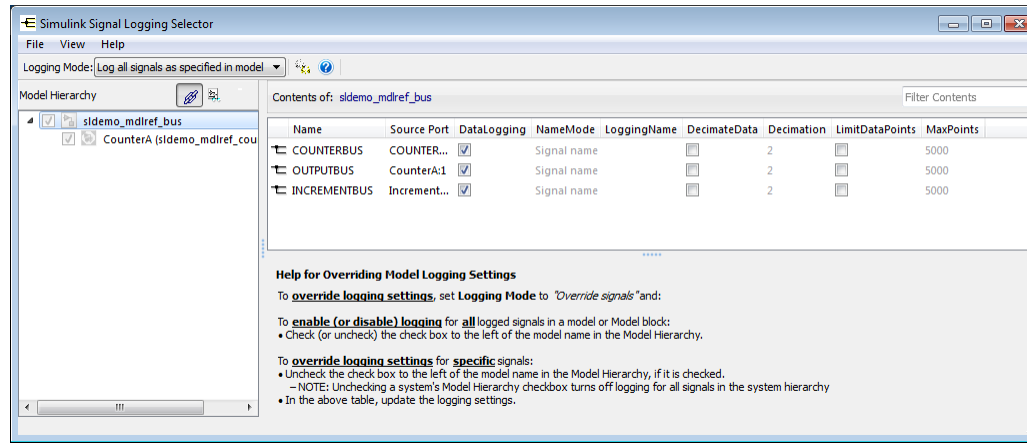
Note To open the **Configuration Parameters > Data Import/Export** pane from the Signal Logging Selector, use the  button.

Models Without Model Referencing: Overriding Signal Logging Settings

If your model does not use model referencing (that is, the model does not include any Model blocks), override signal logging settings using the following procedure.

1 Open the Signal Logging Selector. In the **Configuration Parameters > Data Import/Export** pane, in the **Signals** area, select the **Configure Signals to Log** button.

- If necessary, select **Signal logging** to enable the **Configure Signals to Log** button.



2. Set **Logging Mode** to `Override signals`.

3. View the node containing the logged signals that you want to override. If necessary, expand nodes or configure the Model Hierarchy pane to display masked subsystems. See "Use Signal Logging Selector to View Signal Logging Configuration" on page 45-30.

4. In the **Contents** pane table, select the signal whose logging settings you want to override.

5. Override logging settings:

   - To disable logging for a signal, clear the `DataLogging` check box for that signal.
   - To override other signal logging settings (for example, decimation), ensure that the `DataLogging` check box is selected. Then, edit values in the appropriate columns.

Models with Model Referencing: Overriding Signal Logging Settings

If your model uses model referencing (that is, the model includes at least one Model block), override signal logging settings using the one or more of the following procedures:

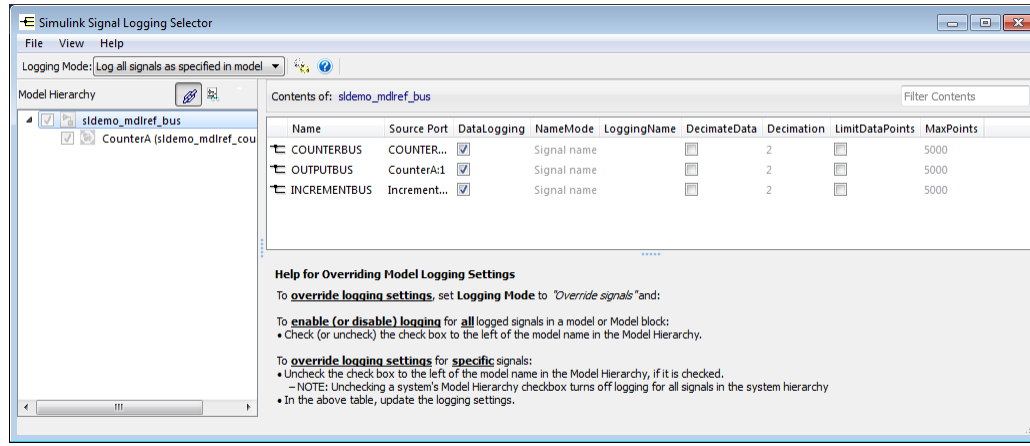
- "Enable Logging for All Logged Signals" on page 45-46

Enable Logging for All Logged Signals. By default, Simulink logs all the logged signals in a model, including the logged signals throughout model reference hierarchies.

If logging is disabled for any logged signals in the top-level model or in the top-level Model block in a model reference hierarchy, then in the **Model Hierarchy** pane, the check box to the left of that node is either) or empty ().

To enable logging of all logged signals for a node:

1. Perform the steps 1–3 in "Signal Logging Selector" on page 45-42.
2. Open the Signal Logging Selector. In the **Configuration Parameters > Data Import/Export** pane, in the **Signals** area, select the **Configure Signals to Log** button.
   - If necessary, select **Signal logging** to enable the **Configure Signals to Log** button.



3 Set **Logging Mode** to `Override signals`.

4 View the node containing the logged signals that you want to override. If necessary, expand nodes or configure the Model Hierarchy pane to display masked subsystems. See "Use Signal Logging Selector to View Signal Logging Configuration" on page 45-30.

5 In the **Model Hierarchy** pane, select the check box to the left of the node, so that the check box has a check mark ().

- For the top-level model, logging is enabled for all logged signals in the top-level model, but not for logged signals in model reference hierarchies.
- For a Model block at the top of a model referencing hierarchy, logging is enabled for the whole model reference hierarchy for the selected referenced model.

Disable Logging for All Logged Signals in a Model Node. If signal logging is enabled for any signals in a model node, then in the **Model Hierarchy** pane, the check box to the left of the node is either checked () or solid blue ().

To disable logging for all logged signals in a node of a model:

1 Perform the steps 1–3 in "Signal Logging Selector" on page 45-42.

2 In the **Model Hierarchy** pane, clear the check box to the left of the node, so that the check box is empty ().

- For the top-level model, logging is disabled for all logged signals in the top-level model, but not for logged signals in model reference hierarchies.
- For a Model block at the top of a model referencing hierarchy, logging is disabled for the whole model reference hierarchy for the selected reference model.

Override Signal Logging for a Subset of Signals. To log some, but not all, logged signals in a model node:

1 Perform the steps 1–3 in "Signal Logging Selector" on page 45-42.

2 In the **Model Hierarchy** pane, ensure that the check box for the top-level model or Model block is either solid blue  or  . Click the check box to cycle through different states.

3 In the **Contents** pane table, for the signals that you want to log, select the check box in the `DataLogging` column.

   To enable logging for multiple signals, hold the **Shift** or **Ctrl** key and select a range of signals or individual signals. Select the check box in the `DataLogging` column of one of the highlighted signals.

Override Other Signal Logging Properties. In addition to overriding the setting for the `DataLogging` property for a signal, you can override other signal logging properties, such as decimation.

1 Perform the steps 1–3 in "Signal Logging Selector" on page 45-42.

2 In the **Model Hierarchy** pane, ensure that the check box for the top-level model or Model block is solid blue  or  . Click the check box to cycle through different states.

3 In the **Contents** pane table, for the signals for which you want to override logging properties, enable logging by selecting the check box in the `DataLogging` column.

   To enable logging for multiple signals, hold the **Shift** or **Ctrl** key and select a range of signals or individual signals. Select the check box in the `DataLogging` column of one of the highlighted signals.

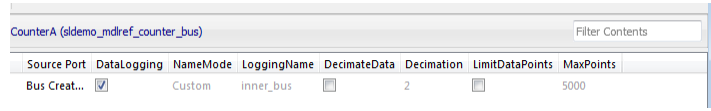
4 In the **Contents** pane table, modify the settings for properties, such as `DecimateData` and `Decimation`.

Command-Line Interface for Overriding Signal Logging Settings

The command-line interface for overriding signal logging settings includes:

- The `DataLoggingOverride` model parameter — Use to view or set signal logging override values for a model
- The following classes:

- `Simulink.SimulationData.ModelLoggingInfo` — Specify signal logging override settings for a model. This class corresponds to the overall Signal Logging Selector interface.
- `Simulink.SimulationData.SignalLoggingInfo` — Override settings for a specific signal. This class corresponds to a row in the logging property table in the Signal Logging Selector:



- `Simulink.SimulationData.LoggingInfo` — Overrides for signal logging settings such as decimation. This class corresponds to the editable columns in a row in the logging property table in the Signal Logging Selector.

To query a model for its signal logging override status, use the `DataLoggingOverride` parameter. To configure signal logging from the command line, use methods and properties of the three classes listed above.

The following sections describe how to use the command-line interface to perform some common signal logging configuration tasks. The examples use the `sldemo_mdlref_bus` model.

- "Create a Model Logging Information Object" on page 45-49
- "Specify Which Models to Log" on page 45-50
- "Log a Subset of Signals" on page 45-52
- "Override Other Signal Logging Properties" on page 45-52

Create a Model Logging Information Object

To use the command-line interface for overriding signal logging settings, create a `Simulink.SimulationData.ModelLoggingInfo` object. For example, use the following command to create the model logging override object for the `sldemo_mdlref_bus` model and automatically add each logged signal in the model to that object:

```
mi = Simulink.SimulationData.ModelLoggingInfo.createFromModel(...
```

```
'sldemo_mdlref_bus')

mi =

  Simulink.SimulationData.ModelLoggingInfo
  Package: Simulink.SimulationData

  Properties:
                     Model: 'sldemo_mdlref_bus'
               LoggingMode: 'OverrideSignals'
    LogAsSpecifiedByModels: {}
                   Signals: [1x4 Simulink.SimulationData.SignalLoggingInfo]

  Methods
```

You can control the kinds of systems from which to include logged signals. By default, the `Simulink.SimulationData.ModelLoggingInfo` object includes logged signals from:

- Libraries
- Masked subsystems
- Referenced models
- Active variants

As an alternative, you can use the `Simulink.SimulationData.ModelLoggingInfo` constructor and specify a `Simulink.SimulationData.SignalLoggingInfo` object for each signal. To ensure that you specified valid signal logging settings for a model, use the `verifySignalAndModelPaths` method with the `Simulink.SimulationData.ModelLoggingInfo` object for the model.

Specify Which Models to Log

Use the `LoggingMode` property of a `Simulink.SimulationData.ModelLoggingInfo` object to specify whether to use the signal logging settings as specified in the model and all referenced models, or to override those settings.

You can control whether a top-level model and referenced models use override signal logging settings or use the signal logging settings specified by the model, as described in the `Simulink.SimulationData.ModelLoggingInfo` documentation.

The following example shows how to log all signals as specified in the top model and all referenced models. The signal logging output is stored in `topOut`.

```
sldemo_mdlref_bus;
mi = Simulink.SimulationData.ModelLoggingInfo...
     ('sldemo_mdlref_bus');
mi.LoggingMode = 'LogAllAsSpecifiedInModel'

mi =

  Simulink.SimulationData.ModelLoggingInfo
  Package: Simulink.SimulationData

  Properties:
                     Model: 'sldemo_mdlref_bus'
               LoggingMode: 'LogAllAsSpecifiedInModel'
    LogAsSpecifiedByModels: {}
                   Signals: []

  Methods

set_param(sldemo_mdlref_bus, 'DataLoggingOverride', mi);
```

The following example shows how to log only signals in the top model:

```
mi = Simulink.SimulationData.ModelLoggingInfo...
     ('sldemo_mdlref_bus');
mi.LoggingMode = 'OverrideSignals';
mi = mi.setLogAsSpecifiedInModel('sldemo_mdlref_bus', true);
set_param(sldemo_mdlref_bus, 'DataLoggingOverride', mi);
```

Log a Subset of Signals

To specify a subset of logged signals to log, use the `findSignal` method with a `Simulink.SimulationData.ModelLoggingInfo` object. For example, to log only one signal from the referenced model instance referenced by :

```
sldemo_mdlref_bus;
mi = Simulink.SimulationData.ModelLoggingInfo.createFromModel(...
             'sldemo_mdlref_bus');
pos = mi.findSignal({'sldemo_mdlref_bus/CounterA' ...
                     'sldemo_mdlref_counter_bus/Bus Creator'}, 1)

pos =
      4
for idx=1:length(mi.Signals)
  mi.Signals(idx).LoggingInfo.DataLogging = (idx == pos);
end

set_param(sldemo_mdlref_bus, 'DataLoggingOverride', mi);
```

Override Other Signal Logging Properties

In addition to overriding the setting for the `DataLogging` property for a signal, you can override other signal logging properties, such as decimation.

Use `Simulink.SimulationData.LoggingInfo` properties to override signal logging properties. The following example shows how to set the decimation override settings.

```
mi = Simulink.SimulationData.ModelLoggingInfo.createFromModel...
    ('sldemo_mdlref_bus');
pos = mi.findSignal({'sldemo_mdlref_bus/CounterA' ...
                     'sldemo_mdlref_counter_bus/Bus Creator'}, 1);
mi.Signals(pos).LoggingInfo.DecimateData = true;
mi.Signals(pos).LoggingInfo.Decimation = 2;
```

Access Signal Logging Data

In this section...

View Signal Logging Data

To generate signal logging data, simulate the model. You can view the signal logging data for a paused or completed simulation, using one of these interfaces:

- The Simulation Data Inspector
- MATLAB commands

To access signal logging data programmatically, the approach you use depends on the signal logging data format (`Dataset` or `ModelDataLogs`). For details, see:

- "Programmatically Access Logged Signal Data Saved in Dataset Format" on page 45-55
- "Programmatically Access Logged Signal Data Saved in ModelDataLogs Format" on page 45-57

Note If you do not see logging data for a signal that you configured in the model for signal logging, check the logging configuration using the Signal Logging Selector. Use the Signal Logging Selector to enable logging for a signal whose logging is overridden. For details, see "View Signal Logging Configuration" on page 45-27 and "Override Signal Logging Settings" on page 45-41.

Signal Logging Object

Simulink saves signal logging data in a signal logging object, which you access with a MATLAB workspace variable.

The type of the signal logging object depends on the signal logging format that you choose. For details, see "Specify the Signal Logging Data Format" on page 45-34.

- `Dataset` format — Uses a `Simulink.SimulationData.Dataset` object
- `ModelDataLogs` format — Uses a `Simulink.ModelDataLogs` object

The default name of the signal logging variable is `logsout`. You can change the signal logging name. For details, see "Specify a Name for the Signal Logging Data" on page 45-40.

View Logged Signal Data with the Simulation Data Inspector

You can use the Simulation Data Inspector to view logged signal data.

To view logged signal data with the Simulation Data Inspector, in the Simulink Editor, use one of the following approaches:

- To display logged signals whenever a simulation ends or you pause a simulation, select **Simulation > Model Configuration Parameters > Inspect signals when simulation is stopped/paused**.
- To launch the Simulation Data Inspector tool to display the data immediately, select **Simulation > Output > Simulation Data Inspector**.

For additional information about using the Simulation Data Inspector, see "Inspect Signal Data with Simulation Data Inspector" on page 17-2.

Programmatically Access Logged Signal Data Saved in Dataset Format

When you use the default `Dataset` signal logging format, Simulink saves the logging data in a `Simulink.SimulationData.Dataset` object. For information on extracting signal data from that object, see `Simulink.SimulationData.Dataset`. The `Simulink.SimulationData.Dataset` object contains `Simulink.SimulationData.Signal` objects for each logged signal.

For bus signals, the `Simulink.SimulationData.Signal` object consists of a structure of MATLAB `timeseries` objects.

The `Simulink.SimulationData.Dataset` class provides two methods for accessing signal logging data.

Name	Description
`get` The `getElement` method shares the same syntax and behavior as the `get` method.	Get element or collection of elements from the dataset, based on index, name, or block path.
`getLength`	Get number of elements in the dataset.

For examples of accessing signal logging data that uses the `Dataset` format, see `Simulink.SimulationData.Dataset`.

Example of Accessing Dataset Format Signal Logging Data

The `sldemo_mdlref_bus` model illustrates how to access signal logging data.

Accessing Data for Signals with a Duplicate Name

For a model with signals with multiple signals that have the same signal name, the signal logging data includes a `Simulink.SimulationData.Signal`

object for each signal that has a duplicate name. Simulink sorts the data for those signals based on the model hierarchy, in top-down order.

To access a specific signal that has a duplicate name, use *one* of these approaches:

- Visually inspect the `Simulink.SimulationData.Signal` objects to find the data for the specific signal.
- Use the `Simulink.SimulationData.Dataset.getElement` method, specifying the blockpath for the source block of the signal.
- Create a script to iterate through the signals with a duplicate signal name, using the `Simulink.SimulationData.Dataset.getElement` method with an index argument.
- Use the following approach, if the signals with a duplicate name do not appear in multiple instances of a referenced model in Normal mode:

  1. In the model, right-click the signal.
  2. In the context menu, select **Properties**.
  3. In the Signal Properties dialog box, set **Logging name** to `Custom` and specify a different name than the signal name.
  4. Simulate the model and use the `Simulink.SimulationData.Dataset.getElement` method with a name argument.

Handling Newline Characters in Signal Logging Data

To handle newline characters in logging names in signal logging data that uses `Dataset` format, use a `sprintf` command within a `getElement` call. For example:

```
topOut.getElement(sprintf('INCREMENT\nBUS'))
```

Programmatically Access Logged Signal Data Saved in ModelDataLogs Format

Note The `ModelDataLogs` signal logging format is supported for backward compatibility. For new models, use the `Dataset` format.

When you use the `ModelDataLogs` signal logging format, Simulink saves the logging data in a `Simulink.ModelDataLogs` object. For information on extracting signal data from that object, see `Simulink.ModelDataLogs`. The `Simulink.ModelDataLogs` object contains signal data objects to capture signal logging information for specific model elements.

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 bus or Mux signal	`Simulink.Timeseries`
Bus signal or Mux signal	`Simulink.TsArray`

Virtual Signals

A *virtual signal* is a signal that graphically represents other signals or parts of other signals. Virtual signals have no functional or mathematical significance. For more information, see "Virtual Signals" on page 47-11.

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 block, the block outputs a virtual signal that has two regions.

When you use the `ModelDataLogs` signal logging format, 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.TsputArray` object. The log gives the duplicate regions unique names, using the syntax: `<signal_name>_reg<#counter>`.

Bus Signals

You can log bus signals. When you use `ModelDataLogs` signal logging format, Simulink stores each logged bus signal data in a separate `Simulink.TsArray` object.

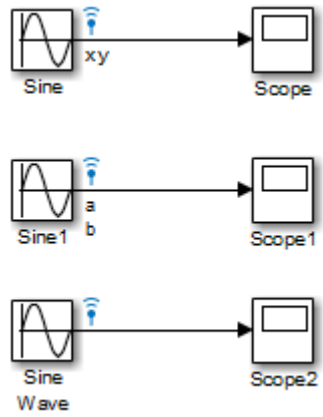
The hierarchy of a bus signal is preserved in the logged signal data. The logged name of a signal in a virtual bus derives from the name of the source signal. The logged name of a signal in a nonvirtual bus derives from the applicable bus object, and can differ from the name of the source signal. See "Composite Signals" for information about those capabilities.

Handling Spaces and Newlines in Logged Names

Signal names in data logs can have spaces or newlines in their names when:

- The signal is named and the name includes a space or newline character.
- The signal is unnamed and originates in a block whose name includes a space or newline character.
- The signal exists in a subsystem or referenced model, and the name of the subsystem, Model block, or of any superior block, includes a space or newline character.

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:



The following example shows how to handle spaces or new lines in logged names, if a model uses:

- `ModelDataLogs` for the signal logging format
- The default of `logsout` for the signal logging data

```
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 `Simulink.Timeseries` objects in this log using TAB name completion or by typing the name to MATLAB. This syntax is not recognized 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 `Simulink.Timeseries` object whose name contains a space, enclose the element containing the space in single quotes:

```
>> 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 `Simulink.Timeseries` object whose name contains a newline, 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:

```
>> 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.

Note You cannot use these techniques for TAB name completion.

Techniques for Importing Signal Data

In this section...

Signal Data Import Techniques Summary

Simulink provides several techniques for importing signal data into a model.

Signal Data Import Technique	Description
Root-level Inport,Trigger, Enable, or Function-Call Subsystem block	Supplies external inputs from the MATLAB (base), model, or mask workspace. Specify the external inputs in the **Configuration Parameters > Data Import/Export > Input** parameter or as a `sim` command argument. To import and map signal and bus data to root-level inports at the same time, you can use the Inport Mapping tool. For details, see "Import and Map Data to Root-Level Inports" on page 45-81. For an example, see "Import Data to Root-Level Input Ports" on page 45-77.
From File block	Reads data from a MAT-file and outputs the data as a signal.

Signal Data Import Technique	Description
From Workspace block	Reads data from the MATLAB (base), model, or mask workspace and outputs the data as a signal. For an example, see "Use From Workspace Block to Import an Input Test Case" on page 45-72.
Signal Builder block	Provides a graphical interface for creating and generating interchangeable groups of signals. For examples, see "Use Signal Builder Block to Import an Input Test Case" on page 45-73 and "Import Signal Data".

Each of these techniques:

- Uses blocks to represent the signal data inport sources visually
- Supports data interpolation and extrapolation, which support the use of incomplete sets of signal data
- Supports zero-crossing detection

Comparison of Techniques

Each technique is well-suited to meet one or more of the following modeling considerations.

Modeling Consideration	Suggested Technique
Purpose of importing signal data	
To perform local, temporary testing by importing a small set of signal data	• From File block • From Workspace block • Signal Builder block • Root-level Inport, Trigger, Enable, or Function-Call Subsystem block
To test a model to be used as a referenced model	Root-level Inport, Trigger, Enable, or Function-Call Subsystem block

Modeling Consideration	Suggested Technique
To verify a model using multiple test cases	Signal Builder block, using signal groups. If the Simulink Verification and Validation software is installed, in signal groups you can use the Verification Manager to enable or disable individual Model Verification blocks. For details, see "Enable and Disable Model Verification Blocks Using the Verification Manager".
To perform local, temporary testing by importing a small set of signal data	Depending on the modeling goal, as discussed in "Time and Signal Values for Imported Data" on page 45-64, choose from the following techniques: • From File block • From Workspace block • Signal Builder block • Root-level Inport, Trigger, Enable, or Function-Call Subsystem block
Signal data	
Very large dataset	From File block, which incrementally loads the data
Data exported using a To File block	From File block
Data exported using a To Workspace block	From Workspace block
Excel spreadsheet	Signal Builder block, which can import Excel spreadsheet data directly into Simulink
Variable-size signals	From Workspace block
Data storage	

Modeling Consideration	Suggested Technique
In a block	Signal Builder block
In the base or model workspace	• From Workspace block • Root-level Inport, Trigger, Enable, or Function-Call Subsystem block
In a MAT-file separate from the model file	From File block

Time and Signal Values for Imported Data

Depending on your model development or testing goal, the approach for specifying time and signal values can vary. Each of these guidelines applies to one or more of the signal data import techniques (From File, From Workspace, Signal Builder, and root-level Inport or Trigger blocks).

Modeling Goal	Time and Signal Values	Additional Notes
Import data representing a continuous plant	Specify a time vector and signal values extracted a continuous plan (for example, data that you acquire experimentally or from the results of a previous simulation). Use any of the data formats listed in "Input Data" on page 45-77. Here are recommended formats for the following imported data sources: • Another simulation — `Dataset` • An equation — MATLAB time expression	In the Inport block parameters dialog box, select **Interpolate data**. To ensure that the Simulink variable time solver executes at the times that you specify in the imported data, set the **Configuration Parameters > Data Import/Export > Output options** parameter to `Produce additional output`.

Modeling Goal	Time and Signal Values	Additional Notes
	• Experimental data — MATLAB `timeseries`, data array, or structure For details, see "Specify Time Data" on page 45-110. For an example of using a structure to specify the time and signal values, see "Import Data to Model a Continuous Plant" on page 45-67.	
Test a discrete algorithm	Use a structure, with an empty time vector. Specify signal values, but no time vector. (One signal value is read at each time step, using the sample time of the source block.) For an example of using a structure to specify the signal values, see "Import Data to Test a Discrete Algorithm" on page 45-70.	In the Inport block parameters dialog box, clear **Interpolate data**.
Create an input test case (An input test case is typically composed of steps and ramps, with discontinuities.)	Specify a time vector and signal values, but specify only the time steps at points where the shape of the output jumps. For details about specifying a time vector, see "Specify Time Data" on page 45-110. Use any of the input data formats described in "Input	Select the **Interpolate data** parameter. For the input, consider using a From Workspace, From File, or Signal Builder block, which trigger a zero-crossing at the discontinuities. For examples of using a From Workspace block and

Modeling Goal	Time and Signal Values	Additional Notes
	Data" on page 45-77, except for MATLAB time expressions.	a Signal Builder block, see "Import Data for an Input Test Case" on page 45-71.

Import Data to Model a Continuous Plant

In this section...

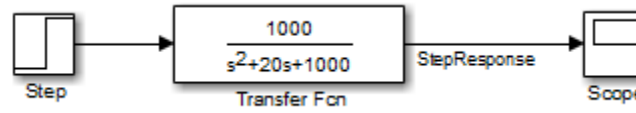
Share Simulation Data Across Models

When reusing data from a variable step size simulation for simulation in another model, the second simulation must read the data at the same time steps as the first simulation.

The following example illustrates how to reuse signal logging data from the simulation of one model in a second model. For more information, see "Import Signal Logging Data" on page 45-75.

Example of Importing Data to Model a Continuous Plant

1 Open the `ex_data_import_continuous` model.



This model uses the `ode15s` solver and produces continuous signals.

2 To use the output of this model as input to the simulation of another model, log the signal that you want to reuse. Select the **Signal Properties > Log signal data**.

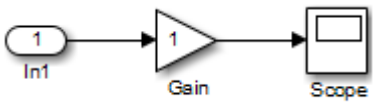
Note To enable signal logging, you must select the **Configuration Parameters > Data Import/Export > Signal logging** parameter. This model has **Signal logging** enabled, and has the **Signal logging format** parameter set to `Dataset`.

3 Simulate the model.

Simulating the model saves a variable-step signal to the workspace, using the `logsout` variable. The signal logging ouput is a `Simulink.SimulationData.Dataset` object.

Use the `Simulink.SimulationData.Dataset.getElement` method to access the logged data. The logging data for individual signals is stored in `Simulink.SimulationData.Signal` objects. For this model, there is one logged signal: `StepResponse`.

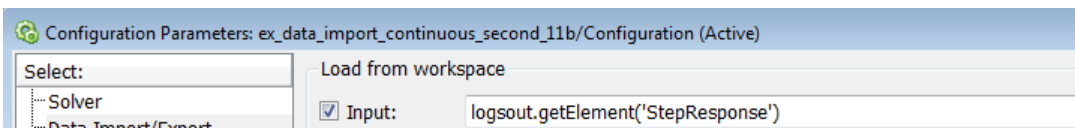
4 Open a second model, named `ex_data_import_continuous_second`.



You can configure this second model to simulate using the logged data from the first model. In this example, the second model uses a root-level Inport block to import the logged data. The Inport block has the **Interpolate data** option selected.

5 In the second model, select the **Configuration Parameters > Data Import/Export > Input** parameter.

Use the `Simulink.SimulationData.Signal.getElement` method to specify the `StepResponse` signal element, as shown below:



6. Specify that for the second model, the Simulink solver runs at the time steps specified in the saved data (`u`). In the Data Import/Export pane, set the **Output options** parameter to `Produce additional output` and the **Output times** parameter to:

   ```
   logsout.getElement('StepResponse').Values.Time
   ```

7. Simulate the second model.

Note Simulink does not feed minor time-step data through root input ports. For details about minor time steps, see "Minor Time Steps" on page 3-23.

Import Data to Test a Discrete Algorithm

In this section...

Specify a Signal-Only Structure

To import data for a discrete signal, specify a signal-only structure as the input value. Do not specify a time vector.

Example of Importing Data to Test a Discrete Algorithm

1. Set the sample time for the Inport, Trigger, or From Workspace block.
2. For the data that you want to import, specify a structure variable that does *not* include a time vector. For example, for the variable called `import_var`:

   ```
   import_var.time = [];
   import_var.signals.values = [0; 1; 5; 8; 10];
   import_var.signals.dimension = 1;
   ```

   The input for the first time step is read from the first element of an input port value array. The value for the second time step is read from the second element of the value array, and so on.

   For details about how to specify the signal value and dimension data, see "Specify Signal Data" on page 45-109.
3. In the block parameters dialog box for the block that imports the data, clear the **Interpolate data** parameter.
4. If you are using a From Workspace block to import data, set the **Form output after final data value by** parameter to a value other than `Extrapolation`.

Import Data for an Input Test Case

In this section...

Guidelines for Importing a Test Case

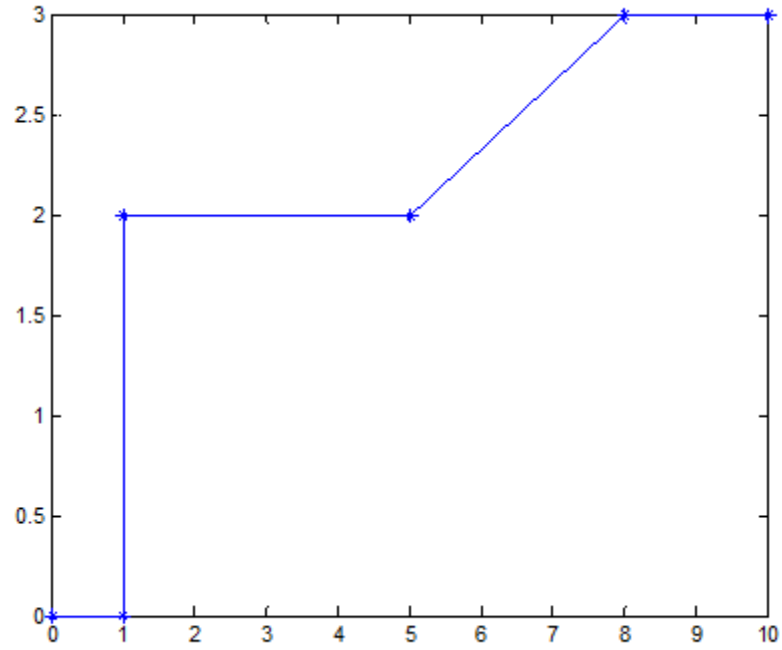
Typically when importing a test case in Simulink, you want to:

- Create a signal that has ramps and steps. In other words, the signal has one or more discontinuities.
- Create the signal using the fewest points possible.
- Have the Simulink solver execute at the specified discontinuities.

To import this signal in Simulink, use a From Workspace, From File, or Signal Builder block, all of which support zero-crossing detection.

Example of Test Case Data

The following is an example of test case data:



The following two examples use this test case data.

Use From Workspace Block to Import an Input Test Case

1 Open the model `ex_data_import_test_case_from_workspace`.

2 Enable zero-crossing detection. In the From Workspace block dialog, select **Enable zero-crossing detection**.

3 Create a signal structure for the test case. At each discontinuity, enter a duplicate entry in the time vector. As described in the From Workspace block documentation, this generates a zero-crossing and forces the variable-step solver to take a time step at this exact time.

   Define the `var` structure representing the test case:

```
var.time = [0 1 1 5 5 8 8 10];
var.signals.values = [0 0 2 2 2 3 3 3]';
var.signals.dimensions = 1;
```

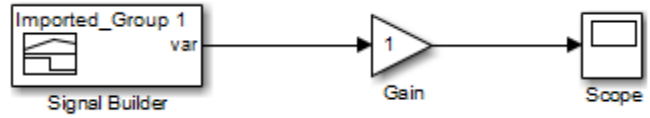
4 To import the test case structure, in the From Workspace block dialog, in the **Data** parameter, specify `var`.

5 Simulate the model. The Scope block reflects the test case data.

Use Signal Builder Block to Import an Input Test Case

As an alternative to using a From Workspace block, you can use a Signal Builder block to either create a signal interactively or to import a signal from a MAT-file.

1 Open the `ex_data_import_signal_builder` model.



2 Create a structure and save it in a MAT-file:

```
var.time = [0 1 1 5 5 8 8 10];
var.signals.values = [0 0 2 2 2 3 3 3]';
var.signals.dimensions = 1;
var.signals.label = 'var';
save var.mat var
```

3 Double-click the Signal Builder block to open its dialog box.

4 Select **File > Import From File** menu item, and select the `var.mat` file.

5 In the **Select** parameter, select `Replace existing dataset`. In the **Data to Import** section, select the **Select All** check box. Confirm the selection and click **OK**.

   The Signal Builder block display reflects the test case data.

For a detailed example that shows how to use a Signal Builder block as the input source for your model and to import your own signal data to the model, see “Import Signal Data”.

Import Signal Logging Data

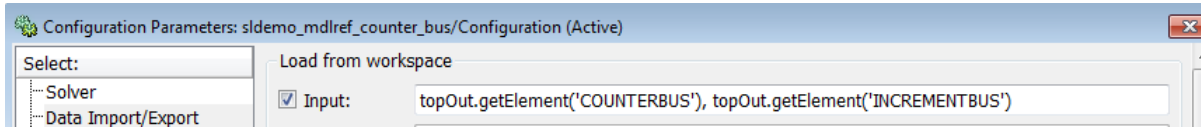
You can log signal data from a simulation, and then import that data into a model. For more information about signal logging, see "Export Signal Data Using Signal Logging" on page 45-19.

The imported signal logging data provides the input for simulating the model. You can use imported signal logging data to perform standalone simulation of a referenced model.

1. Set the **Configuration Parameters > Data Import/Export > Signal logging format** parameter to `Dataset`.
2. Use the default signal logging output variable, `logsout`, or specify a variable using the **Configuration Parameters > Data Import/Export > Signal logging** edit box.
3. Simulate the parent model.

   The signal logging output is a `Simulink.SimulationData.Dataset` object.
4. Use the `Simulink.SimulationData.Dataset.getElement` method to access the logged data. The logging data for individual signals is stored in `Simulink.SimulationData.Signal` objects.
5. For the referenced model that you want to simulate standalone, use the `Simulink.SimulationData.Signal.getElement` method to specify signal elements for the **Configuration Parameters > Data Import/Export > Input** parameter.

   For example:



6. Simulate the referenced model.

For an example of loading logged signal data into a model:

1 Open the `sldemo_mdlref_bus` model.

2 In the right corner of the model, double-click the left question mark block.

3 See the “Logging Model Reference Signals” and “Loading Data” sections.

Import Data to Root-Level Input Ports

In this section...

Root-Level Input Ports

You can import data from a workspace and apply it to a root-level:

- Enable block
- Inport block
- Trigger block that has an edge-based (rising, falling, or either) trigger type

You can also import data from a workspace and apply it to a From Workspace block. For details, see the From Workspace documentation and "Import Data for an Input Test Case" on page 45-71.

Enable Data Import

To enable data import:

1. Select the **Configuration Parameters > Data Import/Export > Input** parameter.
2. Enter an external input specification in the adjacent edit box and click **Apply**.

   For details, see "Input Data" on page 45-77.

Input Data

Use the **Configuration Parameters > Data Import/Export > Input** parameter to import data from a workspace and apply it to the root-level input ports of a model during a simulation run.

Simulink linearly interpolates or extrapolates input values as necessary if you select the **Interpolate data** option for the corresponding Inport or Trigger block.

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 "Symbol Resolution" on page 4-76. See the documentation of the `sim` command for some data import capabilities that are available only for programmatic simulation.

Forms of Input Data

The input data can take any of the following forms:

- MATLAB `timeseries` — For details, see the following sections:
  - "Import MATLAB timeseries Data" on page 45-98
  - "Import Structures of timeseries Objects for Buses" on page 45-100
- Array — See "Import Data Arrays" on page 45-105.
- `Simulink.SimulationData.Signal` — For details, see "Import Signal Logging Data" on page 45-75
- Structure — See "Import Data Structures" on page 45-108.
- Empty matrix — Use an empty matrix for ports for which you want to use ground values, without having to create data structures.
- Time expression — See "Import MATLAB Time Expression Data" on page 45-107.
- `Simulnk.Timeseries` and `Simulink.TsArray` — See "Import Simulink.Timeseries and Simulink.TsArray Data" on page 45-104.

Input Expressions

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. For details, see "Comma-Separated Lists for the Input Parameter" on page 45-79

Comma-Separated Lists for the Input Parameter. Each table corresponds to a specific input port. 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 an Enable or Trigger block, the signal driving the enable or trigger port must be the last item in the comma-separated list. If you have both an enable and a trigger port, then specify the enable port as the next-to-last item in the list, and the trigger port as the last item.

You can load data for a subset of root-level Inport ports, without having to create data structures for the ports for which you want to use ground values. For information about ground values, see "Initialize Signals and Discrete States" on page 47-51.

Using partial specification of ports simplifies the specification of external data to input. You can use partial specification to omit an array of buses signal from the external data to input (you cannot load array of buses data into a root-level Inport block).

Use an empty matrix to specify ground values for a port. For example, to load data for input ports `in1` and `in3`, and to use ground values for port `in2`, enter the following in the **Input** parameter:

```
in1, [], in3
```

Import Bus Data

To import bus data to root input ports, use a structure of MATLAB `timeseries` objects. For details, see "Import Structures of timeseries Objects for Buses" on page 45-100.

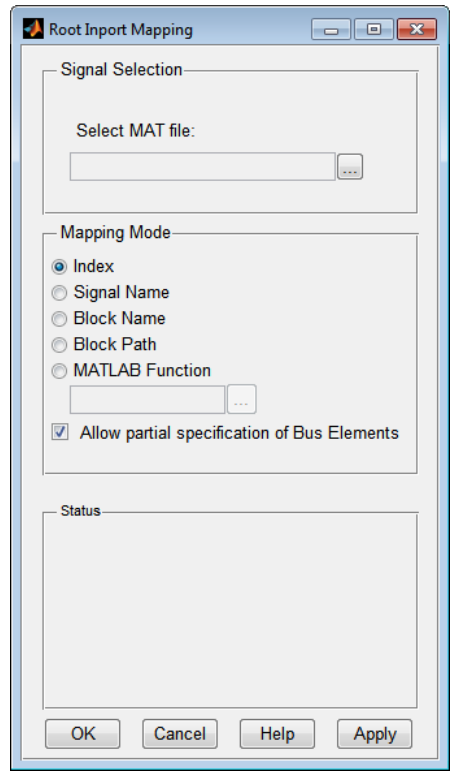
To import an array of buses from a port, you can specify an empty matrix for that port in a comma-separated list of tables. The empty matrix uses the ground values for the bus signal.

For example, to load data for input ports `in1` and `in3`, and to use ground values for port `in2`, enter the following in the **Input** parameter:

```
in1, [], in3
```

Import and Map Data to Root-Level Inports

To import and map signal and bus data to root-level inports at the same time, use the Root Inport Mapping tool.



Note You cannot use this dialog box to map data that already exists in the MATLAB workspace. Use this dialog box to import the data, then map it.

Use the tool to map data to root-level inports in one of the following ways:

- **Index** — Assigns sequential index numbers, starting at 1, to the data in the MAT-file and maps this data to the corresponding inport.

  - If there is more data than inports, the tool maps remaining data to enable and trigger inports, in that order.
  - If the data is not in the form of a dataset, the tool processes the data in the order in which they are passed or parsed from the data file. This process is the order in which they appear in the file.
- **Signal Name** — Assigns data to ports according to the name of the signal on the port. If the tool finds a data element whose name matches the name of a signal at a port, it maps the data to the corresponding port.
- **Block Name** — Assigns data to ports according to the name of the root-inport block. If the tool finds a data element whose name matches the name of a root-inport block, it maps the data to the corresponding port.
- **Block Path** — Assigns data to ports according to the block path of the root-inport block. If the tool finds a data element whose block path matches the block path of a root-inport block, it maps the data to the corresponding port.
- **MATLAB Function** — Applies mappings according to the definitions in the custom file.

To use this tool:

- Identify the signals you want to import and map to the model root-level inports.
- Create a MAT-file that contains the signal or bus data that you want to import into your model and map to the root-level inports of your model (see "MAT-File for Import and Mapping" on page 45-83).
- Determine how you want to map data (for example, by signal index or signal name).

To map data using one of the standard map formats, see:

- "Import and Map Signal Data" on page 45-85
- "Import and Map Bus Data" on page 45-89

If you prefer to create a custom mapping file function to map data to root-level inports, see "Create Custom Mapping File Function" on page 45-95.

Notes:

- You cannot start or access the Root Inport Mapping tool while the model is running or paused. The tool is available only when the model is stopped.
- If you do not click **OK** on the dialog box to close the tool, closing the model also closes the tool.

MAT-File for Import and Mapping

The Root Inport Mapping dialog box requires a MAT-file that contains data with one of the following data types or formats.

Data Formats	Index Mapping	Signal Name Mapping	Block Name Mapping	Block Path Mapping	Custom Mapping
`Simulink.SimulationData.-Dataset`	X	X	X	X	X
timeseries (MATLAB and Simulink)	X	X	X	X (only for Simulink timeseries)	X
`Simulink.SimulationData.-Signal`	X	X	X	X	X
Structure with Time, Structure without Time	X				
TsArray	X			X	X
Data Array	X				
Time Expression	X				

For example, a signal data MAT-file with three signals (*signal1*, *signal2*, and *signal3*) with block path specified might have workspace variables that look like the following. This file has signals that have signal names, block names, block paths, and index values. This means that you can map the data using `Index`, `Signal Name`, `Block Name`, or `Block Path` mapping mode. If there are corresponding root-level inports with corresponding indices, signal names, or block paths, the tool maps the signal to those ports.

```
signal1 =
```

```
  Simulink.SimulationData.Signal
  Package: Simulink.SimulationData

  Properties:
         Name: 'signalGain5'
    BlockPath: [1x1 Simulink.SimulationData.BlockPath]
     PortType: 'outport'
    PortIndex: 1
       Values: [1x1 timeseries]

  Methods, Superclasses
>> signal2

signal2 =

  Simulink.SimulationData.Signal
  Package: Simulink.SimulationData

  Properties:
         Name: 'signalGain10'
    BlockPath: [1x1 Simulink.SimulationData.BlockPath]
     PortType: 'outport'
    PortIndex: 1
       Values: [1x1 timeseries]

  Methods, Superclasses
>> signal3

signal3 =

  Simulink.SimulationData.Signal
  Package: Simulink.SimulationData

  Properties:
         Name: 'signalGain15'
    BlockPath: [1x1 Simulink.SimulationData.BlockPath]
     PortType: 'outport'
    PortIndex: 1
       Values: [1x1 timeseries]
```

```
Methods, Superclasses
```

Notes:

- The tool can load only one `Simulink.SimulationData.Dataset` data set per MAT-file. If the MAT-file has multiple data sets of this type, the tool loads the first data set listed alphabetically.
- The number of signals with the formats structures with and without time , data arrays, and time expressions must be the same as the number of model inports, enable ports, and trigger ports.

Import and Map Signal Data

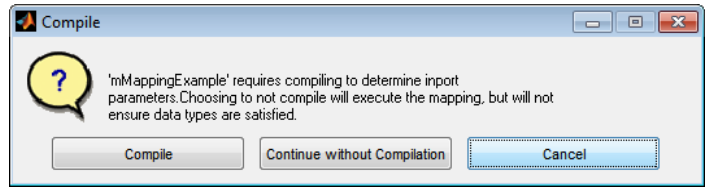
1. Create a MAT-file that contains the signal data you want to import and map.
2. Open a model.
3. Start the Configuration Parameters dialog box for the model.
4. Navigate to the Data Import/Export pane.
5. In the **Load from workspace** section, click **Edit Input**.

   The Root Inport Mapping dialog box is displayed.
6. In the **Select MAT file** parameter, specify the MAT-file that contains the signal data by clicking the browser button to browse to the file.

   A load MAT-file window pops up.
7. Click **Yes** to load the MAT-file in the workspace.
8. In the **Mapping Mode** section, select how you want the imported data to map to the root-level inports:
   - `Index`
   - `Signal Name`
   - `Block Name`

- `Block Path`
- `MATLAB Function`

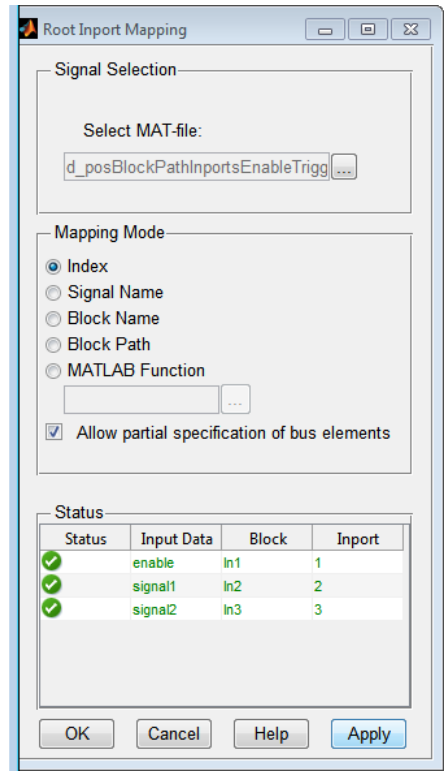
9 Click **Apply**. A Compile dialog pops up, for example:



10 Select one of the following:

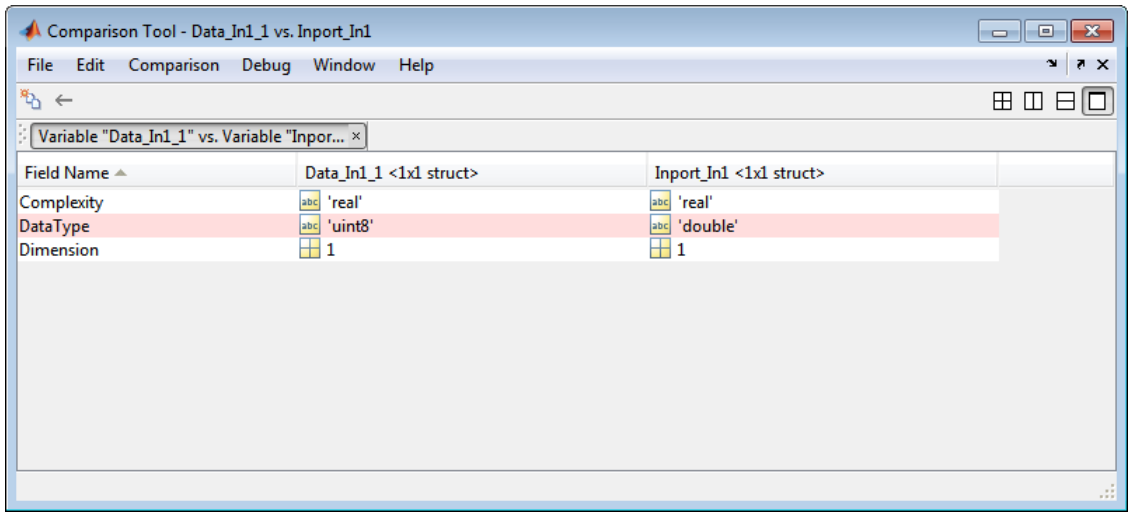
- **Compile** — Maps the imported data to the root-level inport and compiles the model to check data types of root-level inports and imported data.
- **Continue without Compilation** — Maps the imported data to the root-level inport, but does not compile the model. Selecting this option might not check root-level inports, data, and data types.
- **Cancel** — Cancels the import. You can choose another MAT-file to import.

The results of the mapping are displayed in the Status area.



The Status area of the tool lists the input data and the status of the mapping:

- — Successful mapping of data to root-level inports.
- — Potential issue with mapping of data to root-level inports. The tool might not know if all the data types match. If you choose to **Continue without Compilation** as the action, the Status area might show all data with this warning icon. To inspect the data and compare it to the root-level inport, click anywhere in the data line. The Comparison Tool is displayed with the columns in the left-right order of field name, input data, and root-level inport. Use this tool to evaluate your next action. You might want to edit the data in the MAT-file, or you might want to edit the root-level inport.



For more information on the Comparison Tool, see “Comparing Files and Folders”.

By default, each time you click a data line, an independent Comparison Tool window is displayed. To dock all Comparison Tool windows in one window, click the Dock button ( ). To view each Comparison Tool window as a stand-alone window, click the Undock button ( ).

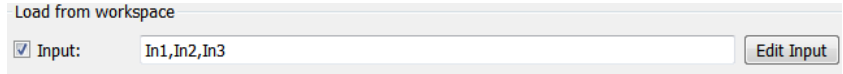
- — Issue with mapping of data to root-level inports. To inspect the data and compare it to the root-level inport, click anywhere in the data line. The Comparison Tool is displayed with the columns in the left-right order field name, input data, and root-level inport. The Comparison Tool is displayed with the columns in the left-right order field name, input data, and root-level inport. Use this tool to evaluate your next action. You might want to edit the data in the MAT-file, or you might want to edit the root-level inport.

  By default, each time you click a data line, an independent Comparison Tool window is displayed. To dock all Comparison Tool windows in one window, click the Dock button ( ). To view each Comparison Tool individually, click the Undock button ( ).

  For more information on the Comparison Tool, see “Comparing Files and Folders”.

11 Click **OK**.

12 If there are no mismatches with the data, in the **Data Import/Export** pane of the Configuration Parameters dialog box, observe that the Input parameter is now selected. In addition, the text box now contains the imported data variables.



If there are root-level input ports that have not been mapped, the Root Inport Mapping tool maps those ports as empty (`[]`).

To inspect the imported data, connect the output to a scope, simulate the model, and observe the data. Optionally, to inspect the imported data, log the signals and use the Simulink Data Inspector tool to observe the data.

13 Optionally, if you are satisfied with the data and mapping, in the Preload tab, enter a load function to load the signal data MAT-file. This step replaces steps 5 and 6 so that you do not need to manually load the signal data MAT-file. For example, to load a MAT-file `d_signal_data.mat`, type:

```
load d_signal_data.mat;
```

14 Save and close the model.

Import and Map Bus Data

This topic assumes that you are familiar with bus objects and how to create them. For more information, see “Bus Objects” on page 48-20.

1 In the MATLAB workspace, create a bus object for the bus data you want to import and map.

2 Save that bus object definition to a MAT-file, for example `d_myBusObj.mat`.

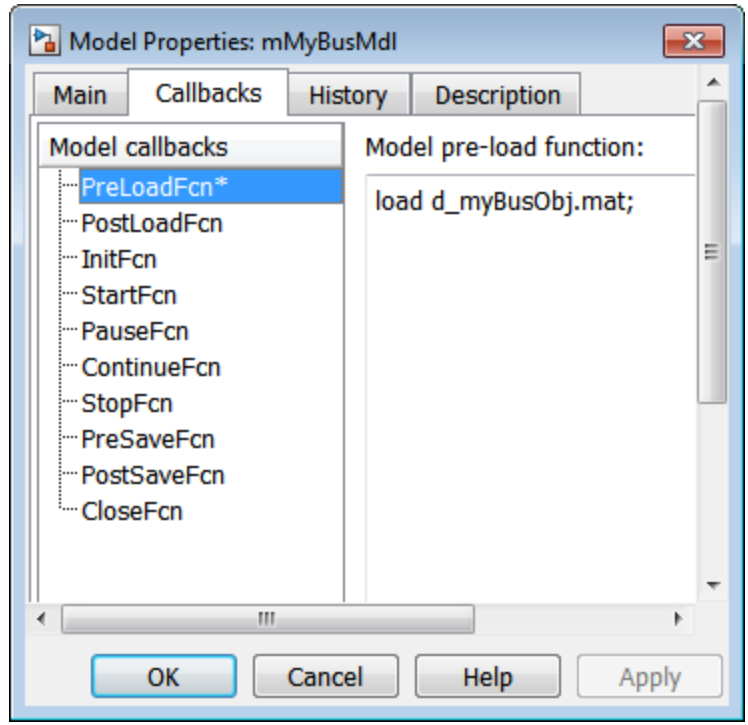
3 Create a MAT-file that contains the bus data you want to import for the bus object.

4 Open a model.

5 In the Simulink Editor, select **File > Model Properties > Model Properties**.

The Model Properties dialog box is displayed.

6 In the Callbacks tab, enter a load function to load the bus object definition. For example, to load a bus object from `d_myBusObj.mat`:



7 Start the Configuration Parameters dialog box for the model

8 Navigate to the Data Import/Export pane.

9 In the **Load from workspace** section, click **Edit Input**.

The Root Inport Mapping dialog box is displayed.

10 In the **Select MAT file** parameter, specify the MAT file that contains the signal data in one of the following ways:

- Enter the full path to the file.
- Click the browser button to browse to the file.

A load MAT file window pops up.

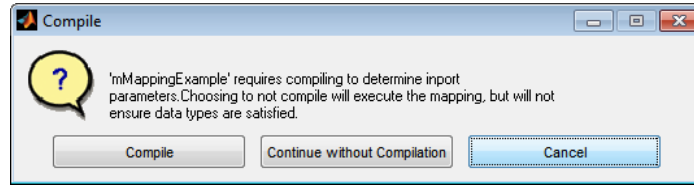
11 Click **Yes** to load the MAT-file.

12 In the **Mapping Mode** section, select how you want the imported data to map to the root-level inports:

- `Index`
- `Signal Name`
- `Block Name`
- `Block Path`
- `MATLAB Function`

13 If you import bus data, optionally select the **Allow partial specification of bus elements** check box. Selecting this check box allows you to import bus data that is only partially defined in the MAT-file. If you clear this check box and import incompletely specified bus data, the tool cannot properly map the partially specified bus data to root-level inports.

14 Click **Apply**. A Compile dialog pops up, for example:

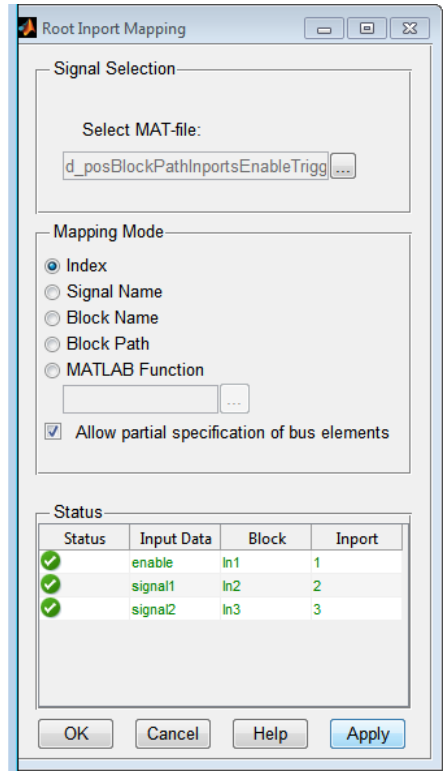


15 Select one of the following:

- **Compile** — Maps the imported data to the root-level inport and compiles the model to check data types of root-level inports and imported data.

- **Continue without Compilation** — Maps the imported data to the root-level inport, but does not compile the model. Selecting this option might not check root-level inports, data, and data types.
- **Cancel** — Cancels the import. You can choose another MAT-file to import.

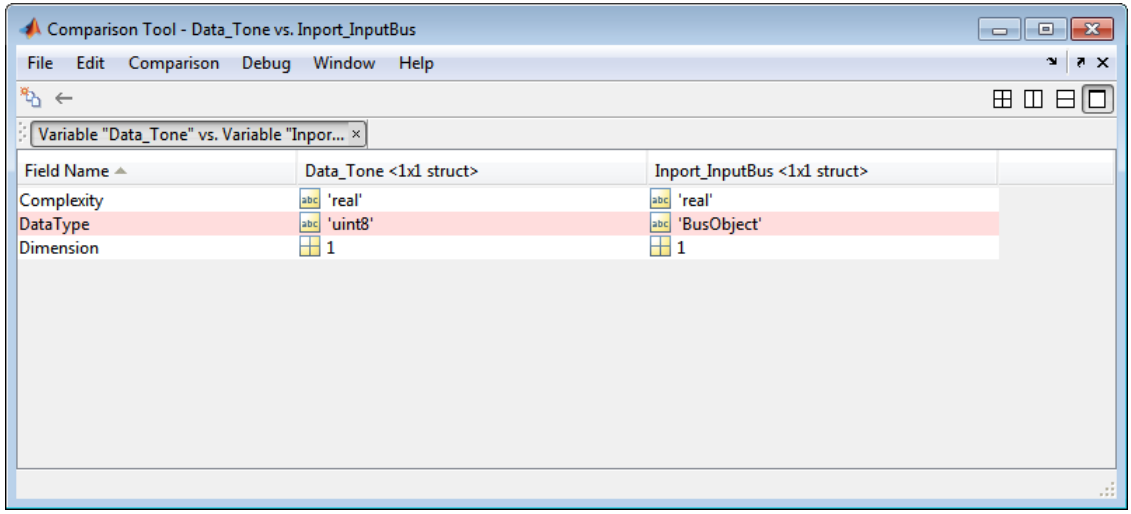
The results of the mapping are displayed in the Status area. If the contents of the imported file cannot be matched with the **Mapping Mode**



The Status area of the tool lists the input data and the status of the mapping:

-  — Successful mapping of data to root-level inports.

- ⚠ — Potential issue with mapping of data to root-level inports. The tool might not know if all the data types match. If you choose to **Continue without Compilation** as the action, the Status area might show all data with this warning icon. To inspect the data and compare it to the root-level inport, click anywhere in the data line. The Comparison Tool is displayed with the columns in the left-right order of field name, input data, and root-level inport. Use this tool to evaluate your next action. You might want to edit the data in the MAT-file, or you might want to edit the root-level inputs.



Note When the input is a bus, click the levels of the bus object to drill down to the individual elements in the bus.

For more information on the Comparison Tool, see “Comparing Files and Folders”.

By default, each time you click a data line, an independent Comparison Tool window is displayed. To dock all Comparison Tool windows in one window, click the Dock button ( ). To view each Comparison Tool window as a stand-alone window, click the Undock button ( ).

- — Issue with mapping of data to root-level inports. To inspect the data and compare it to the root-level inport, click anywhere in the data line. The Comparison Tool is displayed with the columns in the left-right order of field name, input data, and root-level inport. Use this tool to evaluate your next action. You might want to edit the data in the MAT-file, or you might want to edit the root-level inport.

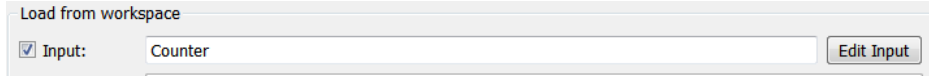
  Note When the input is a bus, click the levels of the bus object to drill down to the individual elements in the bus.

  For more information on the Comparison Tool, see "Comparing Files and Folders".

  By default, each time you click a data line, an independent Comparison Tool window is displayed. To dock all Comparison Tool windows in one window, click the Dock button ( ). To view each Comparison Tool window as a stand-alone window, click the Undock button ( ).

16 Click **OK**.

17 If there are no mismatches with the data, in the **Data Import/Export** pane of the Configuration Parameters dialog box, observe that the Input parameter is now selected. In addition, the text box now contains the imported bus data variables.



18 Optionally, if you are satisfied with the data and mapping, in the Preload tab, enter a load function to load the signal data MAT-file. This step replaces steps 5 and 6 so that you do not need to manually load the signal data MAT-file. For example, to load a MAT-file `d_bus_data.mat`, enter type:

```
load d_bus_data.mat;
```

19 Save and close the model.

If there are root-level input ports that have not been mapped, the Root Inport Mapping tool maps those ports as empty ([]).

To inspect the imported data, connect the output to a scope, simulate the model, and observe the data.

Create Custom Mapping File Function

Create a custom mapping file function if you do not want to rely on one of the existing tool mapping modes to map your data to root-level input ports. You might want to create a custom mapping file function if your signal data contains a common prefix that is not contained in your model. You also might want to create a custom mapping file function to explicitly map a signal. This custom mapping file function might be useful if you want to map by block name but the data contains a signal whose name does not match one of the block names.

See the following files in *`matlabroot`*`\help\toolbox\simulink\example` for an example:

- `BlockNameIgnorePrefixMap.m` — Custom mapping file function that ignores the prefix of a signal name when importing.
- `BlockNameIgnorePrefixData.mat` — MAT-file of signal data to be imported.
- `ex_BlockNameIgnorePrefixExample` — Model file into which you can import and map data.

Follow these guidelines to create a custom mapping file function:

1. Create a MATLAB function with the following input parameters:
   - Model name
   - Signal names specified as a cell array of strings
   - Signals specified as a cell array of signal data
2. In this function, call the `getRootInportMap` function to create a variable that contains the mapping object (for an example, see `BlockNameIgnorePrefixMap.m`).

3 Save and close the MATLAB function file.

4 Add the path for the new function to the MATLAB path.

If there are root-level input ports that have not been mapped, the Root Inport Mapping tool maps those ports as empty ([]).

To use the custom mapping file function, in the Input Mapping Tool:

1 Open the model for which you want to import data (for example, `ex_BlockNameIgnorePrefixExample`).

2 Start the Configuration Parameters dialog box for the model.

3 Navigate to the Data Import/Export pane.

4 In the **Load from workspace** section, click **Edit Input**.

The Root Inport Mapping dialog box is displayed.

5 In the **Select MAT file** parameter, specify the MAT-file that contains the signal data by clicking the browser button to browse to the file (for example, `BlockNameIgnorePrefixData.mat`).

A load MAT-file window pops up.

6 Click **Yes** to load the MAT-file in the workspace.

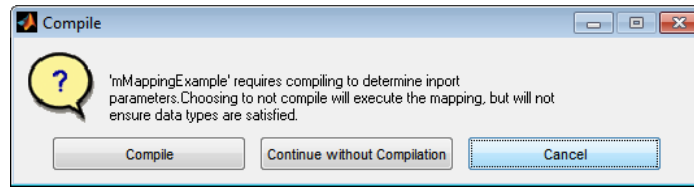
7 From the Mapping Mode list, click **MATLAB Function**.

8 In the **MATLAB Function** parameter, specify the MATLAB function file (for example, `BlockNameIgnorePrefixMap.m`) with the browser button.

Tip The Root Inport Mapping tool parses your custom code. The tool might perform operations such as reordering output alphabetically and verifying that data types are consistent.

---

9 Click **Apply**. The Compile dialog box is displayed, for example:



10 Click **Compile**.

The software compiles the model and updates the Root Inport Mapping dialog box.

11 Click **OK**.

12 In the **Data Import/Export** pane of the Configuration Parameters dialog box, observe that the Input parameter is now selected. In addition, the text box now contains the imported signal data variables. Optionally, to inspect the imported data, log the signals and use the Simulink Data Inspector tool to observe the data.

13 Optionally, if you are satisfied with the data and mapping, in the Preload tab, enter a load function to load the signal data MAT-file. This step replaces steps 5 and 6 so that you do not need to manually load the signal data MAT-file. For example, to load a MAT-file `d_signal_data.mat`, enter type:

```
load d_signal_data.mat;
```

14 Save and close the model.

Import MATLAB timeseries Data

In this section...

A root-level Inport, Enable, Trigger, and From Workspace block can import data specified by a MATLAB `timeseries` object residing in a workspace.

Specify Time Dimension

When you create a MATLAB `timeseries` object to import data to Simulink, the time dimension depends on the dimension and type of signal data:

- If the signal is a scalar or a 1D vector, then time is first.

  Below is an example of a timeseries constructor for a scalar signal. Time is aligned with the first dimension.

  ```
  t = (0:10)';
  ts = timeseries(sin(t)), t);
  ```

- If the signal dimension is 2D (including row and column vectors) or greater, then time is last.

  Below is an example of a timeseries constructor for a matrix signal. Time is aligned with the last dimension.

  ```
  t = 0;
  ts = timeseries([1 2; 3 4], t);
  ```

- If the signal is a 2D row vector, and there is only one time step, then you need align time with the last dimension. Use the following in the constructor:

  ```
  'InterpretSingleRowDataAs3D', true
  ```

  For example:

  ```
  t = 0;
  ts = timeseries([1 2], t, 'InterpretSingleRowDataAs3D', true);
  ```

Models with Multiple Root Inport Blocks

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 or a structure of 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;
```

Import Structures of timeseries Objects for Buses

In this section...

Define Structure of MATLAB timeseries Objects for a Bus Signal

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.

Convert Simulink.TsArray Objects

If you are using logged data from a model whose **Configuration Parameters > Data Import/Export > Signal logging format** parameter is set to `ModelDataLogs` format instead of the default `Dataset` format, consider converting the data to use a structure of MATLAB `timeseries`

objects. The `ModelDataLogs` format is supported for backwards compatibility. The `ModelDataLogs` format will be removed in a future release.

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);
```

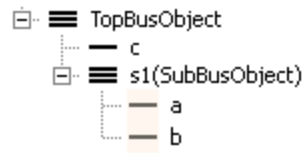
Note If you use a structure of MATLAB `timeseries` objects for a root Inport block in a model that has multiple root Inport blocks, all the root Inport blocks must use MATLAB `timeseries` objects. Convert any root Inport block data that uses `Simulink.TsArray` or `Simulink.Timeseries` objects to be MATLAB `timeseries` objects.

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:

   ```
   N = 10;
   Ts = 1;
   t1 = ((0:N)* Ts)';
   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
   - Data type
   - Dimensions
   - Complexity

   The name of the structure field must match the bus element name. 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):

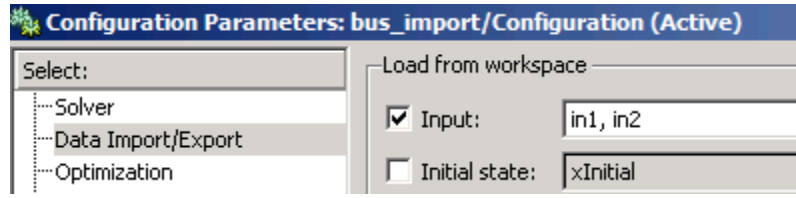
```
num_el = MyBus.getNumLeafBusElements;
el_list = MyBus.getLeafBusElements;
```

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.



Import Simulink.Timeseries and Simulink.TsArray Data

In this section...

Use MATLAB Timeseries for New Models

For new models, have root-level Inport block or Trigger blocks import MATLAB `timeseries` data.

However, you can import existing `Simulink.Timeseries` object data. Importing `Simulink.Timeseries` objects allows you to import data logged by a previous simulation run that used the `ModelDataLogs` format for signal logging (see "Export Signal Data Using Signal Logging" on page 45-19).

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.

Import Data Arrays

In this section...

Data Array Format

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.

Specify the Input Expression

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:

```
N = 10;
Ts = 0.1
t = (0:N)* Ts';
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`.

Import MATLAB Time Expression Data

Specify the Input Expression

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)`.

Import Data Structures

In this section...

Data Structures

The Simulink software can read data from the workspace in the form of a structure, whose name you specify in the **Configuration Parameters > Data Import/Export > Input** parameter.

For information about defining MATLAB structures, see "Create a Structure Array" in the MATLAB documentation.

The structure always includes a signals substructure, which contains a values field and a dimensions field. For details about the signal data, see "Specify Signal Data" on page 45-109. Depending on the modeling task that you want to perform, the structure can also include a time field.

You can specify structures for the model as a whole or on a per-port basis. For information about specifying per-port structures for the **Input** parameter, see "One Structure for All Ports or a Structure for Each Port" on page 45-109.

The form of a structure that you use depends on whether you are importing data for discrete signals (the signal is defined at evenly-spaced values of time) or continuous signals (the signal is defined for all values of time). For discrete signals, use a structure that has an empty time vector. For continuous signals, the approach that you use depends on whether the data represents a smooth curve or a curve that has discontinuities (jumps) over its range. For details, see:

- "Import Data to Test a Discrete Algorithm" on page 45-70

- "Import Data to Model a Continuous Plant" on page 45-67
- "Import Data for an Input Test Case" on page 45-71

For both discrete and continuous signals, specify a `signals` field, which contains an array of substructures, each of which corresponds to a model input port. For details, see "Specify Signal Data" on page 45-109.

For continuous signals, you may want to specify a `time` field, which contains a time vector. See "Time and Signal Values for Imported Data" on page 45-64.

One Structure for All Ports or a Structure for Each Port

You can specify one structure to provide input to all root-level input ports in a model, or you can specify a separated structure for each port.

The per-port structure 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.

The rest of the section about importing structure data focuses on specifying one structure for all ports.

Specify Signal Data

Each `signals` substructure must contain two fields: `values` and `dimensions`.

The Values Field

The `values` field must contain an array of inputs for the corresponding input port. If you specify a time vector, each input must correspond to a time value specified in the `time` field.

If the inputs for a port are scalar or vector values, the `values` field must be an `M-by-N` array. If you specify a time vector, `M` must be the number of time points specified by the `time` field and `N` is the length of each vector value.

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`.

The Dimensions 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.

Specify Time Data

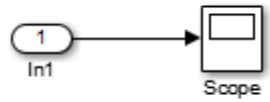
You can specify a time vector as part of the data structure to import. The "Time and Signal Values for Imported Data" on page 45-64 section indicates when you may want to add a time vector.

The following table provides recommendations for how to specify time values, based on the kind of signal data you want to import.

Signal Data	Time Data Recommendation
Inport or Trigger block with a discrete sample time	Do not specify a time vector. Simulink reads one signal value at each time step.
Evenly-spaced discrete signals	Consider using an expression in the following form: `TimeVector = Ts * (0:N);` where `Ts` is the time step and `N` is the number of time steps.
Unevenly-spaced values	Use any valid MATLAB array expression; for example, `[1:5 5:10]` or `(1 6 10 15)`. If the root-level input port is from a From Workspace, From File, or Signal Builder block, which support zero-crossing detection, you can specify a zero-crossing time by using a duplicate time entry.

Examples of Specifying Signal and Time Data

In the first example, consider the following model that has a single input port:



1. Create an input structure for loading 11 time samples of a two-element signal vector of type `int8` into the model:

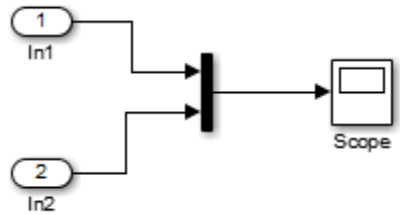
```
N = 10
Ts = 0.1
a.time = (0:N)*Ts';
```

```
c1 = int8([0:1:10]');
c2 = int8([0:10:100]');
a.signals(1).values = [c1 c2];
a.signals(1).dimensions = 2;
```

2. In the **Configuration Parameters > Data Import/Export > Input** parameter edit box, specify the variable `a`.

3. In the Inport block dialog box, in the **Signal Attributes** tab, set **Port dimensions** to `2` and **Data type** to `int8`.

As another example, consider a model that 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 structure, `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;
```

Enter the structure name (`a`) in the **Configuration Parameters > Data Import/Export > Input** parameter edit box.

Note Note that in this model you do not need to specify the dimension and data type, because the default values are `1` and `double`.

Import and Export States

In this section...

State Information

Some blocks maintain state information that Simulink uses for calculating values during simulation. For example, the state information for a Unit Delay block is the output signal value from the previous simulation step, which the block uses for calculating the output signal value for the current simulation step.

You can use saved state information to capture a known state. Some examples of uses of saved state information include:

- Stopping a simulation for a model and using the saved state information as input when you restart the simulation.
- Simulating one model and using the saved state information as input for the simulation of another model that builds on the results of the first model.

Save State Information

You can save state information by either:

- Saving the final state of a simulation, using the `SimState`
- Saving partial state information at the end of a simulation or for each simulation step, using a structure, structure with time, or array

`SimState` provides complete state information. However, use of `SimState` has some limitations, such as:

- You can use only the Normal or the Accelerator mode of simulation.

- `SimState` does not support code generation, including Model Reference in accelerated modes.

To ensure that `SimState` meets your modeling requirements, see "Limitations of the SimState" on page 14-38.

When you save final states without the `SimState`, you save only logged states — the continuous and discrete states of blocks — which are a subset of the complete simulation state of the model. However, if you use a structure or structure with time, you may find that the state information is easier to read than if you use a `SimState`.

For more information, see:

- "Save Complete State Information with SimState" on page 45-114
- "Save Partial Final State Information" on page 45-114

Save Complete State Information with SimState

To save complete state information, save the `SimState` for a simulation.

1. Select the **Configuration Parameters > Data Import/Export > Final states** check box.
2. Also in the Data Import/Export pane, select the **Save complete SimState in final state** parameter.
3. In the edit box adjacent to the **Save complete SimState in final state** parameter, enter a variable name for the `SimState`.
4. Simulate the model.

For more information about using the `SimState`, see "Save and Restore Simulation State as SimState" on page 14-32.

Save Partial Final State Information

To save just the logged states (the continuous and discrete states of blocks):

1. Select the **Configuration Parameters > Data Import/Export > Final states** check box.
2. In the **Final states** edit box, you can specify a different variable for the state information, if you do not want to use the default `xFinal` variable.
3. Also in the **Data Import/Export** pane, set the **Format** parameter to `Structure` or `Structure with time`. For details, see "Format for Saved State Information" on page 45-115
4. Simulate the model.

For details about examining the saved state information, see

Save State Information For Each Simulation Step

You can save state information for logged states for each simulation step during a simulation. That level of state information can be helpful for debugging.

1. Select the **Configuration Parameters > Data Import/Export > States** check box.
2. In the **States** edit box, you can specify a different variable for the state information, if you do not want to use the default `xout` variable.
3. Also in the **Data Import/Export** pane, set the **Format** parameter to `Structure` or `Structure with time`, unless you need to use array format for compatibility with a legacy model. For details, see "Format for Saved State Information" on page 45-115.
4. Simulate the model.

Format for Saved State Information

If you do not use the `SimState` for saving state information, then use **Configuration Parameters > Data Import/Export > Format** to specify the data format for the saved state information.

You can set **Format** to:

- `Array` (default)
- `Structure`
- `Structure with time`

The `Structure` and `Structure with time` formats are easier to read and consistent across simulations. Also, these two formats are useful when using state information to initialize a model for simulation, allowing you to:

- 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.

The `Array` option for the **Configuration Parameters > Data Import/Export > Format** option supports compatibility with models developed in earlier releases, when Simulink supported only the array format for saving state information.

The array format reflects the order of signals. The order of saved state information can change between simulations when you change any of the following:

- The model (even without changing the signal
- The simulation mode
- The code generation mode

Examine State Information Saved Without the SimState

If you enable the **Configuration Parameters > Data Import/Export > Final states** or **States** parameters, Simulink saves the state information in the format that you specify with the **Format** parameter. The default variable for **Final state** information is `xFinal`, and the variable for state information for States information is `xout`.

If a model has no states saved, then `xFinal` and `xout` are empty variables. To determine whether a model has states saved, use the `isempty(xout)` command.

For example, suppose that you saved final state information in a structure with time format, and use the default `xFinal` variable for the saved state information.

To find the simulation time and number of states, at the MATLAB command line, type

```
xFinal
```

```
xFinal =

       time: 20
    signals: [1x2 struct]
```

In this case, the simulation time is 20 and there are two states. To examine the first state, type

```
xFinal.signals(1)
```

```
ans =

              values: 2.0108
          dimensions: 1
               label: 'CSTATE'
           blockName: 'vdp/x1'
           stateName: ''
    inReferencedModel: 0
```

The `values` and `blockName` fields of first state structure shows that the final value for the output signal of the x1 block was 2.018.

Note If you write a script to analyze state information, use a combination of `label` and `blockName` values to uniquely identify a specific state. Do not rely on the order of the states.

Import Initial States

To import states, enable **Configuration Parameters > Data Import/Export > Initial state** and specify a variable that contains the initial state values. For example, you could specify a variable that contains state information saved from a previous simulation.

You can import state information to initialize a simulation:

1. Enable **Configuration Parameters > Data Import/Export > Initial state**.

2. In the **Initial state** edit box, enter the name of the variable for the state information that you want to use for initialization. You can create your own state information in MATLAB or you can use state information saved from a previous simulation. For details about using saved state information, see "Import Saved State Information" on page 45-118.

   The initial values that the variable specifies override the initial state values that the blocks in the model specify in initial condition parameters.

Import Saved State Information

You can import saved state information as the initial state.

1. Enable **Configuration Parameters > Data Import/Export > Initial state**.

2. In the **Initial state** edit box, enter the name of the variable in the **Final states** edit box. The state information that Simulink loads depends on the setting of **Configuration Parameters > Data Import/Export > Save complete SimState in final state**.

Setting for the "Save complete SimState in final state" parameter	State Information
Enabled	Complete state information. For details, see "Save and Restore Simulation State as SimState" on page 14-32.
Cleared	State information for logged states (the continuous and discrete states of blocks), in the format specified in **Configuration Parameters > Data Import/Export > Format**. For details, see "Format for Saved State Information" on page 45-115.

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 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.

Import and Export State Information for Referenced Models

Saved State Information

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 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
```

State Initialization

Use the structure or structure with time format to initialize the states of a top model and the models that it references.

46

Working with Data Stores

About Data Stores

In this section...

Local and Global Data Stores

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. You can define two types of data stores:

- A *local data store* is accessible from anywhere in the model hierarchy that is at or below the level at which you define the data store, except from referenced models. You can define a local data store graphically in a model or by creating a model workspace signal object (`Simulink.Signal`).
- A *global data store* is accessible from throughout the model hierarchy, including from referenced models. Define a global data stores only in the MATLAB base workspace, using a signal object. The only type of data store that a referenced model can access is a global data store.

In general, locate a data store at the lowest level in the model that allows access to the data store by all the parts of the model that need that access. Some examples of local and global data stores appear in "Data Store Examples" on page 46-23.

For information about using referenced models, see "Model Reference".

Customized Data Store Access Functions in Generated Code

Embedded Coder provides a custom storage class that you can use to specify customized data store access functions in generated code. See "Apply Custom Storage Classes" and "GetSet Custom Storage Classes".

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, such as making verification more difficult. See "Data Stores and Software Verification" on page 46-46 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.

Create Data Stores

To create a data store, you create a Data Store Memory block or a `Simulink.Signal` object. The block or signal 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 "Data Stores with Data Store Memory Blocks" on page 46-8.
- A `Simulink.Signal` object can act as a local or global data store. See "Data Stores with Signal Objects" on page 46-12.

Data stores implemented with Data Store Memory blocks:

- Support data store initialization
- Provide control of data store scope and options at specific levels in the model hierarchy
- 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 model-wide 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.

Access 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 in the data store and outputs that value as a signal.

For Data Store Write and Data Store Read blocks, to identify the data store to be read from or written to, specify the data store name as a block parameter. See “Access Data Stores with Simulink Blocks” on page 46-14 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 “Log Data Stores” on page 46-26.

Configure Data Stores

Note To use buses and arrays of buses with data stores, perform *both* the following procedure and "Setting Up a Model to Use Data Stores with Buses and Arrays of Buses" on page 46-6.

The following is a general workflow for configuring data stores. You can perform the tasks 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 46-46.
2. Create data stores using the techniques described in "Data Stores with Data Store Memory Blocks" on page 46-8 or "Data Stores with Signal Objects" on page 46-12. For greater reliability, consider assigning rather than inheriting data store attributes, as described in "Specifying Data Store Memory Block Attributes" on page 46-8.
3. Add to the model Data Store Write and Data Store Read blocks to write to and read from the data stores, as described in "Access Data Stores with Simulink Blocks" on page 46-14.
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 "Order Data Store Access" on page 46-31.
5. Apply the techniques described in "Data Store Diagnostics" on page 46-38 as needed to prevent data store errors, or to diagnose them if they occur during simulation.
6. If you intend to generate code for your model, see "Data Stores" in the Simulink Coder documentation.

Data Stores with Buses and Arrays of Buses

Benefits of using data stores with buses and arrays of buses include:

- Simplifying the model layout by associating multiple signals with a single data store
- Producing generated code that represents the data in the store data as structures that reflect the bus hierarchy
- Writing to and reading from data stores without creating data copies, which results in more efficient data access

You cannot use a bus or array of buses that contains:

- Variable-dimension signals
- Frame-based signals

Setting Up a Model to Use Data Stores with Buses and Arrays of Buses

This procedure applies to local and global data stores, and to data stores defined with a Data Store Memory block or a `Simulink.Signal` object. Before performing the procedure, you must understand how to use data stores in a model, as described in "Configure Data Stores" on page 46-5.

To use buses and arrays of buses with data stores:

1. Use the Bus Editor to define a bus object whose properties match the bus data that you want to write to and read from a data store. For details, see "Manage Bus Objects with the Bus Editor" on page 48-24.

2. Add a data store (using a Data Store Memory block or a `Simulink.Signal` object) for storing the bus data.

3. Specify the bus object as the data type of the data store. For details, see "Specify a Bus Object Data Type" on page 43-26.

4. In the **Model Configuration Parameters > Diagnostics > Data Validity** pane, set the **Mux blocks used to create bus** diagnostic to `error`. For details, see "Mux blocks used to create bus signals".

   If you receive error messages relating to Mux blocks, identify any Mux blocks in the model that create virtual buses. Use the **Analysis > Model**

Advisor > Simulink > Check for proper bus usage check. For details, see “Check for proper bus usage”.

5. If you use a MATLAB structure for the initial value of the data store, then in the **Model Configuration Parameters > Diagnostics > Data Validity** pane, set the **Underspecified initialization detection** diagnostic to `error`. For details, see “Specify Initial Conditions for Bus Signals” on page 48-65 and “Underspecified initialization detection”.

6. (Optional) Select individual bus elements to write to or read from a data store. For details, see “Accessing Specific Bus and Matrix Elements” on page 46-16.

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, but not within Model blocks, drag the Data Store Memory block into the subsystem.

Once you have added 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 of the data store that the Data Store Write and Data Store Read blocks access. See Data Store Memory documentation for details.

You can specify data store properties beyond those definable with Data Store Memory block parameters by selecting the **Data store name must resolve to Simulink signal object** option and using a signal object as the data store name. See "Specifying Attributes Using a Signal Object" on page 46-9 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:

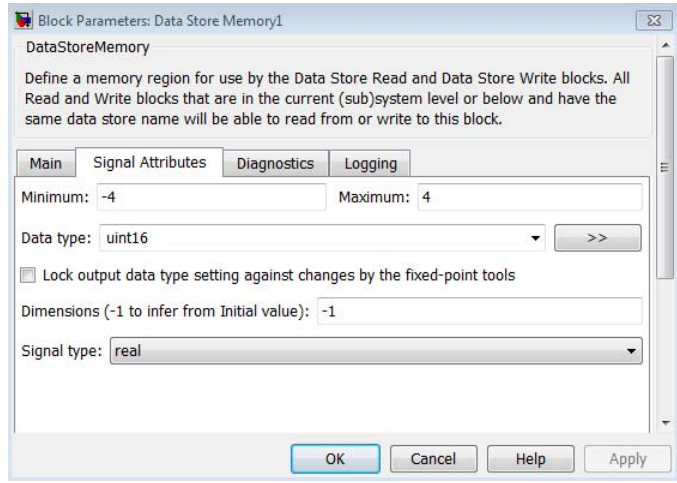
- Data type

- 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. In the next figure, the dialog box sets the **Data type** to `uint16` and the **Signal type** to `real`.

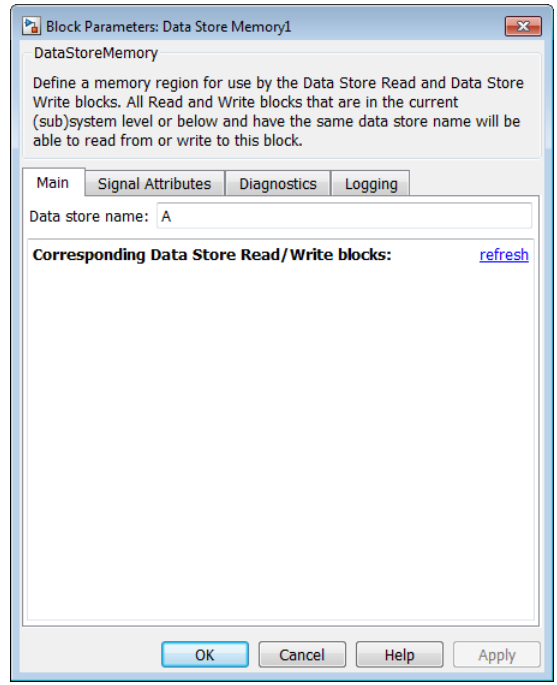


Specifying Attributes Using a Signal Object

You can use a `Simulink.Signal` object to specify data store attributes. To establish an implicit data store, as described in "Data Stores with Signal Objects" on page 46-12, use the same general approach as when you explicitly associate a data object with a Data Store Memory block.

The next figure shows a Data Store Memory block named `A` that specifies resolution to a `Simulink.Signal` object, named `A`. To use a signal object for the

data store, select the **Data store name must resolve to Simulink signal object** parameter and set **Data store name** to the name of the signal object.



The signal object specifies values for all three data attributes that the data store would otherwise inherit: `DataType`, `Complexity`, and `SampleTime`. In this example, the `Simulink.Signal` object `A` might have the following properties:

```
A =

Simulink.Signal (handle)
           CoderInfo: [1x1 Simulink.SignalCoderInfo]
       Description: ''
          DataType: 'auto'
               Min: []
               Max: []
          DocUnits: ''
        Dimensions: 1
```

```
DimensionsMode: 'auto'
    Complexity: 'auto'
    SampleTime: -1
  SamplingMode: 'auto'
  InitialValue: ''
```

Data Stores with Signal Objects

In this section...

Creating the Data Store

To use a `Simulink.Signal` object to define a data store without using a Data Store Memory block, create the signal object in a workspace that is visible to every component that needs to access the data store. 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. Simulink creates an associated data store when you use the signal object for data storage.

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. The parameter values of a signal object used as a data store have different requirements, depending on whether the data store is global or local.

- For a local data store, for each parameter listed in the following table, you can either set value explicitly or you can have the data store inherit the value from the Data Store Write and Data Store Read blocks.

- The following table describes the parameter requirements for global data stores.

Parameter	Global Data Store Value
`DataType`	Must be set explicitly
`Complexity`	Must be set explicitly
`Dimensions`	Must be set explicitly
`SampleTime`	Can be set or inherited
`SamplingMode`	Must be `'Sample based'`

For a local data store defined using a Data Store Memory block that uses a signal object for the **Data store name** parameter, you can select the **Data store must resolve to Simulink signal object** parameter for compile-time checking. The **Data store must resolve to Simulink signal object** parameter causes Simulink to display an error and stop compilation if Simulink cannot find the signal object or if the signal object properties are inconsistent with the signal object properties.

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;
```

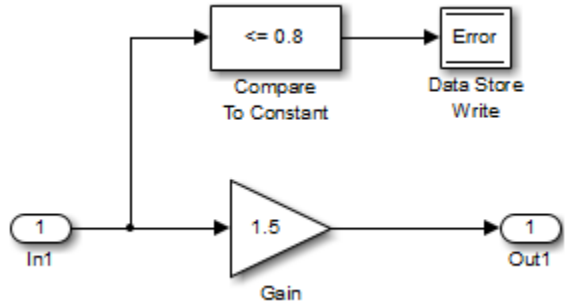
Access Data Stores with Simulink Blocks

In this section...

Writing to a Data Store

To set the value of a data store at each time step:

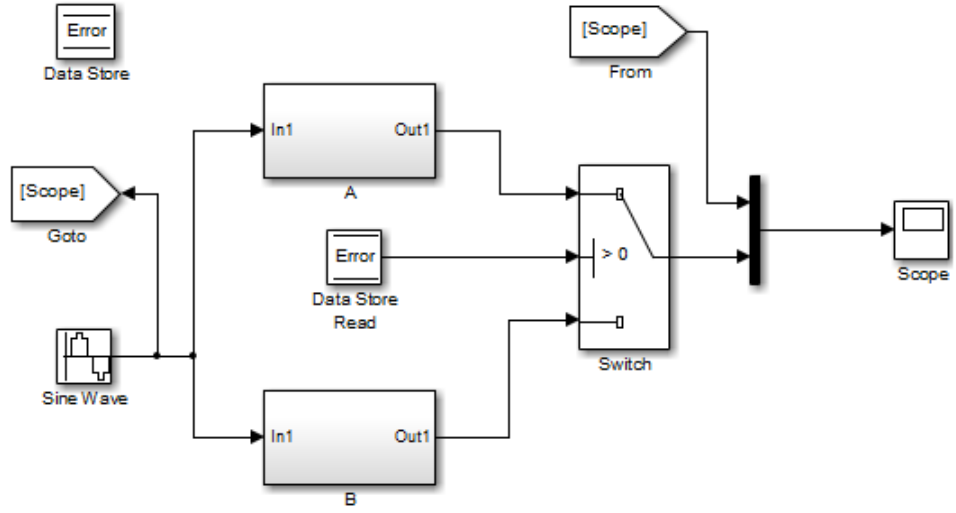
1. Create an instance of a Data Store Write block at the level of your model that computes the value.
2. Set the Data Store Write block **Data store name** parameter to the name of the data store to which you want it to write data.
3. Connect the output of the block that computes the value to the input of the Data Store Write block.



Reading from a Data Store

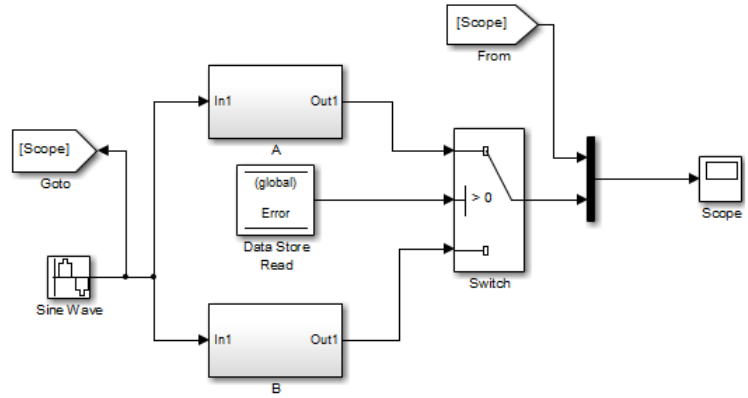
To get the value of a data store at each time step:

1. Create an instance of a Data Store Read block at the level of your model that needs the value.
2. Set the Data Store Read block **Data store name** parameter to the name of the data store from which you want it to read.
3. Connect the output of the Data Store Read block to the input of the block that needs the data store value.



Accessing a Global Data Store

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 name.



Accessing Specific Bus and Matrix Elements

Selecting Specific Bus or Matrix Elements

By default, a model writes and reads all bus and matrix elements to and from a data store.

To select specific bus or matrix elements to write to or read from a data store, use the **Element Assignment** pane of the Data Store Write block and the **Element Selection** pane of the Data Store Read block . Selecting specific bus or matrix elements offers the following benefits:

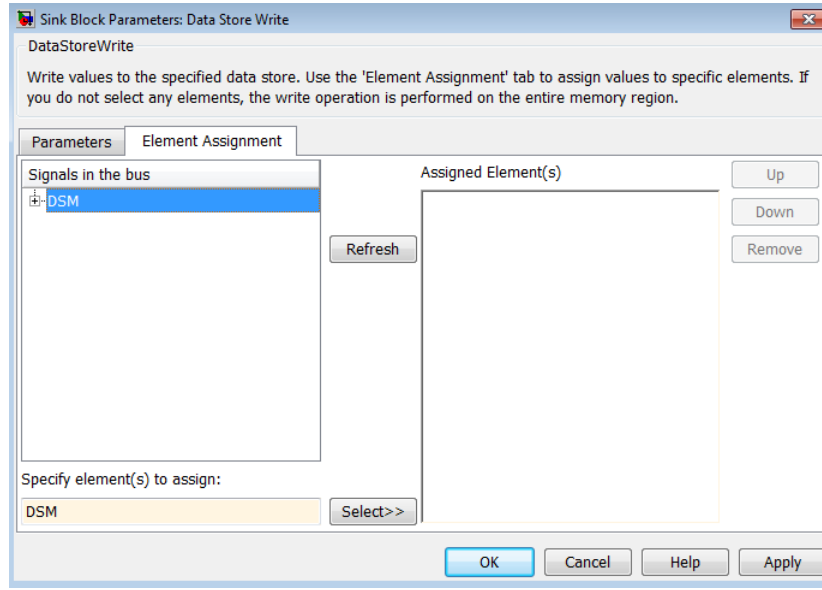
- Reducing the number of blocks in the model. For example, you can eliminate a Data Store Read and Bus Selector block pair or a Data Store Write and Bus Assignment block pair for each specific bus element that you want to access).
- Faster simulation of models with large buses and arrays of buses.

Writing Specific Elements to a Data Store

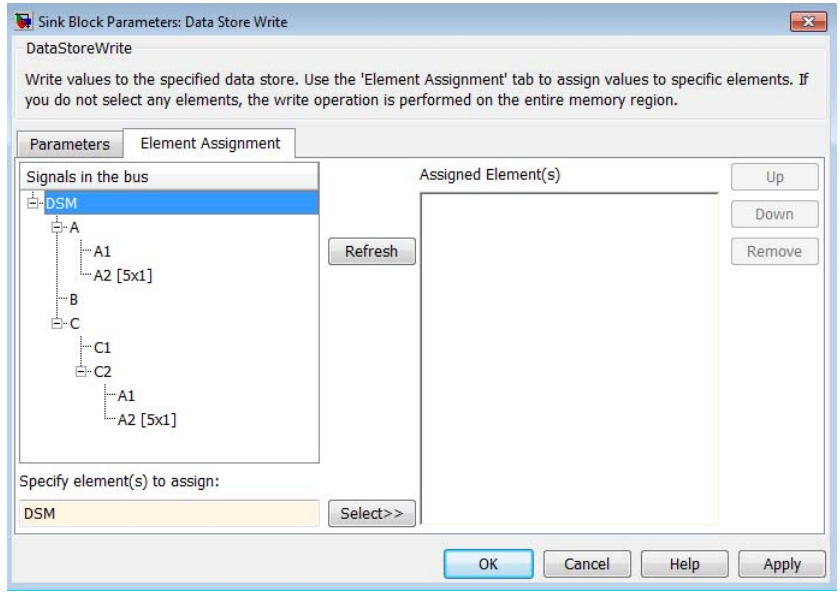
Note The following procedure describes how to use the Data Store Write block interface to write specific elements to a data store. You can also perform this task at the command line, using the `DataStoreElements` parameter to specify elements. For details, see "Specification using the command line" on page 46-22.

To assign specific bus or matrix elements to write to a data store:

1. Select the Data Store Write block and in the parameters dialog box, select the **Element Assignment** pane. For example, suppose you are using a bus with a data store named `DSM`:

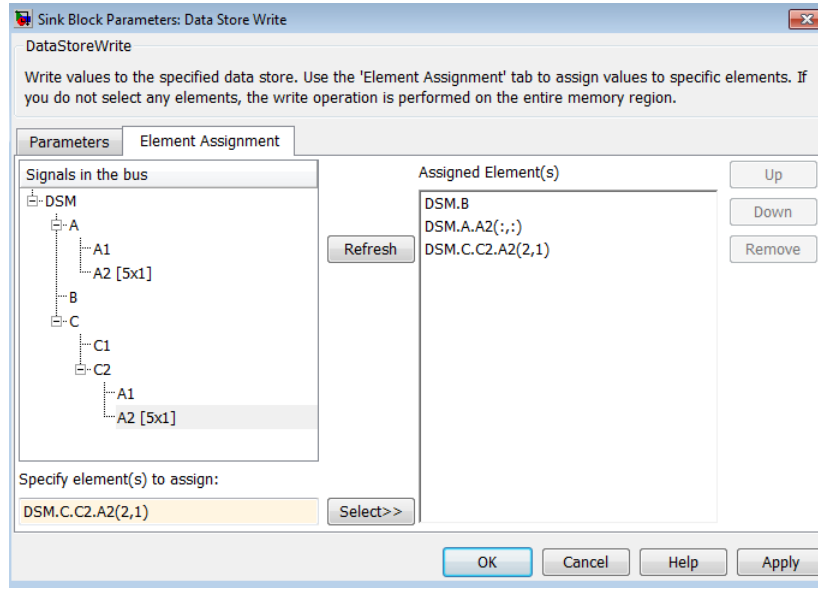


2. Expand all the elements in the **Signals in the bus** list.



3 Specify the elements that you want to write to the data store. For example:

- In the **Signals in the bus** list, click `B`. Then click **Select>>** to select the element `B`.
- To write all the elements of `A2` (in the `A` subbus), select `A2[5x1]`. Then click **Select>>**.
- To write the second element of `A2` in the `C2` subbus, select the `A2[5x1]` element. In the **Specify element(s) to assign** text box, edit the text to say `DSM.C.C2.A2(2,1)`.



For more examples, see “Specifying Elements to Assign or Select” on page 46-20.

4 (Optional) Reorder the assigned elements, which changes the order of the ports of the Data Store Write block.

- To reorder an assigned element, in the **Assigned element(s)** list, select the element that you want to move, and click **Up** or **Down**.
- To remove an assigned element, click **Remove**.

5 To apply the assigned elements, click **OK**.

The Data Store Write block has a port for each assigned element. The names of the selected elements that correspond to each port appear in the block icon. If you assign several signals, these additions may diminish the readability of the model. To improve readability, you can expand the size of the block or create multiple Data Store Write blocks.

Reading Specific Elements from a Data Store

Reading specific elements from a data store involves very similar steps as described in "Writing Specific Elements to a Data Store" on page 46-17. The Data Store Read block differs slightly from the Data Store Write block. A Data Store Read block has:

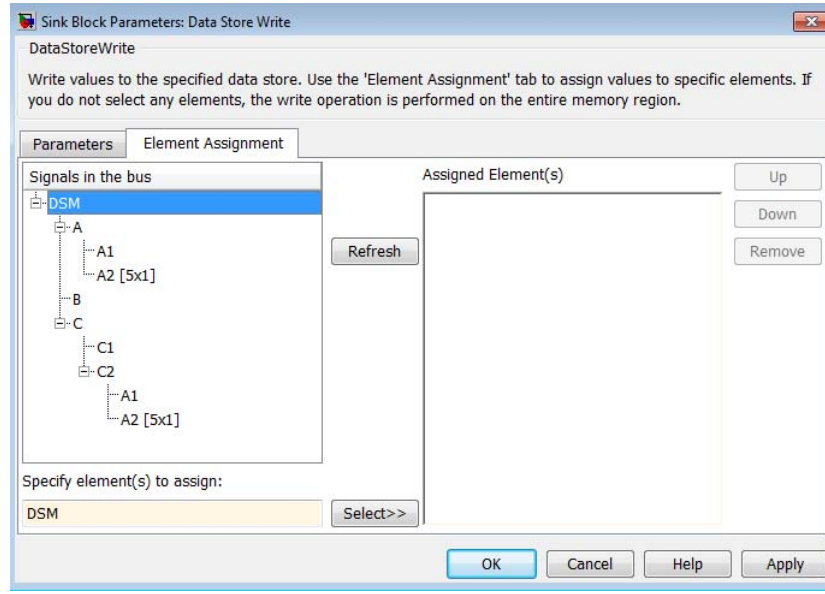
- An **Element Selection** pane instead of an **Element Assignment** pane
- A **Selected element(s)** list instead of an **Assigned element(s)** list

Specifying Elements to Assign or Select

Use MATLAB matrix element syntax to specify specific elements. For details about specifying matrices in MATLAB, see "Creating and Concatenating Matrices".

Note To select matrix elements, you cannot use dynamic indexing with the **Element Assignment** and **Element Selection** panes of Data Store Read and Bus Assignment block pairs or Data Store Write and Bus Selector block pairs. You can, however, use a MATLAB Function block for dynamic indexing.

Valid element specifications. The following table shows examples of valid syntax for specifying elements to assign or select. These examples use the `A2` subbus of the `A` bus, as shown in the bus hierarchy used in "Writing Specific Elements to a Data Store" on page 46-17.



Valid Syntax	Description
`DSM.A.A2(:,:)`	Selects all elements in every dimension
`DSM.A.A2([1,3,5],1)`	Selects the first, third, and fifth elements
`DSM.A.A2(2:5,1)`	Selects the second through the fifth element

Invalid element specifications. The following table shows examples of invalid syntax for specifying elements to assign or select. These examples use the `A2` subbus of the `A` bus, as shown in the bus hierarchy used in "Writing Specific Elements to a Data Store" on page 46-17.

Invalid Syntax	Reason the Syntax Is Invalid
`DSM.A.A2(:)`	You must specify a colon for each dimension. For the bus hierarchy used in these examples, you must use two colons.
`DSM.A.A2(2:end,1)`	You cannot use the `end` operator.
`DSM.A.A2(idx,1)`	You cannot use variables to specify indices. Consider using a MATLAB Function block.
`DSM.A.A2(-1,1)`	The dimension –1 is not within the valid dimension bounds.

Specification using the command line. To set the elements to write to or read from, use the `DataStoreElements` parameter. Use a pound sign (#) to delimit multiple elements. For example, select the Data Store Write or Data Store Read block for which you want to specify elements and enter a command such as:

```
set_param(gcb, 'DataStoreElements', 'DSM.A#DSM.B#DSM.C(3,4)')
```

This specification results in the block now having three ports corresponding to the elements that you specified.

Data Store Examples

In this section...

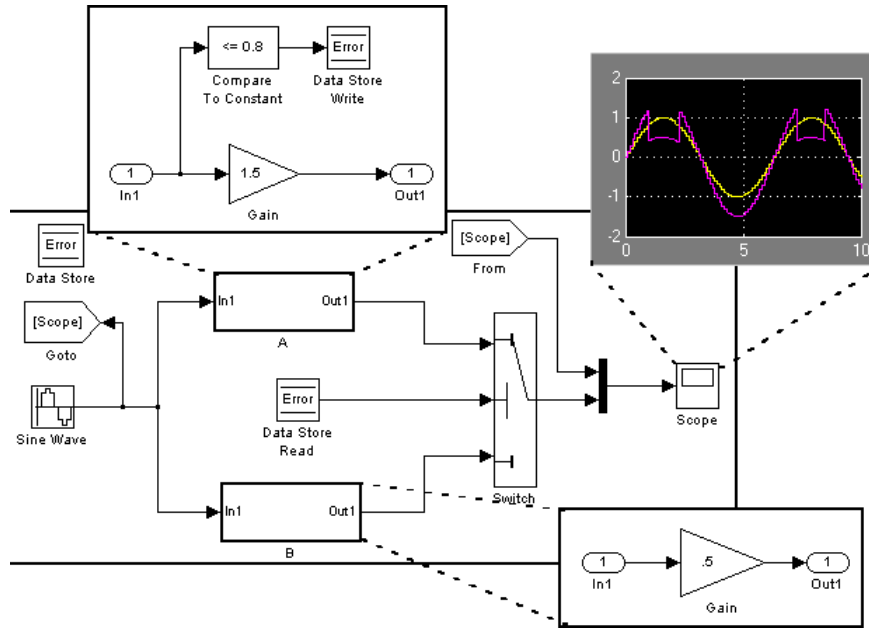
Overview

The following examples illustrate techniques for defining and accessing data stores. See "Order Data Store Access" on page 46-31 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 "Data Store Diagnostics" on page 46-38 for techniques you can use to help detect and correct potential data store errors without needing to run any simulations.

Note In addition to the following examples, see the sldemo_mdlref_dsm model, which shows how to use global data stores to share data among referenced models.

Local Data Store Example

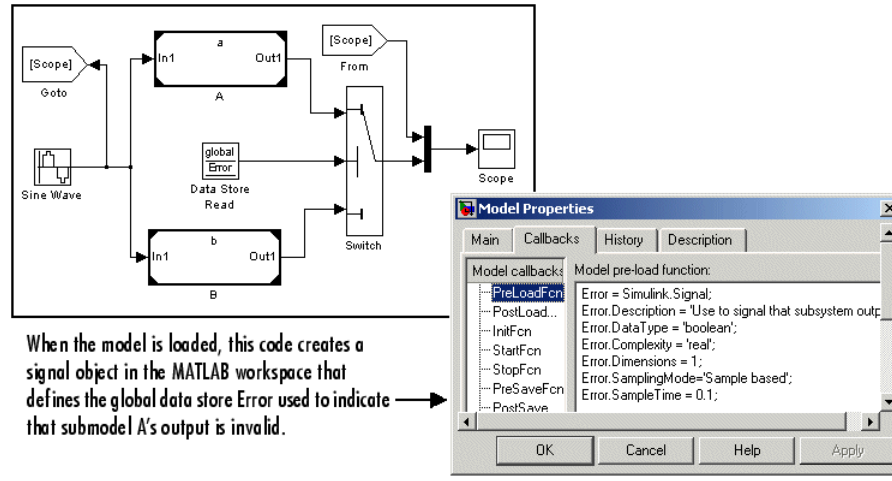
The following model illustrates creation and access of a local data store, which is visible only in a model or particular subsystem.



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.

Log 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, see the sldemo_mdlref_dsm model.

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 **Model 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).

  For details about viewing information about sample times, see "View Sample Time Information" on page 5-9.
- You cannot log data stores that use custom data types.

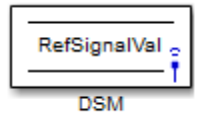
Logging Data Stores Created with a Data Store Memory Block

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. Optionally, specify limits for the amount of data logged, using the **Minimum** and **Maximum** parameters.
4. Enable data store logging with the **Model Configuration Parameters > Data Import/Export > Data stores** parameter.
5. 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.



Logging Data Stores Created with a Simulink.Signal Object

You can create local and global data stores using a `Simulink.Signal` object. See "Data Stores with Signal Objects" on page 46-12 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 "Data Stores with Signal Objects" on page 46-12.

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. Optionally, specify limits for the amount of data logged, using the following properties, which are properties of the `LoggingInfo` property of the `Simulink.Signal` object: `Decimation`, `LimitDataPoints`, and `MaxPoints`.

5. Enable data store logging with the **Model Configuration Parameters > Data Import/Export > Data stores** parameter.

6 Simulate the model.

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 during simulation

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 model illustrates approaches for viewing data store logging data.

Accessing 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 `getElement` method of `Simulink.SimulationData.Dataset`. For example:

```
dsmout.getElement('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.

Order Data Store Access

In this section...

About Data Store Access Order

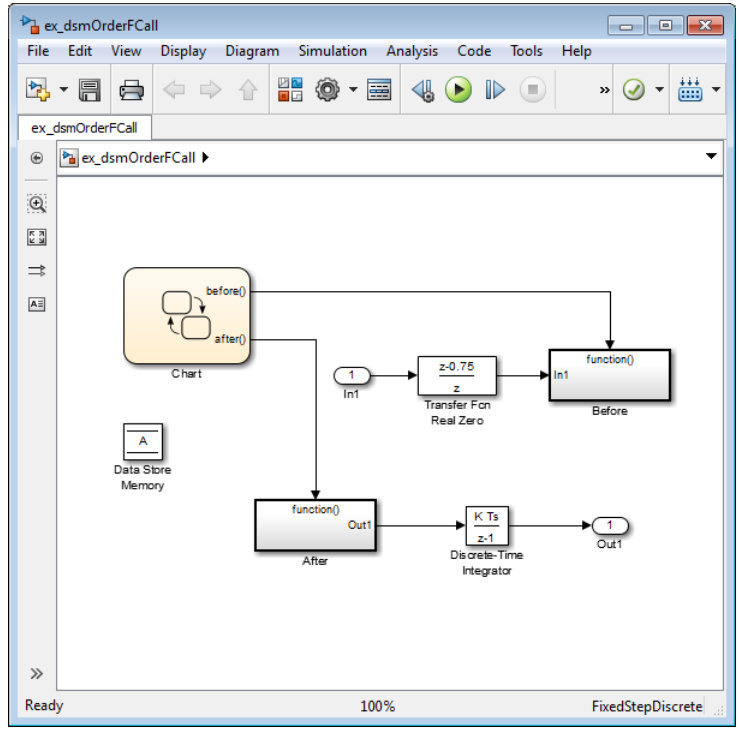
To obtain correct results from data stores, you must control the order of execution of the data store's reads and writes. If a data store's read occurs before its write, latency is introduced into the algorithm: the read obtains the value that was computed and stored in the previous time step, rather than the value computed and stored in the current time step.

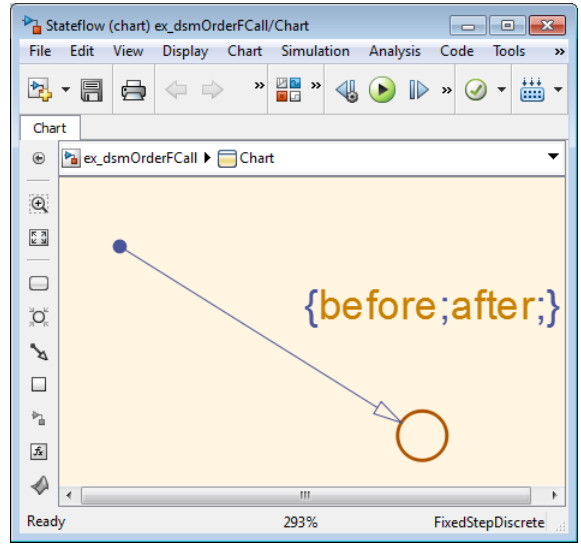
Such latency may cause the system to behave other than as designed, and in some cases may destabilize the system. Even if these problems do not occur, an uncontrolled access order could change from one release of Simulink to the next.

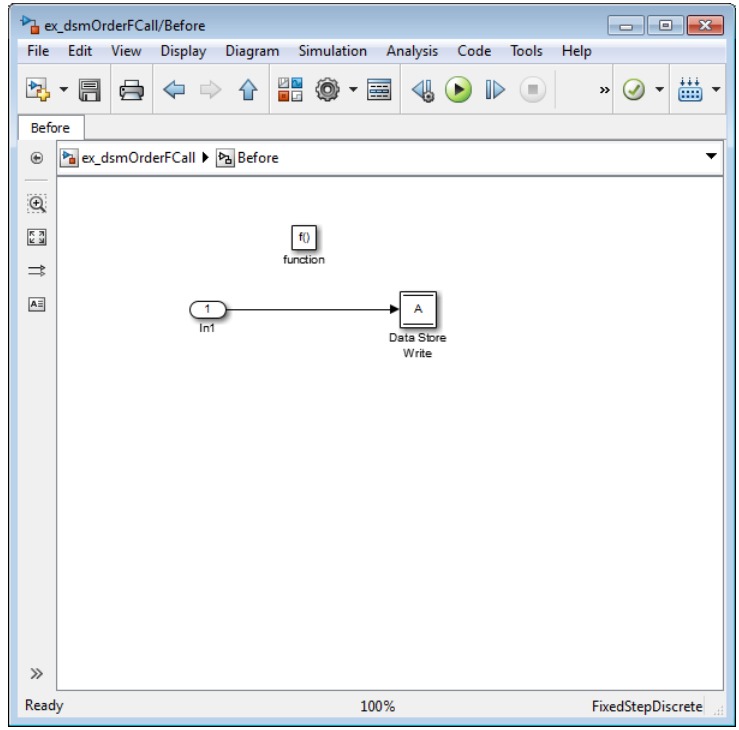
This section describes several strategies for explicitly controlling the order of execution of a data store's reads and writes. See "Data Store Diagnostics" on page 46-38 for techniques you can use to detect and correct potential data store errors without running simulations.

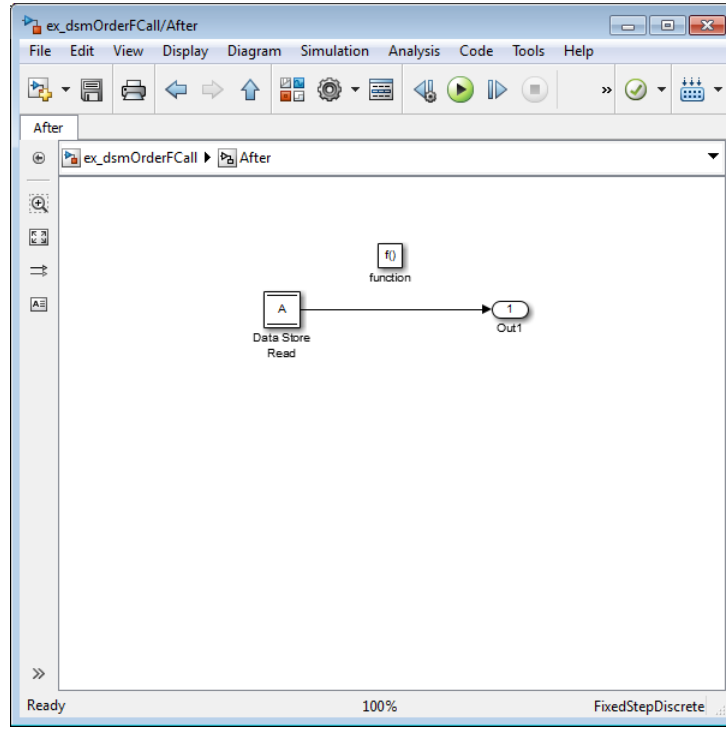
Ordering Access Using Function Call Subsystems

You can use function call subsystems to control the execution order of model components that access data stores. The next figure shows this technique:


ex_dsmOrderFCall
File Edit View Display Diagram Simulation Analysis Code Tools Help
ex_dsmOrderFCall
ex_dsmOrderFCall
before()
after()
Chart
1
In1
z-0.75
z
Transfer Fcn
Real Zero
function()
In1
Before
A
Data Store
Memory
function()
Out1
After
K Ts
z-1
Discrete-Time
Integrator
1
Out1
Ready
100%
FixedStepDiscrete


Stateflow (chart) ex_dsmOrderFCall/Chart
File Edit View Display Chart Simulation Analysis Code Tools
Chart
ex_dsmOrderFCall
Chart
{before;after;}
Ready
293%
FixedStepDiscrete

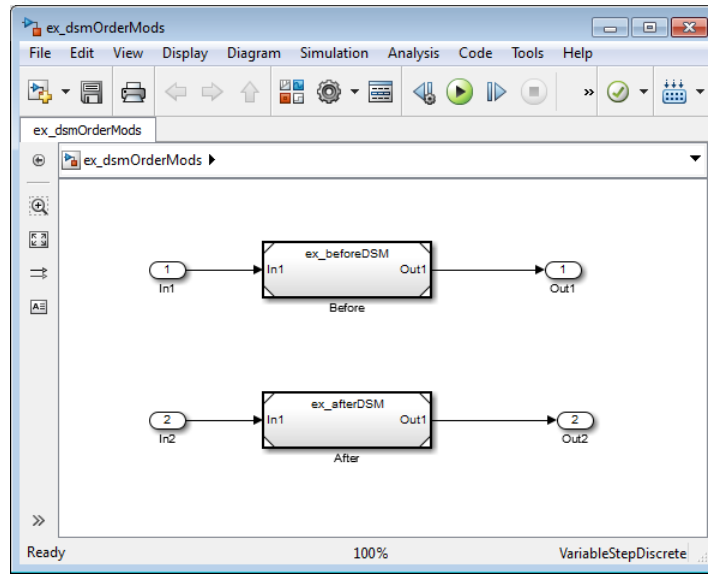

ex_dsmOrderFCall/Before
File Edit View Display Diagram Simulation Analysis Code Tools Help
Before
ex_dsmOrderFCall
Before
f()
function
1
In1
A
Data Store
Write
Ready
100%
FixedStepDiscrete

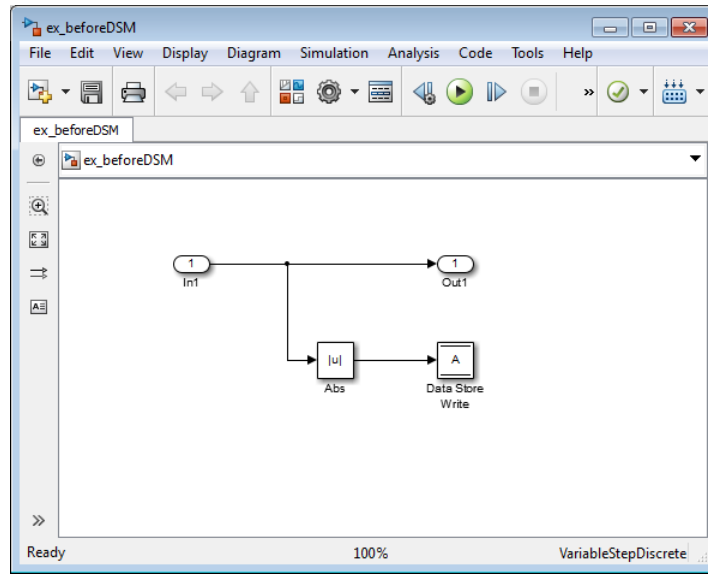


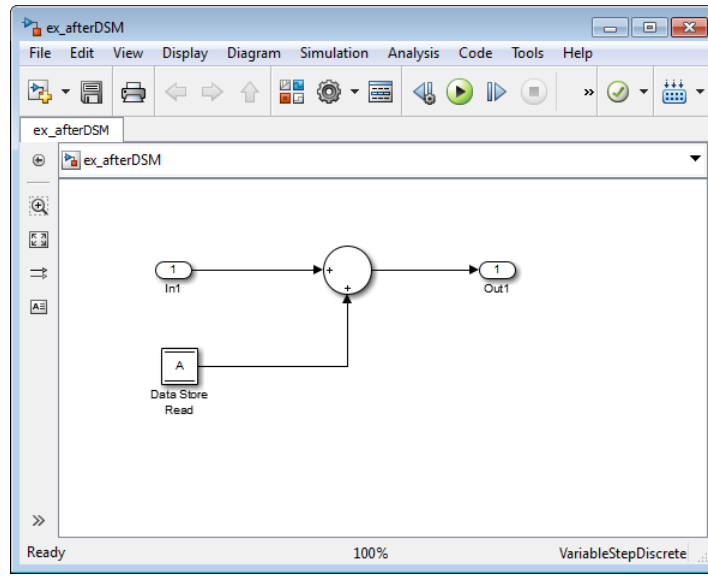
The subsystem `Before` contains the Data Store Write, and the Stateflow chart calls that subsystem before it calls the subsystem `After`, which contains the Data Store Read.

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:


ex_dsmOrderMods
File Edit View Display Diagram Simulation Analysis Code Tools Help
ex_dsmOrderMods
ex_dsmOrderMods
1
In1
ex_beforeDSM
In1
Out1
Before
1
Out1
2
In2
ex_afterDSM
In1
Out1
After
2
Out2
Ready
100%
VariableStepDiscrete


ex_beforeDSM
File Edit View Display Diagram Simulation Analysis Code Tools Help
ex_beforeDSM
ex_beforeDSM
1
In1
1
Out1
|u|
Abs
A
Data Store
Write
Ready
100%
VariableStepDiscrete



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.

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 Model 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:

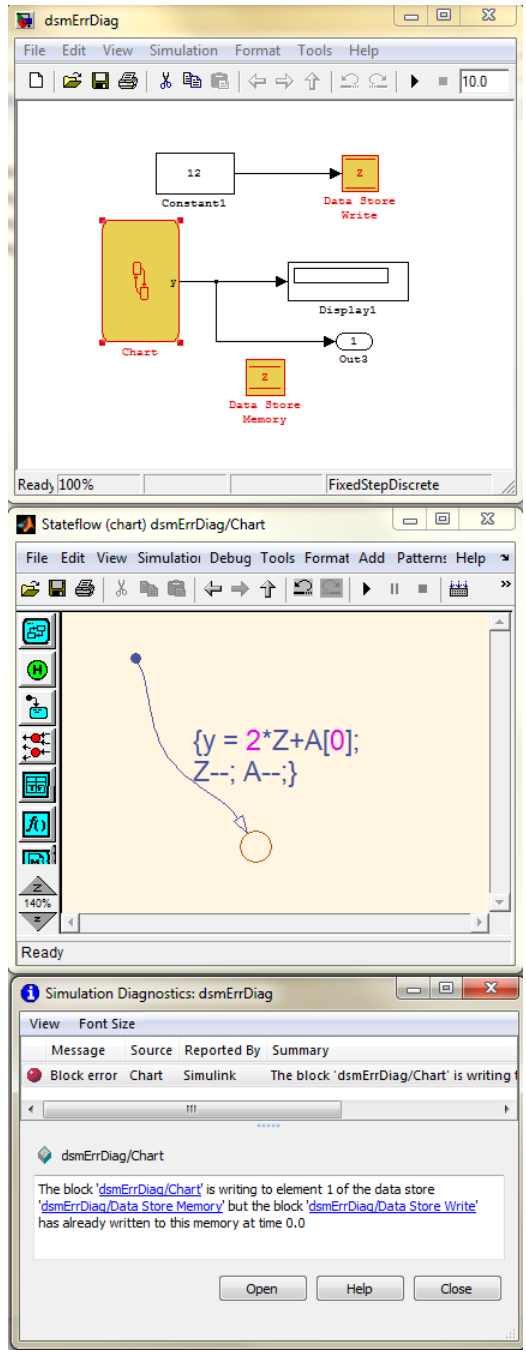
- **Detect read before write:** Detect when a data store is read from before written to within a given time step
- **Detect write after read:** Detect when a data store is written to after being read from within a given time step
- **Detect write after write:** Detect when a data store is written to multiple times within a given time step

These diagnostics appear in the **Model 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 parameters dialog box **Diagnostics** tab. You can set each diagnostic to `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 the Data Store Memory documentation for more information.

The most conservative technique is to set all data store diagnostics to `Enable all as errors` in **Model 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:


dsmErrDiag
File Edit View Simulation Format Tools Help
10.0
12
Constant1
Z
Data Store Write
y
Chart
Display1
1
Out3
Z
Data Store Memory
Ready
100%
FixedStepDiscrete
Stateflow (chart) dsmErrDiag/Chart
File Edit View Simulation Debug Tools Format Add Patterns Help
{y = 2*Z+A[0];
Z--; A--;}
140%
Ready
Simulation Diagnostics: dsmErrDiag
View Font Size
Message Source Reported By Summary
Block error Chart Simulink The block 'dsmErrDiag/Chart' is writing
dsmErrDiag/Chart
The block 'dsmErrDiag/Chart' is writing to element 1 of the data store 'dsmErrDiag/Data Store Memory' but the block 'dsmErrDiag/Data Store Write' has already written to this memory at time 0.0
Open
Help
Close

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 MATLAB Function Block

Diagnostics might be more conservative for data store memory used by MATLAB Function blocks. For example, if you pass arrays of data store memory to MATLAB functions, optimizations such as `A=foo(A)` might result in MATLAB marking the entire contents of the array as read or written, even though only some elements were accessed.

Detecting Multitasking Access Errors

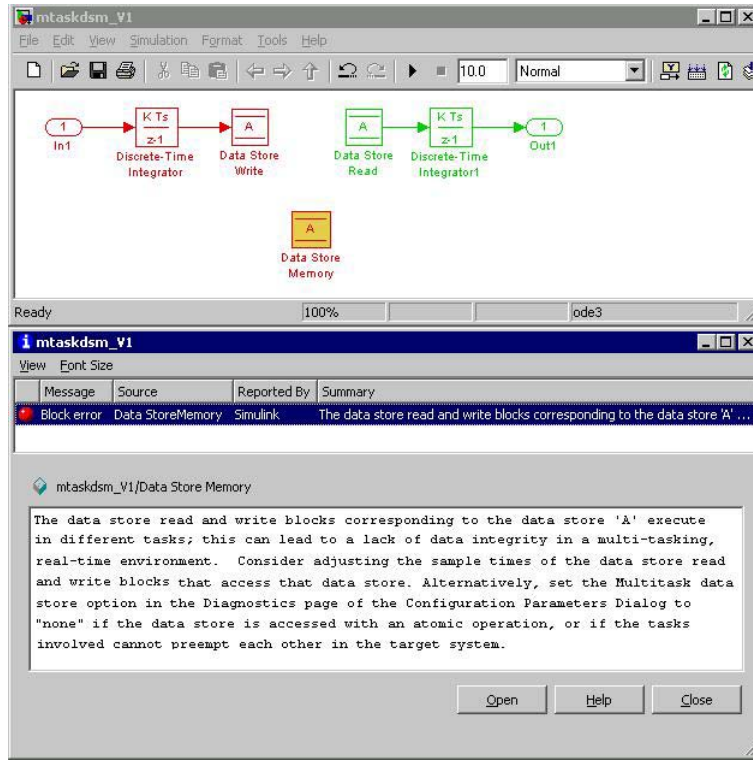
Data integrity may be compromised if a data store is read from in one task and written to in another task. For example, suppose that:

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 data store is 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, it may be left in an inconsistent state that is not even partly correct.

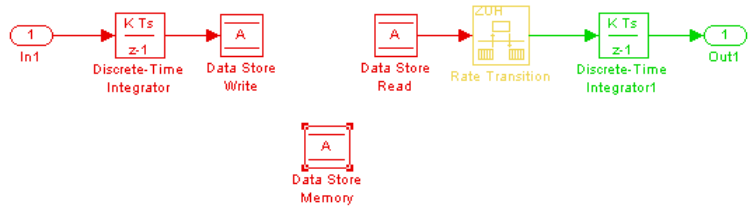
Unless you are certain that task preemption cannot cause data integrity problems, set the compile-time diagnostic **Model Configuration Parameters > Diagnostics > Data Validity > Data Store Memory Block > Multitask Data Store** to `warning` (the default) or `error`. This diagnostic flags any case of 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.



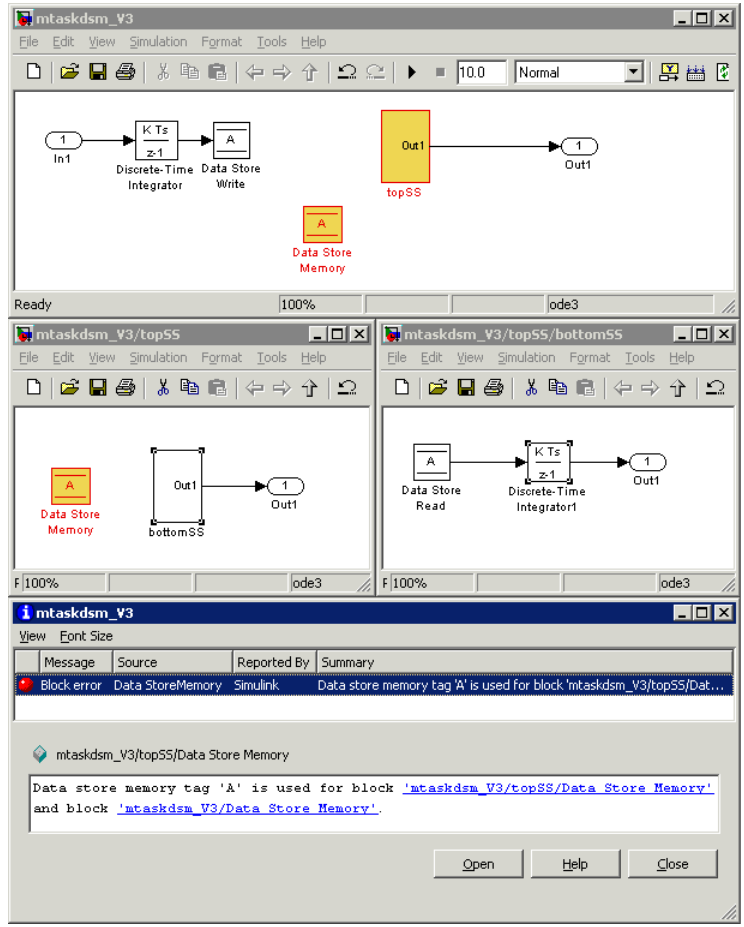
With this change, the data store write can continue to occur at the faster rate. This may be important if that data store must be read at that faster rate elsewhere in the model.

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 **Model 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 data store 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-331, "Model-Based Development and Verification Supplement to DO-178C and DO-278A," Section MB.6.3.3.b.

Managing Signals

47

Working with Signals

Signal Basics

In this section...

About Signals

A *signal* is 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 (for example, 8-bit, 16-bit, or 32-bit integer)
- Numeric type (real or complex)
- Dimensionality (one-dimensional, two-dimensional, or multidimensional array)

Many blocks can accept or output signals of any data or numeric type and dimensionality. Other blocks impose restrictions on the attributes of the signals that they can handle.

In Simulink, signals are 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 of B depends on the signal output of A.

Simulink block diagrams represent signals 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 Simulink signals do not travel along the lines that connect blocks in the same way that electrical signals travel along a 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

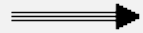
Create a signal by adding a source block to your model. For example, you can create a signal that varies sinusoidally with time, by dragging an instance of the Sine block from the Simulink Sources library into your model. See "Sources" for information about blocks that create signals in a model.

You can also use the Signal & Scope Manager to create signals in your model, without using blocks. See "Signal and Scope Manager" on page 16-23 for more information.

Signal Line Styles

A Simulink model can include many different types of signals. For details, see "Signal Types" on page 47-8.

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.

Signal Type	Line Style	Description
Scalar and Nonscalar		Simulink uses a thin, solid line to represent scalar and nonscalar signals.
Nonscalar (optional)		When you enable the **Wide nonscalar lines** option, Simulink uses a thick, solid line to represent nonscalar signals. For information about line display options, see "Display Signal Attributes" on page 47-61.
Control signal		Simulink uses a thin, dash-dot line to represent control signals.
Virtual Bus		Simulink uses a triple line with a solid core to represent virtual signal buses.
Nonvirtual Bus		Simulink uses a triple line with a dotted core to represent nonvirtual signal buses.
Array of Buses		Simulink uses a heavy triple line with a dotted core to represent array of bus signals.
Variable-Size		Simulink uses a solid wide line with a white dotted core to represent a variable-size signal.

Other than using the **Wide nonscalar lines** option to display nonscalar signals as thick, solid lines, you cannot customize or control the line style of signals. See "Wide Nonscalar Lines" on page 47-65 for more information about this option.

As you construct a block diagram, Simulink uses a thin, solid line to represent all signal types. After you update or start simulation of the block diagram, Simulink redraws the lines, using the specified line styles.

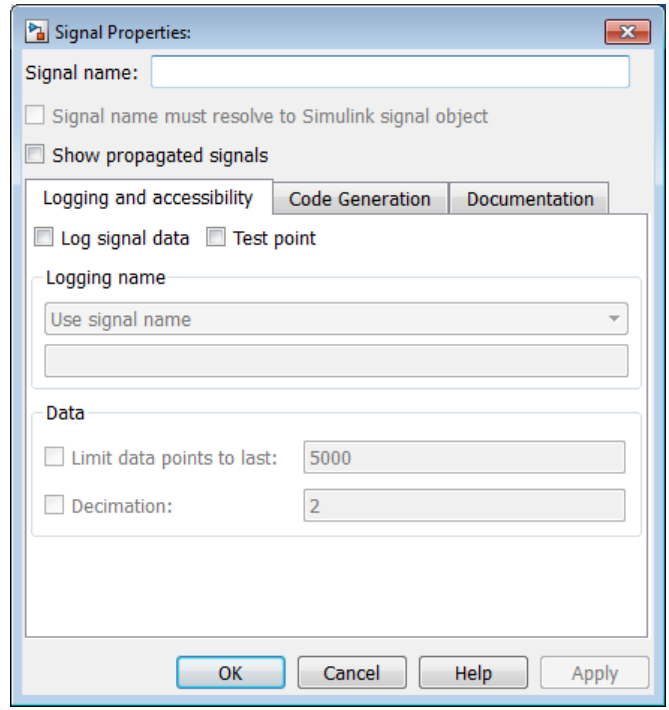
Signal Properties

Specifying Signal Properties

Use the Signal Properties dialog box to specify properties for:

- Signal names and labels
- Signal logging
- Simulink Coder to use to generate code
- Documentation of the signal

To open the Signal Properties dialog box, right-click a signal and choose **Properties**.



Displaying Signal Attributes in the Model

Displaying signal attributes in the model diagram can make the model easier to understand at a glance. For example, in the Simulink Model Editor, use the **Display > Signals & Ports** menu to include in the model layout information about signal attributes, such as:

- Port data types
- Design ranges
- Signal dimensions
- Signal resolution

For details, see "Display Signal Attributes" on page 47-61.

Display Signal Source and Destination

To highlight a signal and its source or destination blocks:

- Right-click a signal.
- In the context menu, select either **Highlight Signal to Source** or **Highlight Signal to Destination**.

For details, see"Display Signal Sources and Destinations" on page 47-41.

Testing Signals

You can perform the following kinds of tests on signals:

Minimum and Maximum Values

For many Simulink blocks, you can specify a range of valid values for the output signals. Simulink provides a diagnostic for detecting when blocks generate signals that exceed their specified ranges during simulation. For details, see "Signal Ranges" on page 47-44.

Connection Validation

Many Simulink blocks have limitations on the types of signals that they accept. Before simulating a model, Simulink checks all blocks to ensure that the blocks can accommodate the types of signals ouput by the ports to which the blocks connect. If any incompatibilities exist, Simulink reports an error and terminates the simulation.

To detect signal compatibility errors before running a simulation, update the diagram. In the Simulink Editor, select **Simulation > Update Diagram**.

Signal Groups

The Signal Builder block displays interchangeable groups of signal sources. Use the Signal Builder to create or edit groups of signals and to switch the groups into and out of a model.

Signal groups can greatly facilitate testing a model, especially when you use them in conjunction with Simulink Assertion blocks and the Model Coverage Tool in the Simulink Verification and Validation product.

For details, see “Signal Groups” on page 47-66.

Signal Types

In this section...

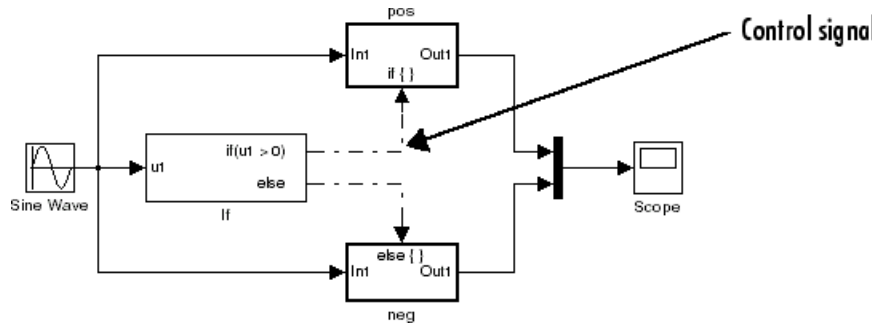
Summary of Signal Types

You can use many different kinds of signals in a model. The following table summarizes the signal types, and links to sections that describe each type in detail.

Signal Type	Description
Array of buses	An array whose elements are buses. See "Combine Buses into an Array of Buses" on page 48-77.
Bus (Composite)	A Simulink composite signal made up of other signals, optionally including other bus signals. See "Composite (Bus) Signals" on page 47-9.
Control	Signal used by one block to initiate execution of another block. For example, a signal that executes a function-call or action subsystem. For details, see "Control Signals" on page 47-9.
Nonvirtual	Signal that occupies its own storage. A nonvirtual bus reads inputs and writes outputs by accessing copies of the component signals.
Mux	A virtual vector created with a Mux block. See "Mux Signals" on page 47-11.
Variable-Size	Signal whose size (the number of elements in a dimension), in addition to its values, can change during a model simulation.
Virtual	Signal that represents another signal or set of signals. A virtual signal is used for graphical purposes and has no functional effect. See "Virtual Signals" on page 47-11.

Control Signals

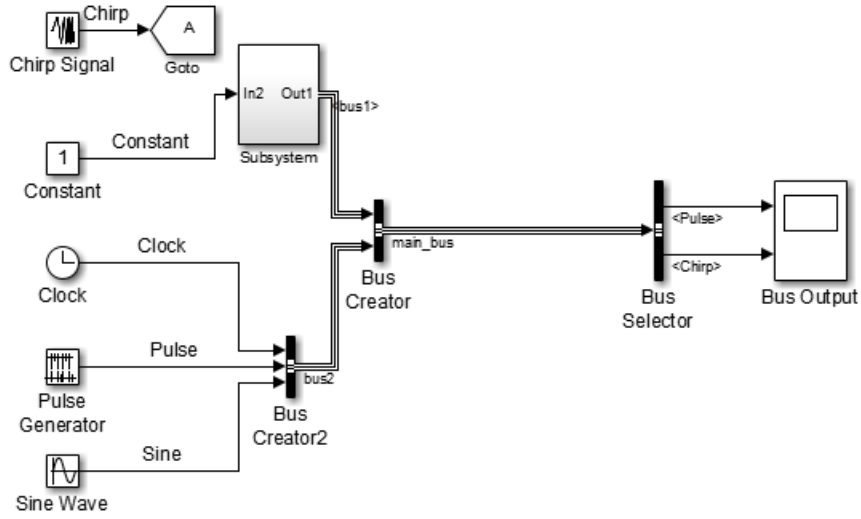
A *control signal* is a signal used by one block to initiate execution of another block. For example, a signal that executes a function-call or action subsystem is a control signal. When you update or simulate a block diagram, Simulink uses a dash-dot pattern to redraw lines representing the control signals.



Composite (Bus) Signals

You can 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. When you have many parallel signals, buses can simplify the appearance of a model and help to clarify generated code. A bus can be either virtual or nonvirtual.

For example, if you open and simulate the `Bus Signal` example model, the `bus1`, `bus2`, and `main_bus` signals are bus signals. These virtual bus signals use the triple line style.



For details, see “About Composite Signals” on page 48-2.

Virtual Signals

In this section...

About 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.

Bus signals can also be virtual or nonvirtual. For details, see "Types of Simulink Buses" on page 48-3.

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 is not 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 its only purpose is to simplify the visual appearance of a model. 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. For example, you can perform calculations on a mux. 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. Using a

mux to perform computations on multiple vectors avoids the overhead of 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 a *virtual* vector signal. The constituent signals of a mux 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.

To create a composite signal whose constituent signals retain their identities and can have different data types, use a Bus Creator block rather than a Mux block. For details, see “About Composite Signals” on page 48-2. Although you can use a Mux block to create a composite signal in some cases, MathWorks discourages this practice. See “Avoid Mux/Bus Mixtures” on page 48-95 for more information.

Using Muxes

The Signal Routing library provides two virtual blocks for implementing muxes:

Mux
: Combine several input signals into a mux (virtual vector) signal

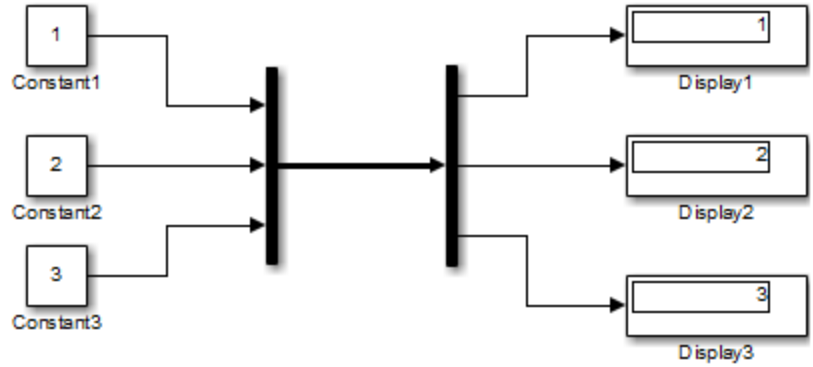
Demux
: Extract and output the values in a mux (virtual vector) signal

To implement a mux signal:

1. Select a Mux and Demux block from the Signal Routing library.
2. Set the Mux block **Number of inputs** and the Demux block **Number of outputs** block parameters 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. To reduce visual complexity, neither block displays a name. In this example, the line connecting the blocks, representing the mux signal, is wide because the model has been built with **Display > Signals & Ports > Wide Nonscalar Lines** option enabled. See "Display Signal Attributes" on page 47-61 for details.

Signals input to a Mux block can be 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 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. However, the Demux block cannot rearrange the order of those values. For details, see Demux.

Note MathWorks discourages using Mux and Demux blocks to create and access buses under any circumstances. See "Avoid Mux/Bus Mixtures" on page 48-95 for details.

Signal Values

In this section...

Signal Data Types

Data type refers to the format used to represent signal values internally. By default, the data type of Simulink signals is double. You can create signals of other data types. Simulink signals support the same range of data types as MATLAB. See "Data Types" on page 43-2 for more information.

Signal Dimensions, Size, and Width

Simulink blocks can output one-dimensional, two-dimensional, or multidimensional signals. 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.

The size of a signal refers to the 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. The size of a vector signal is referred to as the width of the signal.

For more information, see "Signal Dimensions" on page 47-34.

Complex Signals

The values of signals can be complex numbers or real numbers. A signal whose values are complex numbers is a complex signal. Create a complex-valued signal using one of the following approaches:

- 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.

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.

Initializing Signal Values

If a signal does not have an explicit initial value, the initial value that Simulink uses depends on the data type of the signal.

Signal Data Type	Default Initial Value
Numeric (other than fixed-point)	Zero
Fixed-point	Ground value
Boolean	False
Enumerated	Default value

You can specify the non-default initial values of signals for Simulink to use at the beginning of simulation.

- For any signal, you can define a signal object (`Simulink.Signal`), and use that signal object to specify an initial value for the signal.
- For some blocks, such as Outport, Data Store Memory, and 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.

For details, see “Initialize Signals and Discrete States” on page 47-51.

Viewing Signal Values

You can use either blocks or the signal viewers (such as 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. For general information about options for viewing signal values, see “View Simulation Results” on page 16-2. For detailed information about:

- Blocks that you can use to display signals in a model, see “Sinks”
- Signal viewers, see “Signal Viewer Tasks” on page 16-6
- The Signal & Scope Manager, see “Signal and Scope Manager” on page 16-23
- Test points, which are signals that Simulink guarantees to be observable when using a Floating Scope block in a model, see “Test Points” on page 47-58.

Displaying Signal Values in Model Diagrams

To include graphical displays of signal values in a model diagram, use one of the following approaches:

- “Display Data Tips During Simulation” on page 47-17
- “Display Signal Value After Simulation” on page 47-18

Display Data Tips During Simulation

For many blocks, Simulink can display block output (port values) as data tips on the block diagram while a simulation is running.

1. In the Simulink Editor, select **Display > Data Display in Simulation**.
2. From the submenu, select either **Show Value Labels When Hovering** or **Show Value Labels When Clicked**.
3. To change display options, use the **Options** submenu.

For details, see “Display Port Values” on page 23-29.

Display Signal Value After Simulation

To display, below a specific signal, the signal value after simulation:

1. Right-click the signal.
2. In the context menu, select **Show Value Label of Selected Port**.

Exporting Signal Data

You can save signal values to the MATLAB workspace during simulation, for later retrieval and postprocessing. For a summary of different approaches, see “Approaches for Exporting Signal Data” on page 45-4.

Signal Names and Labels

In this section...

Signal Names

You can name a signal. The signal name appears below a signal, displayed as a signal label (for details, see "Signal Labels" on page 47-22).

Choosing a Signal Name

The syntactic requirements for a signal name depend on how the name is 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 "Export Signal Data Using Signal Logging" on page 45-19.) 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 45-58.
- 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.
- The signal is an element of a bus object. Use a valid C language identifier for the signal name.
- Inputs to a Bus Creator block must have unique names. If there are duplicate names, the Bus Creator block appends `(signal#)` to all input signal names, where # is the input port index.

Making every signal name a legal MATLAB identifier handles a wide range of model configurations. 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.

To name a signal, use one of the following approaches:

- "Assign a name from the Simulink block diagram" on page 47-20
- "Assign a Name in the Signal Properties Dialog Box" on page 47-20
- "Assign a name from the MATLAB Command Window" on page 47-21

Assign a name from the Simulink block diagram

1. Double-click a signal.

   An edit box appears next to the signal.

   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.

2. Enter the desired name, then click somewhere outside the edit box.

   The signal now has the specified name. A label that shows the 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.

Assign a Name in the Signal Properties Dialog Box

1. Right-click a signal and from the context menu, choose **Properties**.

   A Signal Properties dialog box opens.

2 In the **Signal Name** field, enter a name. Click **OK** or **Apply**.

   A label showing the name appears on every branch of the signal.

Assign a name from the MATLAB Command Window

You can also use the MATLAB Command Window to set the name parameter of the port or line that represents the signal:

1 Select the source block for the line or port.

2 In the MATLAB Command Window, type code similar to the following:

```
p = get_param(gcb, 'PortHandles')
l = get_param(p.Outport, 'Line')
set_param(l, 'Name', 's9')
```

Change the Name of a Signal

To change the name of a signal:

1 Double-click a signal line.

   An editing box opens around the label.

2 Change the text and then click away from the label.

   All labels update to reflect the change.

Alternatively, you can edit the name in the **Signal Properties > Signal name** field.

Remove a Signal Name

To remove a signal name, 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**.

Signal Labels

A signal label is text that appears next to the line representing a signal. The signal label displays the signal name. Simulink creates a label for a signal when you assign it a name. For details, see“Signal Names” on page 47-19 .

Move Signal Labels

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. You cannot drag a label away from its signal, but only to a different location adjacent to the signal.

Edit Signal Labels

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.

Change the Font of a Signal Label

To change the font of a signal label:

1. Select the signal.
2. Click **Diagram > Format > Font Style**.
3. Select a font from the **Select Font** dialog box.

Copy Signal Labels

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.

Delete Signal Labels

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.

Show Propagated Signal Labels

You can have Simulink pass a signal name to downstream connection blocks. Examples of connection blocks that support signal label propagation include the Subsystem and Signal Specification blocks.

For details, see “Signal Label Propagation” on page 47-24.

Signal Label Propagation

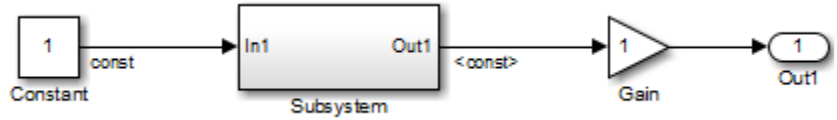
In this section...

Propagated Signal Labels

When you enable the display of signal label propagation for output signals of the blocks listed in "Blocks That Support Signal Label Propagation" on page 47-25:

- If there is a user-specified signal name that Simulink can propagate, the propagated signal label includes the name in angle brackets (for example, `<sig1>`).
- If there is no signal name to propagate, Simulink displays an empty set of angle brackets (<>) for the label.

For example, in the following model, the output signal from the Subsystem block is configured for signal label propagation. The propagated signal label (`<const>`) is based on the name of the upstream output signal of the Constant block (`const`).



For more information on how Simulink creates propagated signal labels, see "How Simulink Propagates Signal Labels" on page 47-26.

Blocks That Support Signal Label Propagation

You can use signal label propagation with output signals for several *connection* blocks, which route signals through the model without changing the data. Connection blocks perform no signal transformation.

Also, Model blocks support signal label propagation.

The connection blocks that support signal label propagation are:

- Enable
- From
- Function Call Split
- Goto
- Inport (subsystem only; not root inports)
- Signal Specification
- Subsystem (through subsystem Inport and Outport blocks)
- Trigger
- Two-Way Connection (a Simscape block)

The Bus Creator and Bus Selector blocks do *not* support signal label propagation. However, if you want to view the hierarchy for any bus signal, use the Signal Hierarchy Viewer.

The Signal Properties dialog box for a signal indicates whether that signal supports signal label propagation. The **Show propagated signals** parameter is available only for blocks that support signal label propagation. For details, see "Display Propagated Signal Labels" on page 47-25.

Display Propagated Signal Labels

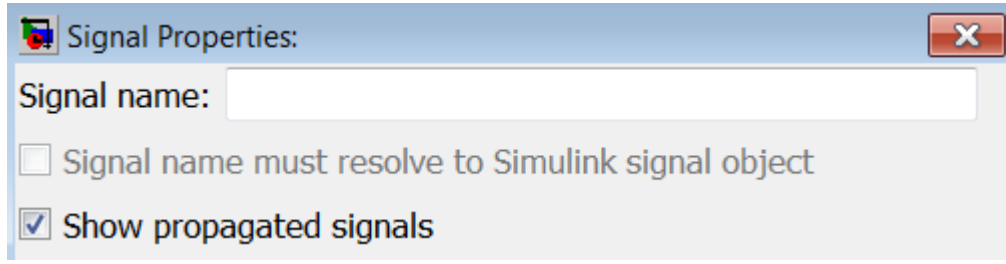
To display a propagated signal label:

1. Set **Model Configuration Parameters > Diagnostics > Connectivity > Mux blocks used to create bus signals** to `error`.

2 Right-click the signal for which you want to display a propagated signal label.

   The Signal Properties dialog box opens.

3 Select **Show propagated signals**.



   The **Show propagated signals** parameter is available only for output signals from blocks that support signal label propagation.

If a signal already has a label, then an *alternative* approach for displaying a propagated signal label is:

1 Click the signal label.

2 Remove the label text.

3 In the signal label text box, enter an angle bracket (<).

4 Click outside the signal label.

   Simulink displays the propagated signal label.

How Simulink Propagates Signal Labels

Understanding how Simulink propagates signal labels helps you to:

- Anticipate the scope of the signal label propagation, from source to final destination
- Configure your model to display signal labels for the signals that you want

For output signals from supported blocks, you can choose to have Simulink display propagated signal labels. For a list of supported blocks, see "Blocks That Support Signal Label Propagation" on page 47-25.

In general, Simulink performs signal label propagation consistently:

- For different modeling constructs (for example, non-bus and bus signals, virtual and nonvirtual buses, subsystem and model variants, model referencing, and libraries)
- In models with or without hidden blocks, which Simulink inserts in certain cases to enable simulation
- At model load, edit, update, and simulation times

For information about some special cases, see:

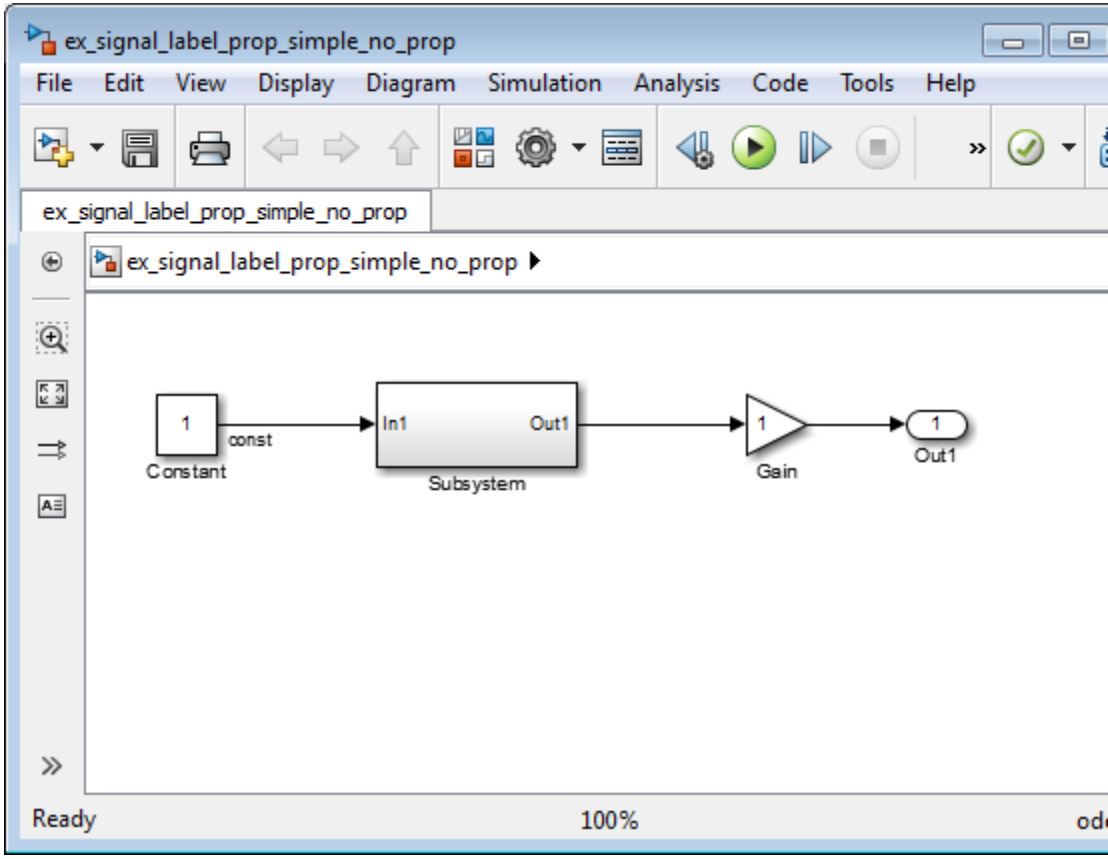
- "Processing for Referenced Models" on page 47-31
- "Processing for Variants and Configurable Subsystems" on page 47-33

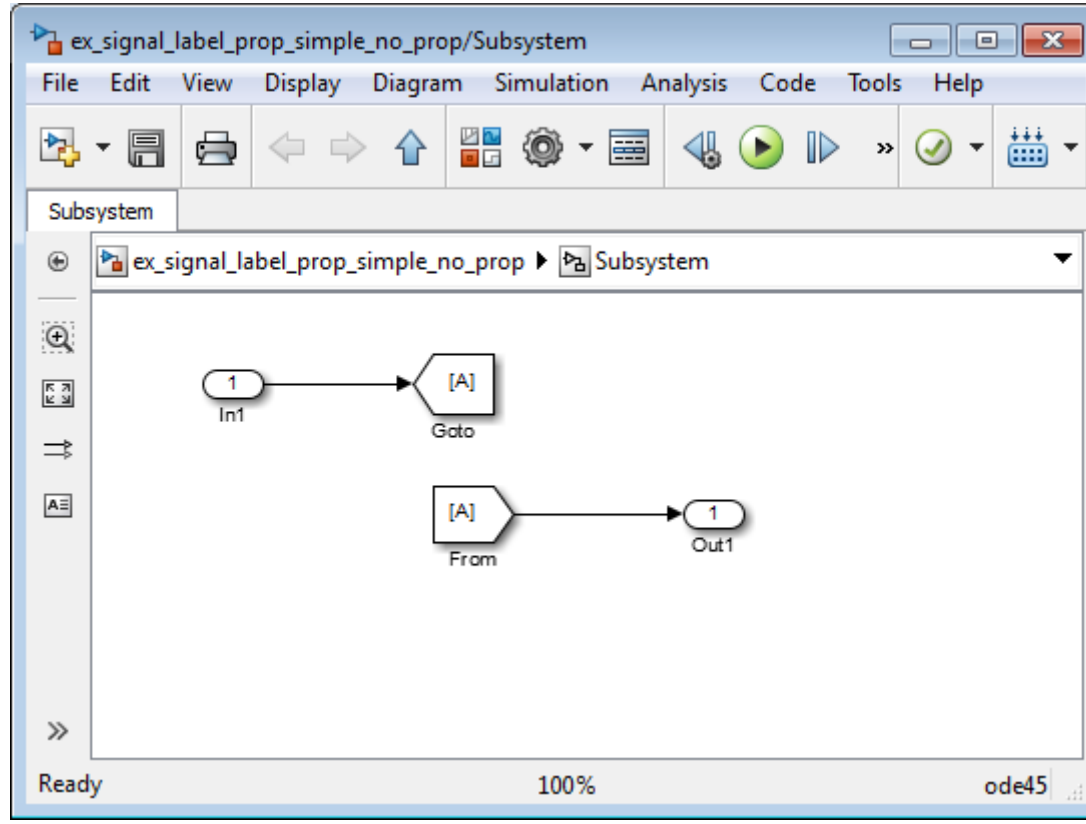
General Signal Label Propagation Processing

In general, when you enable signal label propagation for an output signal of a block (for example, BlockA), Simulink performs the following processing to find the source signal name to propagate:

1. Checks the block whose output signal connects to BlockA, and if necessary, continues checking upstream blocks, working backward from the closest block to the farthest block.
2. Stops when it encounters a block that either:
   - Supports signal label propagation and has a signal name
   - Does not support signal label propagation
3. Obtains the signal name, if any, of the output signal for the block at which Simulink stops.
4. Uses that signal name for the propagated signal label of any output signals of downstream blocks for which you enable signal label propagation.

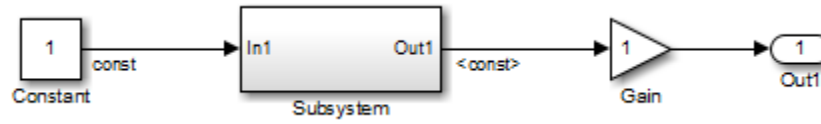
For example, in the following model, suppose that you enable signal label propagation for the output signal for the Subsystem block (that is, the signal connected to the `Out1` port).



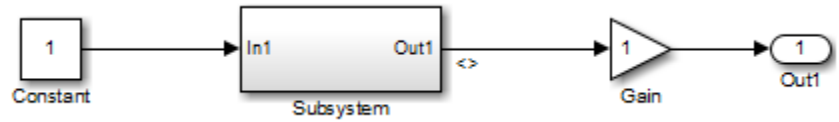


Simulink checks inside the subsystem, checks upstream from the From and GoTo blocks (which support signal label propagation and do not have a name), and then checks farther upstream, to the Constant block, which does not support signal label propagation.

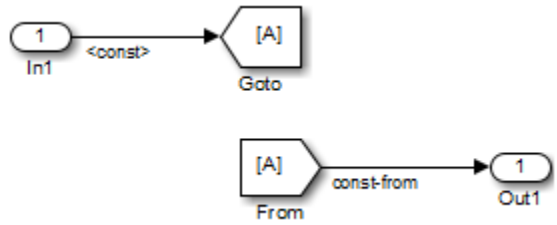
Simulink uses the signal name of the Constant block output signal, `const`. The propagated signal label for the Subsystem output signal is `<const>`.



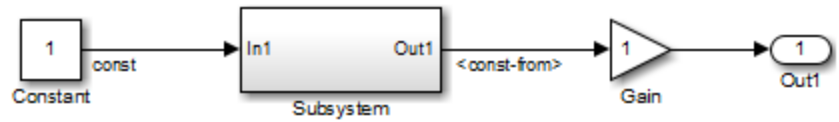
If the output signal from the Constant block did not have a signal name, then the propagated signal label would be an empty set of angle brackets (<>).



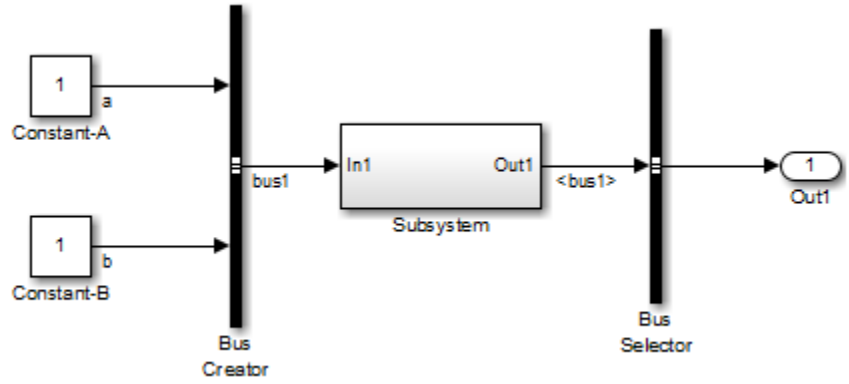
Suppose that in the Subsystem block you enable signal label propagation for the output signal from the In1 block, and you use the Signal Properties dialog box to specify the signal name `const-from` for the output signal of the From block, as shown below.



The propagated signal label for the Subsystem output signal changes to `<const-from>`, because that is the first named signal that Simulink encounters in its signal label propagation processing.



In the following model, the signal label propagation for the output signal of the Subsystem block uses the signal name `bus1`, which is the name of the output bus signal of the Bus Creator block. The propagated signal label does not include the names of the bus element signals (`a` and `b`).



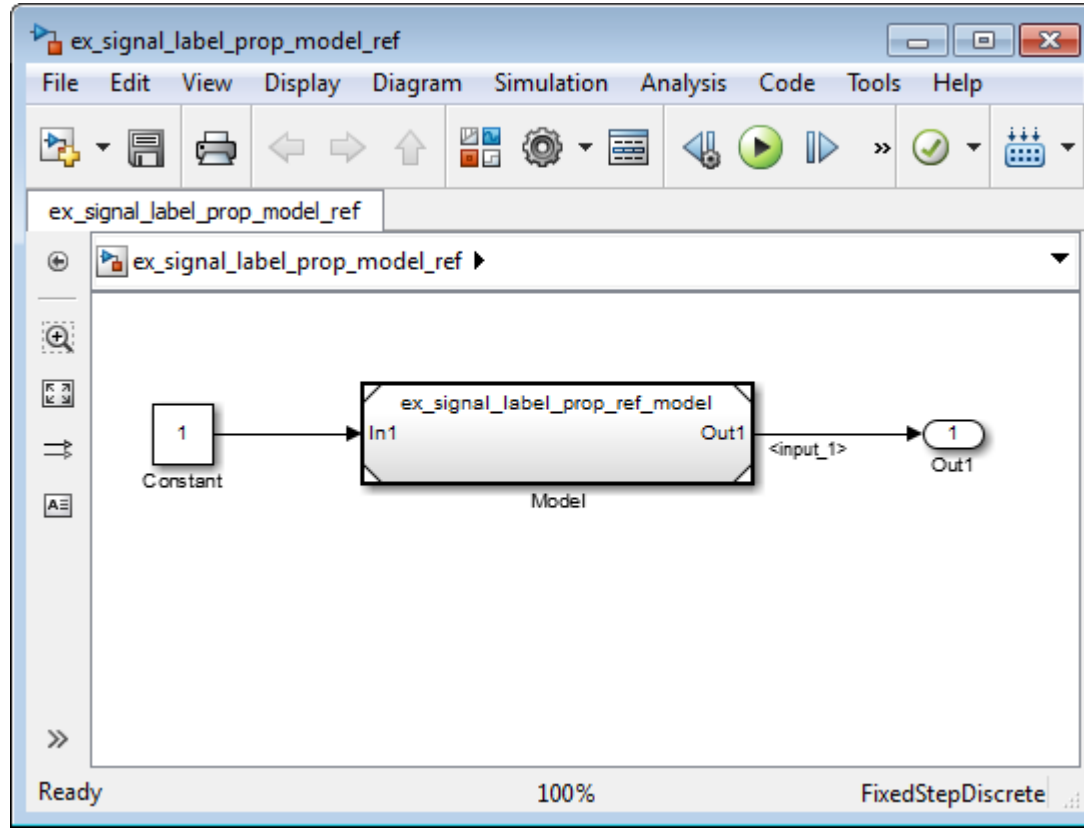
Processing for Referenced Models

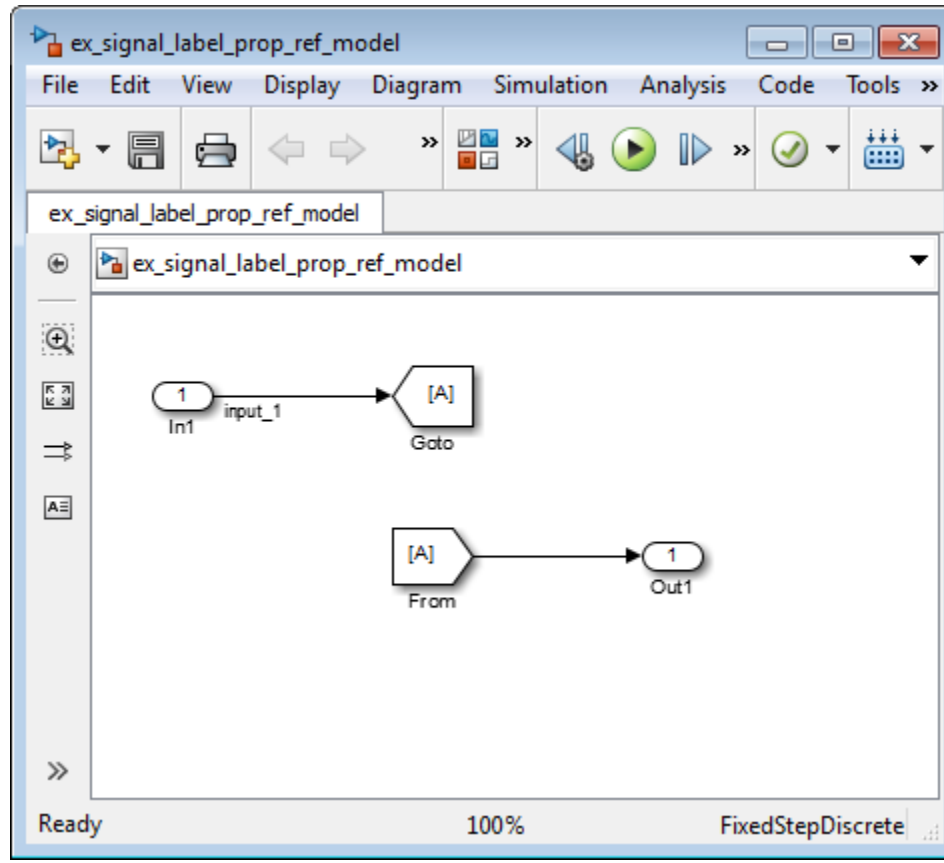
To enable signal label propagation for referenced models, in addition to the steps described in "Display Propagated Signal Labels" on page 47-25, enable the **Model Configuration Parameters > Model Referencing > Propagate all signal labels out of the model** parameter.

If you make a change inside a referenced model that affects signal label propagation, the propagated signal labels outside of the referenced model do not reflect those changes until after you update the diagram or simulate the model.

For example, the model `ex_signal_label_prop_model_ref` has a referenced model that includes an output signal from the In1 block that has a signal name of `input_1`.

If you enable signal label propagation for the signal from the Out1 port of the Model block, that signal does *not* reflect the name `input_1` until after you update the diagram or simulate the model.


ex_signal_label_prop_model_ref
File Edit View Display Diagram Simulation Analysis Code Tools Help
ex_signal_label_prop_model_ref
ex_signal_label_prop_model_ref
1
Constant
ex_signal_label_prop_ref_model
In1
Out1
Model
<input_1>
1
Out1
Ready
100%
FixedStepDiscrete



Processing for Variants and Configurable Subsystems

Simulink updates the propagated signal label (if enabled) for the output signal of the Subsystem or Model block, when *both* of these conditions occur:

- The output signals for model reference variants have different signal names.
- You change the active variant model or variant subsystem.

For Subsystem blocks, the signal label updates at edit time. For Model blocks, the update occurs when you update diagram or simulate the model.

Signal Dimensions

In this section...

About Signal Dimensions

Simulink blocks can output one-dimensional, two-dimensional, or multidimensional signals. 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.

- A one-dimensional (1-D) signal consists of a series 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 series of two-dimensional arrays output at a frequency of one 2-D array (matrix) per block sample time.
- A multidimensional signal consists of a series 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" for information on multidimensional arrays.

Simulink blocks vary in the dimensionality of the signals they can accept or output. Some blocks can accept or output signals of any dimension. Some can accept or output only scalar or vector signals. To determine the signal dimensionality of a particular block, see the block documentation. See "Determine Output Signal Dimensions" on page 47-36 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 a simulation. That is, the dimension of a signal must remain constant while a simulation is executing. However, you can change the size of a signal during a simulation. See "Variable-Size Signal Basics" on page 49-2.

Simulink Blocks that Support Multidimensional Signals

The Simulink Block Data Type Support table includes a column identifying the blocks with multi-dimension signal support.

1. In the Simulink editor, from the **Help** menu, click **Simulink > Block Data Types & Code Generation Support > All Tables**.

   A separate window with the Simulink Block Data Type Support table opens.

2. In the Block column, locate the name of a Simulink block. Columns to the right are data types or features. An a **X** in a column indicates support for that feature.

Simulink supports signals with up to 32 dimensions. Do not use signals with more than 32 dimensions.

Determine 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 parameters, if the block is a source block; otherwise, the output dimensions depend on the dimensions of the block 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 "Sources" 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 47-37).

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 47-39) 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 47-39) 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

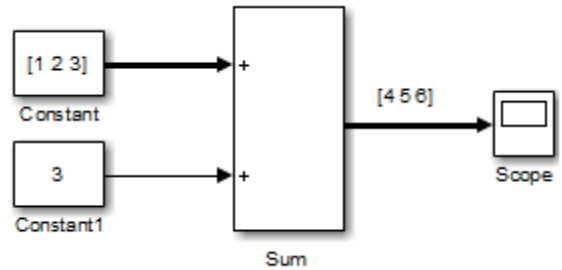
Scalar expansion is the conversion of a scalar value into a nonscalar array of the same dimensions. Many Simulink blocks support scalar expansion of

inputs and parameters. Block-specific descriptions 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]`.

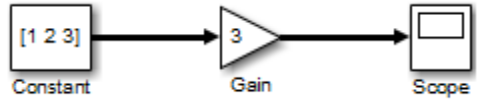


When a block's output is a function of a parameter and the parameter is nonscalar, Simulink expands a scalar input to match the dimensions of the parameter. For example, Simulink expands a scalar input to a Gain block to match the dimensions of a nonscalar gain parameter.

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.



Display Signal Sources and Destinations

In this section...

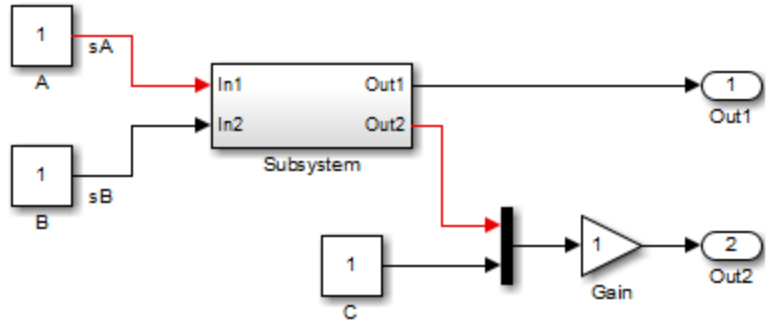
About Signal Highlighting

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 "About Composite Signals" on page 48-2.)

Highlighting Signal Sources

To display the source block(s) of a signal, select the **Highlight Signal 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

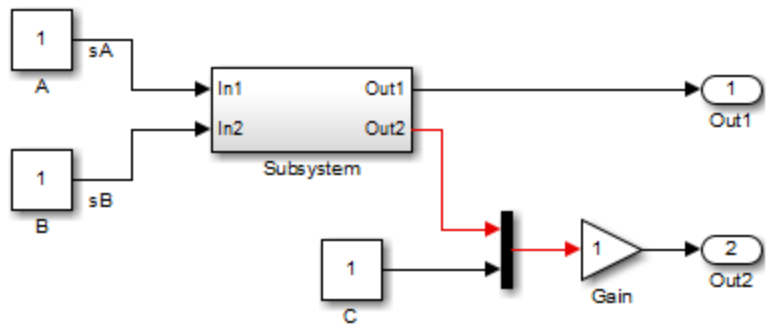


Highlighting Signal Destinations

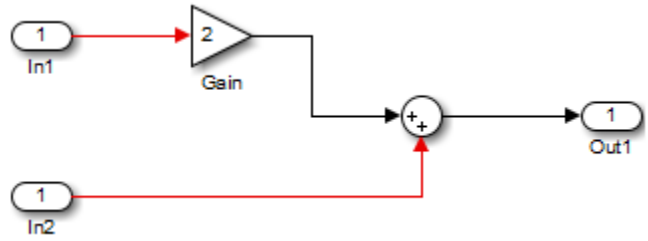
To display the destination blocks of a signal, select the **Highlight Signal to Destination** option from the context menu for the signal. This option highlights:

- 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 Signal 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, select **Remove Highlighting** from the model's context menu, or select **Display > 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.

Signal Ranges

In this section...

About Signal Ranges

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
- 1-D Lookup Table
- 2-D Lookup Table

- n-D Lookup Table
- 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

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 47-44 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 values for the minimum and maximum are `[]` (unspecified). 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 47-38).

Note You cannot specify the minimum or maximum value as `NaN`, `inf`, or `-inf`.

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 47-45) 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.

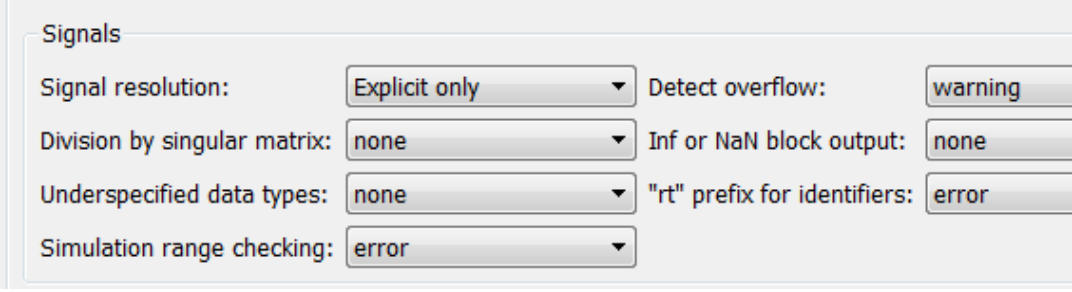
Enabling Simulation Range Checking

To enable the **Simulation range checking** diagnostic:

1. In your model window, select **Simulation > Model 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” for more information.

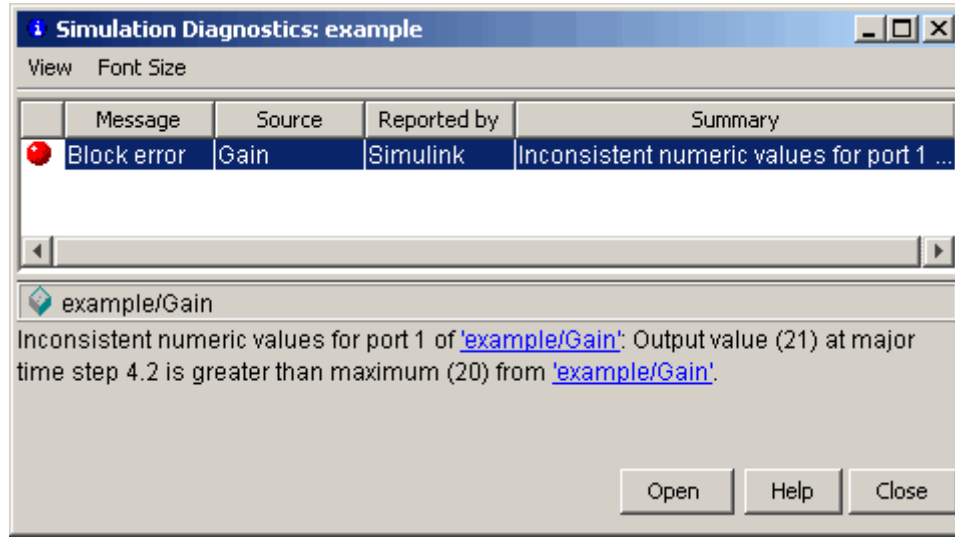
Simulating Models with Simulation Range Checking

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 47-47).

2 In your model window, select **Simulation > Run** 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:

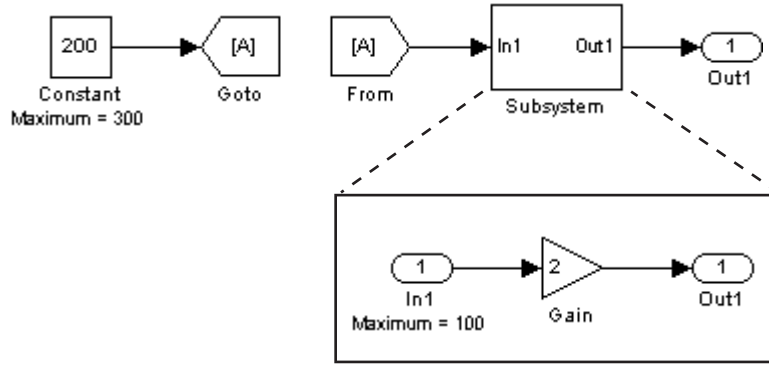
```
Warning: Inconsistent numeric values for port 1
of 'example/Gain': Output value (21) at major
time step 4.2 is greater than maximum (20) from
'example/Gain'.
```

Each message identifies the block whose output signal exceeds its specified range, and the time step at which this violation occurs.

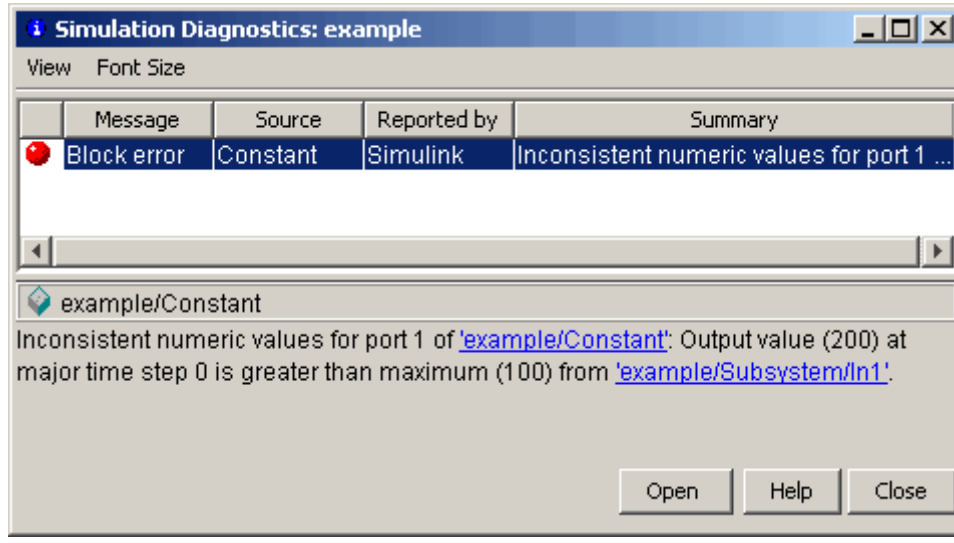
Signal Range Propagation for Virtual Blocks

Some virtual blocks (see "Virtual Blocks" on page 23-2) 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

Initialize Signals and Discrete States

In this section...

About Initialization

Note For information about initializing bus signals, see "Specify Initial Conditions for Bus Signals" on page 48-65.

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.

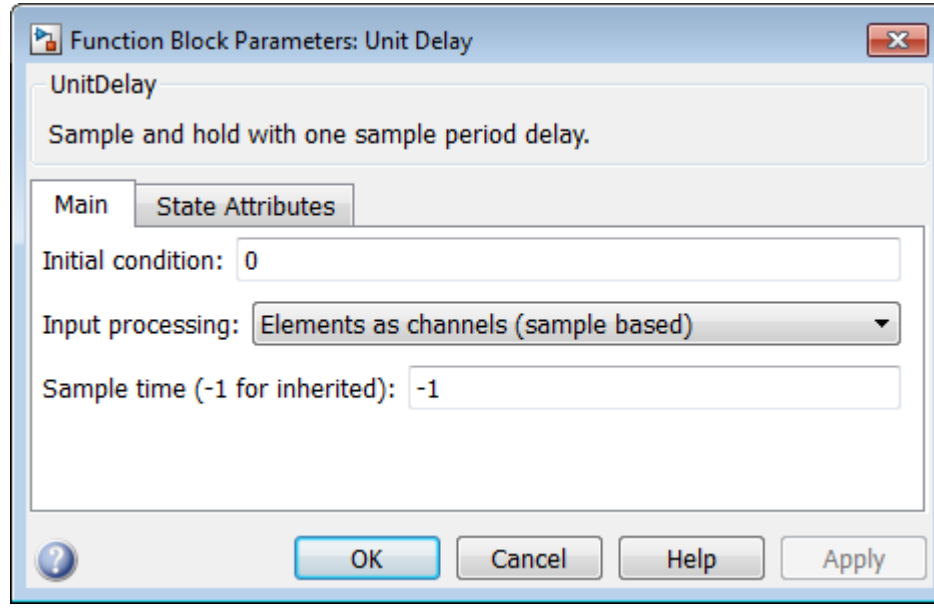
When you specify a signal object for signal or discrete state initialization, or a variable as the value of a block parameter, Simulink resolves the name that you specify to an appropriate object or variable, as described in "Symbol Resolution" on page 4-76.

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 "Data Objects" on page 43-37.

   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) 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.

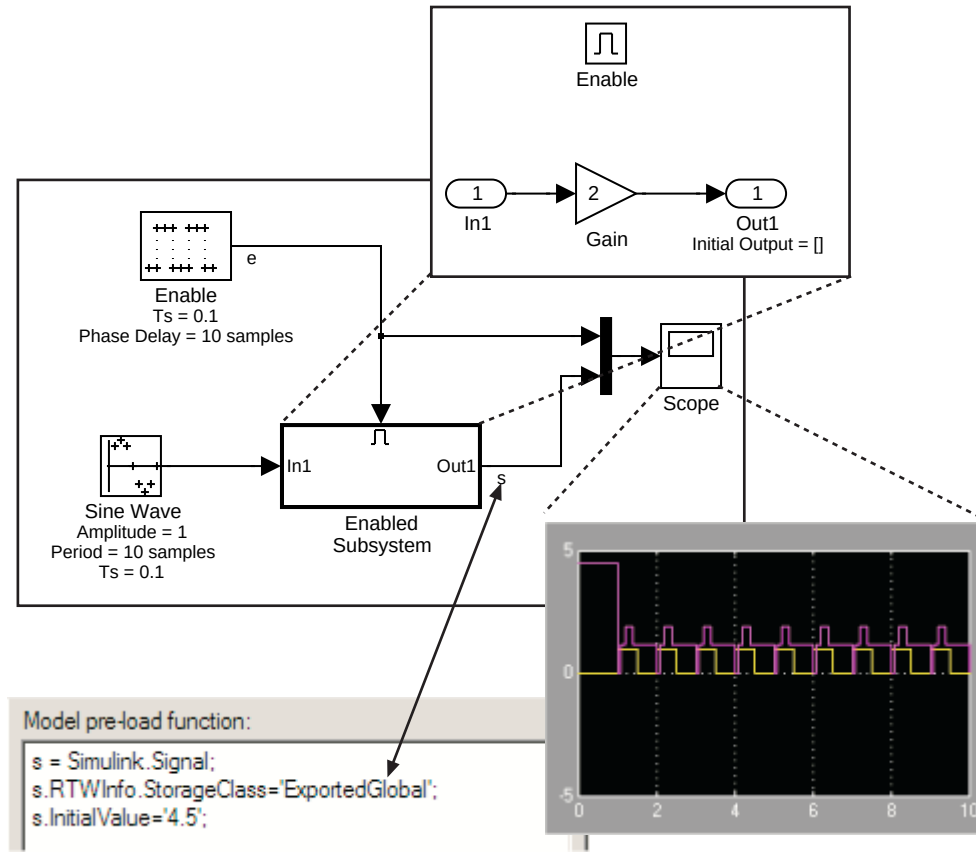
For example, suppose you want to tune the initial value of a Memory block state named `M1`. To do this, you might create a signal object named

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 3-9 and "Tunable Parameters" on page 24-13.

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.

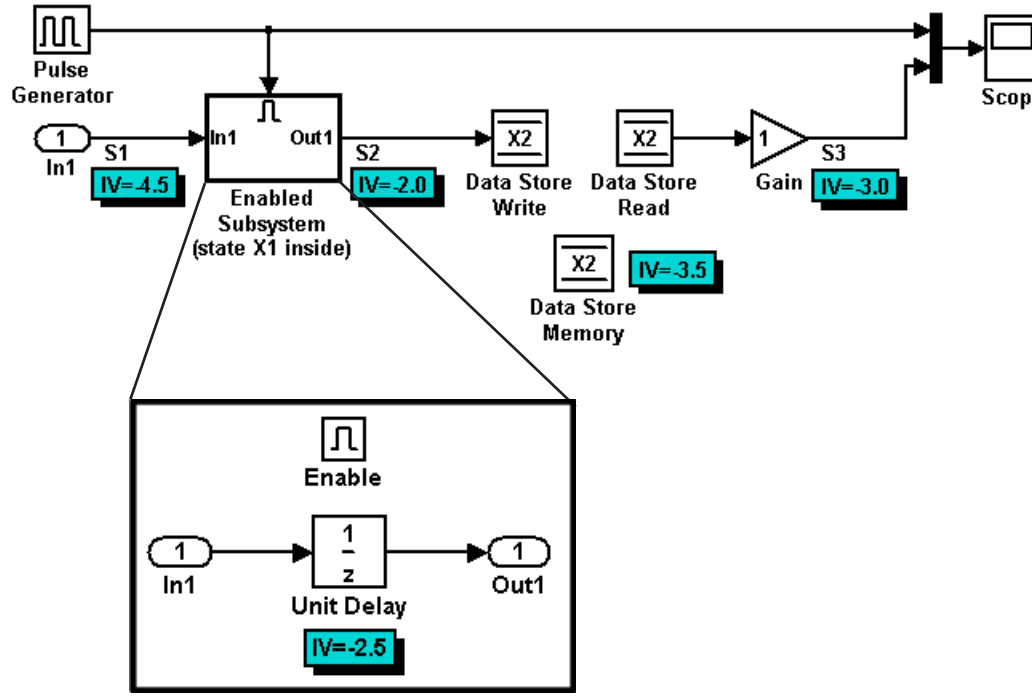


Signal `s` is initialized to 4.5. To avoid a consistency error, the initial value of the enabled subsystem's Outport block must be `[ ]` or 4.5.

If you need a signal object and its initial value setting to persist across Simulink sessions, see "Creating Persistent Data Objects" on page 43-47.

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 "DWork Vector Basics". • 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.

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 3-39).

Test points are primarily intended for use when generating code from a model with Simulink Coder. For more information about test points in the context of code generation, see "Signals with Test Points".

Marking a signal as a test point has no impact on signal logging that uses the `Dataset` logging format. For information about logging signals, see "Export Signal Data Using Signal Logging" on page 45-19.

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:

- In the **Signal Properties** dialog box, select the **Code Generation** tab, and then set **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**.

Model Referencing Limitation

Simulink might not log all signals configured for signal logging in a referenced model, if *all* of these conditions exist:

- The referenced model sets the **Model Configuration Parameters > Data Import/Export > Signal logging format** parameter to `ModelDataLogs`.
- The referenced model uses a library and you make a change that affects the set of test points in a library, or that changes the set of models that a library references.

To ensure proper signal logging for the referenced model:

1. Open the referenced model.
2. Perform an update diagram on the referenced model (for example, by pressing **Ctrl+D**).
3. Save the referenced model.

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 "Export Signal Data Using Signal Logging" on page 45-19 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, in the Simulink Editor, select or clear**Display > Signals & Ports > Testpoint & Logging Indicators**.

Display Signal Attributes

In this section...

Ports & Signals Menu

The **Display > Signals & Ports** submenu of the Simulink Editor offers the following options for displaying signal properties on the block diagram:

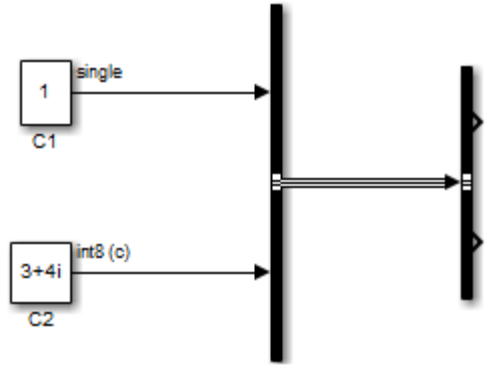
- Linearization Indicators
- Port Data Types (See "Port Data Types" on page 47-62)
- Design Ranges (See "Design Ranges" on page 47-62)
- Signal Dimensions (See "Signal Dimensions" on page 47-63)
- Storage Class
- Testpoint/Logging Indicators
- Signal Resolution Indicators (See "Signal to Object Resolution Indicator" on page 47-64)
- Viewer Indicators
- Wide Nonscalar Lines (See "Wide Nonscalar Lines" on page 47-65)

In addition, you can display sample time information. If you first select **Display > Sample Time**, 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

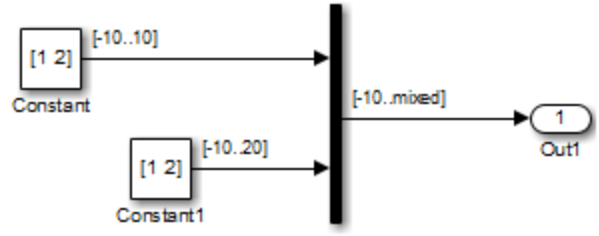
Displays the data type of a signal next to the output port that emits the signal.



The notation `(c)` following the data type of a signal indicates that the signal is complex.

Design Ranges

Displays the compiled design range of a signal next to the output port that emits the signal. The ranges are computed during an update diagram.

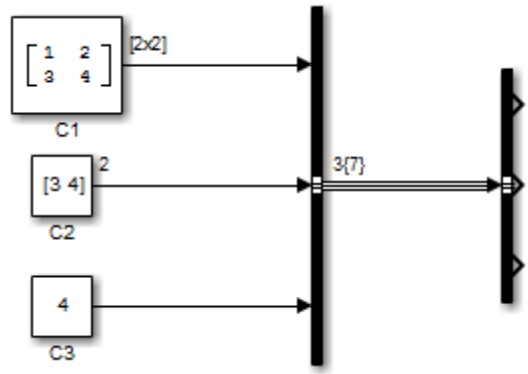


Ranges are displayed in the format `[min..max]`. In the above example, the design range at the output port of the Mux block is displayed as `[-10..mixed]`, because the two signals the Mux block combines have the same design minimum but different design maximums.

You can also use command-line parameters `CompiledPortDesignMin` and `CompiledPortDesignMax` to access the design minimum and maximum of port signals, respectively, at compile time. For more information, see "Common Block Parameters".

Signal Dimensions

Display the dimensions of nonscalar signals next to the line that carries the signal.



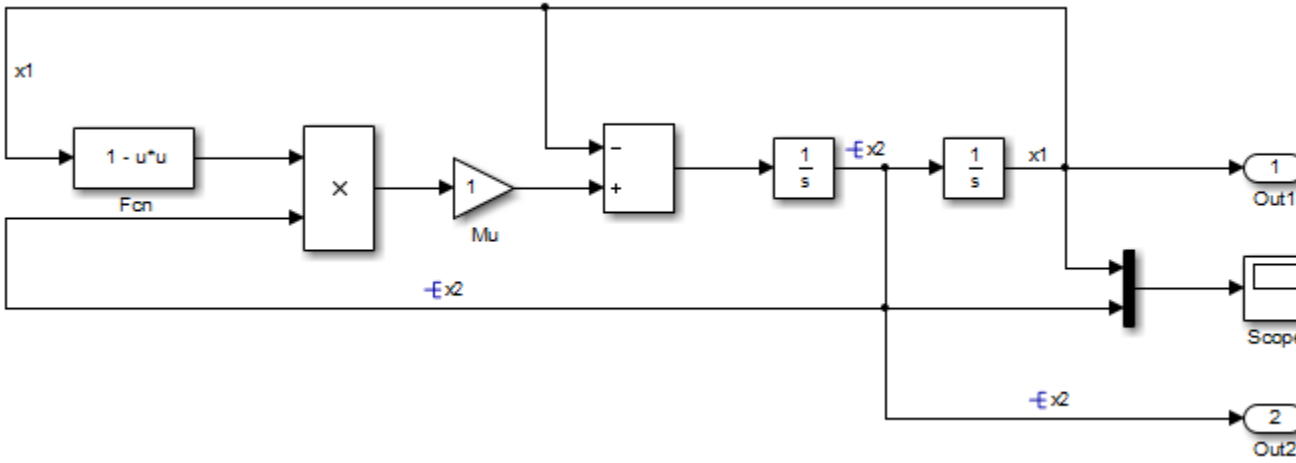
The format of the display depends on whether the line represents a single signal or a bus. If the line represents a single vector signal, Simulink displays the width of the signal. If the line represents a single matrix signal, Simulink displays its dimensions as $[N_1 x N_2]$ where N_i is the size of the ith 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 to Object Resolution Indicator

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:



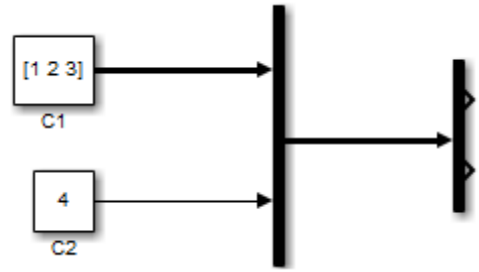
To suppress the display of signal resolution icons, in the model window deselect **Display > Signals & Ports > Signal to Object Resolution Indicator**, which is selected by default. To restore signal resolution icons,

reselect **Signal to Object Resolution Indicator**. Individual signals cannot be set to show or hide signal resolution indicators independently of the setting for the whole model. For additional information, see:

- "Symbol Resolution" on page 4-76
- "Initialize Signals and Discrete States" on page 47-51
- Simulink.Signal

Wide Nonscalar Lines

Draws lines that carry vector or matrix signals wider than lines that carry scalar signals.



See "About Composite Signals" on page 48-2 for more information about vector and matrix signals.

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.

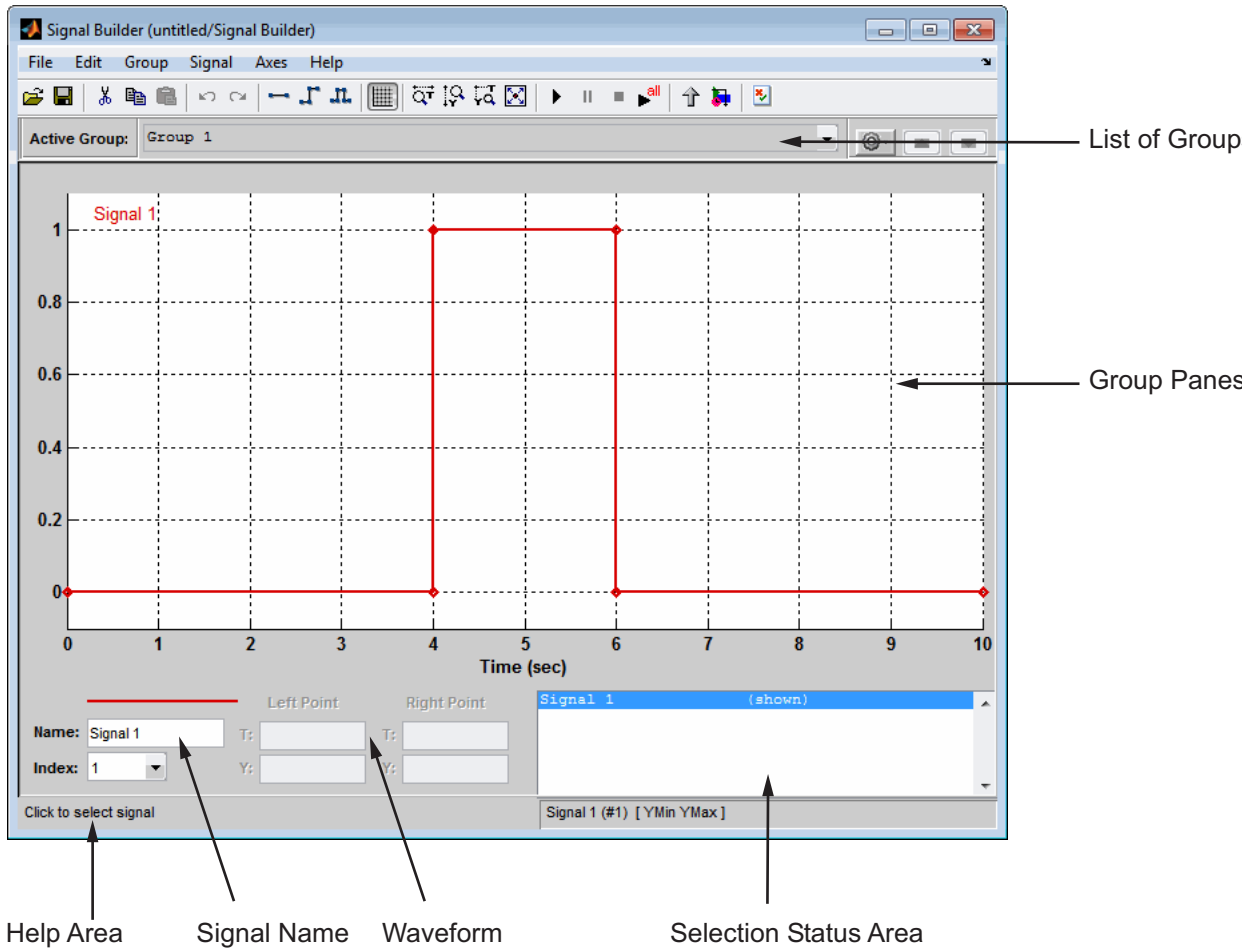
Signal groups can greatly facilitate testing a model, especially when you use them with conjunction with Simulink Assertion blocks and the Model Coverage Tool from the Simulink Verification and Validation. For a description of the Model Coverage Tool, see "Model Coverage Collection Workflow".

Model Configuration Parameter **Solver** pane settings can affect the Signal Builder block output. See "Solvers" on page 3-21 for a description of how solvers affect simulation.

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 at the top of the pane. Only one pane is visible at a time. To display a group that is not visible, from the list, select the group name. The block outputs the group of signals whose pane is currently visible. Each pane occupies a pane 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 47-108). 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 47-69) 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 47-102).

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 47-72).

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 47-72).

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, then 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, then modify it to suit your needs. To copy an existing signal group, select the group from the list, then select **Copy** from the Signal Builder **Group** menu. To delete a group, select the group from the list, and select **Delete** from the **Group** menu.

Renaming Signal Groups. To rename a signal group, select the group from the list, 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**.

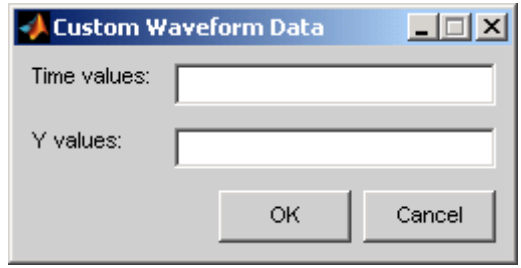
Moving Signal Groups. To reposition a group in the stack of group panes, select the pane and then select **Move Down** from the Signal Builder **Group** menu to move the group lower in the stack or **Move Up** to move the pane higher in the stack.

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.

Note Signal Builder returns a warning if you add a custom waveform with a large number of data points (100,000,000 or more). You can then cancel the action.

Defining Signal Output. To specify the type of output to use for sending test signals:

1. In the Signal Builder window, select **Signal > Output**.

   A list of output options appears.

2. From the list, select:

- `Ports`

  Default. Sends individual signals from the block. An output port named Signal *N* appears for each Signal *N*.

- `Bus`

  Sends single, virtual, nonhierarchical bus of signals from the block.

Tip

- You cannot use the `Bus` option to create a bus of non-virtual signals. An output port named Bus appears.
- The `Bus` option enables you to change your model layout without having to reroute Signal Builder block signals. Use the Bus Selector block to select the signals from this bus.
- If you create a Signal Builder block with the Signal & Scope Manager or with the **Create & Connect Generator** context menu option from a signal line context menu, you cannot define signal output. In these cases, the block sends individual signals.

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 47-68).

Creating Signal Group Sets

You can create signal groups in the Signal Builder block by:

- "Creating Signal Group Sets Manually" on page 47-73

- "Importing Signal Group Sets" on page 47-74
- "Importing Data with Custom Formats" on page 47-100

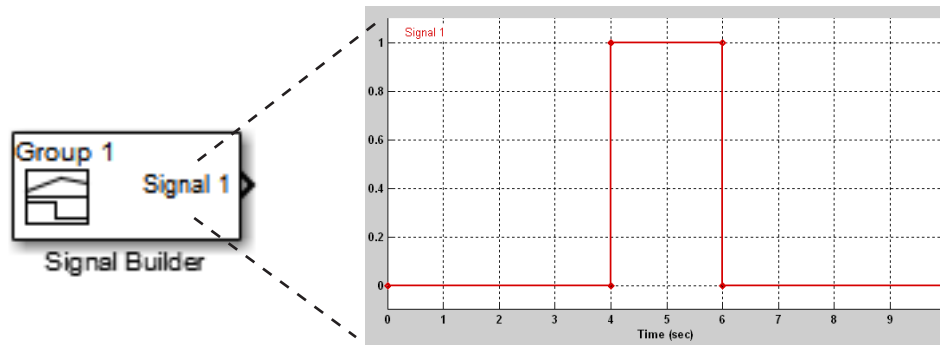
You can also use the `signalbuilder` function to populate the Signal Builder block.

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 47-74.

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 47-66) 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 47-110 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 47-74 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 "Data Import and Logging Workflow" 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`)

Note Signal Builder block uses the `xlsread` function. See the `xlsread` documentation for information on supported platforms.

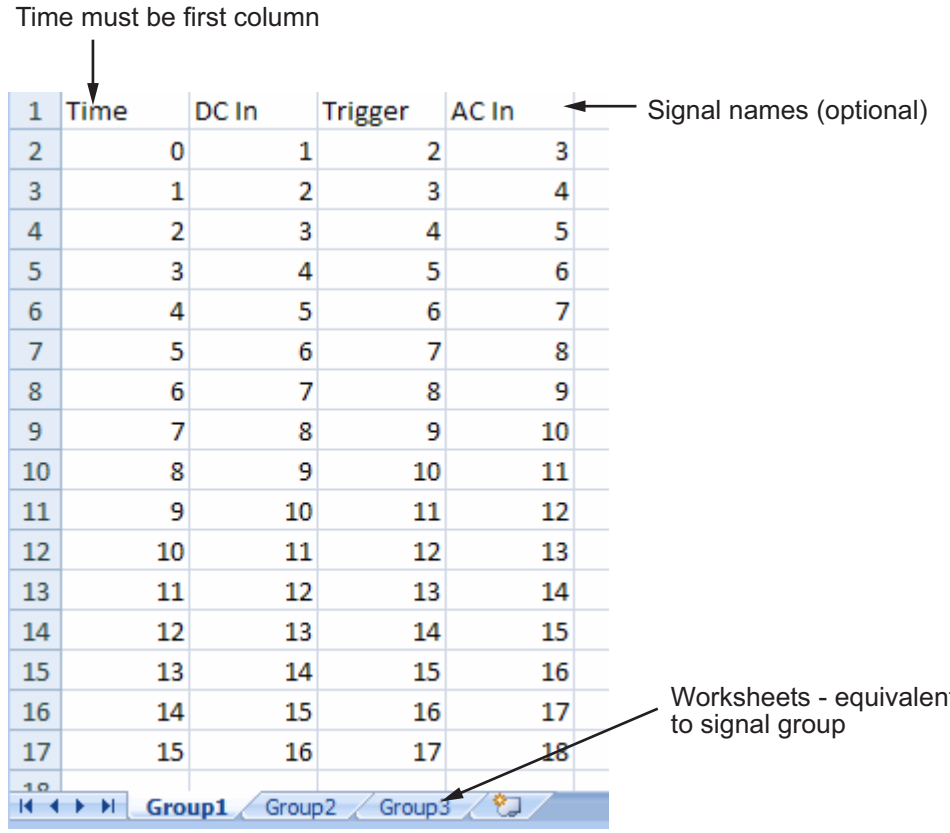
You can import your data set file only if it is appropriately formatted.

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.

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 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`

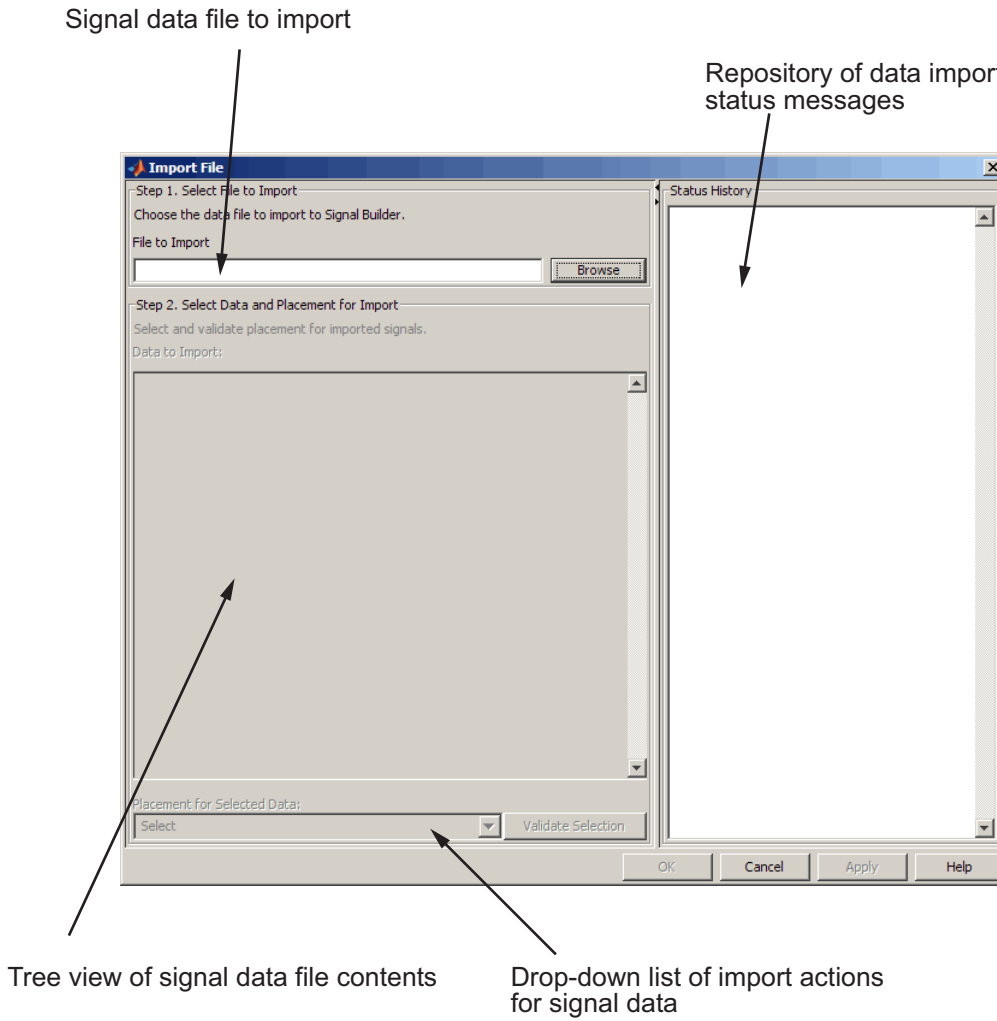
  `sigName` and `groupName` are optional.

- For backwards compatibility, the Signal Builder block supports logged data from the `Simulink.ModelDataLogs` object and interprets this data as a single group. The `ModelDataLogs` format will be removed in a future release.
- Signal Builder block does not support:
  - Simulink output as only a structure
  - Simulink output as only an array

Note Signal Builder returns a warning if you import a large number of data points (100,000,000 or more). You can then cancel the action.

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**.

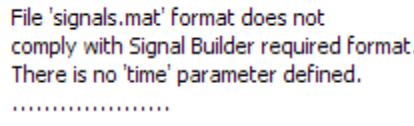
The Import File dialog box appears.

4 In the **File to Import** field, enter a signal data file name or click **Browse**.

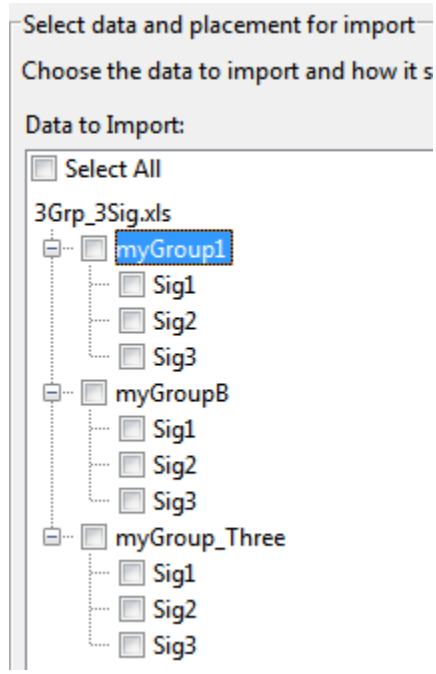
The file browser appears.

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.

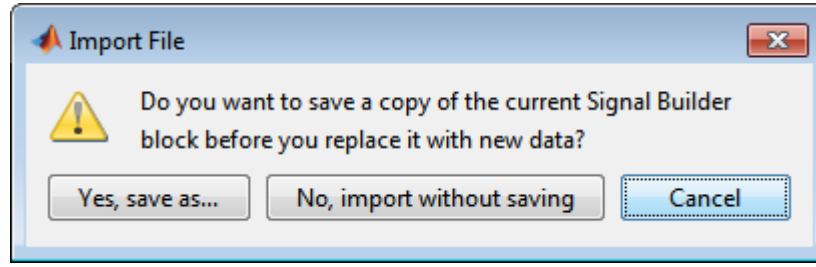
If the requested action is a valid one, the Status History pane displays messages to indicate the status. For example:

```
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 selecting `Replace existing dataset`, the software gives you the opportunity to save the existing contents of the Signal Builder block.

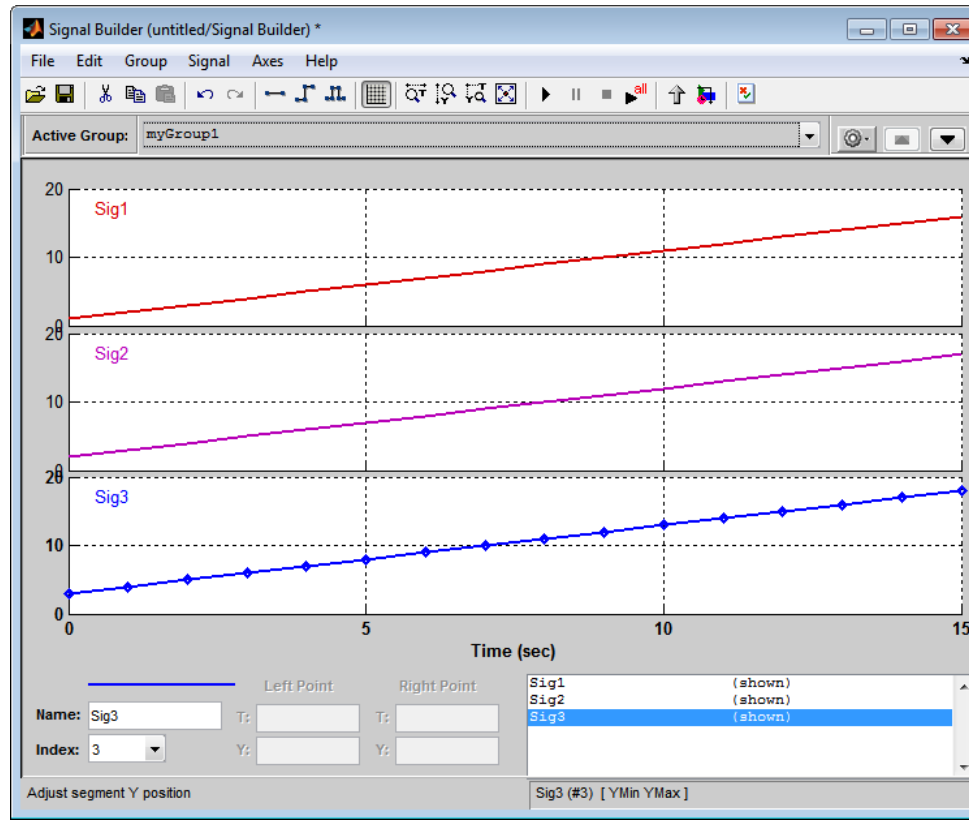


10 Click a button, as follows:

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`.

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` from the procedure in "Replacing All Signal Data with Selected Data" on page 47-79.

1. In the MATLAB Command Window, type `signalbuilder1`.
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**.

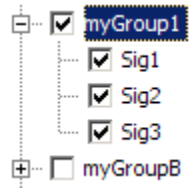
   The file browser is displayed.
5. If you select the file browser, navigate to and select a signal data file. For example, select `3Grp_3Sig.xls`.

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.

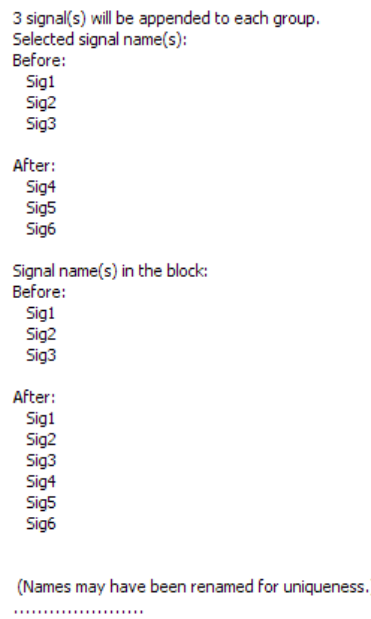


7 From the **Placement for Selected Data** list, select the action to take on the signal data. For example, select `Append selected signals to all groups`.

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:

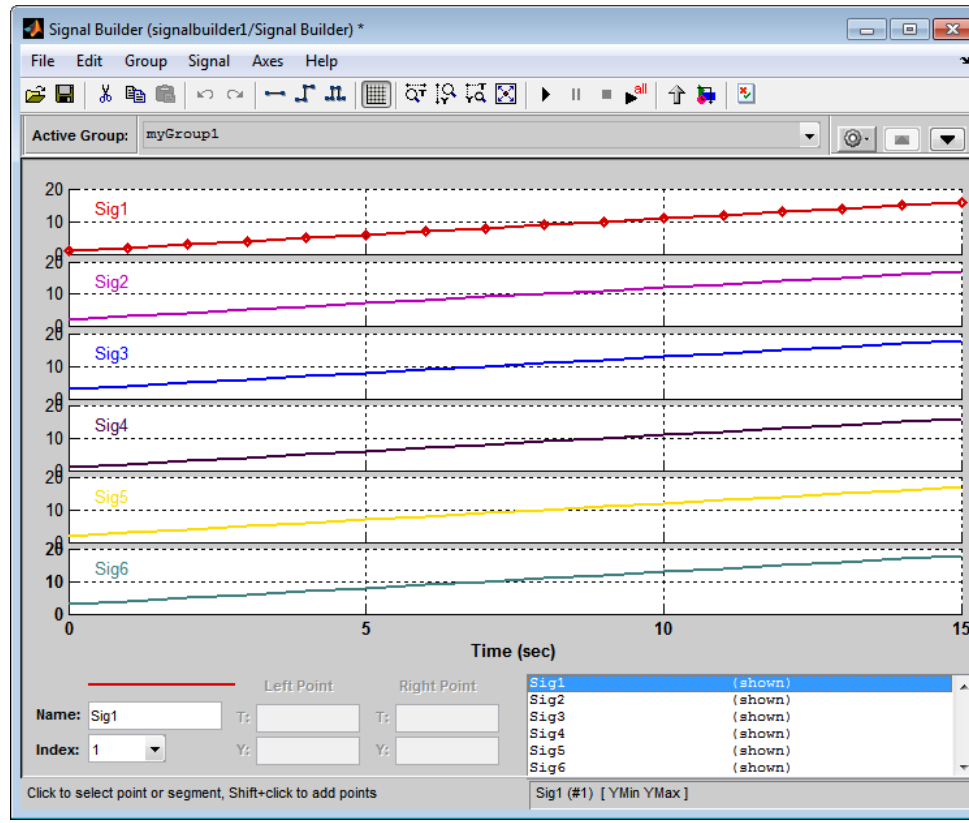


The confirmation also enables the **OK** and **Apply** buttons.

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.

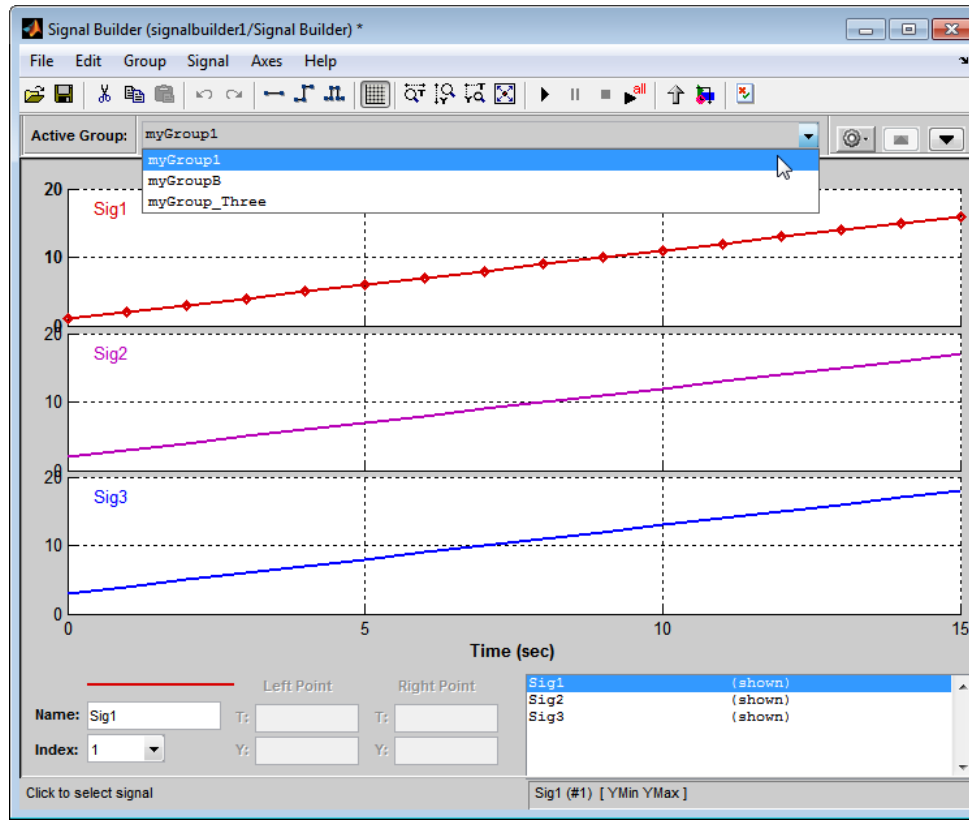
13 Close the Signal Builder window and save and close the model. For example, save the model as `signalbuilder2`.

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` from the procedure in "Replacing All Signal Data with Selected Data" on page 47-79.

1. In the MATLAB Command Window, type `signalbuilder1`.
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.

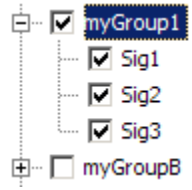
6 If you select the file browser, navigate to and select a signal data file. For example, select `3Grp_3Sig.xls`.

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:

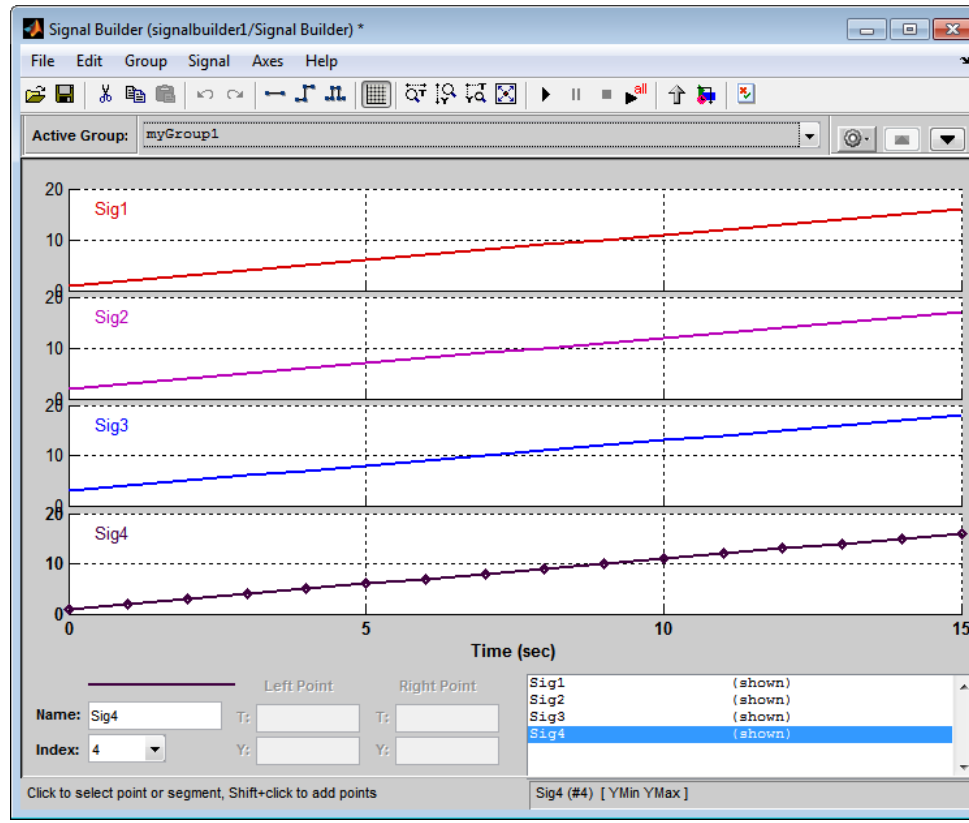
```
 1 signal will be appended to each group.
Selected signal names:
Before:
  Sig1
  Sig2
  Sig3

Selected unique signal name:
After:
  Sig4
```

The confirmation also enables the **OK** and **Apply** buttons.

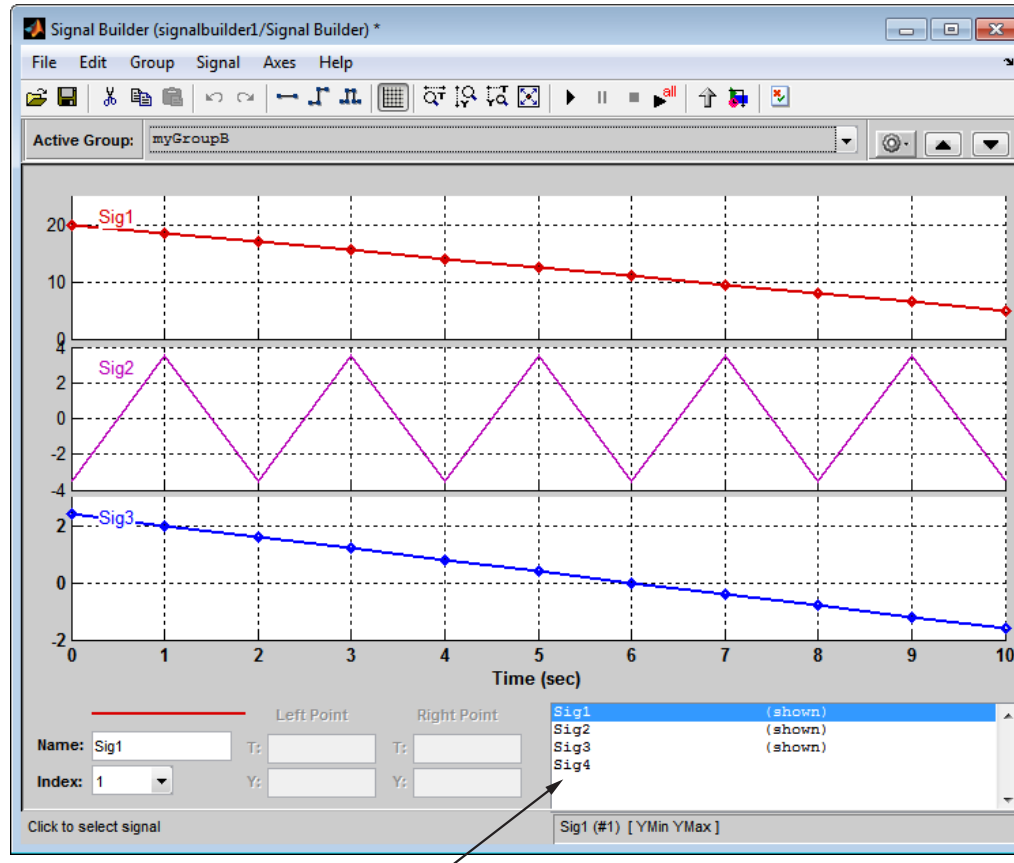
10 If you are satisfied with the status message, click **Apply** to append the signals.

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.

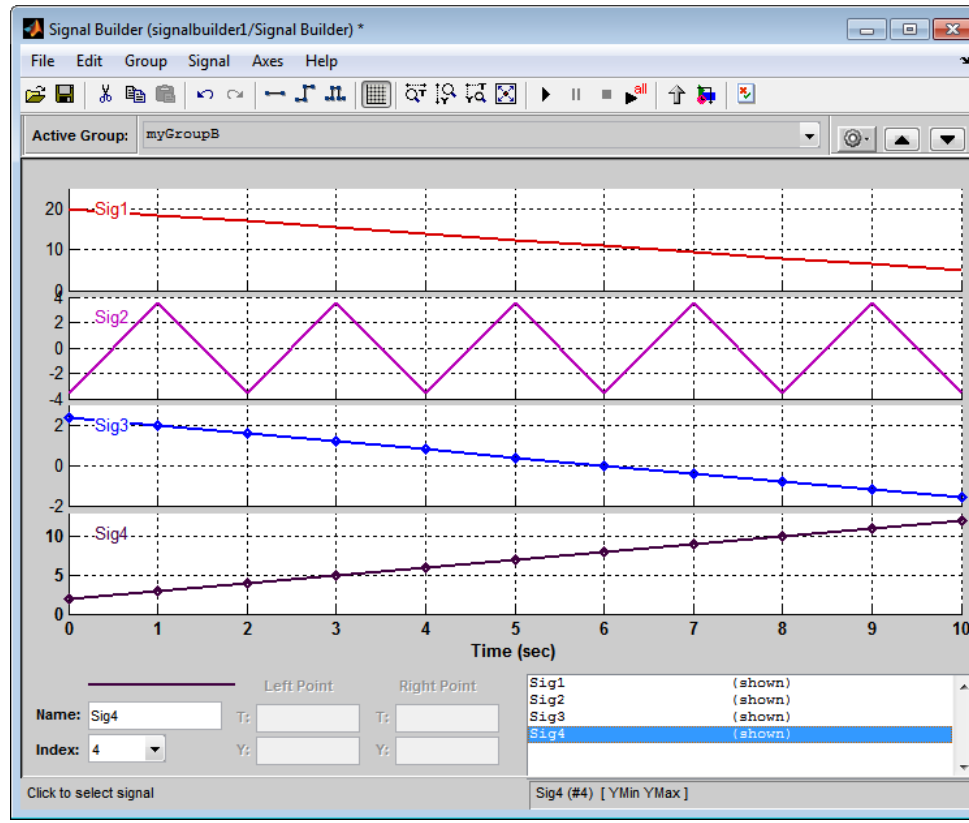
The topmost signal group, myGroup1, shows all signals by default, including the new Sig4.



11 Click another group name, for example, myGroupB. Notice that Sig4 exists for the group, hidden by default.



12 To show Sig4 on this pane, double-click Sig4 in the Selection Status area of the pane. The graph is updated to reflect Sig4.



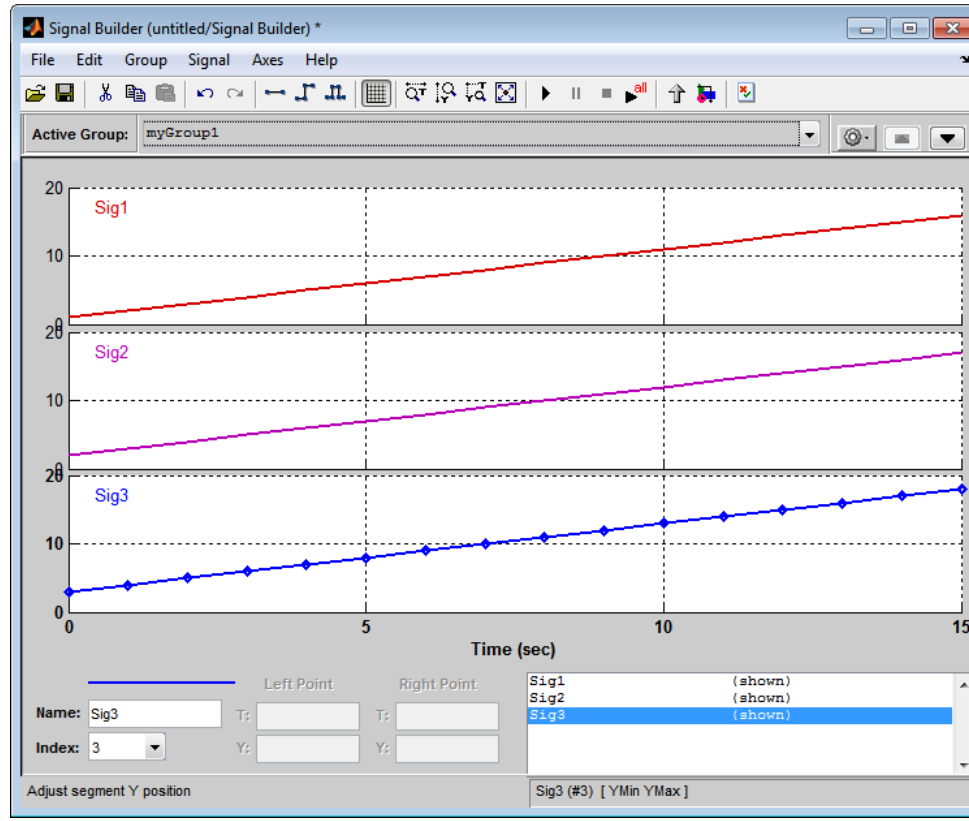
13 Close the Signal Builder window and save and close the model. For example, save the model as `signalbuilder3`.

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` from the procedure in “Replacing All Signal Data with Selected Data” on page 47-79.

1. In the MATLAB Command Window, type `signalbuilder1`.
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 myGroupB.

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:

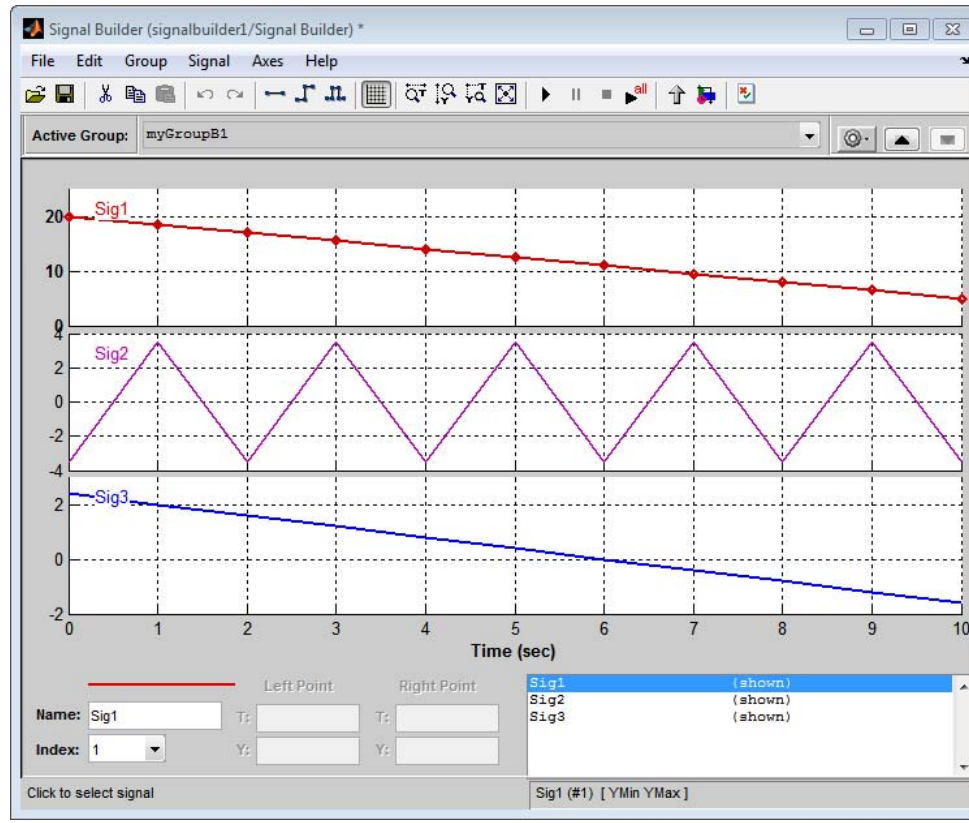
```
1 group(s) (each with 3 signal(s)),
will be appended to the existing block.
Selected group name(s):
Before:
  myGroupB

After:
  myGroupB1


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 pane. 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`.

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`.

Importing Data with Custom Formats

This topic describes how to import signal data formatted in a custom format. You should already have a signal data from a file whose contents you want to import. See "Importing Signal Groups from Existing Data Sets" on page 47-74 for a description of the data formats that the Signal Builder block accepts. If your data is not formatted using one of these data formats, use the following workflow to import the custom formatted data. This workflow uses the following files, located in *`matlabroot`*`\help\toolbox\simulink\examples`, as examples:

- `SigBldCustomFile.xls` — Signal data Microsoft Excel file using a format that Signal Builder block does not accept, for example:

Group1	Time	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Signal1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Signal2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Signal3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Signal4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Group2	Signal1	1.6	2.6	3.6	4.6	5.6	6.6	7.6	8.6	9.6	10.6	11.6	12.6	13.6	14.6	15.6	16.6
	Signal2	1.8	2.8	3.8	4.8	5.8	6.8	7.8	8.8	9.8	10.8	11.8	12.8	13.8	14.8	15.8	16.8
	Signal3	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	Signal4	2.2	3.2	4.2	5.2	6.2	7.2	8.2	9.2	10.2	11.2	12.2	13.2	14.2	15.2	16.2	17.2

- `createSignalBuilderSupportedFormat.m` — Custom MATLAB function that uses `xlsread` to read Microsoft Excel spreadsheets. This example

function reformats the custom data, in a format that the Signal Builder block supports, as follows:

- *grpNames* — Cell array that contains group name strings with number of rows = 1, number of columns = number of groups.
- *sigNames* — Cell array that contains signal name strings with number of rows = 1, columns = number of signals.
- *time* — Cell array that contains time data with number of rows = number of signals, columns = number of groups.
- *data* — Cell array that contains signal data with number of rows = number of signals, columns = number of groups.

Signal Builder has the following requirements for this custom function:

- Number of signals in each group must be the same.
- Signal names in each group must be the same.
- Number of data points in each signal must be the same.
- Each element in the *time* and *data* cell array holds a matrix of real numbers. This matrix can be [1x*N*] or [*N*x1], where *N* is the number of data points in every signal.

1 Identify the format of your custom signal data, for example:

```
SigBldCustomFile.xls
```

2 Create a custom MATLAB function that:

a Uses a MATLAB I/O function, such as `xlsread`, to read your custom formatted signal data. For example, `createSignalBuilderSupportedFormat.m`.

b Formats the custom formatted signal data to one that the Signal Builder block accepts, for example, a MAT-file.

3 Use your custom MATLAB function to write your custom formatted signal data to a file that Signal Builder block accepts. For example:

```
createSignalBuilderSupportedFormat('SigBldCustomFile.xls', 'OutputData.mat')
```

4 Import the reformatted signal data file, `OutputData.mat`, into the Signal Builder block (see “Importing Signal Group Sets” on page 47-74).

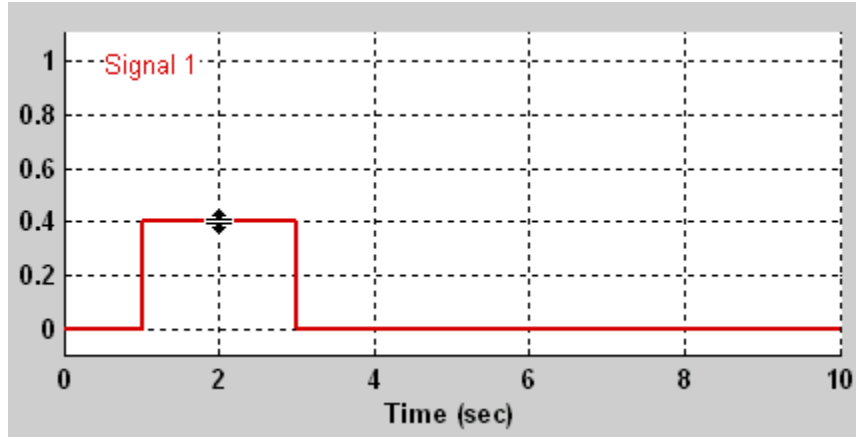
Editing Waveforms

The Signal Builder window allows you to change the shape, color, and line style and thickness of the waveforms output by a group.

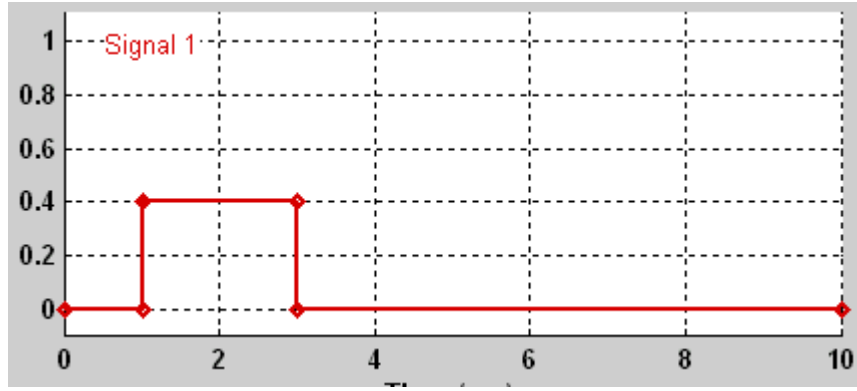
Reshaping a Waveform

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.

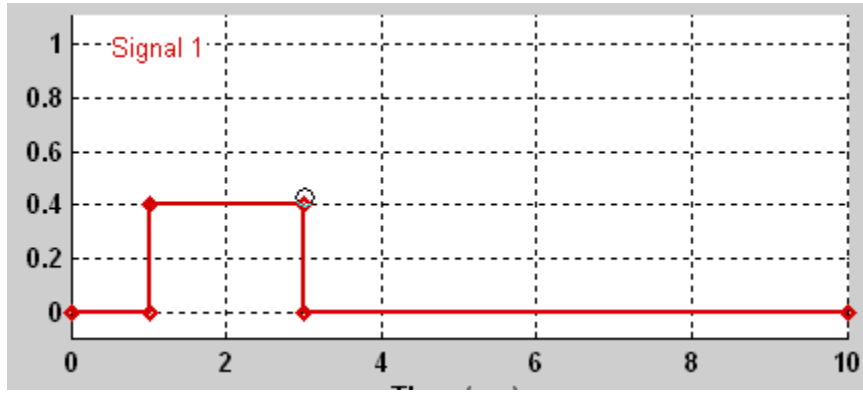


The Signal Builder displays the waveform points to indicate that the waveform is selected.

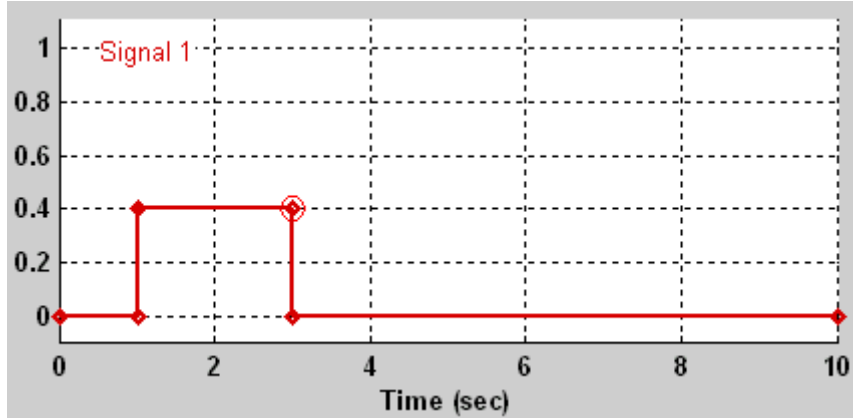


To deselect a waveform, left-click any point on the waveform axis that is not on the waveform itself or press the **Esc** key.

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.

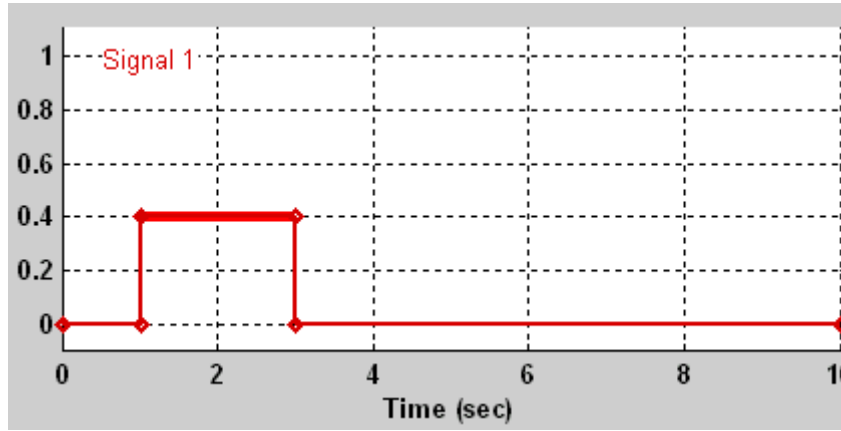


Left-click the point with the mouse. The Signal Builder draws a circle around the point to indicate your selection.



To deselect the point, press the **Esc** key.

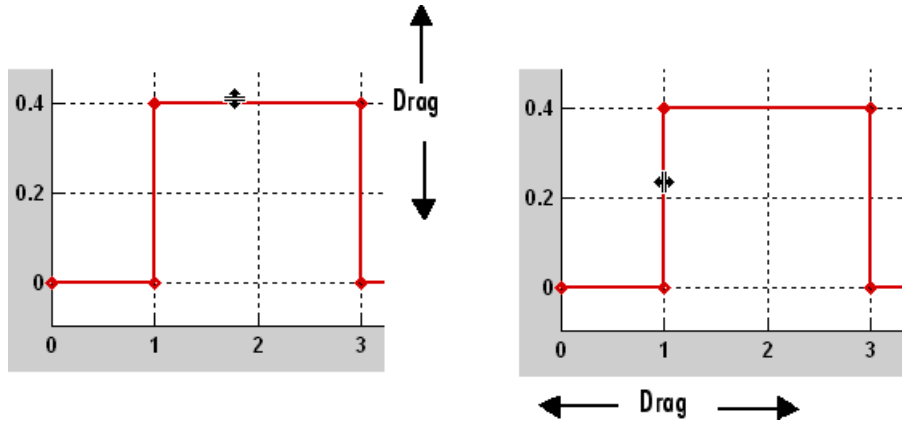
Selecting Segments. To select a line segment, first select the waveform that contains it. Then left-click the segment. The Signal Builder thickens the segment to indicate that it is selected.



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 47-106) 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**.

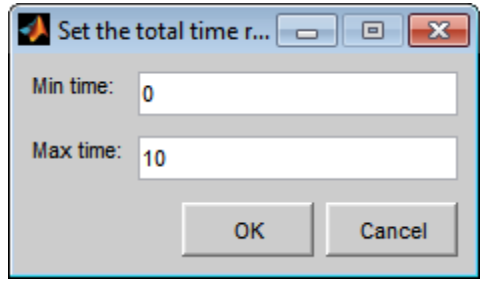
Signal Builder Time Range

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 47-108).

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 47-111 for more information).

Changing a Signal Builder Time Range

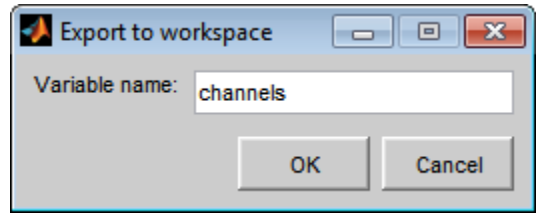
To change the time range, select **Change Time Range** from the Signal Builder **Axes** menu. A dialog box appears.



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 47-110).

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

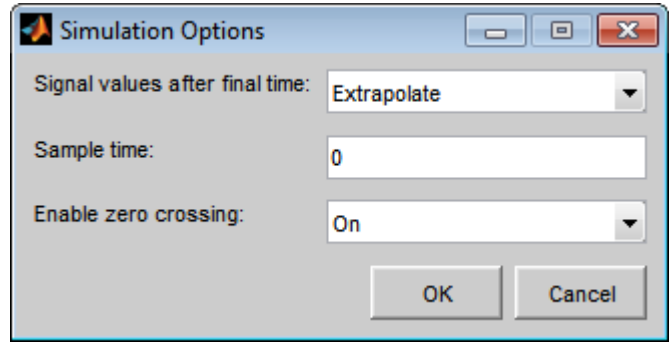
from the Signal Builder toolbar. The **Run all** command runs a series of simulations, one for each signal group defined by the block. If you installed Simulink Verification and Validation on your system and are using the Model Coverage Tool, the **Run all** command configures the tool to collect and 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.



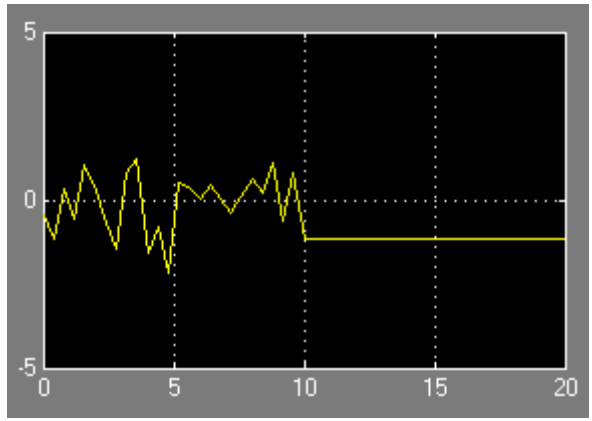
The dialog box allows you to specify the following options.

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

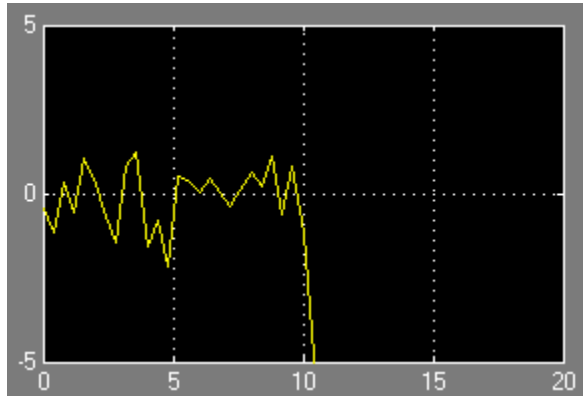
- `Hold final value`

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.



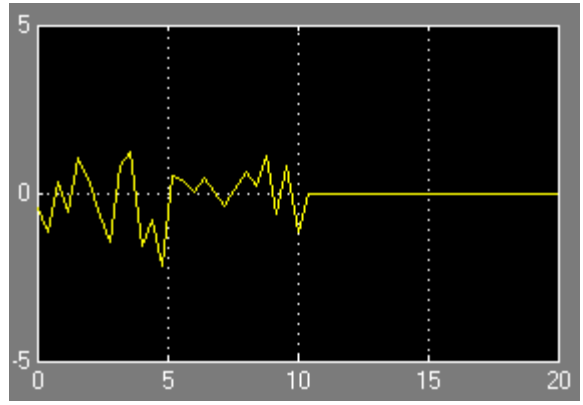
- `Extrapolate`

  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.



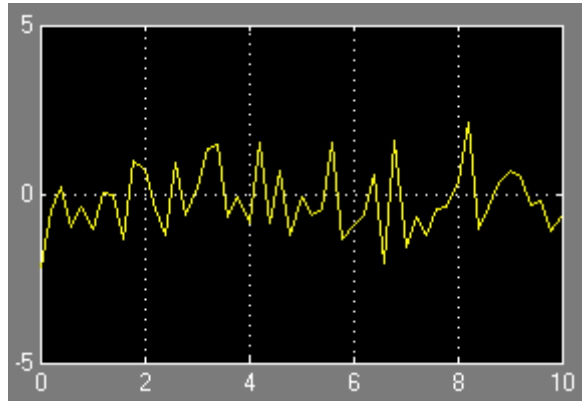
- `Set to zero`

Selecting this option causes the Signal Builder block to output zero for the remainder of the simulation.

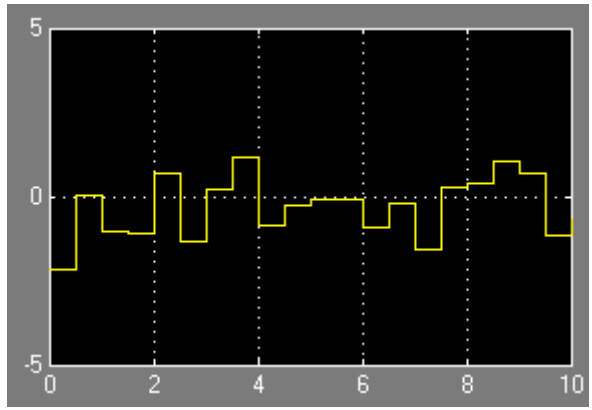


Sample time

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 3-23.

48

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 48-19, "Connect Buses to Inports and Outports" on page 48-61, and "Composite Signal Limitations" on page 48-106 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 47-11 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 48-10 for more information.

View Information about Buses

To view information about buses, use one of the following approaches:

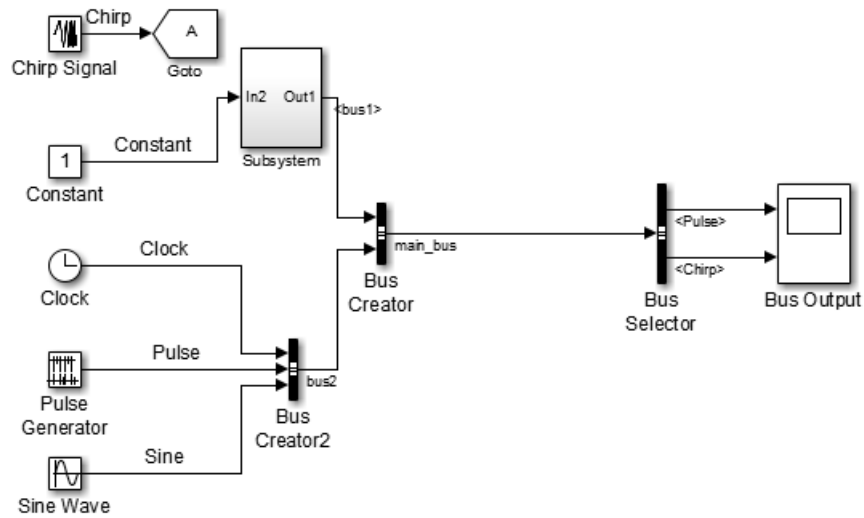
- Use the Signal Hierarchy Viewer to interactively display bus hierarchy (for bus signals)
- From the MATLAB command line, display the type and hierarchy of a bus signal in a compiled model. For details, see "CompiledBusType and SignalHierarchy Parameters" on page 48-6.

Signal Hierarchy Viewer

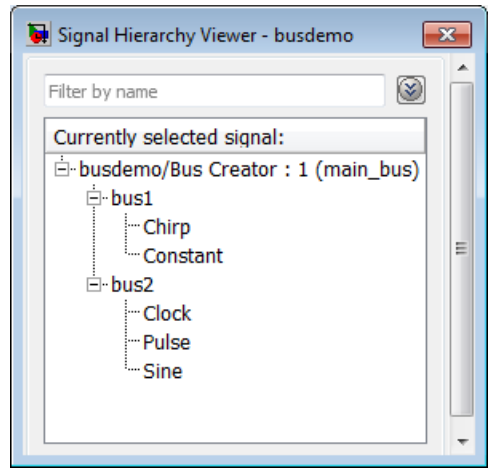
Use the Signal Hierarchy Viewer to interactively display information about a signal. For a bus signal, the Signal Hierarchy Viewer displays the bus hierarchy.

1. Check that the **Configuration Parameters > Diagnostics > Connectivity > Mux blocks used to create bus signals** parameter is set to `error`.
2. Right-click a signal line.
3. Select the **Signal Hierarchy** option. The Signal Hierarchy Viewer dialog box appears.

For example, open the `busdemo` model.



Right-click the `main_bus` signal (output signal for the Bus Creator block), and select **Signal Hierarchy**. The following information appears:



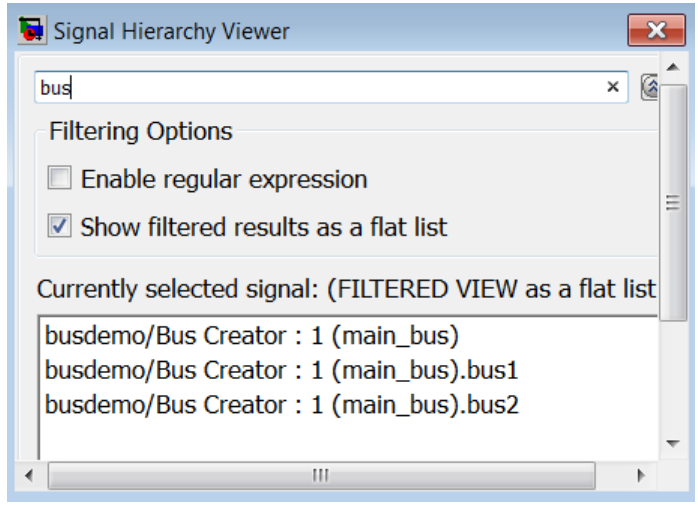
Each Signal Hierarchy Viewer is associated with a specific model. If you edit a model while the associated Signal Hierarchy Viewer is open, the Signal Hierarchy Viewer reflects those updates.

You can also open the Signal Hierarchy Viewer in the Simulink Model Editor.

1. Select **View > Signal Hierarchy**.
2. Select a signal

To filter the displayed signals, click the **Options** button on the right-hand side of the **Filter by name** edit box ( ).

- To use MATLAB regular expressions for filtering signal names, select **Enable regular expression**. For example, entering `r$` in the **Filter by name** edit box displays all signals whose names end with a lowercase `r` (and their immediate parents). For details, see "Regular Expressions".
- To use a flat list format to display the list of filtered signals, based on the search text in the **Filter by name** edit box, select **Show filtered results as a flat list**. The flat list format uses dot notation to reflect the hierarchy of bus signals. The following is an example of a flat list format for a filtered set of nested bus signals.



CompiledBusType and SignalHierarchy Parameters

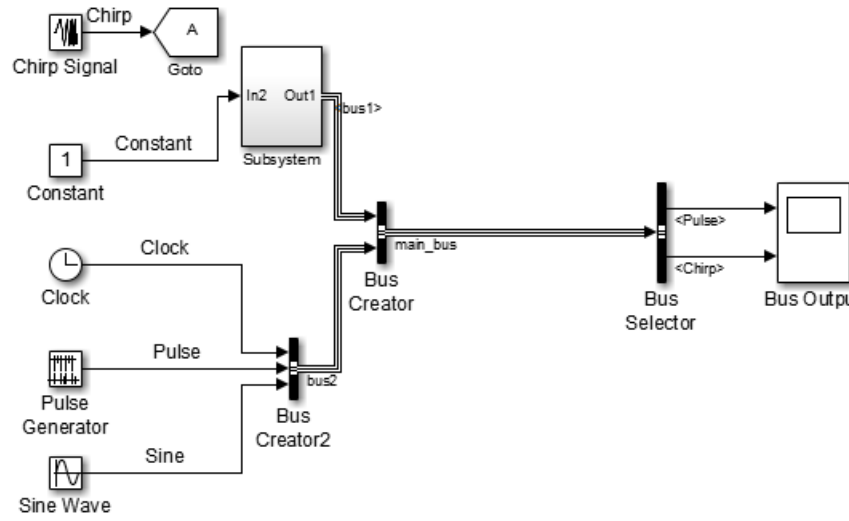
To get information about the type and hierarchy of a bus signal in a compiled model, use these parameters with the `get_param` command:

- `CompiledBusType` — For a compiled model, 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` — If the signal is a bus, returns the name and hierarchy of the signals in the bus.

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. Update the diagram or simulate the model.

For example, if you open and simulate the `busdemo` model, the model looks as shown below:



The following code illustrates how you can use the `SignalHierarchy` and `CompiledBusType` parameters:

```
mdl = 'busdemo';
open_system(mdl)
% Obtain the handle a port
ph = get_param([mdl '/Bus Creator'], 'PortHandles');
% SignalHierarchy is available at edit time
sh = get_param(ph.Outport, 'SignalHierarchy')
% Compile the model
busdemo([],[],[],'compile');
bt = get_param(ph.Outport, 'CompiledBusType')
% Terminate the model
busdemo([],[],[],'term');
```

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. For more information, see “Mux Signals” on page 47-11. 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 "Avoid Mux/Bus Mixtures" on page 48-95 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 "Bus Objects" on page 48-20 for more information. You can create bus objects programmatically or by using the Simulink Bus Editor, which facilitates bus object creation and management. See "Manage Bus Objects with the Bus Editor" on page 48-24 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 “Buses” for information about the best techniques to use.

Virtual and Nonvirtual Buses

In this section...

Virtual and Nonvirtual Buses

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.

Bus 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.
- 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.

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.

A nonvirtual bus is represented by a structure in generated code, which can be helpful when tracing the correspondence between the model and the code.

Simulation Results and Generated Code

For a *virtual* bus, simulation results and generated code are exactly the same as if the bus did not exist, which functionally it does not.

Generated code for a *nonvirtual* bus represents the bus data with a structure. The use of a structure in the generated code can be helpful when tracing the correspondence between the model and the code. For example, below is the generated code for Bus Creator block in the `sldemo_mdlref_bus` model.

```
50
51      /* BusCreator: '<Root>/COUNTERBUSCreator' incorporates:
52       *  BusCreator: '<Root>/LIMITBUSCreator'
53       *  Constant: '<Root>/lower_ saturation_ limit'
54       *  Constant: '<Root>/upper_saturation_limit'
55       */
56      sldemo_mdlref_bus_B.COUNTERBUS_n.data = rtb_data;
57      sldemo_mdlref_bus_B.COUNTERBUS_n.limits.upper_saturation_limit = 40;
58      sldemo_mdlref_bus_B.COUNTERBUS_n.limits.lower_saturation_limit = 0;
59
```

Choosing Between Virtual and Nonvirtual Buses

Whether to use a virtual or nonvirtual bus depends on your modeling goal. Frequently, model contain both virtual and nonvirtual buses.

Modeling Goal	Type of Bus
Use bus signals within a functional units, such as within a referenced model	Virtual
Use signals with different sample rates in a bus	Virtual (required)
Have bus data packaged as data structures in the generated code	Nonvirtual
Have bus data cross model reference, MATLAB Function block, or Stateflow chart boundaries	Nonvirtual

Not all blocks can accept buses. See "Bus-Capable Blocks" on page 48-19 for more about which blocks can handle which types of buses. Virtual buses are the default except where nonvirtual buses are explicitly required. See "Connect Buses to Inports and Outports" on page 48-61 for more information.

For additional guidelines for generated code for buses, see "About Buses and Code Generation".

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
- Constant
- Data Store Memory

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 48-21.
2. For the block that creates the bus, open the Block Parameters dialog box.
3. Set **Data type** to `Bus: <object name>` and replace `<object name>` with the bus object name.
4. For any Bus Creator, Inport, or Outport blocks that have an associated bus object, enable the **Enable output as nonvirtual bus** parameter.
5. 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.

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 “Bus Objects” on page 48-20. Conversion to a nonvirtual bus fails if no bus object is specified, and the Simulink software posts an error message describing the problem.

Explicit Bus Conversion

You can eliminate the need for the automatic conversion by using one of these approaches:

- Specify a nonvirtual bus in the block where the bus originates. For example, if you use a Bus Creator block to create a bus, then to specify a

nonvirtual bus, set the Bus Creator block **Data type** parameter to use a `Simulink.Bus` object.

- Manually insert a Signal Conversion block. Using a Signal Conversion block can reduce memory usage, support modeling constructs such as Model blocks that require that input buses be nonvirtual, and reduce generated code. For details, see the Signal Conversion documentation.

Create and Access 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

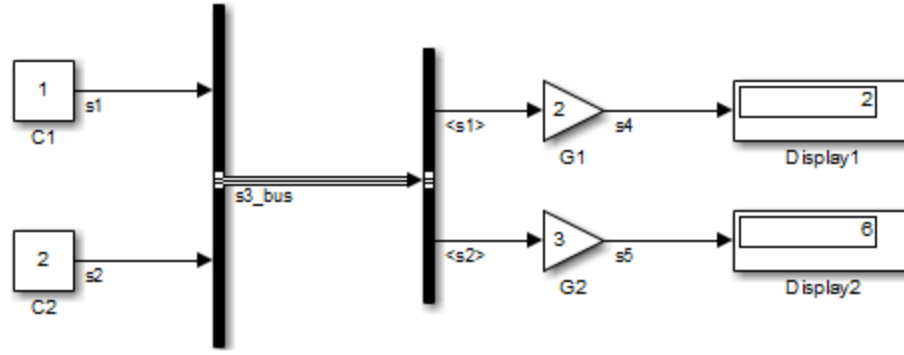
Bus Selector
Select elements from a bus

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.

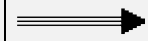
To create and access a bus signal that has default properties:

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 (`s1` and `s2`) that are input to a Bus Creator block, transmitted as a bus signal (`s3_bus`) 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 (`s3_bus`), 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 47-4 for more about the graphical appearance of signals. You can also display other signal characteristics graphically, as described under “Display Signal Attributes” on page 47-61.

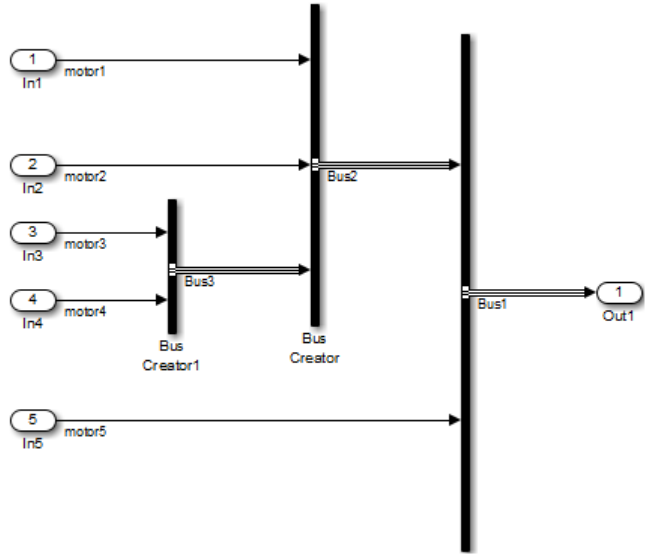
Simulink automatically labels the output signals of the Bus Selector block to reflect the name of the selected bus elements (for example, in the above model, `s1` and `s2`).

For more information about creating and accessing buses, see the reference documentation for the Bus Creator, Bus Selector, and Bus Assignment blocks.

Nest Buses

You can nest buses to any depth. To create a nested bus, use a Bus Creator block. If one of the inputs to the Bus Creator block is a bus, then the output is a nested bus. To select a signal within a nested bus, use a Bus Selector block.

For example, in the next model, the `Bus3` bus signal combines two signals, `motor3` and `motor4`. The `Bus2` signal combines the `Bus3` bus signal and the `motor1` and `motor2` signals. The `Bus1` signal combines the `Bus2` bus signal and the `motor5` signal.



All of the signals retain their separate identities, just as if no bus creation and selection occurred. You can use Bus Selector blocks to select individual signals from a nested bus.

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 Signal to Source** or **Highlight Signal to Destination** from the signal's context menu. (See "Display Signal Sources and Destinations" on page 47-41 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 specific blocks 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 “Avoid Mux/Bus Mixtures” on page 48-95 for details.

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 MATLAB Function 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 several blocks. For details, see "Associating Bus Objects with Simulink Blocks" on page 48-21.

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 "Manage Bus Objects with the Bus Editor" on page 48-24, or you can use the Simulink API, as described in "Bus Object API" on page 48-23. 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 the following blocks:

- Bus Creator
- Data Store Memory
- Data Store Read
- Data Store Write
- From File
- From Workspace
- Inport

- Outport
- Permute Dimensions
- Probe
- Reshape
- Signal Conversion
- Signal Specification

In the Block Parameters dialog box for the block that you want to associate with a bus, set **Data type** to `Bus: <object name>` and replace `<object name>` with the bus object name.

Note Do not set the minimum and maximum values for bus data on blocks with bus object data type. Simulink ignores these settings. Instead, set the minimum and maximum values for bus elements of the bus object specified as the data type. The values should be finite real double scalar.

For information on the Minimum and Maximum properties of a bus element, see `Simulink.BusElement`.

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.

Manage Bus Objects with 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 "Bus Objects" on page 48-20.

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

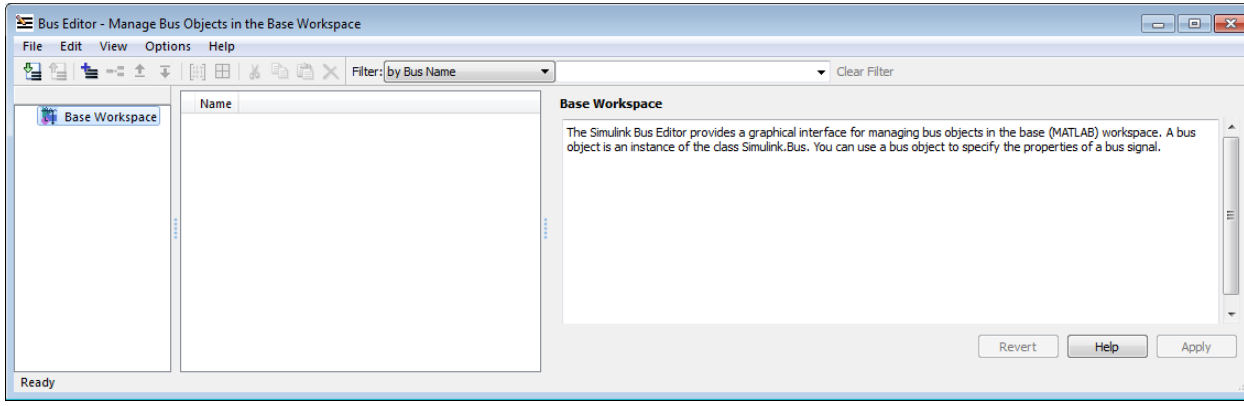
MAT-files. To save changed bus object definitions, export them from the base workspace into MATLAB code files or MAT-files, as described in "Export Bus Objects" on page 48-42.

Open the Bus Editor

You can open the Bus Editor in any of these ways:

- In the Simulink Editor, select **Edit > Bus Editor**.
- In a bus object's dialog box in the Model Explorer, click the **Launch Bus Editor** button.
- Enter `buseditor` at the command line of the MATLAB software.

If no bus objects exist, the Bus Editor looks like the one shown here:



Bus Editor Commands

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 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.
Create/Edit a Simulink.Parameter object		Create or edit a `Simulink.Parameter` object for the selected bus object.
Create a MATLAB structure		Create a MATLAB structure for the selected bus object.

You can use toolbar icons and keyboard shortcuts instead of menu commands whenever you prefer.

Display Bus Objects

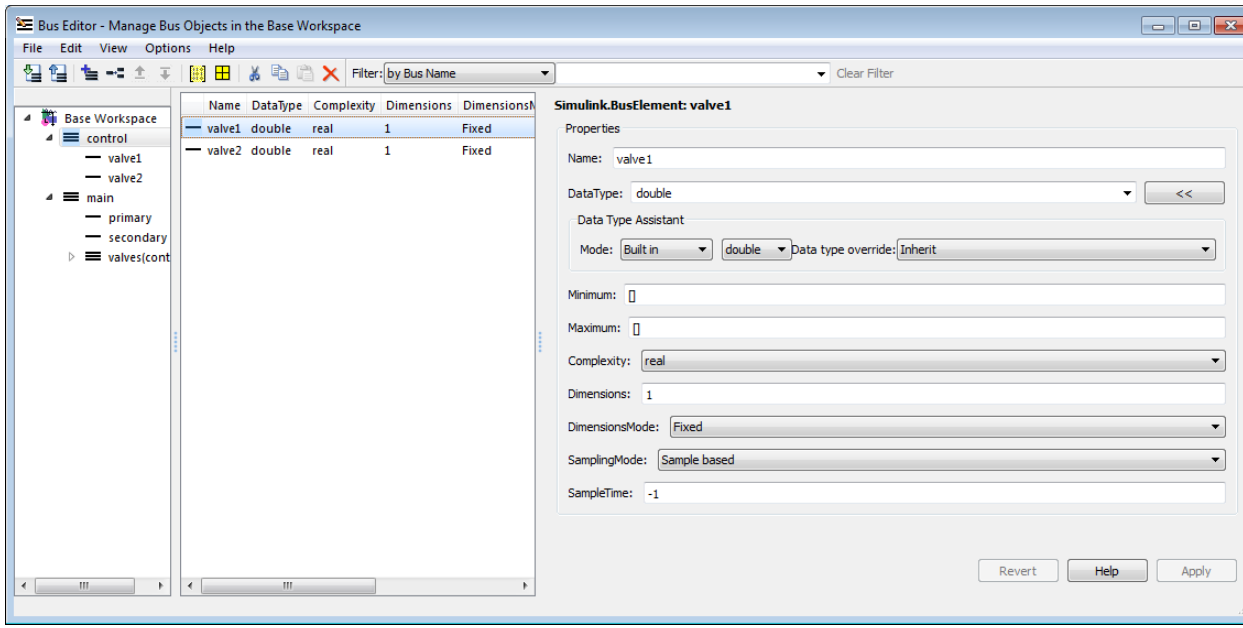
The Bus Editor is similar to the Model Explorer (which can display bus objects but cannot edit them) and uses the same three panes to display bus objects:

- **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 48-39.

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 48-41.

Filter Boxes

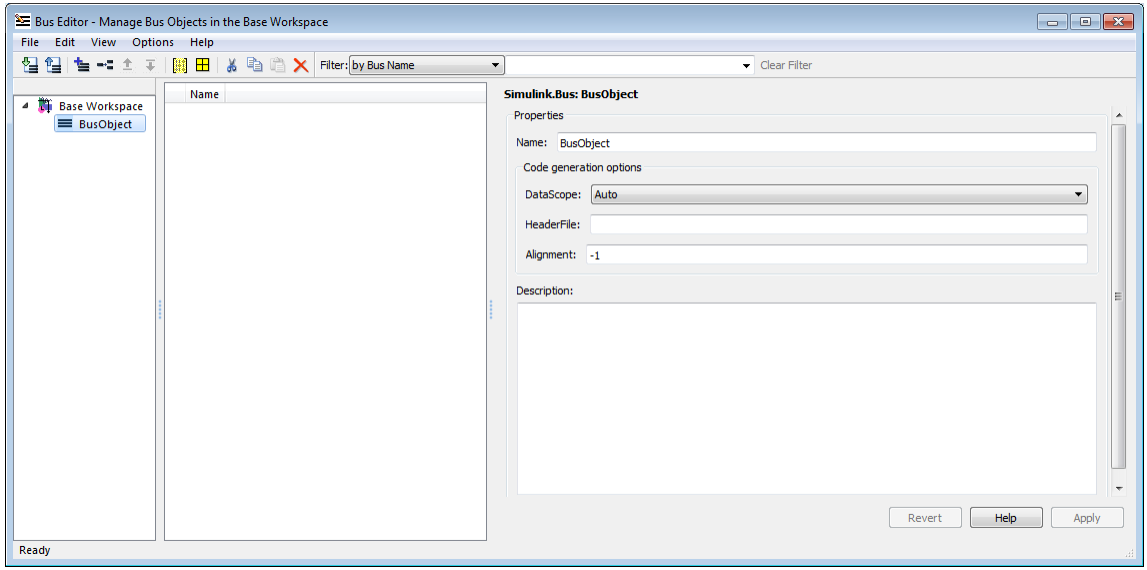
By default, the Bus Editor displays all bus objects that exist in the base workspace. Where a model contains large numbers of bus objects, seeing them all at the same time can be inconvenient. To facilitate working efficiently with large collections of bus objects, you can use the **Filter** boxes, to the right of the iconic tools in the toolbar, to show a selected subset of bus objects. See "Filter Displayed Bus Objects" on page 48-49 for details.

Create 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:

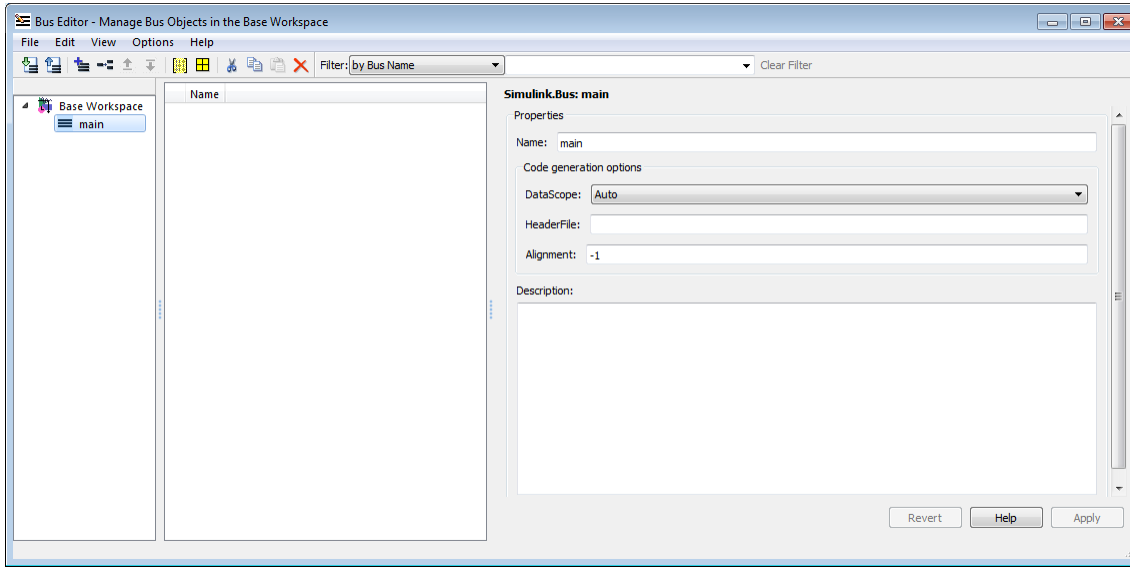
a Specify the **Name** of the of the new bus object (or you can retain the default name). The name must be unique in the base workspace. See "Choosing a Signal Name" on page 47-19 for guidelines for signal names.

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 Simulink Coder software to generate code.

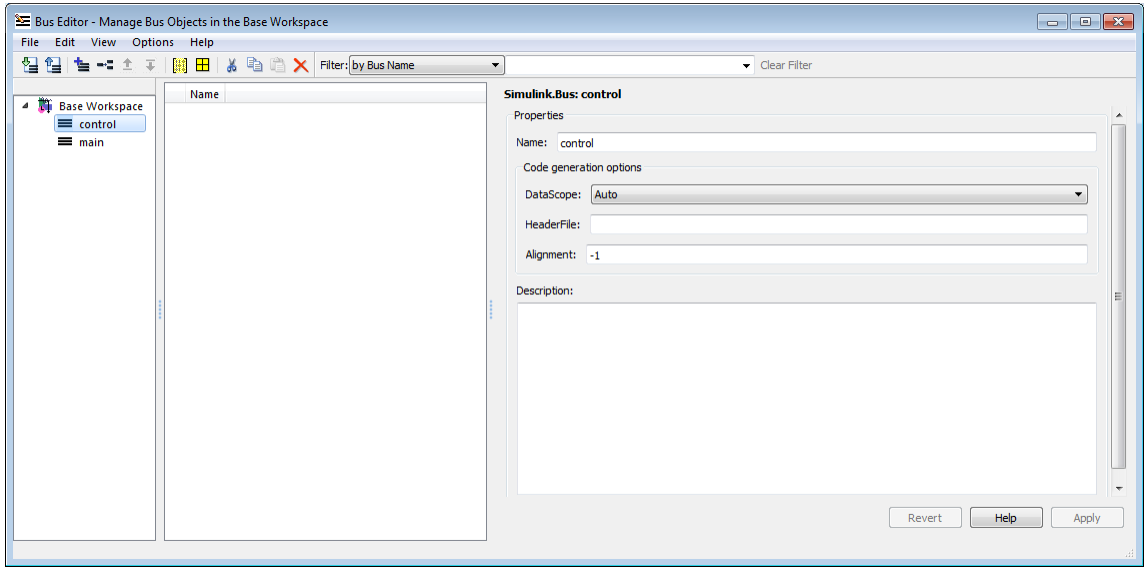
c Optionally, specify a **Description** that provides information about the bus object to human readers. This description has no effect on Simulink simulation; it exists only for human convenience.

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.

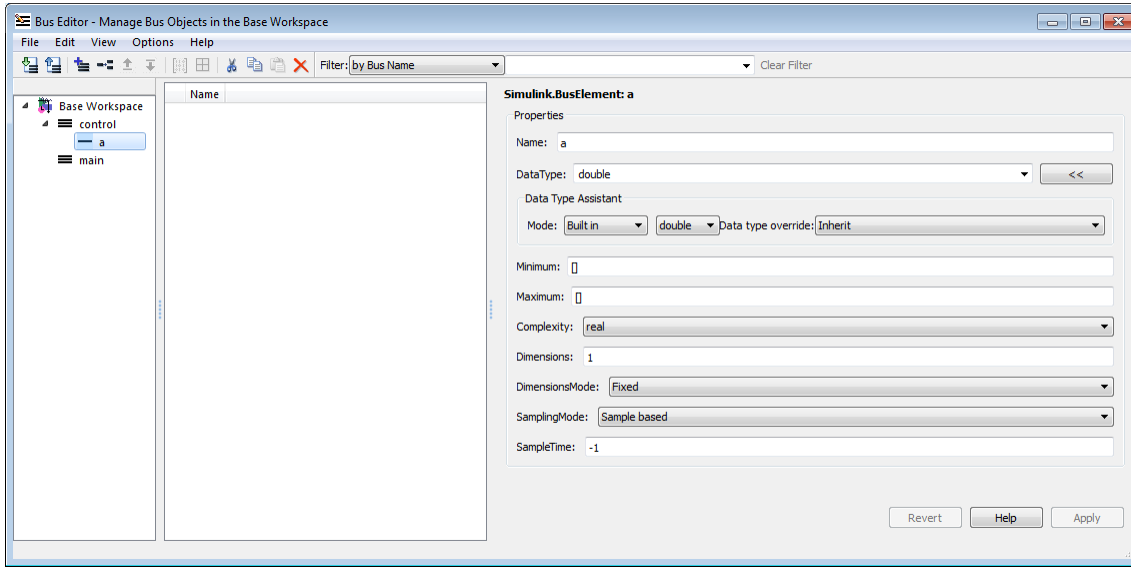
Create Bus Elements

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:



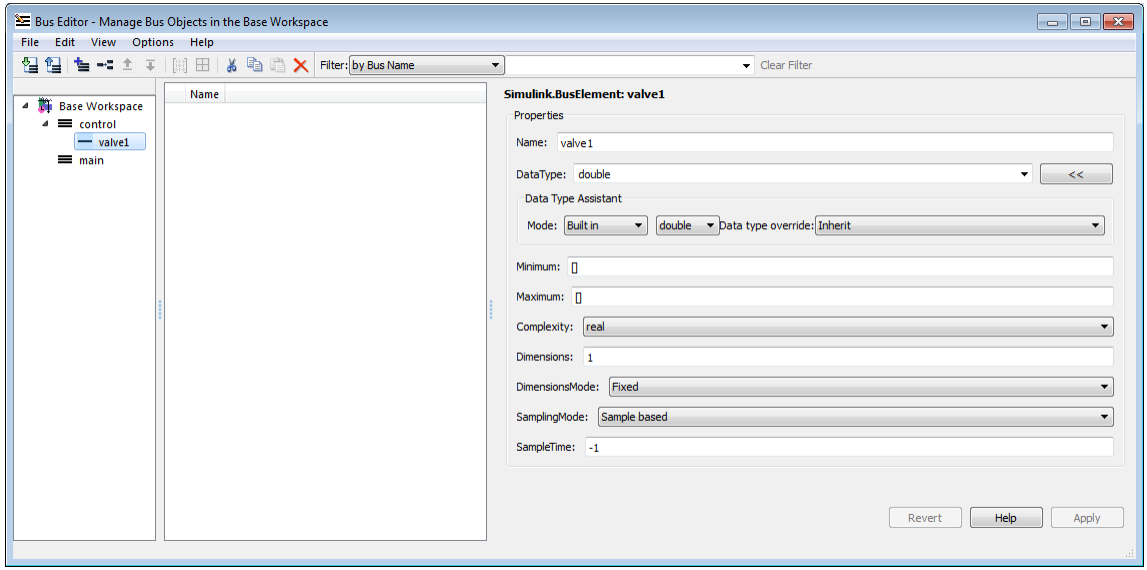
3 To specify the bus element name and other properties, in the Dialog pane:

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 “Signal Names” on page 47-19 for guidelines for signal names.

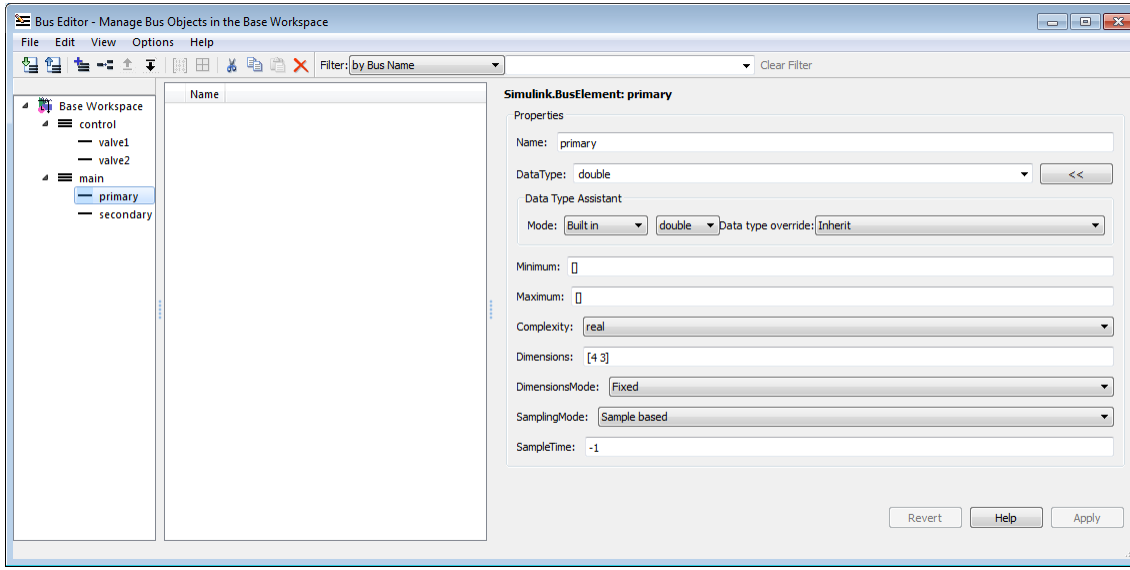
b Specify the other properties of the element. The properties must match the properties of the corresponding signal within the bus exactly, and can be anything that a legal signal might have. The Data Type Assistant appears in the Dialog pane to help specify the element’s data type. You can specify any 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.

Nest Bus Definitions

As described in “Nest Buses” on page 48-17, 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.

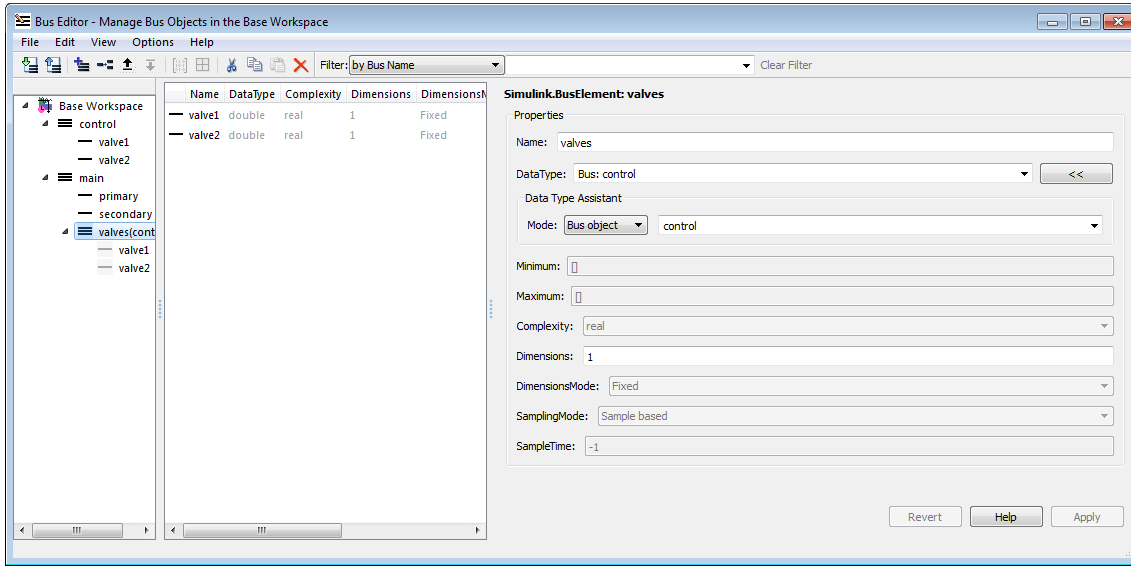
A data type defined by a bus object is called a *bus type*. Nesting buses by assigning bus types to elements, rather than by subordinating the bus objects that define the types, allows the same bus definition to be used conveniently

in multiple contexts without unwanted interactions. To specify that an element of a bus object represents a nested bus definition:

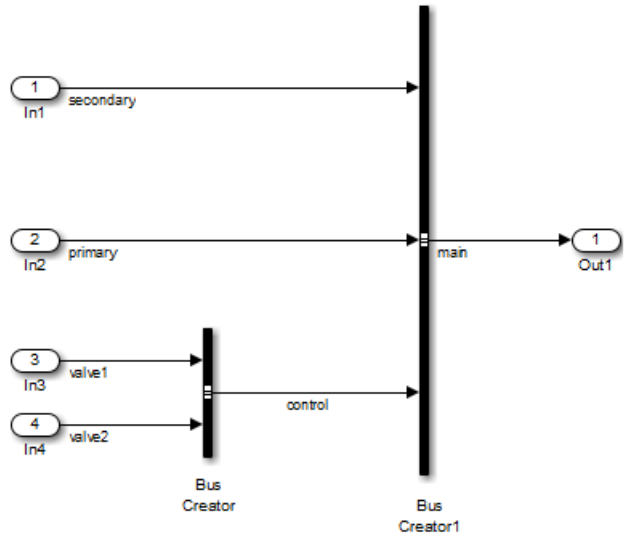
1. Create a bus element to represent the nested bus definition, in the appropriate position under the containing bus object, and give the element the desired name. (You can also use an existing element.)

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.

Change 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 "Filter Displayed Bus Objects" on page 48-49 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 "Nest Buses" on page 48-17.

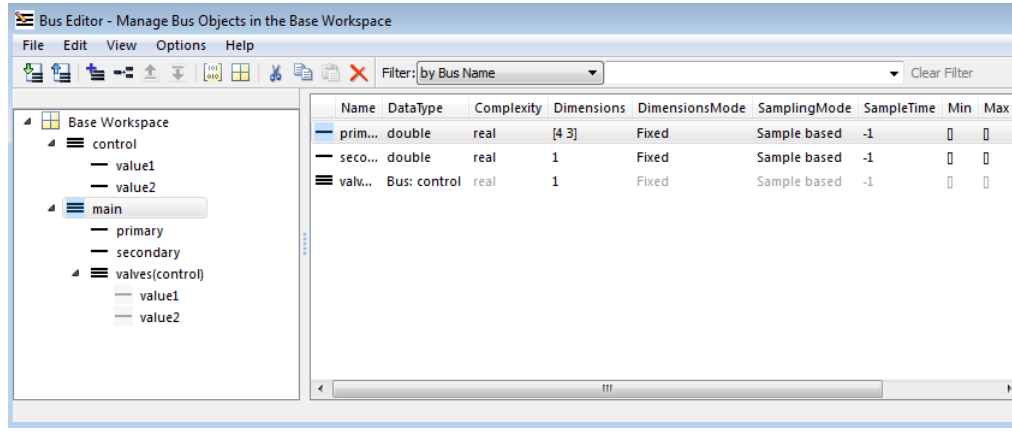
Editing in the Contents Pane

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**.

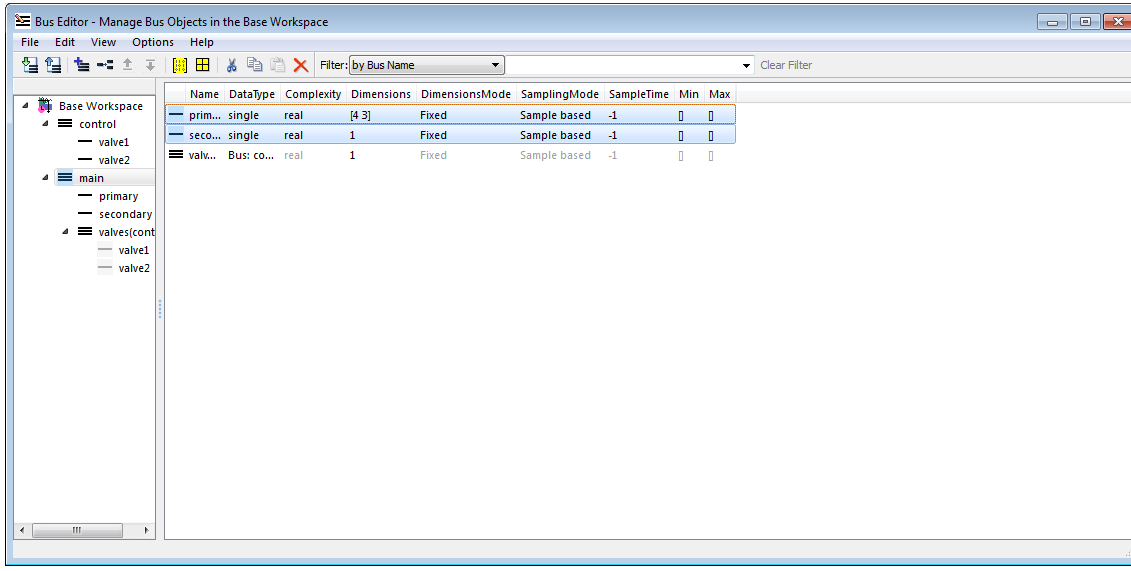
Choose **View > Dialog View** to hide the Dialog pane to provide more room to display properties in the Contents pane. Choose the command again to redisplay the Dialog pane.

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:

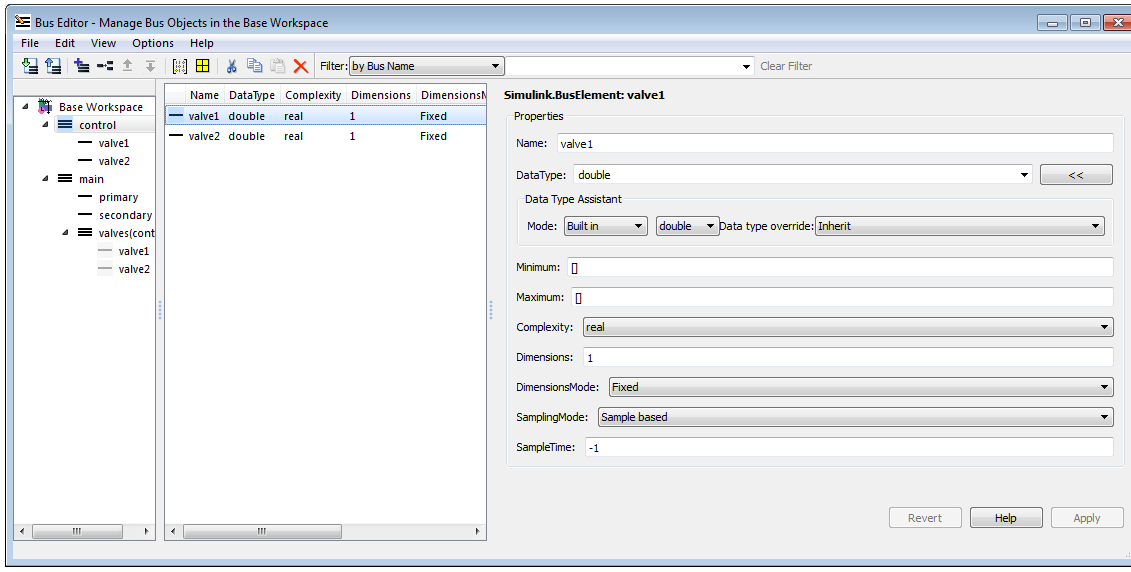


If you change the value of **DataType** to `single` and press Return, the value changes for both elements. The effect is the same no matter which element you edit in a multiple selection:

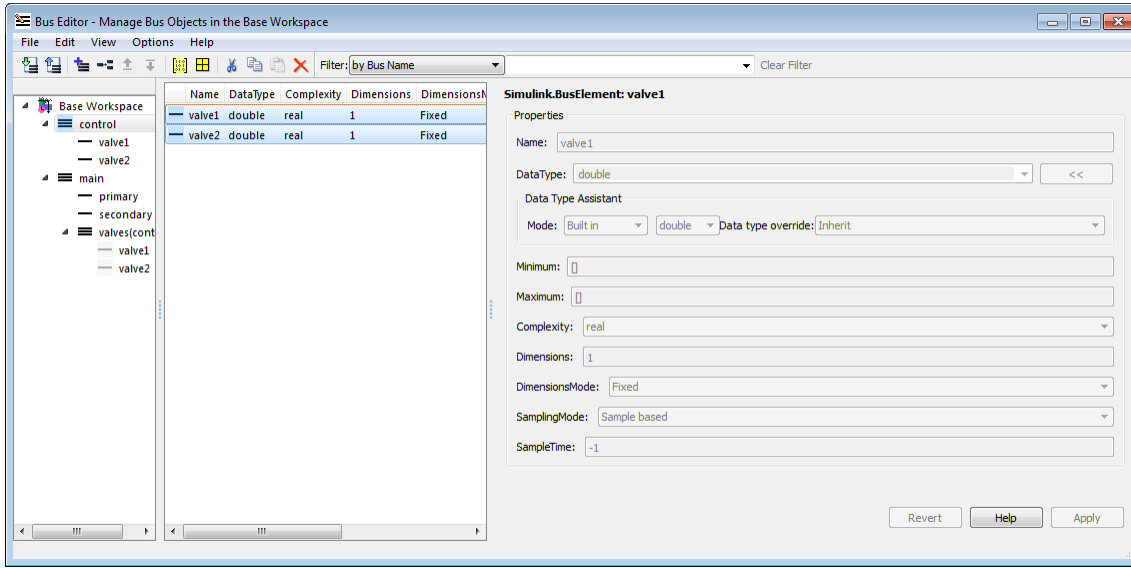


Editing in the Dialog Pane

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**.

Export 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. In the Bus Editor, 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 "Customize Bus Object Import and Export" on page 48-55 for details.

Import 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 "Customize Bus Object Import and Export" on page 48-55 for details.

Close 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 "Export Bus

Objects" on page 48-42. 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**.

Store and Load Bus Objects

In this section...

You can store bus object objects in a variety formats.

Format	When to Use
MATLAB code file	For traceability and model differencing using MATLAB code
MATLAB data file (MAT-file)	For faster bus loading and saving
Database or other external data source	For comparing bus interface information with design documents stored in an external data source.

MATLAB Code Files

You can read and save bus data with MATLAB code files.

To save all bus objects (instances of the `Simulnk.Bus` class) in the MATLAB base workspace to a MATLAB code file, use *one* of the following approaches:

- Use the Bus Editor (see "Export Bus Objects" on page 48-42 and "Import Bus Objects" on page 48-44).
- From the MATLAB command line, use the `Simulink.Bus.save` command.

To save variables from the base workspace to a MATLAB code file, use the `Simulink.saveVars` command. The file containing the variables is formatted to be easily understood and editable. Running the file restores the saved variables to the base workspace.

For traceability, consider using a clearly named separate file for each model.

MATLAB Data Files (MAT-Files)

You can load bus objects in MATLAB data files (MAT-files), using *one* of the following approaches:

- Use the Bus Editor (see "Export Bus Objects" on page 48-42 and "Import Bus Objects" on page 48-44).
- From the MATLAB command line, use the `load` command.

Loading large data from MAT-files is faster than loading from MATLAB code files.

Database or Other External Source Files

You can capture bus interface information in a database or other external source, and use scripts and Database Toolbox™ functionality to read that information into MATLAB.

You can use `sl_customization.m` to customize the Bus Editor to import bus data from a database or other external source. For details, see "Customize Bus Object Import and Export" on page 48-55.

Map Bus Objects to Models

As models become complex, you need to keep track of which models use which bus objects. From any model or bus object, you should be able to tell what component it needs or is needed by.

A model must load all of its bus objects before you execute the model. For automation and consistency across models, it is important to map bus objects to models.

- By identifying all of the bus objects a model needs, you can ensure that those objects are loaded before model execution.
- By identifying all models that use a bus object, you can ensure that changes to a bus object do not cause unexpected changes in any of the models that use that bus object.

To map bus objects to models, consider:

- Using Simulink Projects. For details, see "Project Management"
- Capturing the mapping information in an external data source, such as a database.

Use a Rigorous Naming Convention

Using a rigorous and standard naming convention for bus mapping information is a straightforward approach. For example, consider the model and data required for an actuator control function. You could name the model `Actuator` and name the input and output ports `Actuator_bus_in` and `Actuator_bus_out`, respectively. This naming convention makes it clear to what models a particular bus object is related, and vice versa.

Note that this approach can cause issues if the output from one model reference is fed directly to another model reference. In this case, the naming mismatch results in an error.

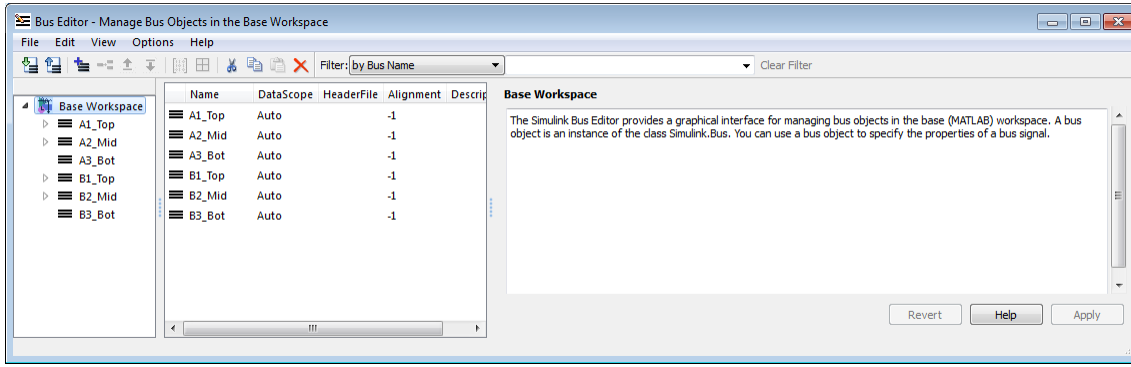
Filter Displayed Bus Objects

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

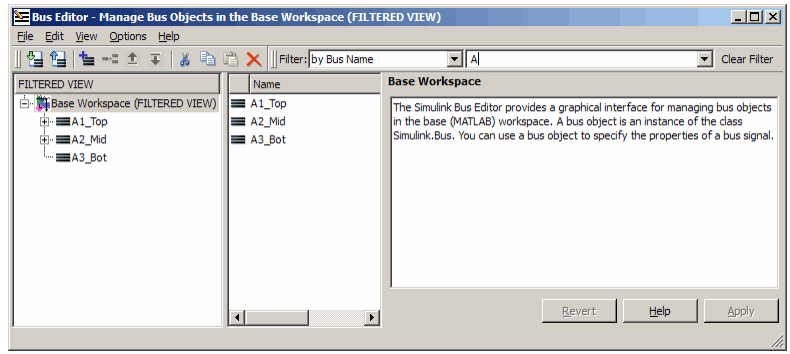
To set a filter, you specify values in the **Filter** boxes to the right of the tools in the toolbar. The left **Filter** box specifies the type of filtering. This box always appears, and is called the **Filter Type** box. Depending on the specified type of filtering, one or two boxes appear to the right of the **Filter Type** box. The next figure includes the **Filter** boxes (near the top of the dialog box) and shows that six bus objects exist in the Base Workspace:



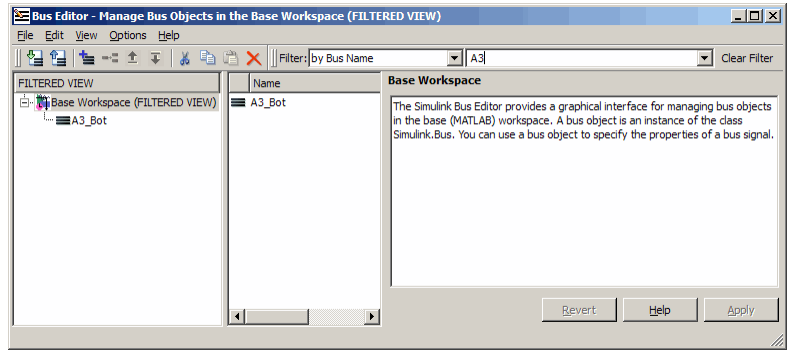
The bus objects shown form two disjoint hierarchies. `A1_Top` is the parent of `A2_Mid`, which is the parent of `A3_Bot`. Similarly, `B1_Top` > `B2_Mid` > `B3_Bot`. See “Nest Buses” on page 48-17 for information about bus object hierarchies.

Filter by Name

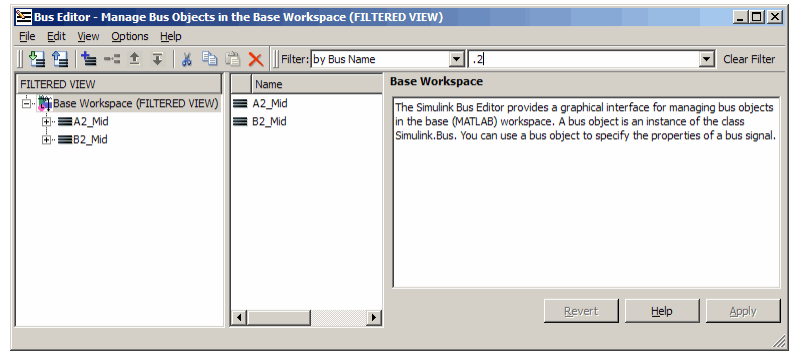
To filter bus objects by name, set the **Filter Type** box to `by Bus Name` (which is the default). The right **Filter** box is the **Object Name** box. Type any MATLAB regular expression (which can just be a string) into the **Object Name** box. As you type, the Bus Editor updates dynamically to show 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:



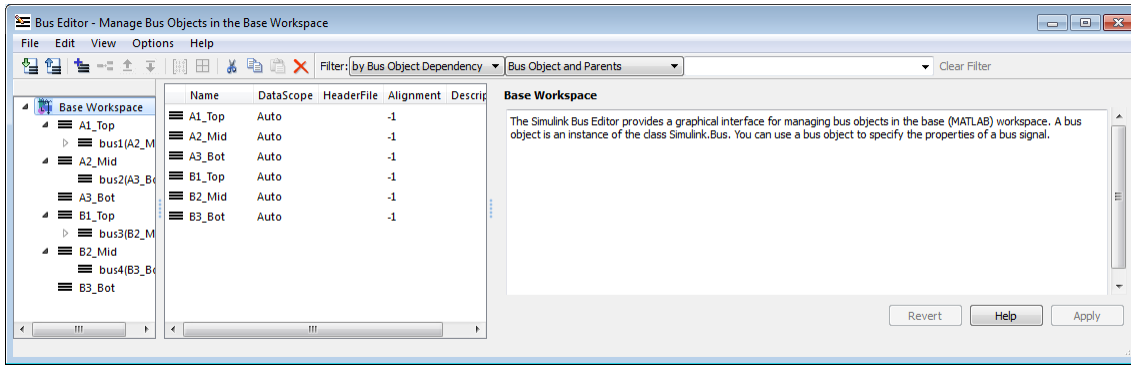
In a MATLAB regular expression, the metacharacter `dot` (.) matches any character, so entering `.2` displays:



See “Regular Expressions” for complete information about MATLAB regular expression syntax.

Filter 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:

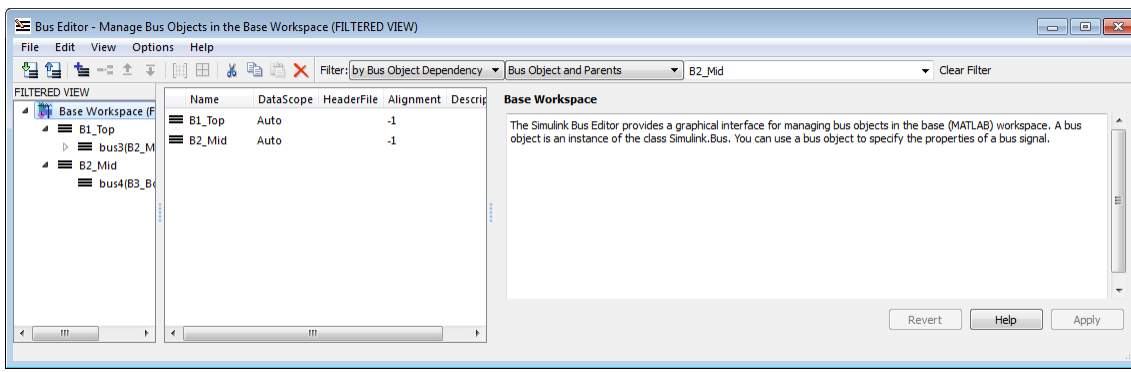
- `Bus Object and Parents` — Show a specified bus object and all superior bus objects in the hierarchy (default)
- `Bus Object and Dependents` — Show a specified bus object and all subordinate bus objects in the hierarchy
- `Bus Object and Related Objects` — Show a specified bus object and all superior 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:

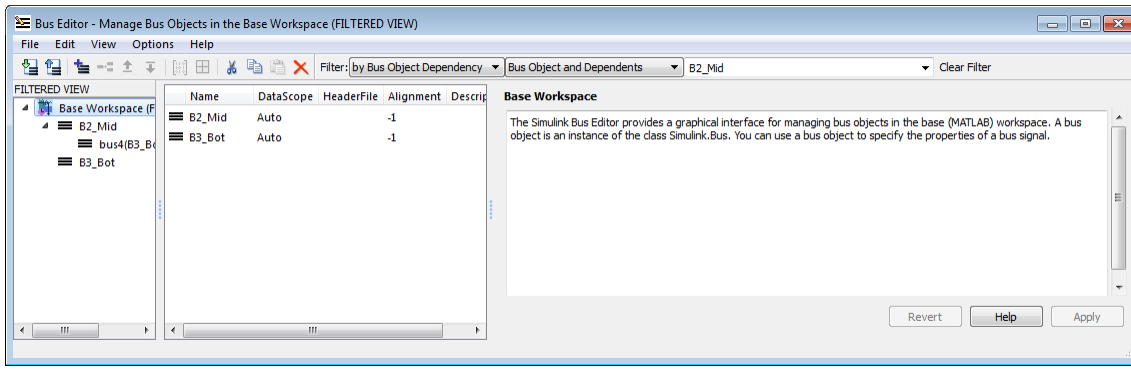
- Dynamically completes the field to indicate the first bus object that alphabetically matches what you have typed.
- Updates the display panes to show only that object and any objects that have the specified relationship to it.

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:

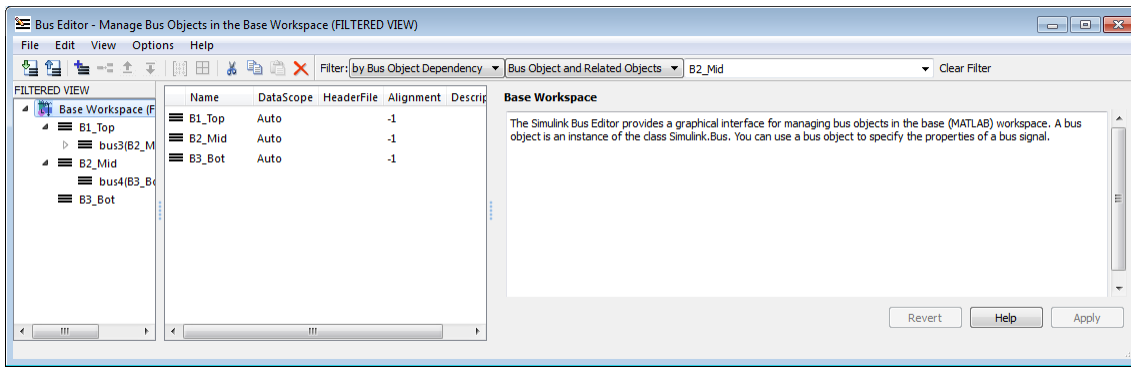
Bus Object and Parents



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.

Change Filtered Objects

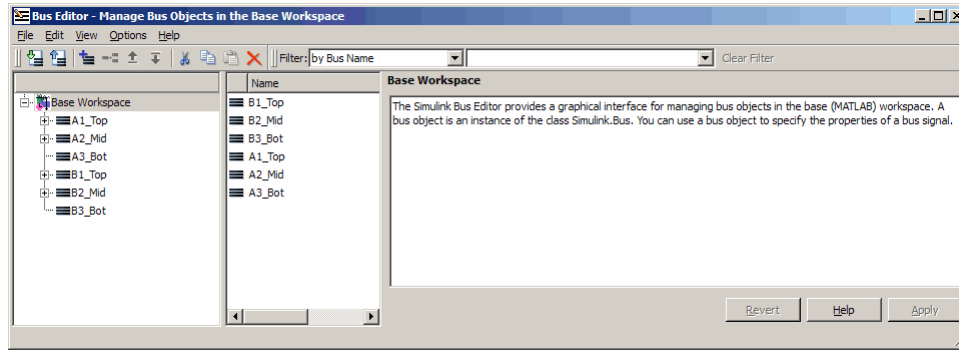
You can work with any bus object that is visible in a filtered display exactly as you could in an unfiltered display. If you change the name or dependency of an object so that it no longer passes the current filter, the object vanishes from the display. Conversely, if some activity outside the Bus Editor 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.

Clear 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.

Customize 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 "Import Bus Objects" on page 48-44, and to export bus objects from the base workspace, as described in "Export Bus Objects" on page 48-42. 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.
- Simulink bus object syntax. See "About Bus Objects" on page 48-20, `Simulink.Bus`, `Simulink.BusElement`, and "Nest Bus Definitions" on page 48-35.
- 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 "Simulink Environment Customization".

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 `myExportCallBack(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 manager object (see "Registering Customizations" on page 48-58).

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.

Connect Buses to Inports and Outports

In this section...

Connect 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 "Bus Objects" on page 48-20 for more information.

Connect 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 48-13. See "Bus Objects" on page 48-20 more information.

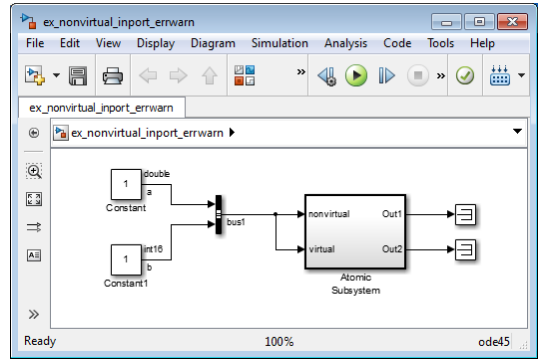
Connect Buses to Nonvirtual Inports

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

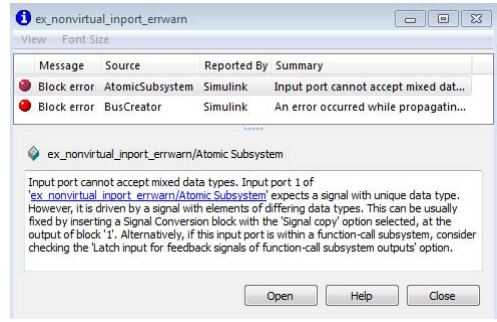
is directly connected to an output of the subsystem or model. In such a case, the Inport block can accept a bus only if all elements of the bus have the same data type.

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, the following model, which includes an atomic subsystem, does not simulate.

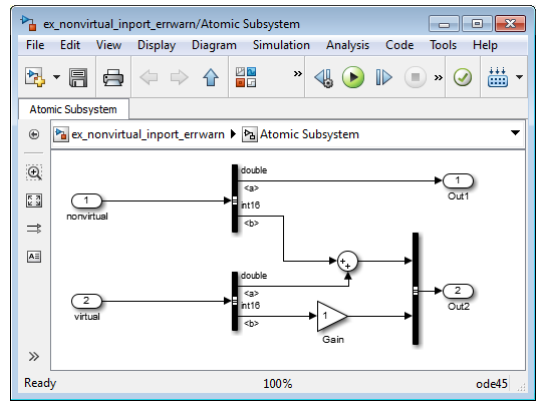


Starting the simulation generates the following error messages:

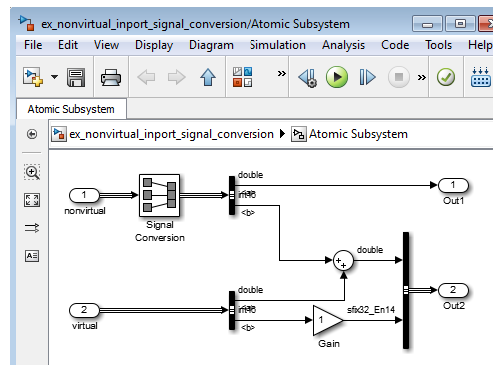


Opening the subsystem reveals that in this model, the Inport block labeled `nonvirtual` is nonvirtual because it resides in an atomic subsystem and one

of its components (labeled `a`) is directly connected to one of the subsystem's outputs. Further, the bus (`bus1`) connected to the subsystem's inputs has components of differing data types. As a result, you cannot simulate this model.



To break the direct connection to the subsystem's output, insert a Signal Conversion block. Set the Signal Conversion block **Output** parameter to `Signal copy`. Inserting the Signal Conversion block enables the Simulink software to simulate the model.



Connect Buses to Model, Stateflow, and MATLAB Function Blocks

Referenced models, Stateflow charts, and MATLAB Function 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 48-13 for details.

Connect 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.

Specify 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 "Initialize Signals and Discrete States" on page 47-51.

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:

- Data Store Memory
- 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	"Create Initial Condition (IC) Structures" on page 48-67
Use an IC structure to specify a nonzero initial condition.	"Three Ways to Initialize Bus Signals Using Block Parameters" on page 48-72
Set Configuration Parameters dialog box diagnostics	"Setting Diagnostics to Support Bus Signal Initialization" on page 48-76

Create 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

For information about defining MATLAB structures, see "Create a Structure Array" in the MATLAB documentation.

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.

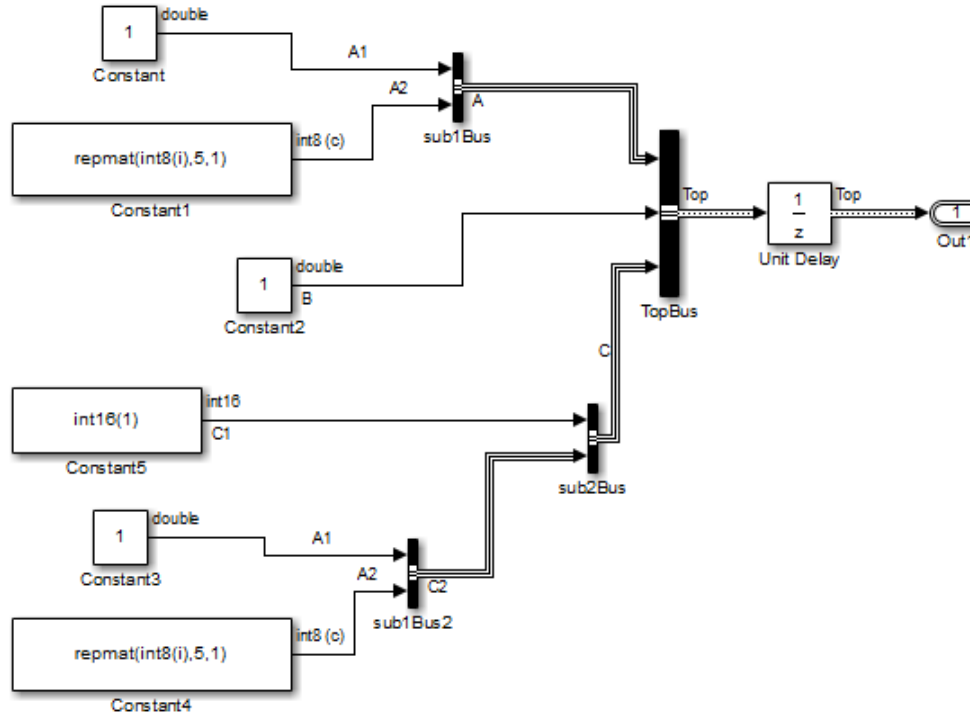
Note The value of an IC structure must lie within the design minimum and maximum range of the corresponding bus element. Simulink performs this range checking during an update diagram and when you run the model.

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.

The following table shows valid initial condition specifications.

Valid Syntax	Description
`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.

These three initial condition specifications are *not* valid:

Invalid Syntax	Reason the Syntax Is Invalid
`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

You can invoke the `Simulink.Bus.createMATLABStruct` function from the Bus Editor, using one of these approaches:

- Select the **File > Create a MATLAB structure** menu item.
- Select the bus object for which you want to create a full MATLAB structure and click the **Create a MATLAB structure** icon () from the toolbar.

You can then edit the MATLAB structure in the MATLAB Editor.

See the `Simulink.Bus.createMATLABStruct` documentation for details.

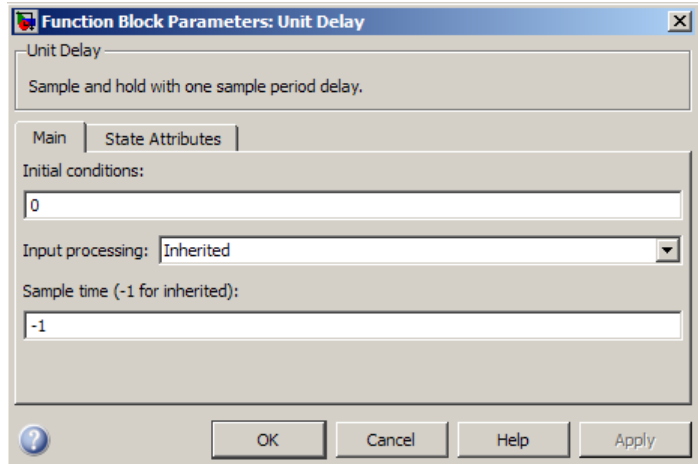
Using Model Advisor to Check for Partial Structures

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 receives a bus signal as input and that supports bus initialization (see "Blocks that Support Bus Signal Initialization" on page 48-65).

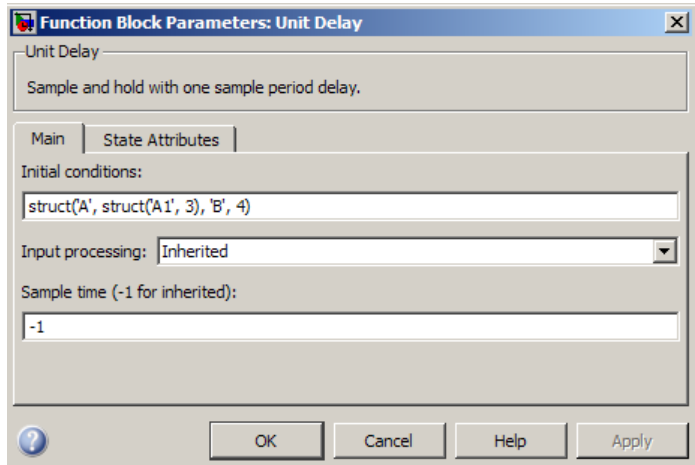
For example, the Block Parameters dialog box for the Unit Delay block has an **Initial conditions** parameter.



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:

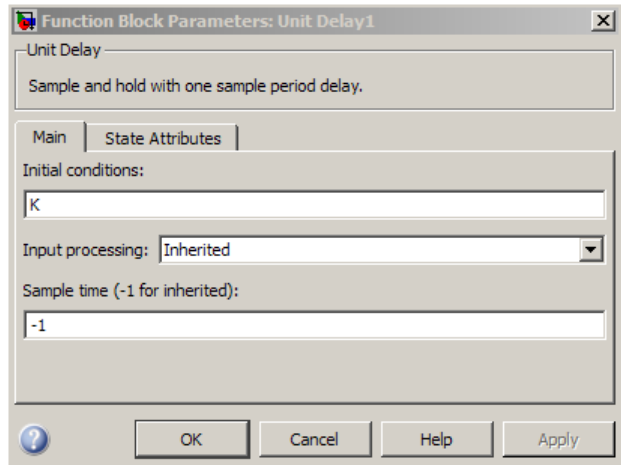


- A MATLAB variable that you define as an IC structure with the appropriate values.

  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:

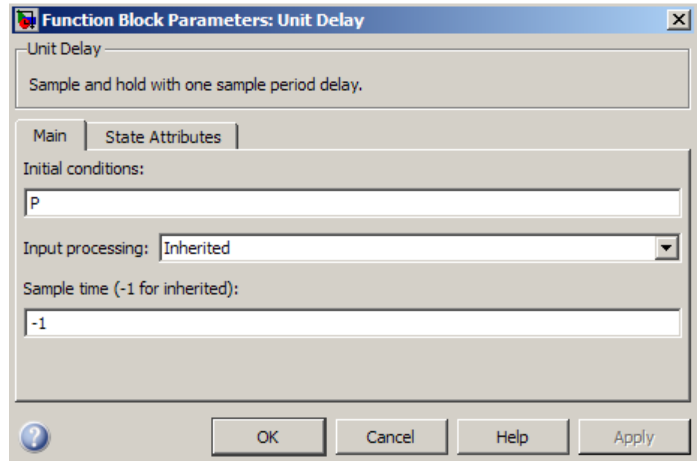


- A `Simulink.Parameter` object that uses an IC structure for the `Value` property

  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 "Create Initial Condition (IC) Structures" on page 48-67). 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.

Combine Buses into an Array of Buses

In this section...

What Is an Array of Buses?

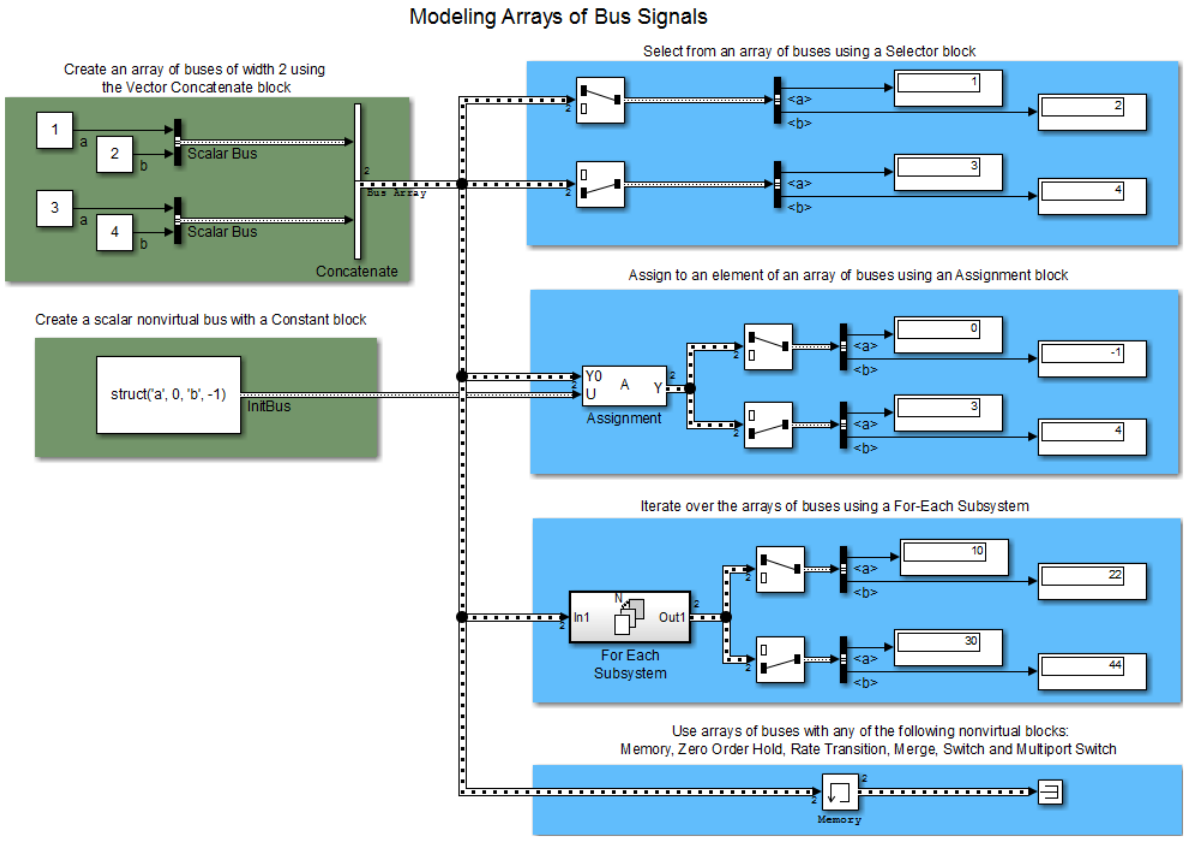
An array of buses is an array whose elements are buses. Each element in an array of buses must be nonvirtual and must have the same bus type. (That is, each bus object has the same signal name, hierarchy, and attributes for its bus elements.)

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 the channels could have a different value.

Using arrays of buses involves:

- Using a bus object as a data type (See "Specify a Bus Object Data Type" on page 43-26.)
- Working with arrays (See "Create Numeric Arrays")

To see an example of a model that uses an array of buses, open the `sldemo_bus_arrays` model. In this example, the nonvirtual bus input signals connect to a Concatenate block that creates an array of bus signals. When you update the diagram, the 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 of an Array of Buses” on page 48-79

- "Blocks That Support Arrays of Buses" on page 48-80
- "Array of Buses Limitations" on page 48-81

For details about working with an array of buses, see:

- "Define an Array of Buses" on page 48-83
- "Using an Array of Buses in a Model" on page 48-86
- "Generated Code for an Array of Buses" on page 48-89

For information about converting an existing model, see "Convert a Model to Use an Array of Buses" on page 48-90.

Benefits of 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 a 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 23-2)
- These nonvirtual blocks:
  - Data Store Memory
  - Data Store Read
  - Data Store Write
  - Merge
  - Multiport Switch
  - Rate Transition
  - Switch
  - Zero-Order Hold
- Assignment
- MATLAB Function
- Matrix Concatenate
- Selector
- Signal Conversion
- Vector Concatenate
- Width
- Two-Way Connection (a Simscape block)

For requirements for using some of these blocks with arrays of buses, see "Block Limitations" on page 48-82.

Using Arrays of Buses with Bus-Related Blocks

To select a signal within an array of buses:

1. Use a Selector block to find the appropriate bus within the vector.
2. Use a Bus Selector block to select the signal.

To assign to a signal within an array of buses:

1. Use a Bus Assignment block to assign to a bus element.
2. Use the Assignment block to assign the bus to the vector.

Bus Selector and Bus Assignment blocks can only accept scalar buses, no arrays of buses.

A Bus Creator block can accept an array of buses as input, but cannot have array of buses as output.

Array of Buses Limitations

Bus Limitations

The buses combined 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 "Specify Initial Conditions for Bus Signals" on page 48-65.

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.

For limitations for bus-related blocks, see "Using Arrays of Buses with Bus-Related Blocks" on page 48-81.

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 `Signal 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.

Define 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 48-81.

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 48-84.

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 "Create Bus Objects" on page 48-29.

   The `sldemo_bus_arrays` model 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` model 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` model, 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:

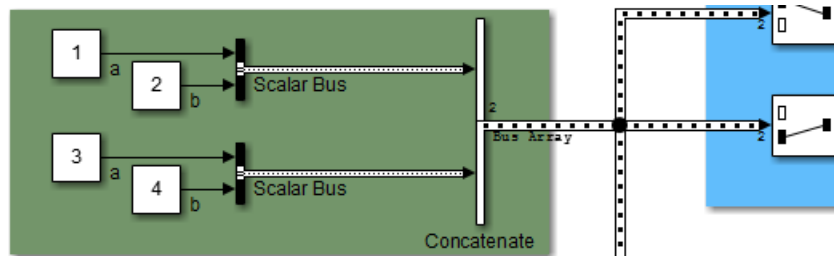
   - `1` to concatenate input arrays vertically
   - `2` to concatenate input arrays horizontally
   - A higher dimension than 2, to perform multidimensional concatenation on the inputs

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` model, 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.



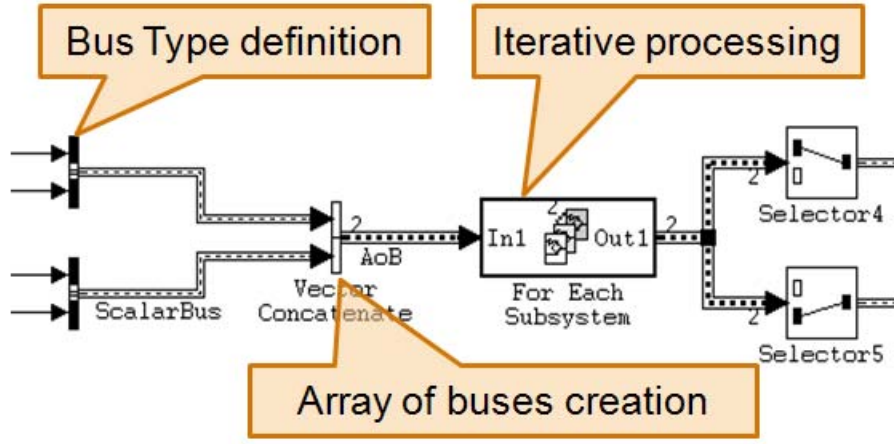
Using an Array of Buses in a Model

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 "Define an Array of Buses" on page 48-83.
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 48-87.
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). Operate on the array first (using Selector and Assignment blocks), and then use the Bus Selector and Bus Assignment blocks to select elements from, or assign elements to, a scalar bus within the subsystem.

This simplified picture reflects the general workflow described above.



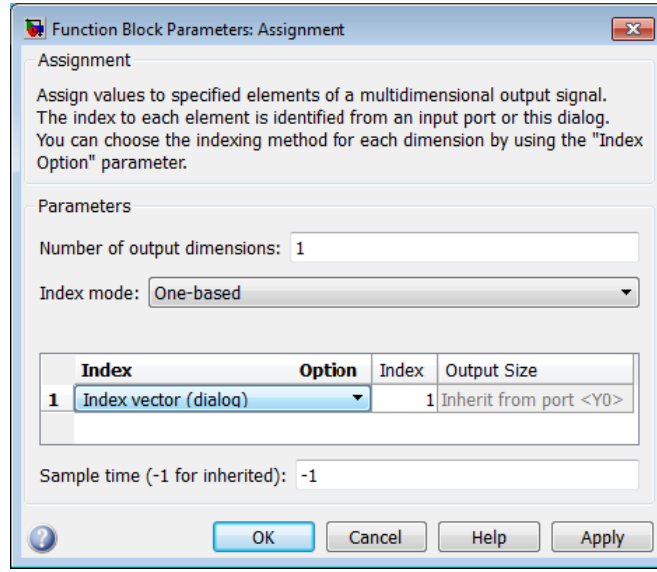
Performing Iterative Processing with an Array of Buses

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` model, 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:



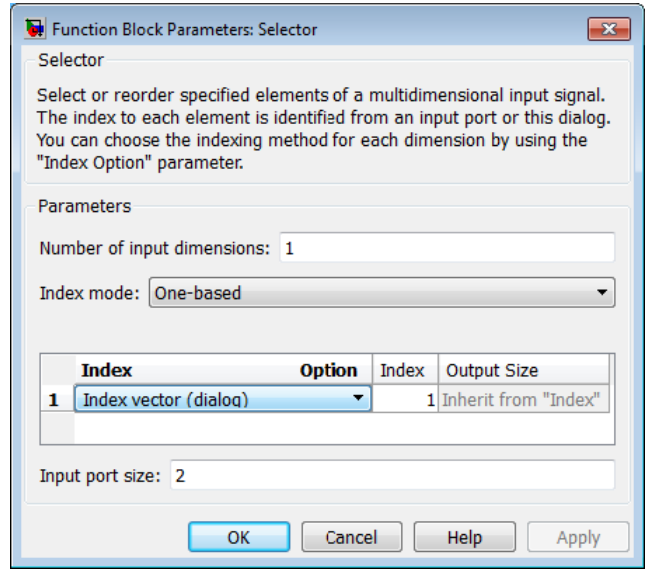
To assign bus elements within a bus signal, use the Bus Assignment block. The input for the Bus Assignment block must be a scalar bus signal.

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` model 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;
```

Convert a Model to Use an Array of Buses

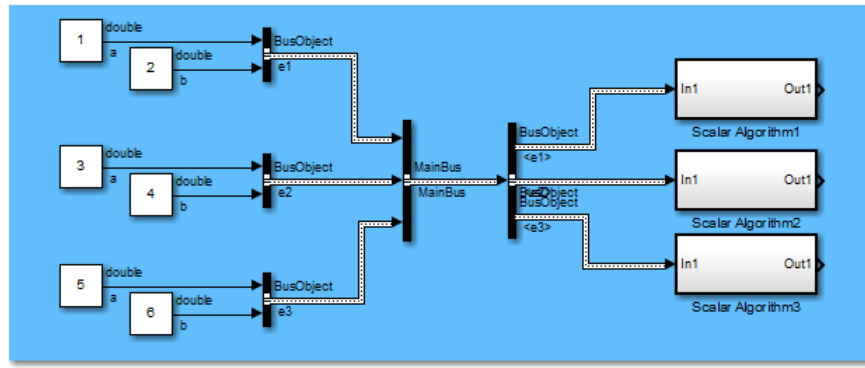
There are several reasons to convert a model to use an array of buses (see "Benefits of an Array of Buses" on page 48-79). For example:

- 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.

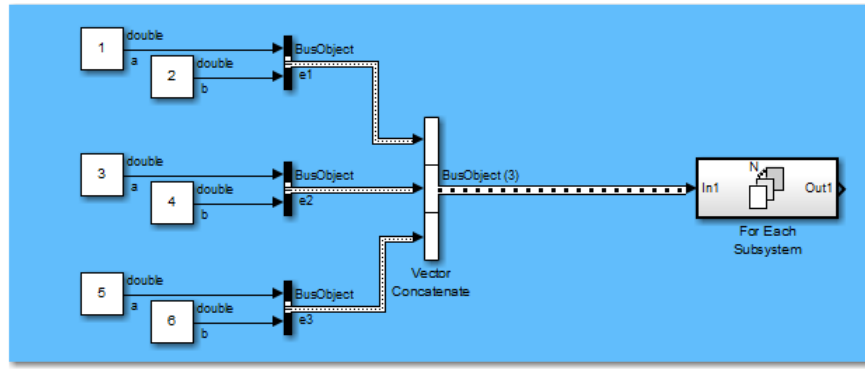
General Workflow for Converting a Model to Use an Array of Buses

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 "Combine Buses into an Array of Buses" on page 48-77.

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.

Bus Data Crossing Model Reference Boundaries

A model reference boundary refers to the boundary between a model that contains a Model block and the referenced model. If you have bus data in a model that is passed to a Model block, then that data crosses the boundary to the referenced model.

To have bus data cross model reference boundaries:

1. Use a nonvirtual bus (required). Using a nonvirtual bus provides a well-defined data interface for code generation.

   Use a bus object (`Simulink.Bus`) to define the bus. For details, see "Creating Nonvirtual Buses" on page 48-12.

2. Consider stripping out unneeded data from bus objects crossing model reference boundaries.

   In large models, bus objects can become quite large and have several levels of hierarchy. Often referenced models need some, but not all, of the data contained in large buses. Passing unneeded data across model reference boundaries impacts performance negatively. The interface definition for a model should specify exactly what data the model uses.

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 "Bus Objects" on page 48-20. 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 "Block Libraries" for information about creating block libraries and copying library blocks to and from them.

Avoid 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 47-11 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 48-96 and "Using the Model Advisor for Mux/Bus Mixtures" on page 48-100 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

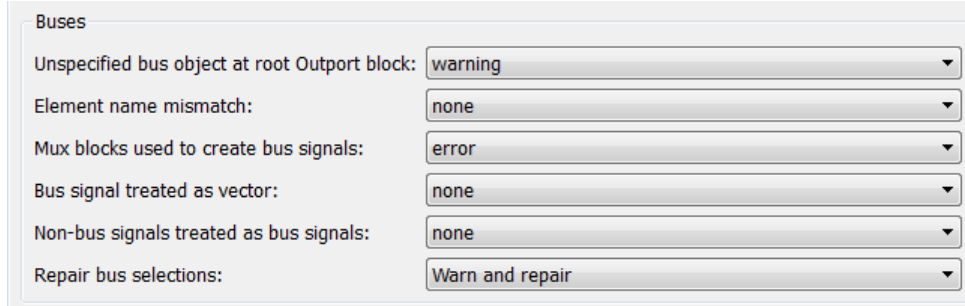
You can use these diagnostics as described in this section, or you can use the Model Advisor to perform the some of these checks and also to obtain advice about corrections, as described in "Consult the Model Advisor" on page 4-81. For complete information about the **Connectivity** pane, see "Connectivity 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".

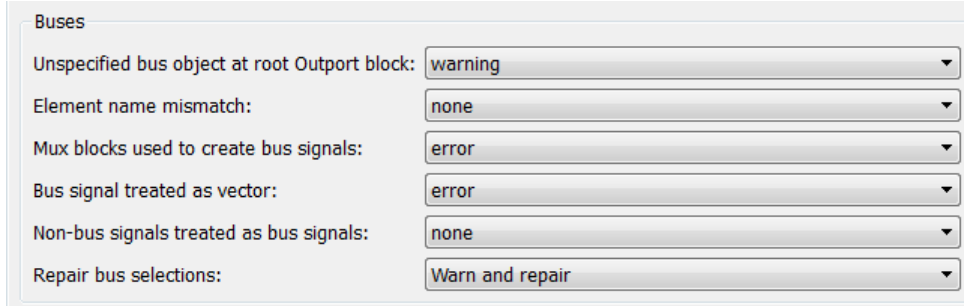
Bus signal treated as vector

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 48-96.

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 48-101.

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:

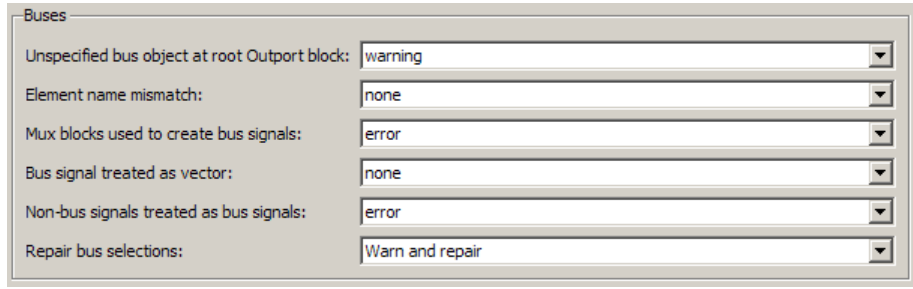
Value of `StrictBusMsg` (API)	Mux blocks used to create bus signals (GUI)	Bus signal treated as vector (GUI)
`None`	`none`	`none`
`Warning`	`warning`	`none`

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 48-96.
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`.



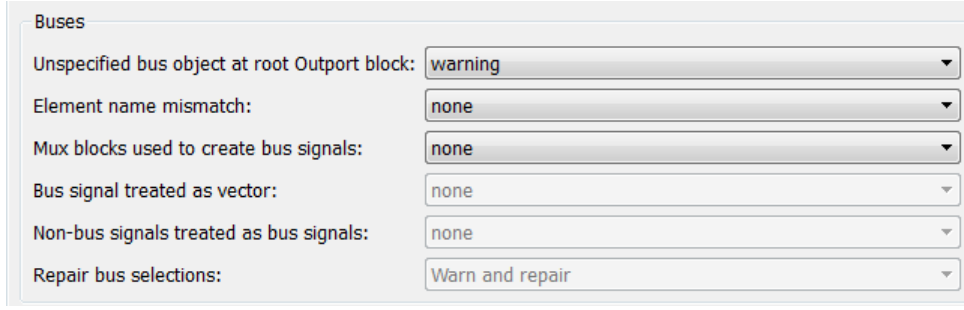
4. Click **OK** or **Apply**.
5. Build the model.
6. Correct the model where needed as described under "Correcting Buses Used as Muxes" on page 48-101.

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**.

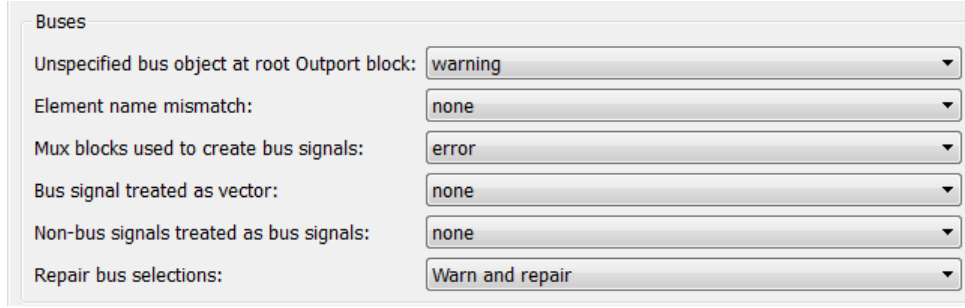
3. Select and run the Model Advisor check **Simulink > Check for proper bus usage**.

   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 48-101 to correct any errors discovered by the check.

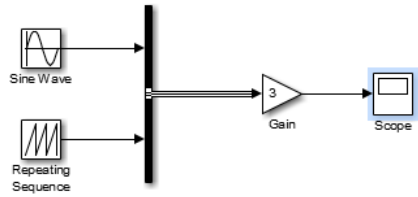
Instructions for using the Model Advisor appear in "Consult the Model Advisor" on page 4-81.

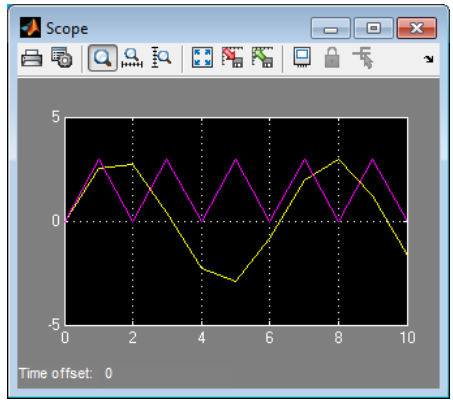
Correcting Buses Used as Muxes

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:

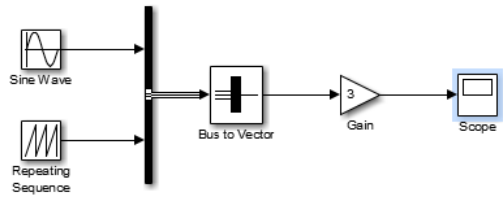
- The Bus to Vector block (Signal Attributes library), which you can insert into any bus used implicitly as a mux to explicitly convert the bus to a mux (vector).
- The `Simulink.BlockDiagram.addBusToVector` function, which automatically inserts Bus to Vector blocks wherever needed.

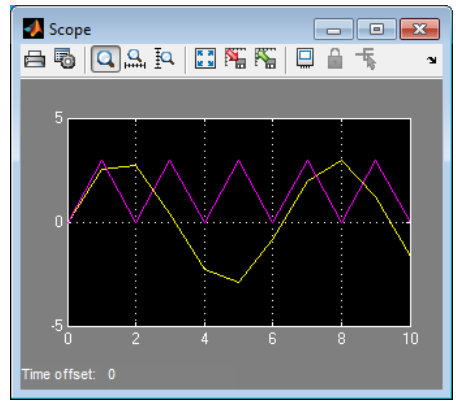
For example, this model uses a bus as a mux by inputting the bus to a Gain block. The Scope block shows the results.





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

If you have a Simulink Coder license, 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. The use of a structure in the generated code can be helpful when tracing the correspondence between the model and the code. For example, below is the generated code for Bus Creator block in the `sldemo_mdlref_bus` model.

```
50
51      /* BusCreator: '<Root>/COUNTERBUSCreator' incorporates:
52       *  BusCreator: '<Root>/LIMITBUSCreator'
53       *  Constant: '<Root>/lower_ saturation_ limit'
54       *  Constant: '<Root>/upper_saturation_limit'
55       */
56      sldemo_mdlref_bus_B.COUNTERBUS_n.data = rtb_data;
57      sldemo_mdlref_bus_B.COUNTERBUS_n.limits.upper_saturation_limit = 40;
58      sldemo_mdlref_bus_B.COUNTERBUS_n.limits.lower_saturation_limit = 0;
59
```

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 “Buses” for information about the best techniques to use.

Composite Signal Limitations

- Buses that contain signals of enumerated data types cannot pass through a block that requires a nonzero scalar initial value (such as a Unit Delay block).
- 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 "Export Signal Data Using Signal Logging" on page 45-19.
- Inputs to a Bus Creator block must have unique names. If there are duplicate names, the Bus Creator block appends `(signal#)` to all input signal names, where `#` is the input port index.

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 47-2 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:

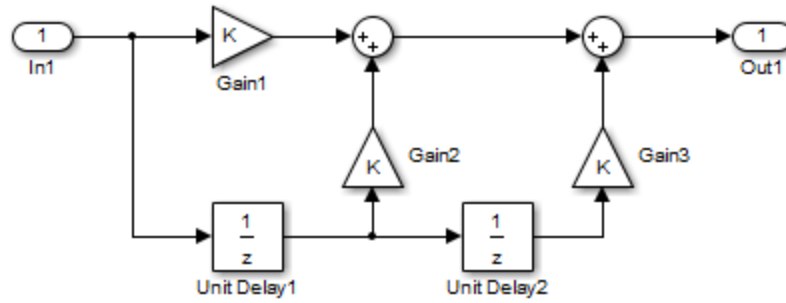
- **At every step of model execution.**

  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.

"Mode-Dependent Variable-Size Signals" on page 49-14 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...

Variable-Size Signal Generation and Operations

This example 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.

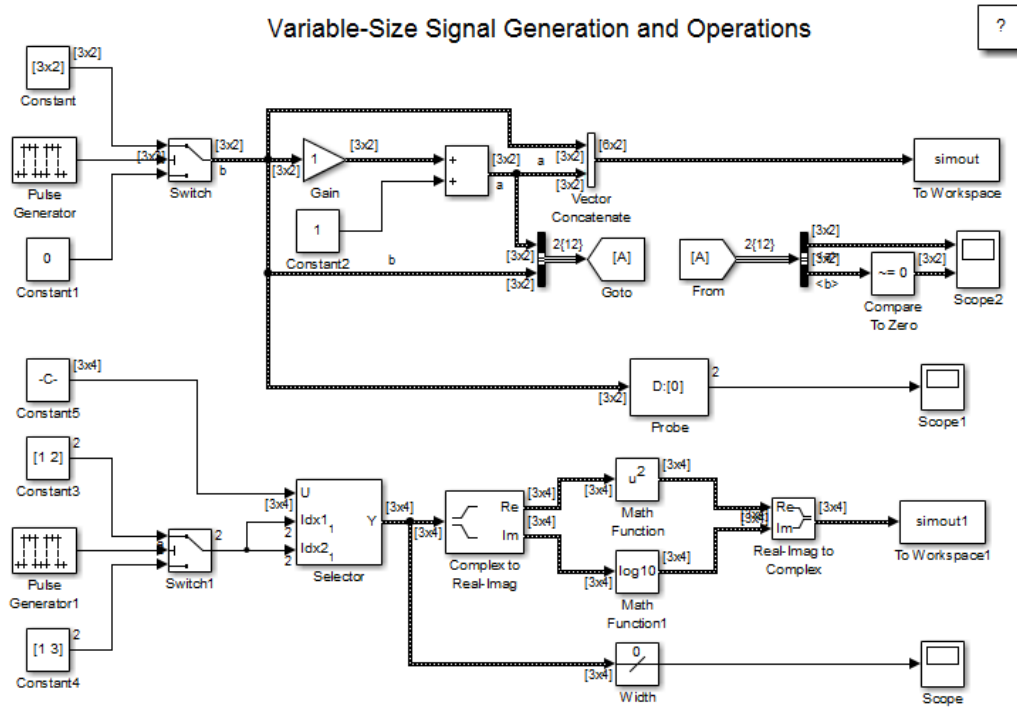
For a complete list of blocks that support variable-size signals, see "Simulink Block Support for Variable-Size Signals" on page 49-23.

1. In the MATLAB Command Window, type

   ```
   sldemo_varsize_basic
   ```

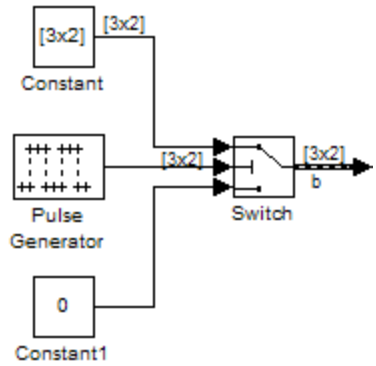
2. In the Simulink Editor, select **Display > Signals & Ports > Signal Dimensions**. Run a simulation or press `Ctrl-D`.

   The Simulink editor displays the signal dimensions and line styles. See "Signal Basics" on page 47-2 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:

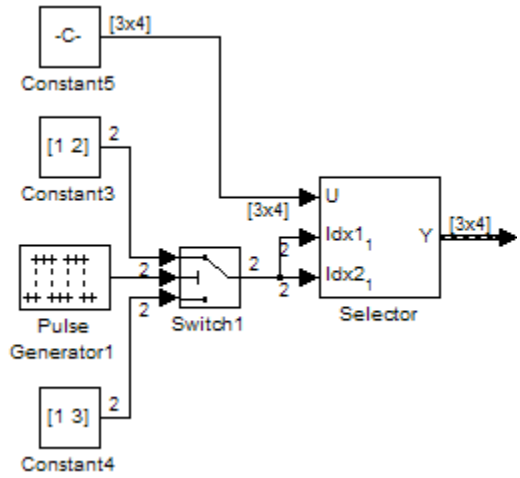
```
simout2.signals.valueDimensions
```

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 shows 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.

Variable-Size Signal Length Adaptation

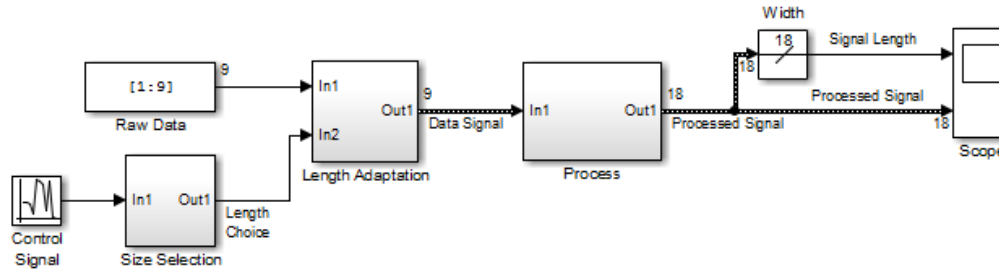
This example model corresponds to a hypothetical system where the model adapts the length of a signal over time. Length adaptation is based on the value of a control signal. When the control signal falls within one of three

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. A 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 49-23.

To open the example model, in the MATLAB® Command Window, type:

```
sldemo_varsize_dataLengthAdapt
```



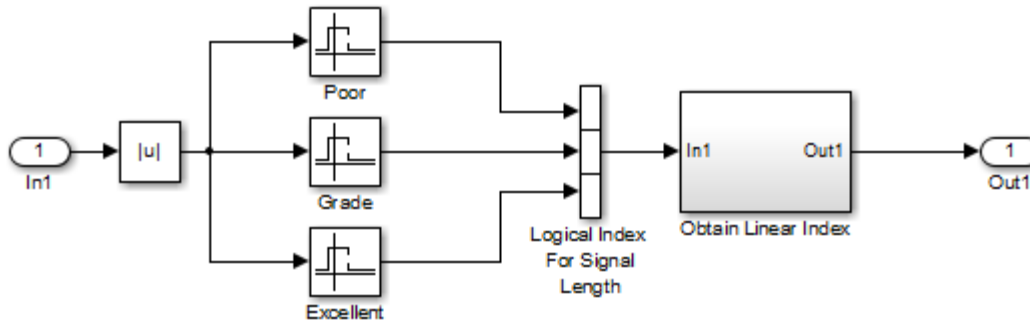
Creating a Variable-Size Signal by Adapting the Length of a Data Signal

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.

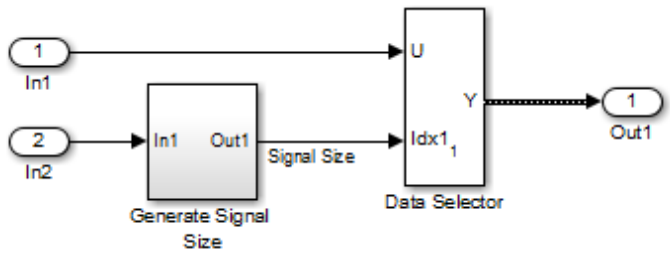
```
[1:9].'

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.

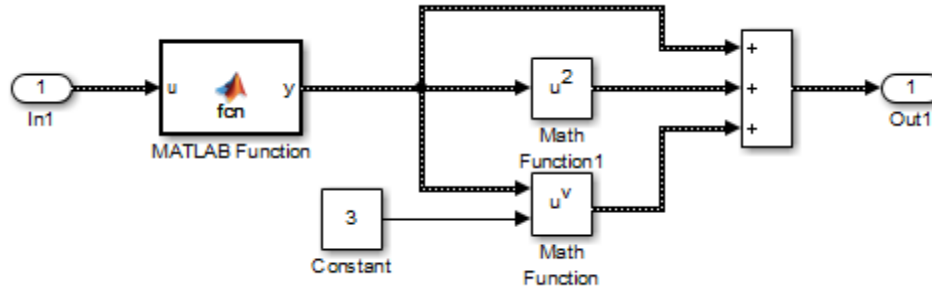


In the Length Adaptation subsystem, the Signal Size subsystem generates an index based on the quality value from the Size Selection subsystem (In2). The Data Selector block uses the starting and ending indices to adapt the length of the data signal (In1) and output a variable-size signal.



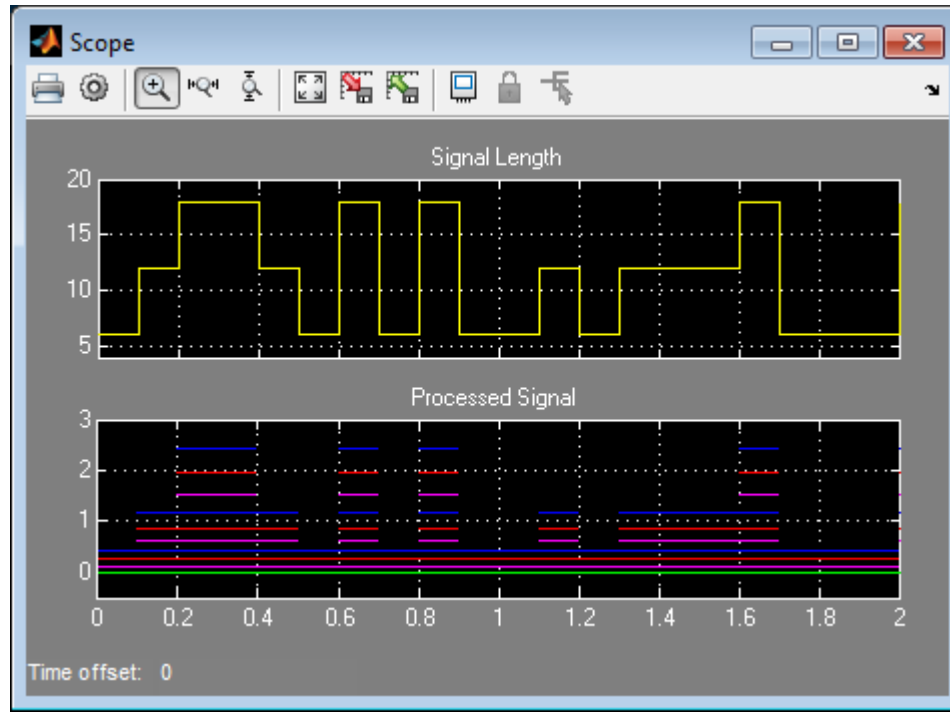
Processing a Variable-Size Signal

The center section of the model processes the variable-size signal. The 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 shows 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.



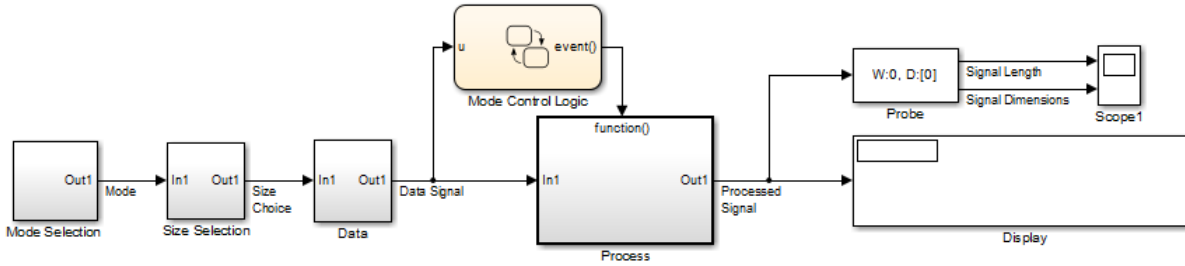
Mode-Dependent Variable-Size Signals

This example 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:

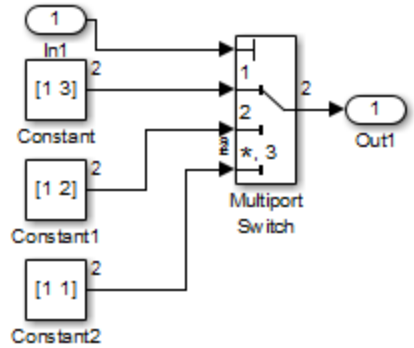
```
sldemo_varsize_multimode
```



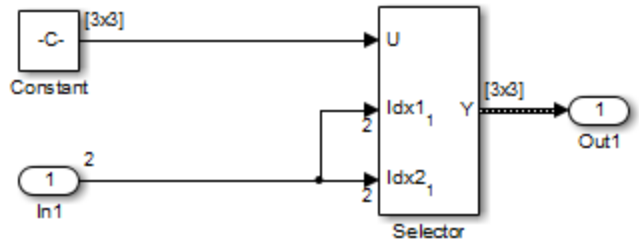
Creating a Variable-Size Signal Based on Mode

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.

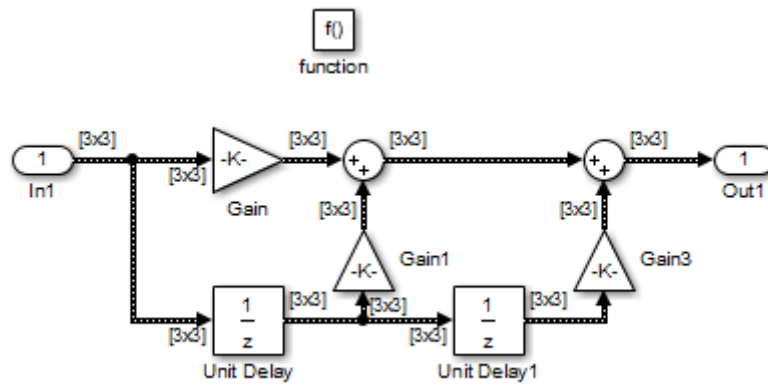
```
simout.signals.values

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
```

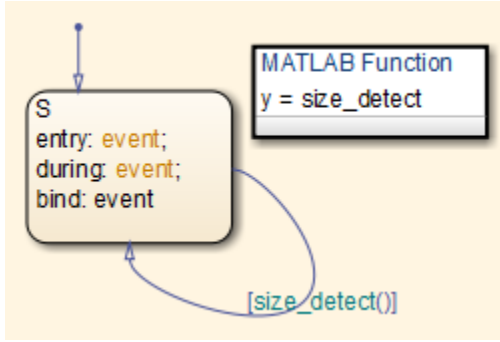
Processing a Variable-Size Signal with a Conditionally Executed Subsystem

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 49-3.

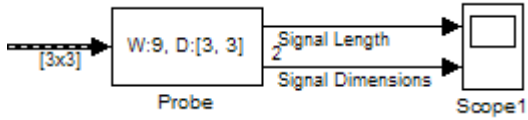


The Stateflow chart determines if there is a change in the size of the signal. The function `size_detect` calculates the width of the variable-size signal at each time step, and compares the current width to the previous width. If there is a change in signal size, the chart outputs a function-call output event that resets and repropagates the signal sizes within the Process subsystem.

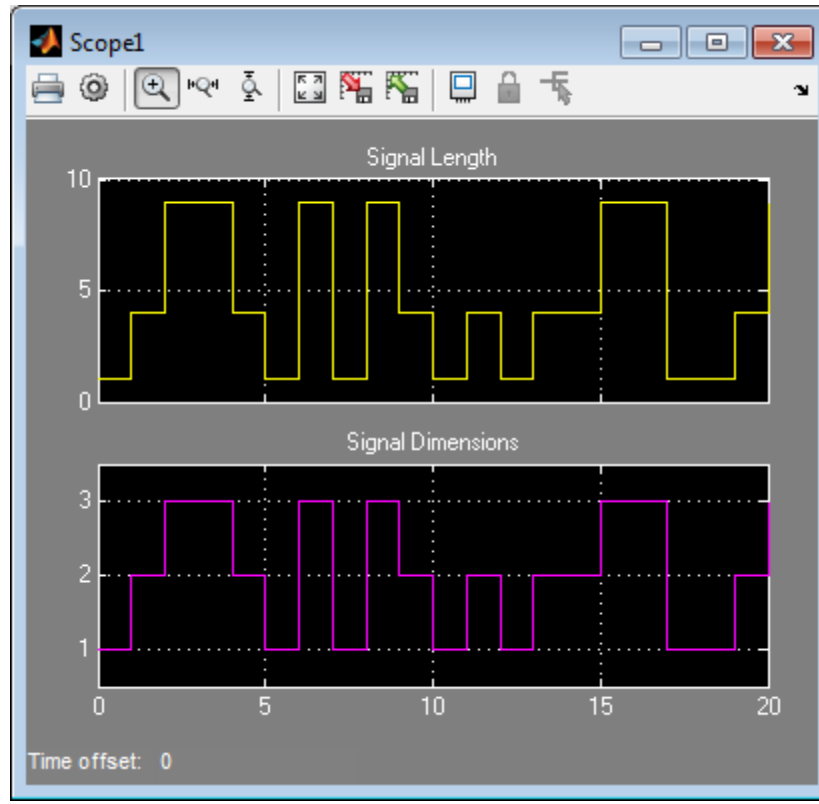


Visualizing Data

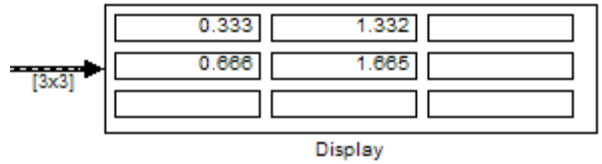
Use the Probe block to visualize signal size and signal dimension.



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

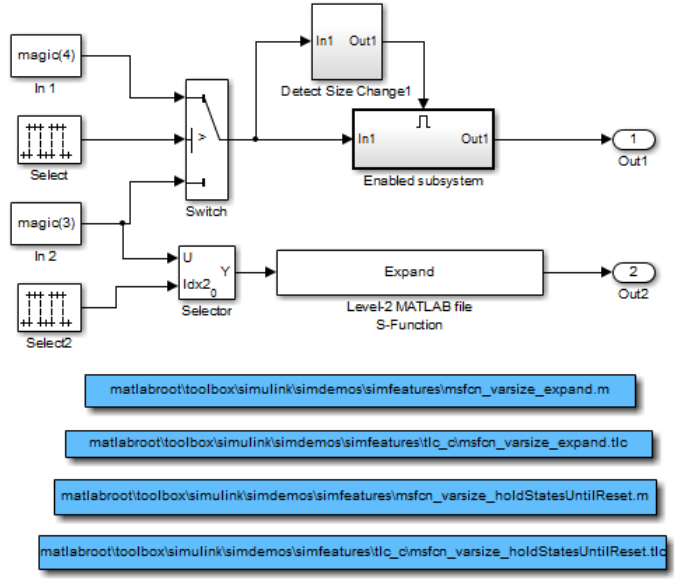
In this section...

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 example model, in the MATLAB Command Window, type:

```
msfcndemo_varsize
```



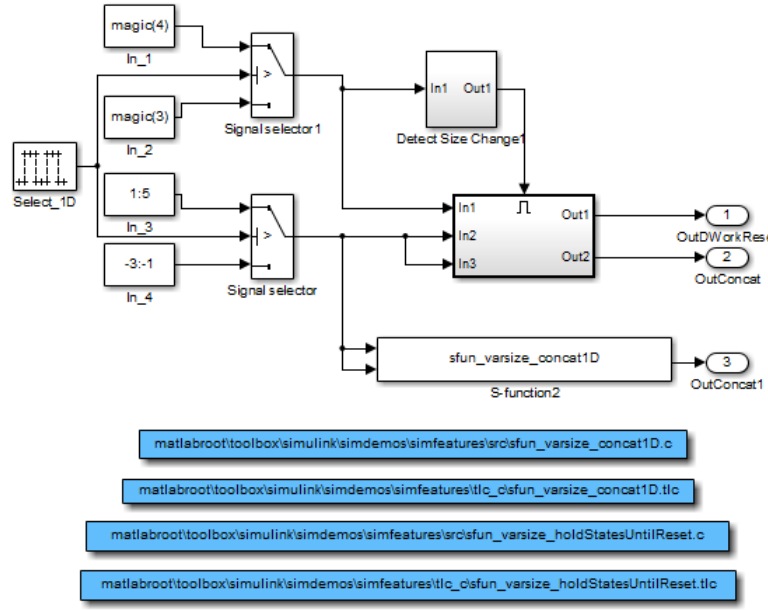
The Enabled subsystem includes a Level-2 MATLAB S-Function which shows how to implement a block that holds its states until reset. Because this block contains states and delays the input signal, the input size can change only when a reset occurs.

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.

C S-Function with Variable-Size Signals

To open this example 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:

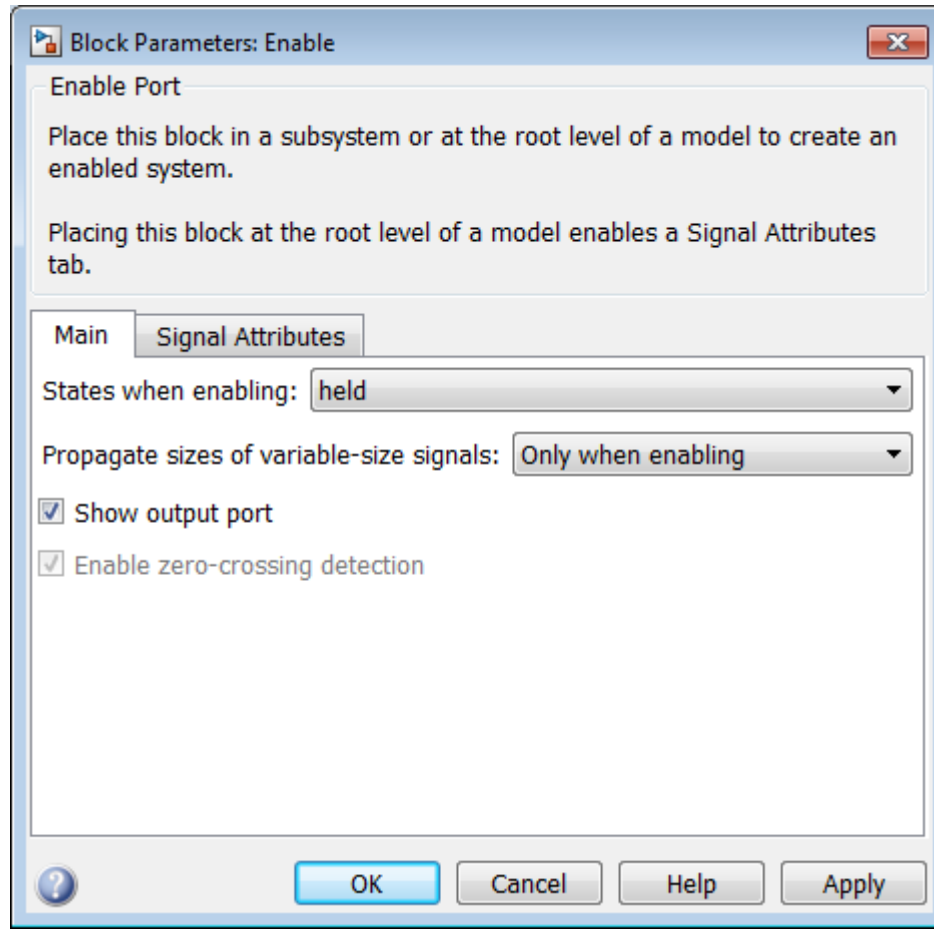
1. Open a Simulink model.
2. Select **Help > Simulink > Block Data Ty[es & Code Generation Support > Simulink**.

An `X` in the **Variable-Size Support** column indicates support for that block.

Tip You can also view the table by entering `showblockdatatypetable` at the command prompt.

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).

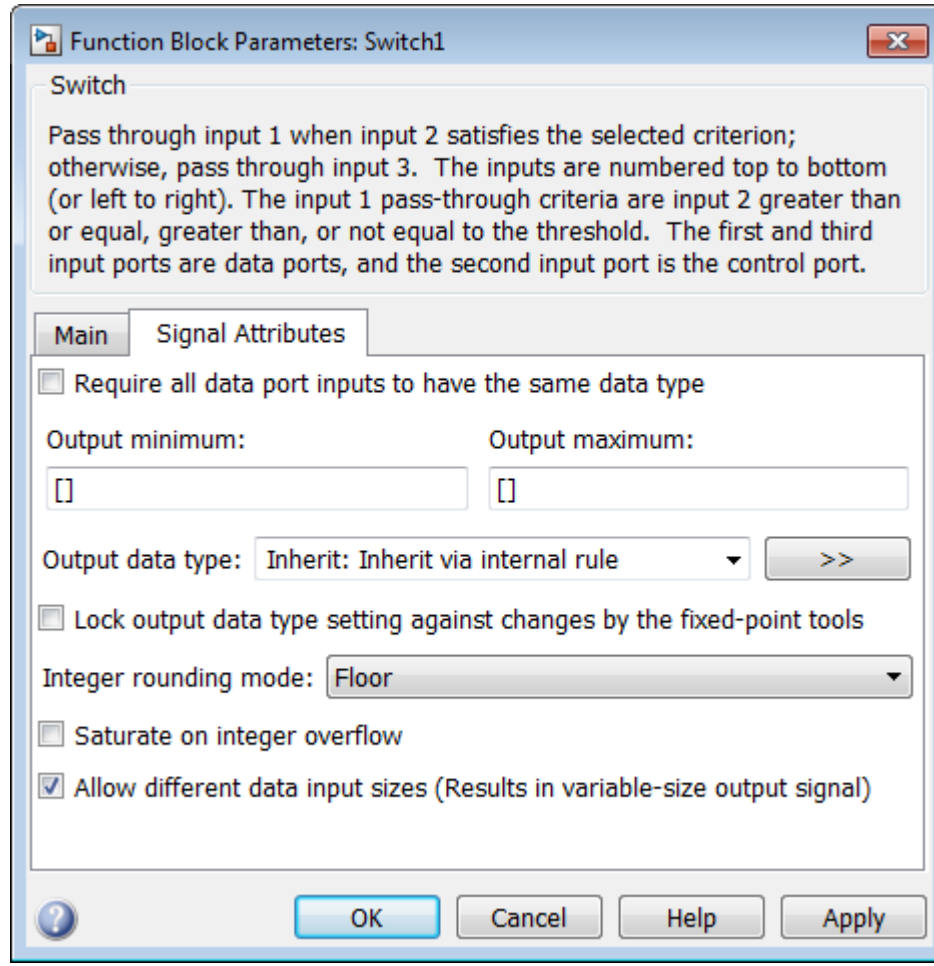


- Action Port
- Enable
- Trigger — **Trigger type** set to `function-call`

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 `Structure With Time` format for logging variable-size signals.
Right-click signal logging does not support variable-size signals.	Use a To Workspace block (with `Structure` or `Structure With Time` format) or a root Outport block for logging variable-size signals.
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 DSP System Toolbox 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`.	—
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.	—

Limitation	Workaround
Simulink does not support variable-size parameter or DWork vectors.	—
Rapid accelerator mode does not support models having root-level input ports with variable-size signals.	—

Customizing Simulink Environment and Printed Models

50

Customizing the Simulink User Interface

Add Items to Model Editor Menus

In this section...

About Adding Items

You can add commands and submenus to the following menu locations for the Simulink Editor and Stateflow Editor:

- The end of top-level menus
- The menu bar
- The beginning or end of a context menu

To add an item to an editor menu:

- For each item, create a function, called a *schema function*, that defines the item (see "Define Menu Items" on page 50-4).
- Register the menu customizations with the Simulink customization manager at startup, e.g., in an `sl_customization.m` file on the MATLAB path (see "Register Menu Customizations" on page 50-10).
- Create callback functions that implement the commands triggered by the items that you add to the menus.

Code for Adding Menu Items

The following `sl_customization.m` file adds four items to the Simulink 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
```

Define 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 50-4
- "Defining Custom Submenus" on page 50-8

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 50-11) and create and return an action schema object (see "Action Schema Object" on page 50-5) 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';
  schema.userdata = 'item1';
  %% 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`

Property 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.

- `autoDisableWhen`

  Property that controls when a menu item is automatically disabled.

Setting	When Menu Items Are Disabled
`'Locked'`	(default) When the active editor is locked or when the model is busy
`'Busy'`	Only if the model is busy
`'Never'`	Never

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`

  Specify whether the menu item displays a check mark. Valid values are `'unchecked'` (default) and `'checked'`

- `state`

  String that specifies the state of this toggle action. Valid values are `'Enabled'` (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.

- `autoDisableWhen`

  Property that controls when a menu item is automatically disabled.

Setting	When Menu Items Are Disabled
`'Locked'`	(default) When the active editor is locked or when the model is busy
`'Busy'`	Only if the model is busy
`'Never'`	Never

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 50-8) 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 50-4.

```
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.

- `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 "Define Menu Items" on page 50-4)

- 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 50-11) 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. The case is ignored for this entry (for example, `'SEPARATOR'` and `'Separator'` are both valid entries). A separator is also suppressed if it appears at the beginning or end of the submenu and separators that would appear successively are combined into a single separator (for example, as a result of an item being hidden).

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.

- `userdata`

  Data of any type that is passed to `generateFcn`.

- `autoDisableWhen`

  Property that controls when a menu item is automatically disabled.

Setting	When Menu Items Are Disabled
`'Locked'`	(default) When the active editor is locked or when the model is busy
`'Busy'`	Only if the model is busy
`'Never'`	Never

Register 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 50-27) 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 50-27). Each invocation should pass the tag of the menu (see "Menu Tags" on page 50-11) 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 50-10) . 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 cell array of schema functions that define custom items that you want to appear on the model editor menus (see "Define Menu Items" on page 50-4). The custom menu function returns a cell array similar to that returned by the `generateFcn` function.

Your custom menu function should accept a callback info object (see "Callback Info Object" on page 50-11) 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.

Menu Tags

A menu tag is a string that identifies a Simulink Editor or the Stateflow Editor menu bar or menu. You need to know a menu's tag to add custom items to it (see "Register Menu Customizations" on page 50-10). You can configure the editor to display all (see "Displaying Menu Tags" on page 50-13) but the following tags:

Tag	Add...
Simulink tags	
`Simulink:MenuBar`	Menu to Simulink Editor's menu bar
`Simulink:PreContextMenu`	Item to the beginning of Simulink Editor's context menu
`Simulink:PostContextMenu`	Item to the end of Simulink Editor's context menu
`Simulink:FileMenu`	Item near the end of the Simulink Editor's **File** menu, but before the **Exit MATLAB** item
`Simulink:EditMenu`	Item to the end of the Simulink Editor's **Edit** menu
`Simulink:ViewMenu`	Item to the end of the Simulink Editor's **View** menu
`Simulink:DisplayMenu`	Item to the end of the Simulink Editor's **Display** menu
`Simulink:DiagramMenu`	Item to the end of the Simulink Editor's **Diagram** menu
`Simulink:SimulationMenu`	Item to the end of the Simulink Editor's **Simulation** menu
`Simulink:AnalysisMenu`	Item to the end of the Simulink Editor's **Analysis** menu
`Simulink:CodeMenu`	Item to the end of the Simulink Editor's **Code** menu
`Simulink:ToolsMenu`	Item to the end of the Simulink Editor's **Tools** menu
`Simulink:HelpMenu`	Item to the end of Simulink Editor's **Help** menu
Stateflow tags	
`Stateflow:MenuBar`	Menu to Stateflow Editor's menu bar
`Stateflow:PreContextMenu`	Item to the beginning of Stateflow Editor's context menu.

Tag	Add...
`Stateflow:ContextMenu`	Items to the end of Stateflow Editor's context menu.
`Stateflow:FileMenu`	Item near the end of the Stateflow Editor's **File** menu, but before the **Exit MATLAB** item
`Stateflow:EditMenu`	Item to the end of Stateflow Editor's **Edit** menu
`Stateflow:ViewMenu`	Item to the end of the Stateflow Editor's **View** menu
`Stateflow:DisplayMenu`	Item to the end of the Stateflow Editor's **Display** menu
`Stateflow:ChartMenu`	Item to the end of the Stateflow Editor's **Chart** menu
`Stateflow:SimulationMenu`	Item to the end of the Stateflow Editor's **Simulation** menu
`Stateflow:AnalysisMenu`	Item to the end of the Stateflow Editor's **Analysis** menu
`Stateflow:CodeMenu`	Item to the end of the Stateflow Editor's **Code** menu
`Stateflow:ToolsMenu`	Item to the end of the Stateflow Editor's **Tools** menu
`Stateflow:HelpMenu`	Item to the end of the Stateflow Editor's **Help** menu

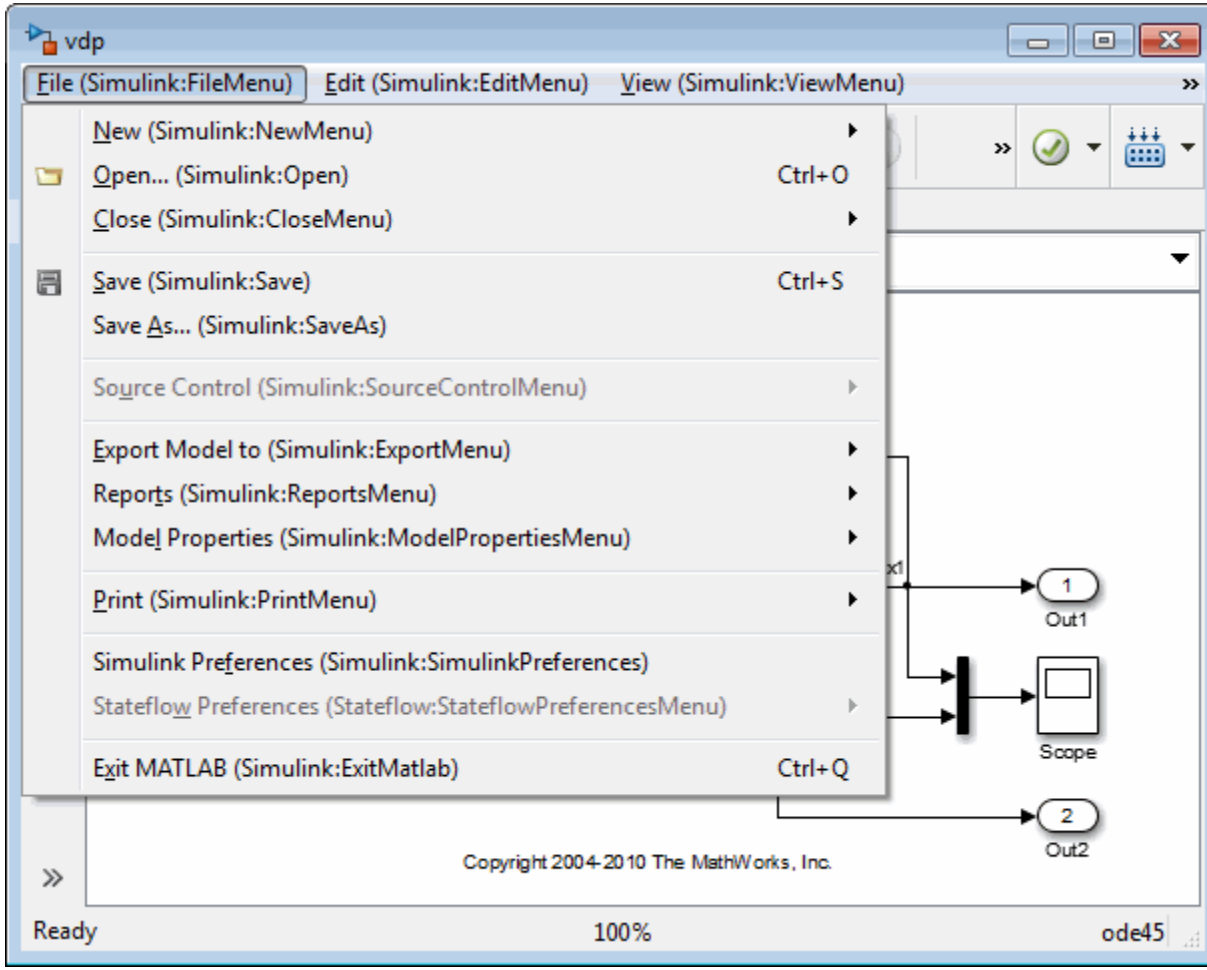
Displaying Menu Tags

You can configure the Simulink and Stateflow software 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. The `Simulink:TagName` customizations appear only if the current editor is the Simulink Editor. The `Stateflow:TagName` customizations appear only if the current editor is the Stateflow Editor.

To configure the editor to display menu tags, at the MATLAB command line, set the customization manager's `showWidgetIdAsToolTip` property to `true`. For example:

```
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.

Simulink and Stateflow Editor Menu Customization

Use the same general procedures to customize Stateflow Editor menus as you use for Simulink Editor. The addition of custom menu functions to the ends of top-level menus depends on the active editor:

- Menus bound to `Simulink:FileMenu` only appear when the Simulink Editor is active.
- Menus bound to `Stateflow:FileMenu` only appear when the Stateflow Editor is active.
- To have a menu to appear in both of the editors, call `addCustomMenuFcn` twice, once for each tag. Check that the code works in both editors.

Disable and Hide 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 50-16).
- Register the filter function with the customization manager (see "Registering a Filter Function" on page 50-17).

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 50-13) 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
```

Disable and Hide 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 50-21), 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 MATLAB 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 "Write Control Customization Callback Functions" on page 50-20) and registering the callback functions via an object called the customization manager (see "Register Control Customization Callback Functions" on page 50-22). 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:

Disable a Button on a Dialog Box

The following `sl_customization.m` file disables the **Build** button on the **Code Generation** 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 50-27).

3 Open the `sldemo_engine` model, for example, by entering the command `sldemo_engine` at the command line.

Write 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 **Code Generation** 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)`

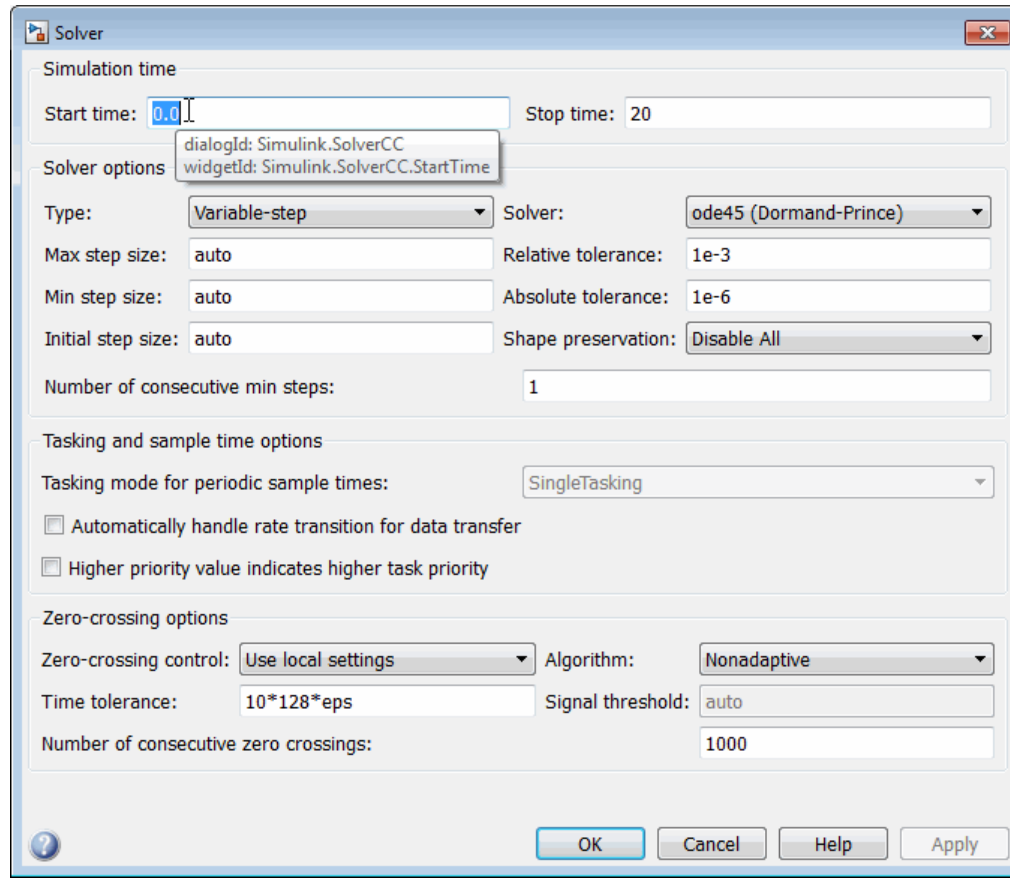
where `widgetIDs` is a cell array of widget identifiers (see "Dialog Box and Widget IDs" on page 50-21) that specify the widgets to be disabled or hidden.

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.

Register 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 50-27) 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 50-21) 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 **Code Generation** pane of the Configuration Parameters dialog box (see "Write Control Customization Callback Functions" on page 50-20).

```
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.

Customize the Library Browser

In this section...

Reorder 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 50-27) on the MATLAB path:

```
cm.LibraryBrowserCustomizer.applyOrder( {'LIBNAME1', PRIORITY1, ...
                                         'LIBNAME2, 'PRIORITY2, ...
                                          .
                                          .
                                         'LIBNAMEN', PRIORITYN} );
```

where `LIBNAMEn` is the name of the library or its model 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} );
```

Disable and Hide 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 50-27) 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'});
```

Customize the Library Browser Menu

You can perform the same kinds of customizations to the Library Browser 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 50-27). 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.

- "Add Items to Model Editor Menus" on page 50-2
- "Disable and Hide Model Editor Menu Items" on page 50-16
- "Disable and Hide Dialog Box Controls" on page 50-18

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 50-13 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 "Add Items to Model Editor Menus" on page 50-2 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 50-13 for more information) . The `filterFcn` argument is a pointer to a function that hides or disables the specified menu item. See "Disable and Hide Model Editor Menu Items" on page 50-16 for more information.

51

PrintFrame Editor

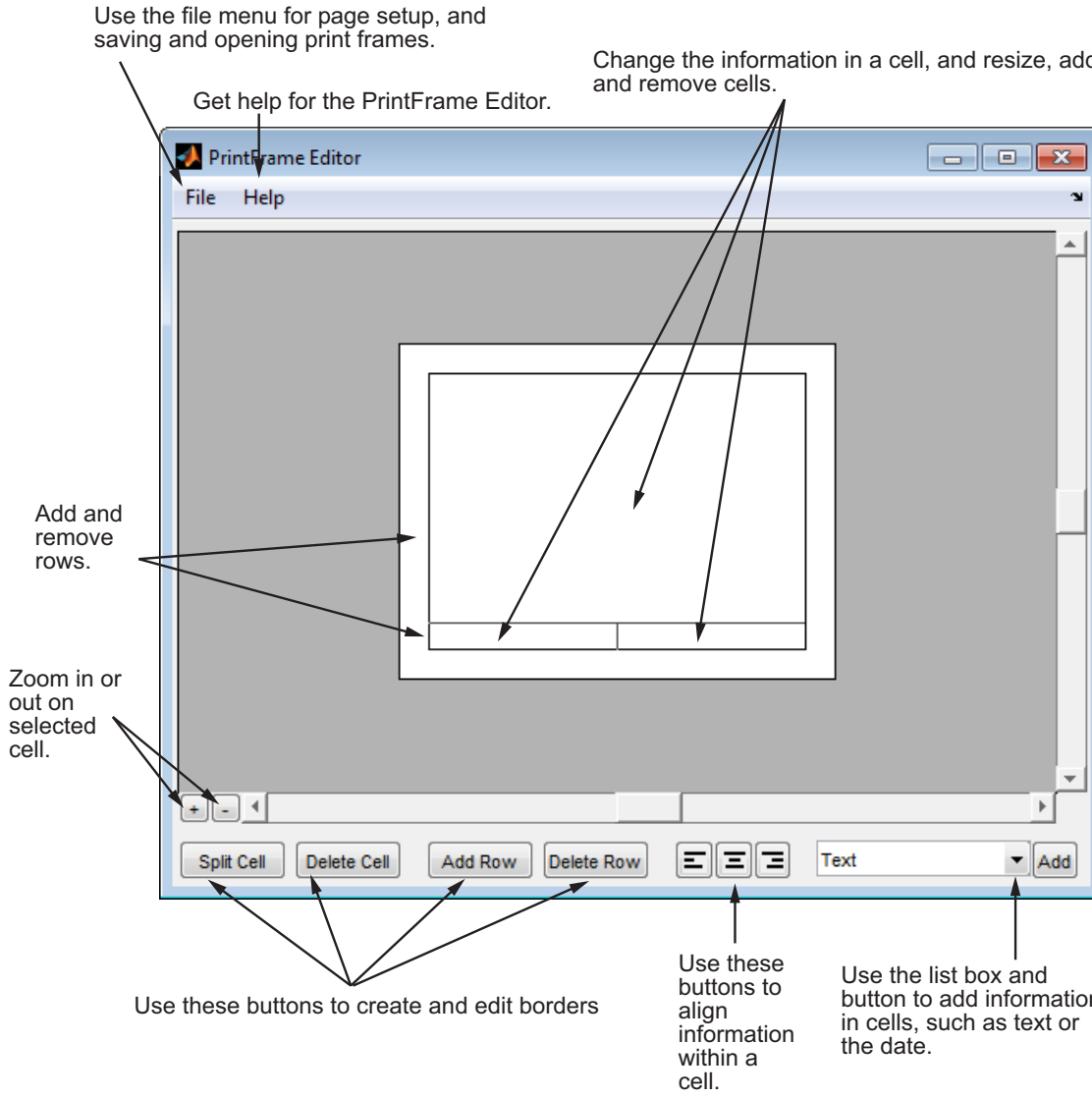
PrintFrame Editor Overview

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.

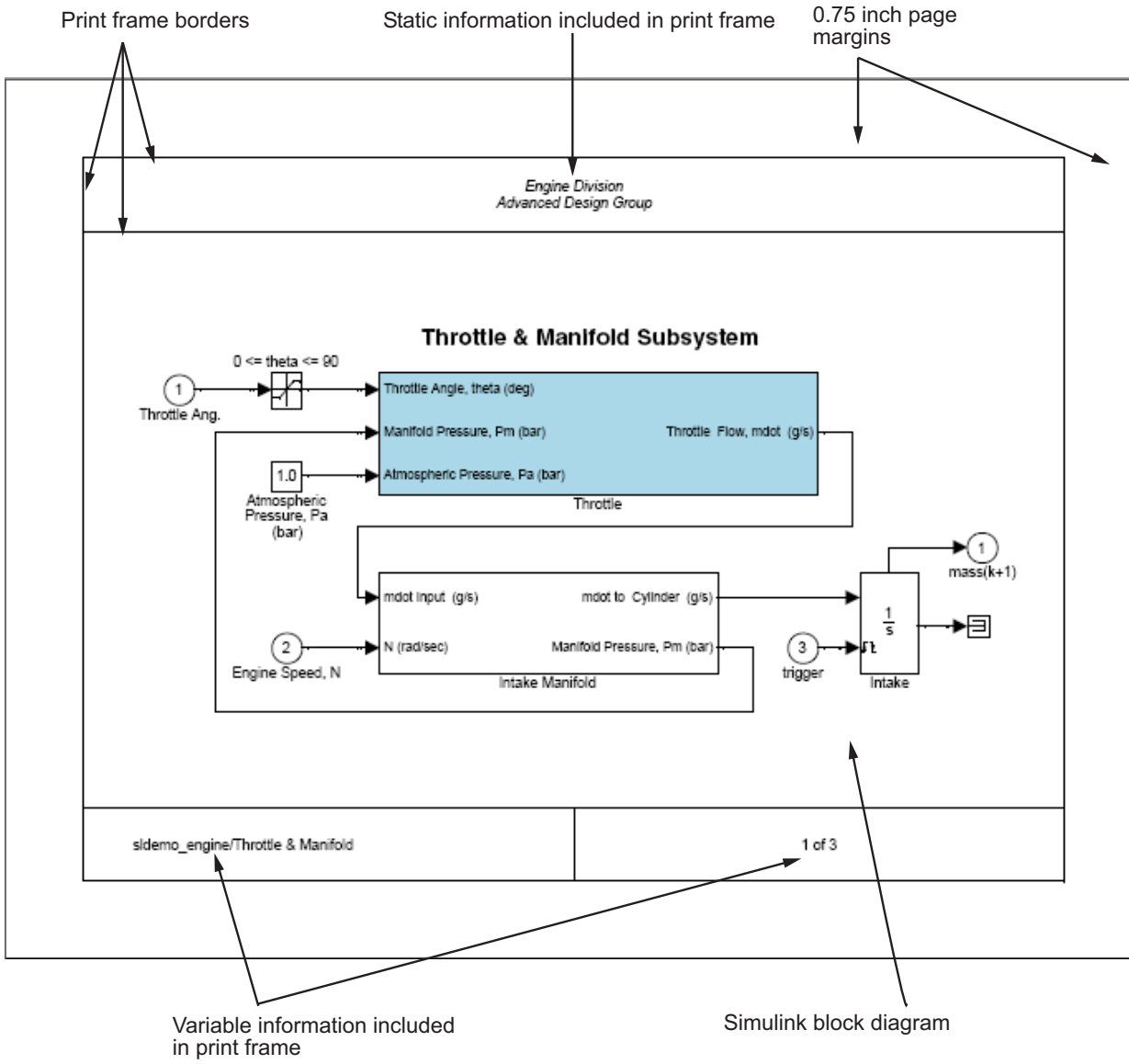


What PrintFrames Are

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 "Create and Use a Print Frame" on page 51-26 for specific instructions to create this print frame.

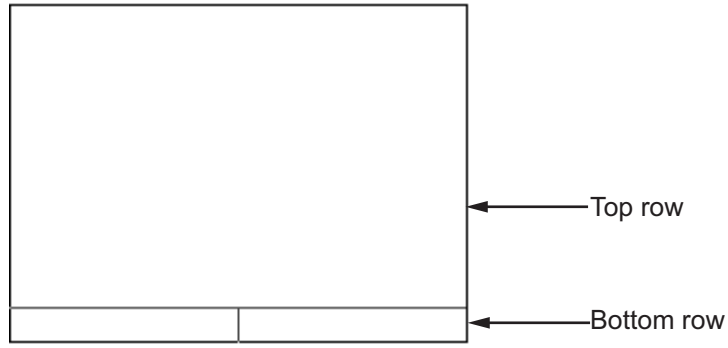
Start the PrintFrame Editor

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 file name, 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.

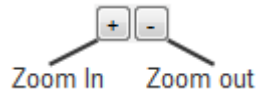
Zooming In and Out

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.

Help for the PrintFrame Editor

Select **PrintFrame Editor Help** from the **Help** menu in the PrintFrame Editor window to access this online help.

Close 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:

- “Design the Print Frame” on page 51-8
- “Specify the Print Frame Page Setup” on page 51-9
- “Create Borders (Rows and Cells)” on page 51-11
- “Add Information to Cells” on page 51-14
- “Change Information in Cells” on page 51-18
- “Save and Open Print Frames” on page 51-22
- “Print Block Diagrams with Print Frames” on page 51-23

See also the “Create and Use a Print Frame” on page 51-26.

Design 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.

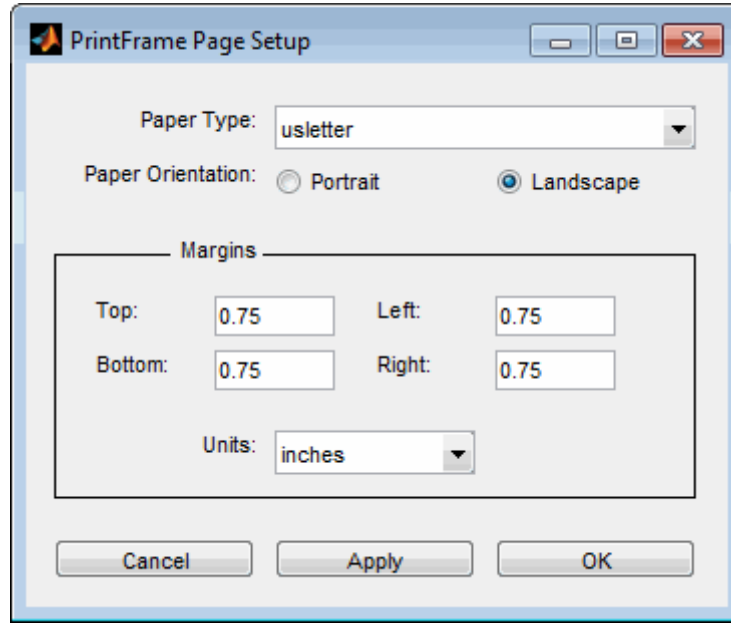
Specify the Print Frame Page Setup

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.

Create 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.

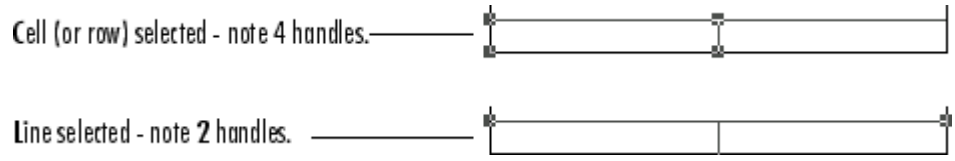
Important Always specify the PrintFrame page setup before creating borders and adding information (see "Specify the Print Frame Page Setup" on page 51-9). Otherwise, you might have to correct the borders and placement of the information. For example, if you add information to cells and then change the paper orientation from landscape to portrait, the information you added might not fit in the cells, given the new orientation.

Add and Remove 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.

Add and Remove 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.

Resize 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 “Specify the Print Frame Page Setup” on page 51-9.

Add Information to Cells

In this section...

Adding Information to Cells

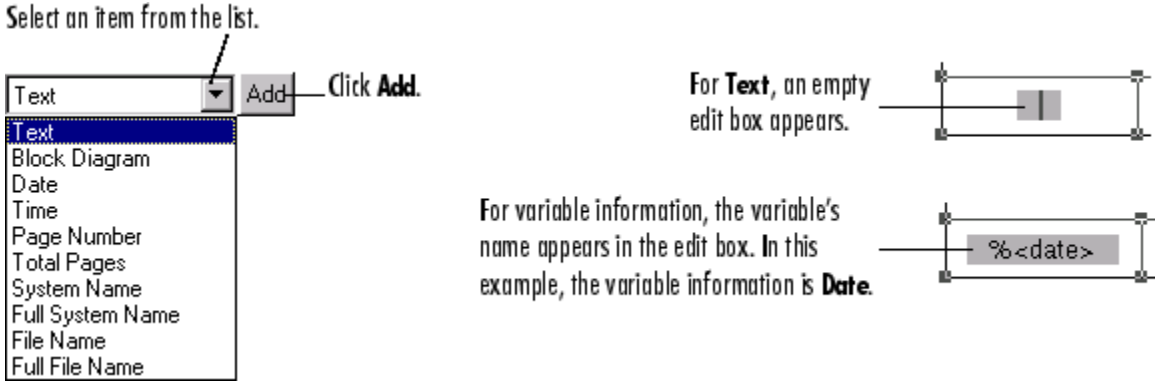
Use the following steps to add information to cells.

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 file name of the block diagram, for example, `sldemo_engine.mdl`.
- **Full File Name** — The full path and file name for the block diagram, for example, `\\matlab\toolbox\simulink\simdemos\automotive\sldemo_engine.mdl`.

Note: Adding the system name or file name does not mean that you can then specify a file name 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 file name 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.

Change Information in Cells

In this section...

Align 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.

Edit 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.

Remove and Copy 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.

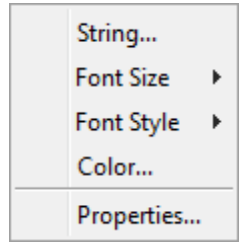
5 Click somewhere outside of the edit box to end editing mode.

Change 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.

Save and Open Print Frames

In this section...

Save 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.

Open 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.

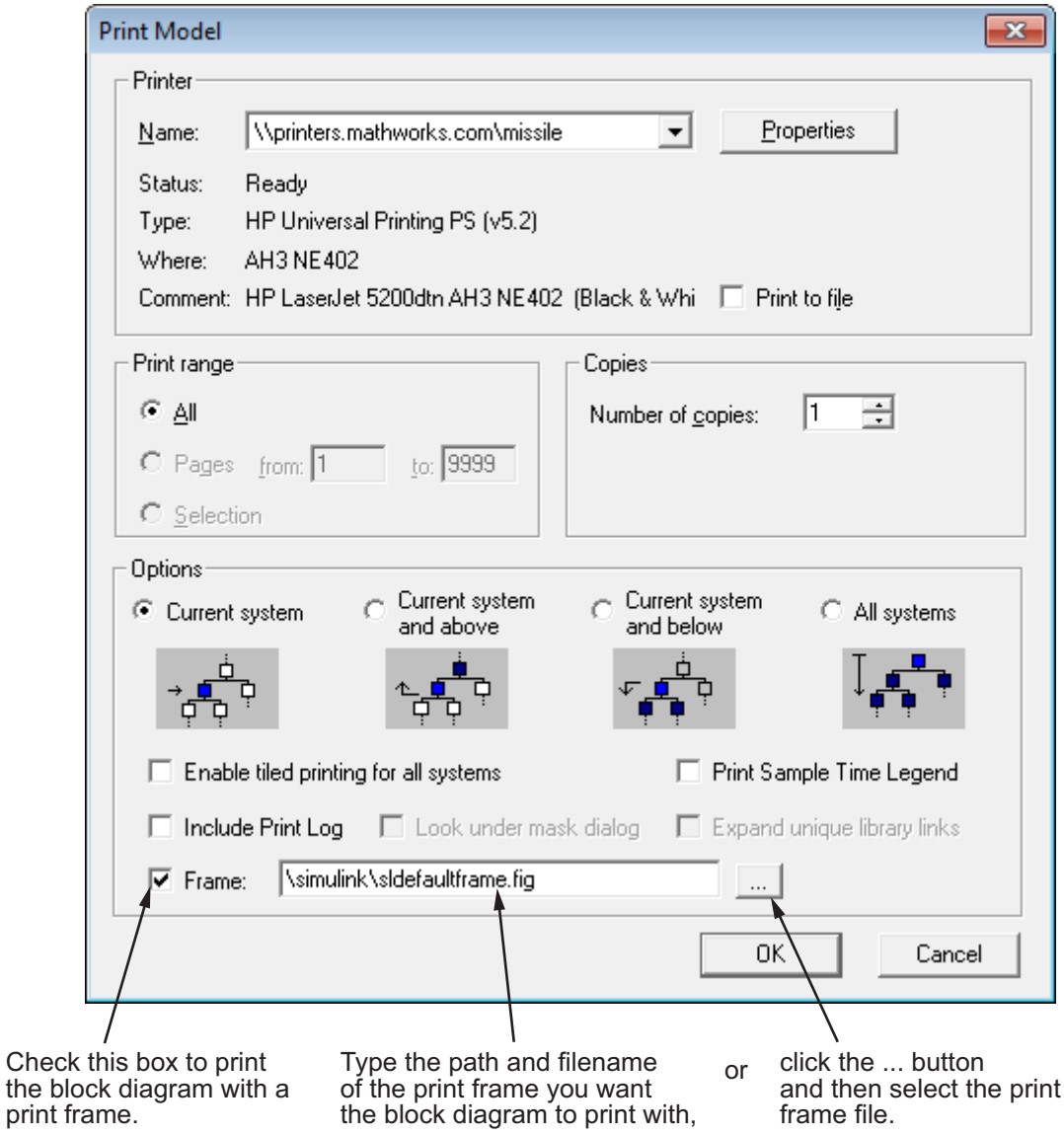
Alternatively, you can open a print frame from the MATLAB prompt. Type `frameedit filename` and the PrintFrame Editor opens with the print frame file you specified.

Print 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 **File > Print > Print**.

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.



In the **Print Model** dialog box:

1 Select the **Frame** check box.

2. Supply the file name for the print frame you want to use. Either type the path and file name 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 file name, `sldefaultframe.fig`, appears in the file name edit box until you specify a different file name.

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.

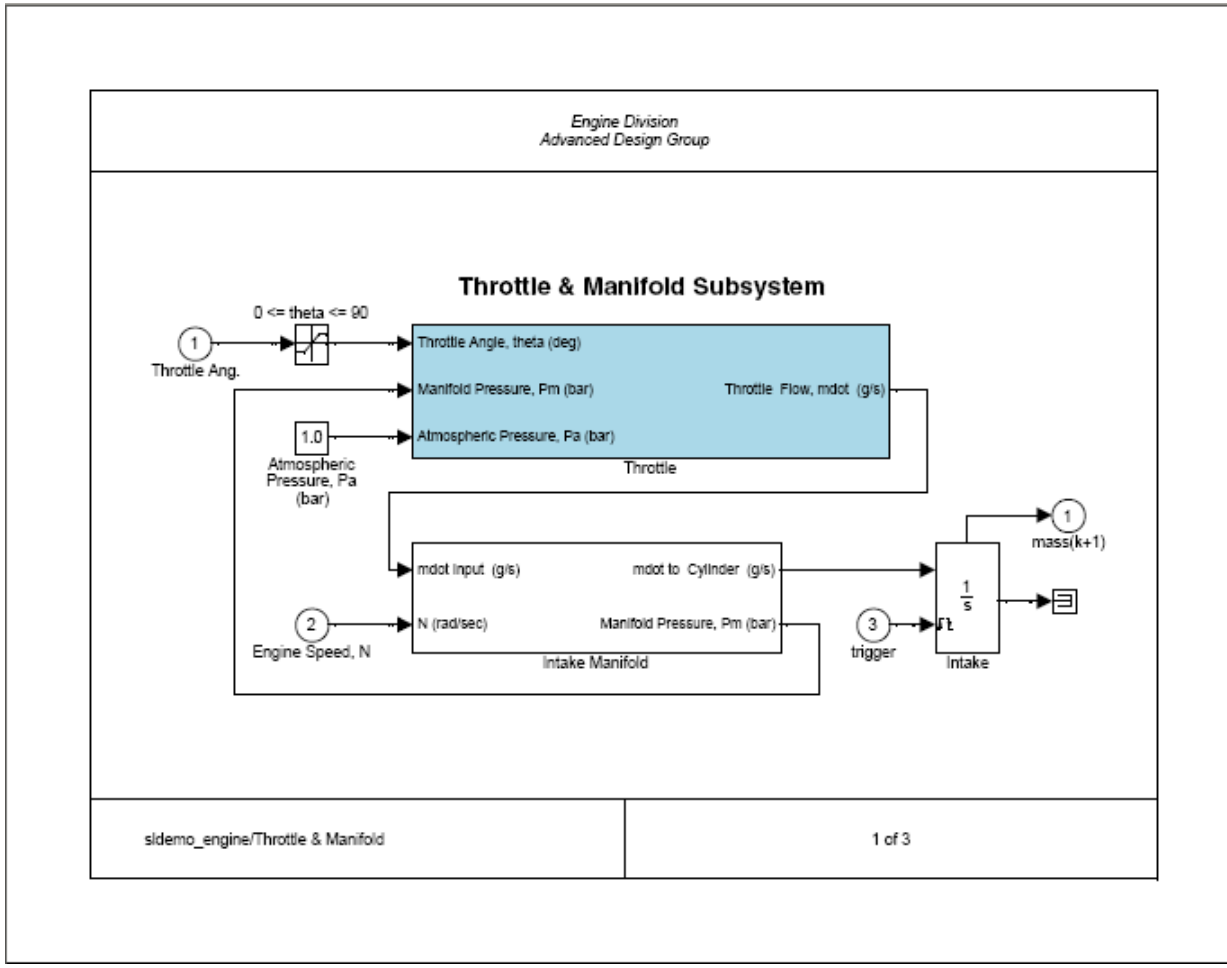
See also the example, "Print the Block Diagram with the Print Frame" on page 51-30.

Create and Use a Print Frame

In this section...

About the Example

This example uses a Simulink model of an engine. 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.

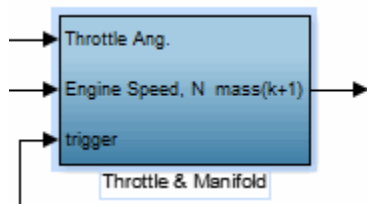
11 You can close the **PrintFrame Editor** window by clicking the close box.

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.

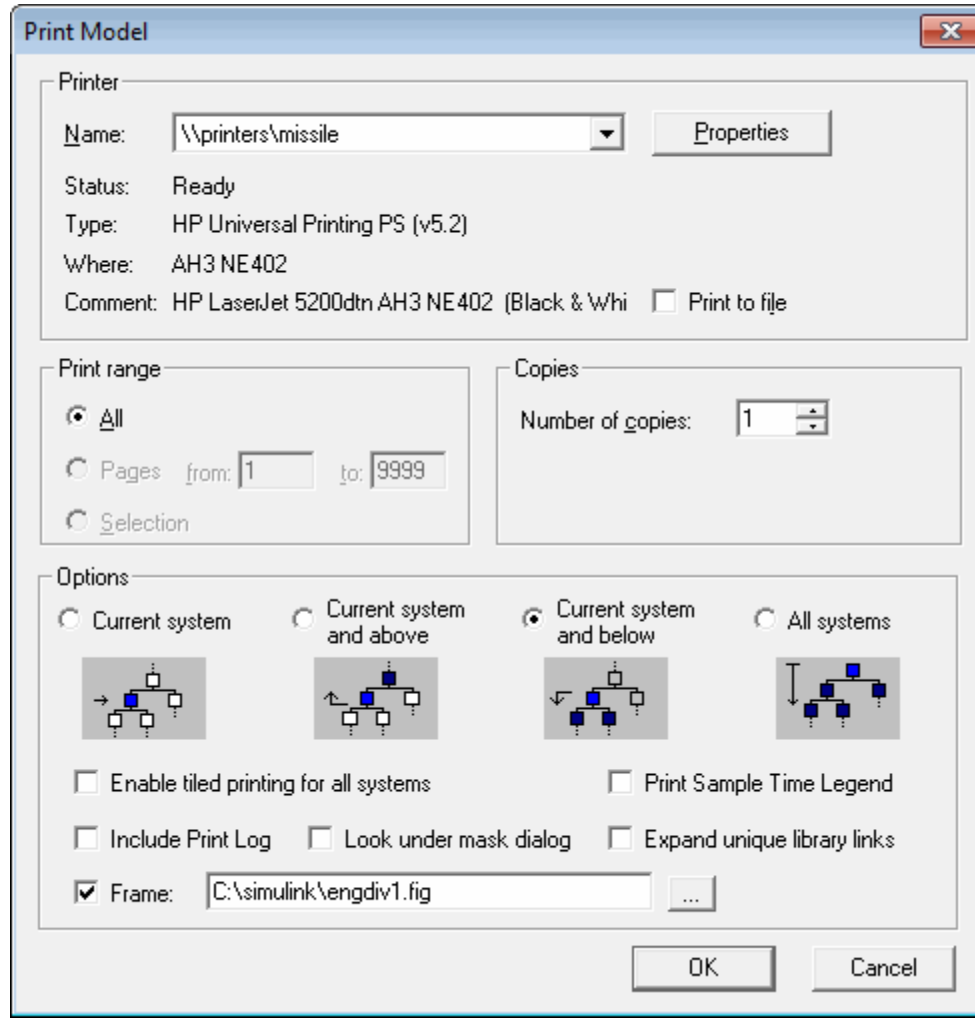
2 Double-click the Throttle & Manifold block.



The Throttle & Manifold subsystem opens in a new window.

3 In the **Throttle & Manifold** window, select **File > Print > Print**.

The **Print Model** dialog box opens.



4 Click the Properties button, and set the page orientation to landscape.

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 file name of the print frame you just created, `engdivl.fig`, and select it.

c Click the **Open** button.

The path and file name 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.

Running Models on Target Hardware

About Run on Target Hardware Feature

About Run on Target Hardware Feature

Run on Target Hardware is a feature of the Simulink product that runs a Simulink model on *target hardware*.

At the time of publication, Simulink software supports the following target hardware:

- Arduino Mega 2560 and Arduino Uno
- BeagleBoard Xm, BeagleBoard Bx, and BeagleBoard Cx
- LEGO™ MINDSTORMS® NXT
- PandaBoard

To use this feature, open a Simulink model, and select **Tools > Run on Target Hardware**.

To start using Run on Target Hardware, first use the *Target Installer* to install support for your target hardware. The Target Installer guides you through the process of getting a *support package*, installing a *target*, and in some cases, replacing the firmware on your target hardware. To use Target Installer, open a Simulink model, and select **Tools > Run on Target Hardware > Install/Update Support Package**.

You can have the Target Installer download a support package from MathWorks.com, or use a support package in a local folder. The Target Installer uses the support package to install a *target*, which provides the software tools and features required for a specific type of target hardware, including:

- A Simulink block library
- A pane in the Configuration Parameters dialog
- Third-party software
- Examples

For detailed information about using the Target Installer with your hardware, see:

- "Install Support for Arduino Hardware" on page 53-2
- "Install Support for BeagleBoard Hardware" on page 54-2
- "Install Support for LEGO MINDSTORMS NXT Hardware" on page 55-2
- "Install Support for PandaBoard Hardware" on page 56-2

After installing the appropriate target, you can run a model on your target hardware using the following menu items under **Tools > Run on Target Hardware**:

- **Prepare to Run** — Before using this menu item, create a backup copy of your model. Clicking **Prepare to Run** changes the model Configuration Parameters and opens the Run on Target Hardware pane in the Configuration Parameters dialog. In the Run on Target Hardware pane, set the **Target hardware** parameter, and then save the changes to your model.
- **Run** — This menu item appears after you have prepared the model to run. Clicking **Run** creates an executable file from the model and runs it on the target hardware.
- **Options** — This menu item opens the Run on Target Hardware pane in the model Configuration Parameters dialog. You can use this pane to specify the target hardware and configure optional settings, such as External mode.

Work with Arduino Hardware

Install Support for Arduino Hardware

This topic shows how to add support for Arduino® hardware to the Simulink product. After you complete this process, you can run Simulink models on your Arduino hardware.

The installation process adds the following items to your host computer:

- Third-party software development tools, such as the Arduino software
- A Simulink block library for configuring and accessing Arduino sensors, actuators, and communication interfaces
- Examples for getting started and learning about specific features

To check for updates, repeat this process when a new version of MATLAB software is released. You can also check for updates between releases.

Note You can use this software on host computers running versions of 32-bit or 64-bit Windows that Simulink software supports.

To install support for Arduino hardware:

1. Start Target Installer using one of the following methods:

   - In a MATLAB Command Window, enter `targetinstaller`.
   - In a model, click the **Tools** menu, and select **Run on Target Hardware** > **Install/Update Support Package**.

2. Choose to get the support package from the Internet or from a folder.

Note The time required to downloading the support package and third-party software varies depending on the bandwidth and speed of your Internet connection.

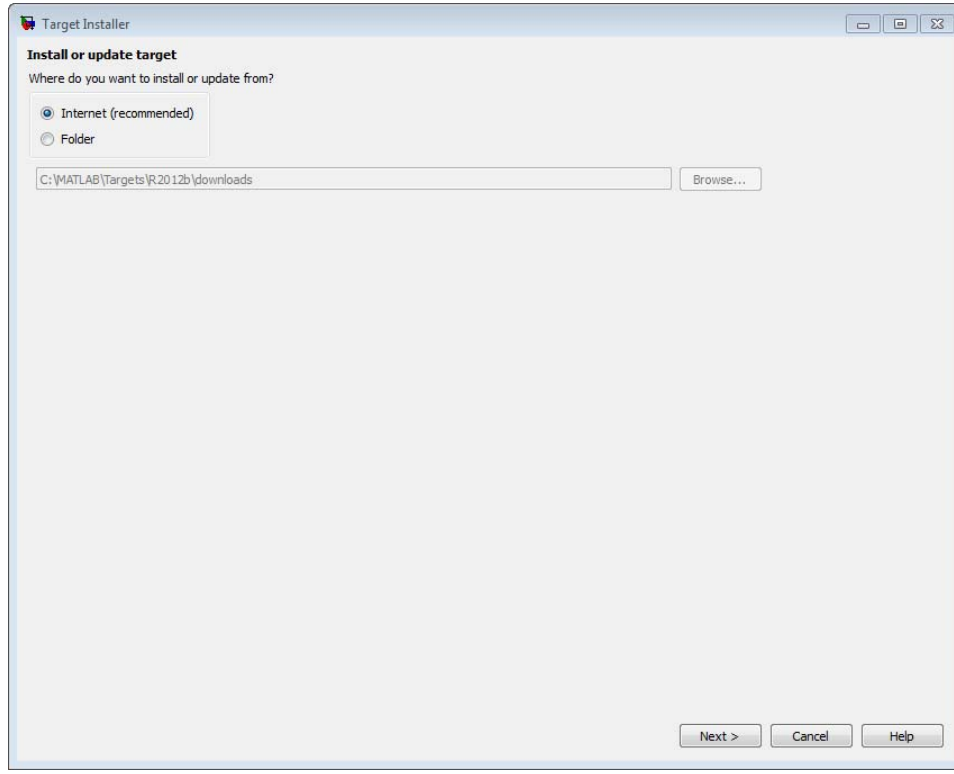
Internet: This option is selected by default. Target Installer downloads and installs the support package and third-party software from the Internet.

Folder: Target Installer gets the support package and third-party software installers from the specified folder. If the third-party software installers are not available, Target Installer downloads and installs those from the Internet.

You must have write privileges for this folder. Having write privileges for the default folder is typically not an issue. If you change to a new folder for which you do not have write permissions, such as a shared folder on a network, Target Installer generates an error message.

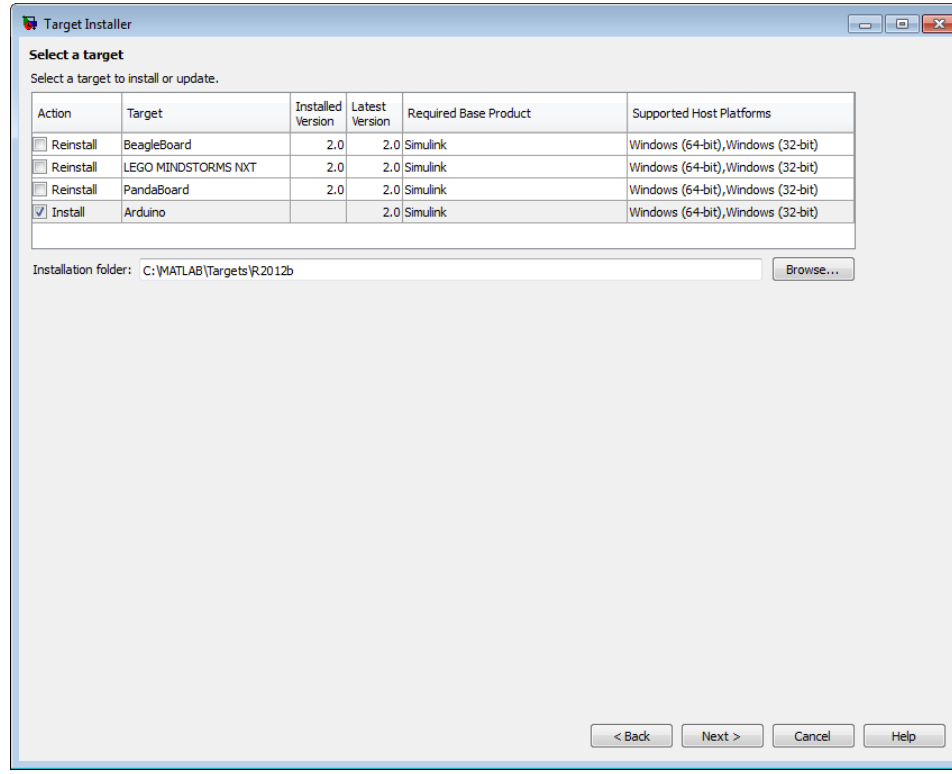
To solve this issue, copy the support package to a folder for which you have write privileges, and point Target Installer to that same folder. For example, copy the support package to `C:\MATLAB\Targets\`*`version`*`\downloads`. If they are available, also copy the third-party software installers associated with the support package.

To locate the support package in a folder, search for a filename that begins with `arduino` and ends with `.zip`. For example: `arduinouno_r2012a_v1_0.zip`



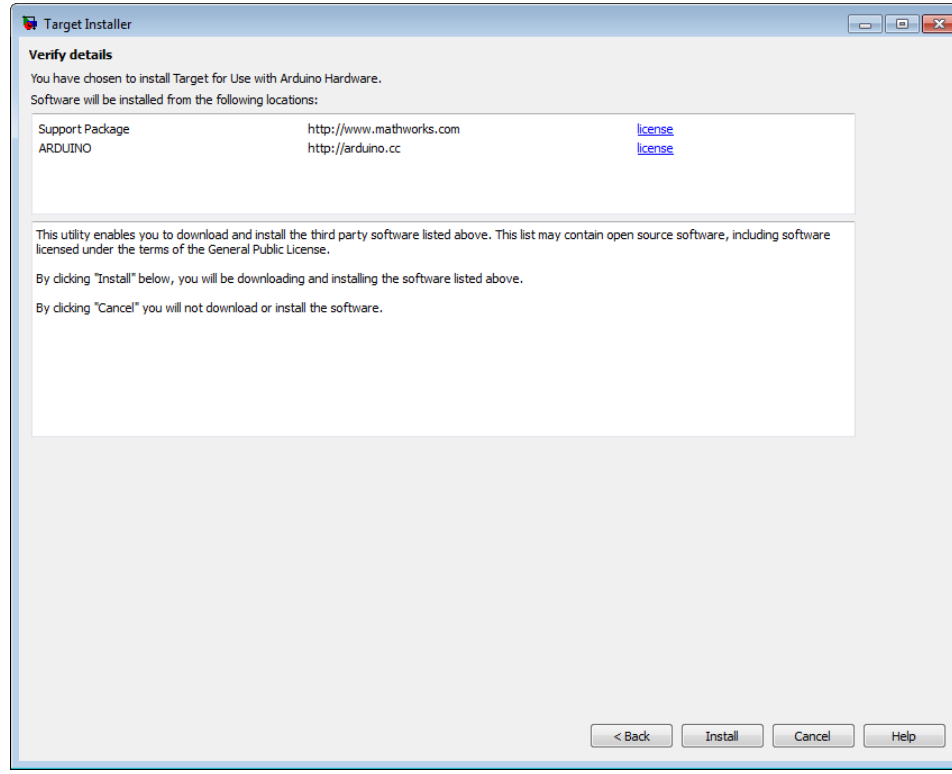
3 Select the **Install** check box for either Arduino target, and click **Next**. (To install another target, run Target Installer again later on.)

The **Installation folder** parameter specifies where Target Installer puts the target files. You must have write privileges for this folder.

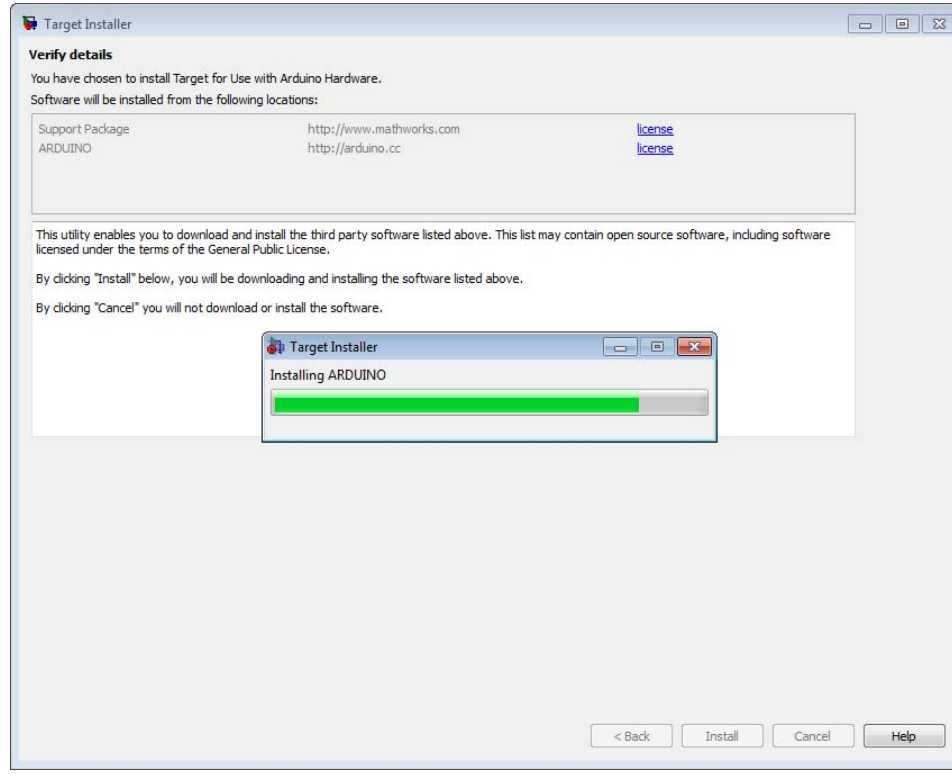


4 Target Installer confirms that you are installing the target, and lists third-party software it will install.

Review the information, including the license agreements, and click **Install**.

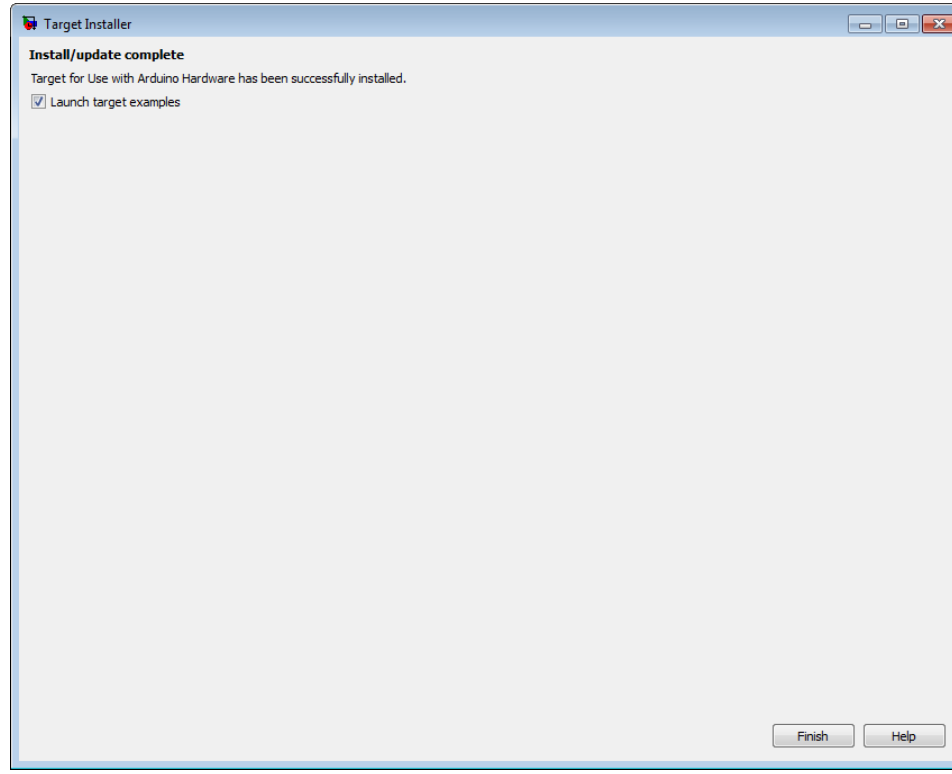


Target Installer displays a progress bar while it downloads and installs the third-party software.



Note If you installed the target previously, Target Installer may remove files from that installation before installing the current target. If Target Installer cannot remove those files automatically, it instructs you to delete the files manually. Close the MATLAB software before removing the files. Then, restart MATLAB software and run Target Installer again.

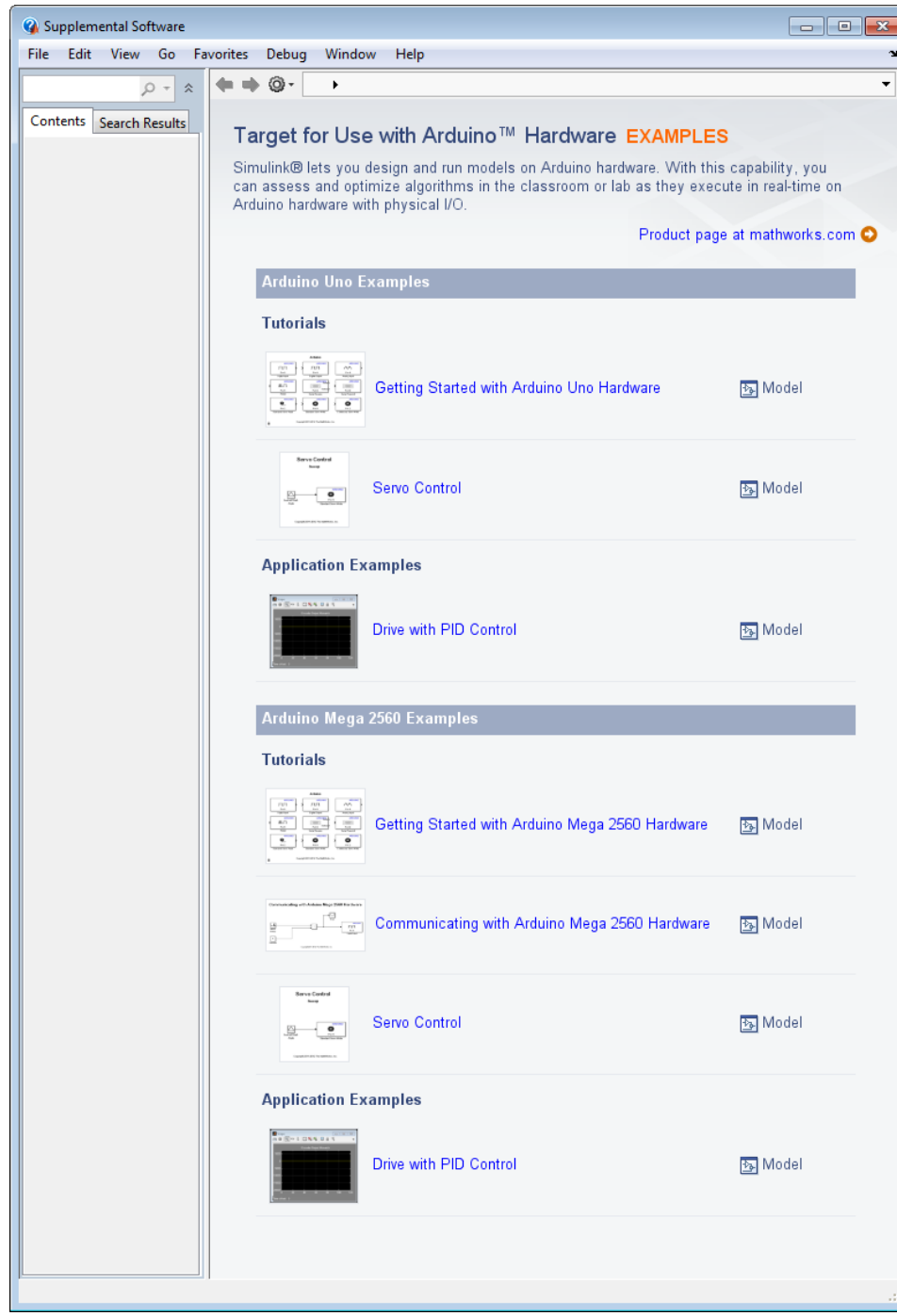
5 To view target examples, leave the **Launch target examples** checkbox selected and click **Finish**.



The Help that opens displays the appropriate examples for your hardware.

Note To reopen the examples later, enter the following text in a MATLAB Command Window:

```
demo simulink 'Target for Use with Arduino'
```


Supplemental Software
File Edit View Go Favorites Debug Window Help
Contents
Search Results
Target for Use with Arduino™ Hardware EXAMPLES
Simulink® lets you design and run models on Arduino hardware. With this capability, you can assess and optimize algorithms in the classroom or lab as they execute in real-time on Arduino hardware with physical I/O.
Product page at mathworks.com
Arduino Uno Examples
Tutorials
Getting Started with Arduino Uno Hardware
Model
Servo Control
Model
Application Examples
Drive with PID Control
Model
Arduino Mega 2560 Examples
Tutorials
Getting Started with Arduino Mega 2560 Hardware
Model
Communicating with Arduino Mega 2560 Hardware
Model
Servo Control
Model
Application Examples
Drive with PID Control
Model

Open Block Libraries for Arduino Hardware

You can open the block libraries for your Arduino hardware from the MATLAB Command Window or from the Simulink Library Browser.

The blocks in these block libraries provide support for various peripherals available on the Arduino hardware.

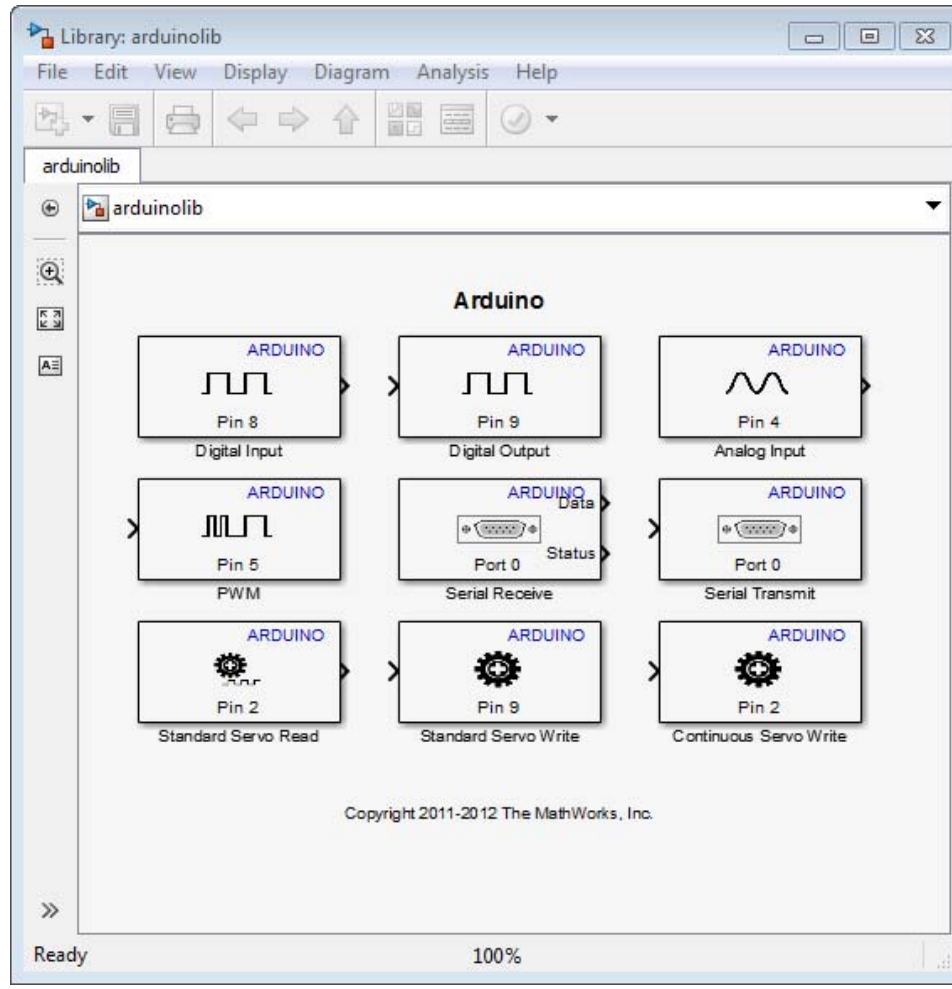
From the Command Line

After installing support for your Arduino hardware, you can open its block library from the MATLAB Command Window.

After installing support for Arduino hardware, enter:

```
arduinolib
```

The software opens the corresponding block library.



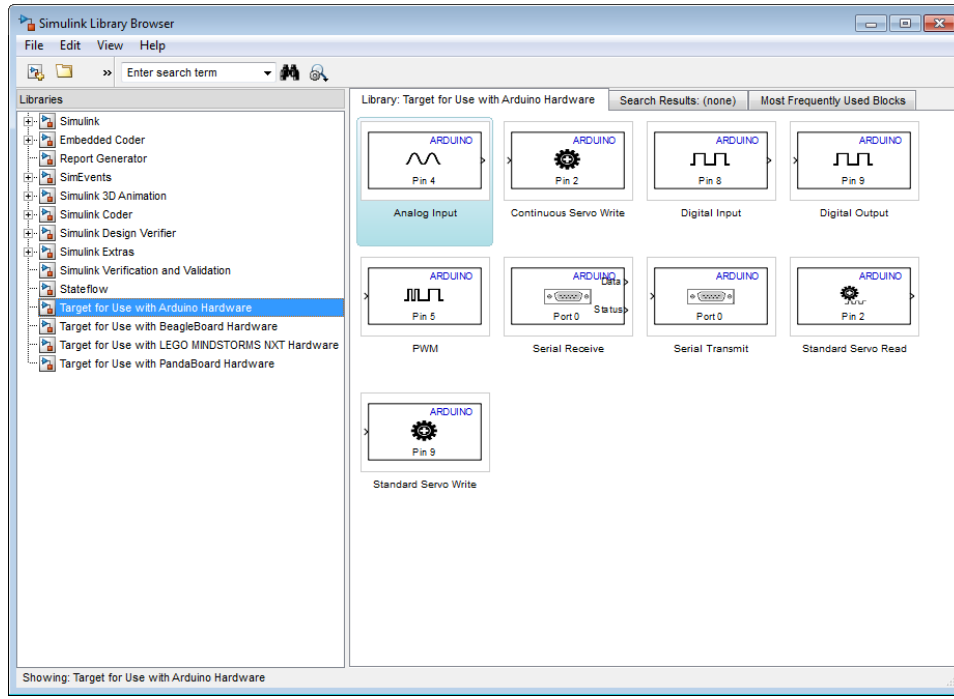
From the Simulink Library Browser

To open the block library from the Simulink Library Browser:

Enter `simulink` in the MATLAB Command Window, or click the following icon on the MATLAB toolbar.

In the Simulink Library Browser, click **Target for Use with Arduino Hardware**.

Simulink Library Browser displays the corresponding block library.



Run Model on Arduino Hardware

You can prepare, configure, and run a model on your Arduino hardware.

Before starting:

- Connect your Arduino hardware to the host computer using a USB cable.
- Create or open a Simulink model located on a local drive or a mapped network drive that has a drive letter assigned to it.

  The software generates an error message if the location of the model contains a UNC path. For example, `\\server-00\user$\MATLAB\`

To prepare and run the model:

1. Use **File > Save As** to create a working copy of your model. Keep the original model as a backup copy.
2. Click the **Tools** menu in the model, and select **Run on Target Hardware > Prepare to Run**. This action changes the model Configuration Parameters.
3. In the Run on Target Hardware pane that opens, set the **Target hardware** parameter to `Arduino Mega 2560` or `Arduino Uno`.
4. If your model contains one or more Model blocks, configure the submodels as described in “Prepare Models That Use Model Reference” on page 53-14.
5. Click the **Tools** menu, and select **Run on Target Hardware > Run**. This action automatically downloads and runs your model on the Arduino hardware.

   The lower left corner of the model window displays status while Simulink software prepares, downloads, and runs the model on the target hardware.

   To stop a model running on Arduino hardware, you can:

   - Disconnect the power from the hardware. When you reconnect the power, the model will start running again.
   - Run a new or updated model on the hardware. This action automatically stops and erases the previous model running on the Arduino hardware.

To restart the model running on the Arduino hardware, press the RESET button on the board.

Prepare Models That Use Model Reference

You can use Model blocks to include one model in another. Each instance of a Model block represents a reference to another model, called a *referenced model* or *submodel*. The model that contains a referenced model is its *parent model*. When you run the parent model on your target hardware, the submodel effectively replaces the Model block that references it. For more information, see "Overview of Model Referencing" on page 6-2

When you run a model on target hardware, the parent model and the submodels must have the same Configuration Parameter settings.

If your model contains Model blocks, perform the following steps for each Model block:

1. Open the model associated with the Model block.
2. Click the **Tools** menu, and select **Run on Target Hardware** > **Prepare to Run**.
3. Apply the same Configuration Parameters settings to the submodel as you applied to the parent model.

If the model and Model blocks have different settings, the software generates an error when you try to run the model on the target hardware.

See Also

- "Create the Simple Model"
- "Troubleshoot Running Models on Arduino Hardware" on page 53-24
- "Configure Host COM Port Manually" on page 53-26
- "Tune and Monitor Models Running on Arduino Mega 2560 Hardware" on page 53-15
- "Overview of Model Referencing" on page 6-2

Tune and Monitor Models Running on Arduino Mega 2560 Hardware

In this section...

About External Mode

You can use External mode to tune parameters in, and monitor data from, your model while it is running on the Arduino Mega 2560 hardware. This capability is not available with Arduino Uno hardware.

External mode enables you to tune model parameters and evaluate the effects of different parameter values on the model results in real-time, in order to find the optimal values to achieve the desired performance. This process is called *parameter tuning*.

External mode accelerates parameter tuning because you do not have to re-run the model each time you change parameters. External mode also lets you develop and validate your model using the actual data and hardware for which it is designed. This software-hardware interaction is not available solely by simulating a model.

The following list provides an overview of the parameter tuning process with External mode:

- In the model on your host computer, you enable External mode in the Configuration Parameters.
- In the model on your host computer, you configure Simulink software to run your model on the target hardware.
- You use the model on the host computer as a user interface for interacting with the model running on the target hardware:

  - When you open blocks and apply new parameter values on the host computer, External mode updates the corresponding values in the model running on the target hardware.
  - If your model contains blocks for viewing data, such as Scope or Display blocks, External mode sends the corresponding data from the target hardware to those blocks on the host computer.
- You determine the optimal parameter settings by adjusting parameter values on the host computer and observing data/outputs from the target hardware.

When you have finished tuning a model, you can disable External mode and run the tuned model on your hardware.

Some limitations apply while you are using External mode:

- Do not configure Serial Receive or Serial Transmit blocks in your model to use serial port 0. External mode uses serial port 0.
- Do not use the following Arduino® servo blocks: Standard Servo Read, Standard Servo Write, and Continuous Servo Write.

Run Your Model in External Mode

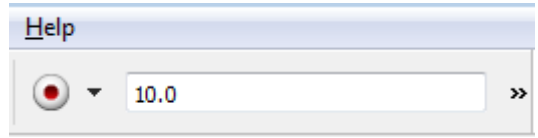
Before starting:

- Connect your Arduino Mega 2560 hardware to the host computer using a USB cable.
- Create or open a Simulink model located on a local drive or a mapped network drive that has a drive letter assigned to it.

  The software generates an error message if the location of the model contains a UNC path. For example, `\\server-OO\user$\MATLAB\`

To prepare and run the model:

1. Open your Simulink model.
2. Review the value of the **Simulation stop time** parameter, located on the model toolbar, as shown here.



- To run the model for an indefinite period, enter `inf`.
- To run the model for a finite period, enter a number of seconds. For example, entering `120` runs the model on the Arduino hardware for 2 minutes.

3 Click the **Tools** menu, and select **Run on Target Hardware** > **Options**.

4 In the Run on Target Hardware pane that opens, select the **Enable External mode** checkbox.

5 Click **OK**, and then save the changes to your model.

6 Click the **Tools** menu, and select **Run on Target Hardware** > **Run**.

The lower left corner of the model window displays status while Simulink software prepares, downloads, and runs the model on the target hardware.

7 While the model is running in External mode, you can change tunable parameter values in the model on your host computer and observe the corresponding changes in the model running on the hardware.

If your model contains blocks from the Simulink Sinks block library, the sink blocks in the model on your host computer display the values generated by the model running on the hardware.

If your model does not contain a sink block to which External mode can send data, the MATLAB Command Window displays a "No data has been selected for uploading" warning. You can disregard this warning, or you can add a sink block to the model and rerun your model.

When you have finished tuning and monitoring your model, you can disable External mode.

To deploy model to your hardware without using External mode. See "Run Model on Arduino Hardware" on page 53-13:

Note External mode increases the processing burden of the model running on the hardware. If the software reports an overrun, you can apply the solutions described in "Detect and Fix Task Overruns on Arduino Hardware" on page 53-22.

Stop External Mode

To stop the model running in External mode, click the black square Stop button located on the model toolbar, as shown here.

This action stops the process for the model running on the Arduino hardware, and stops the model simulation running on your host computer.

If the **Simulation stop time** parameter is set to a specific number of seconds, External mode stops when that period has elapsed.

To disable External mode:

1. Click the **Tools** menu, and select **Run on Target Hardware** > **Options**.
2. In the Run on Target Hardware pane that opens, clear the **Enable External mode** checkbox.
3. Click **OK**, and then save the changes to your model.

Use Serial Communications with Arduino Hardware

In this section...

Arduino hardware has serial ports, also known as UARTs, that can communicate with other devices that have serial interfaces.

Hardware

The Arduino Uno board has one serial port, serial port 0, connected to:

- The digital pins marked `TX 1` (transmit) and `RX 0` (receive).
- The USB port, through a serial-to-USB converter.

The Arduino Mega 2560 board has four serial ports:

- Serial port 0 is connected to Communication pins marked `TX0 1` (transmit) and `RX0 0` (receive). Serial port 0 is also connected to the USB port through a converter.
- Serial port 1 is connected to Communication pins marked `TX1 18` (transmit) and `RX1 19` (receive).
- Serial port 2 is connected to Communication pins marked `TX2 16` (transmit) and `RX2 17` (receive).
- Serial port 3 is connected to Communication pins marked `TX3 14` (transmit) and `RX3 15` (receive).

You can use serial port 0 to communicate with other devices that have serial ports, or to communicate with a computer over the USB port.

Each serial port supports one Serial Transmit and one Serial Receive block, one block per pin.

If you intend to use External mode with Arduino Mega 2560 hardware, use serial ports 1 through 3 for serial communications. Serial port 0 is not available for serial communications because it is connected to the USB port, which External mode uses to communicate with the host computer. This restriction does not apply to Arduino Uno hardware, because External mode is not supported. For more information, see "Tune and Monitor Models Running on Arduino Mega 2560 Hardware" on page 53-15.

Serial communications are not supported in models that also use the Arduino Standard Servo Read, Standard Servo Write, and Continuous Servo Write blocks.

Warning **Only connect serial port pins to devices that use 5 Volt TTL logic. Do not connect these pins to an RS-232 serial interface, such as the DE-9M connector on a computer, without limiting the voltage. The RS-232 standard allows higher voltages that can damage your hardware. For details, read the documentation for your Arduino hardware.**

Transmit Serial Data

To transmit data through a serial port or USB port on the Arduino hardware:

1. Add the Arduino Serial Transmit block to your model.
2. Connect a data source to the block input on the Serial Transmit block.

   If the data type is not uint8, use a Data Type Conversion block to convert it to uint8.
3. In the Arduino Serial Transmit block, select a **Port number**.
4. Click the **Tools** menu in the model, and select **Run on Target Hardware > Options**.

   In the Configuration Parameters dialog that opens, on the Run on Target Hardware pane, set the baud rate for the serial port you selected in the Arduino Serial Transmit block.
5. Connect the appropriate digital transmit pin to the hardware that receives the data.

6 Run the model, as described in "Run Model on Arduino Hardware" on page 53-13.

7 If your model uses the Arduino USB port (Serial port 0) to transmit data to a device that is not your host computer, reconnect the USB cable to that device and press the RESET button.

Receive Serial Data

To receive data through a serial port or USB port on the Arduino hardware:

1 Add the Arduino Serial Receive block to your model.

2 On the Arduino Serial Receive block, connect the **Data** block output to a block that uses the data.

3 Open the Arduino Serial Receive block and specify the **Port number**.

4 Click the **Tools** menu in the model, and select **Run on Target Hardware > Options**.

   In the Configuration Parameters dialog that opens, on the Run on Target Hardware pane, set the baud rate for the serial port you selected in the Arduino Serial Receive block.

5 Connect the digital receive pin to the hardware that transmits the data.

6 Run the model, as described in "Run Model on Arduino Hardware" on page 53-13.

7 If your model uses the Arduino USB port (Serial port 0) to receive data from a device that is not your host computer, reconnect the USB cable to that device and press the RESET button.

Detect and Fix Task Overruns on Arduino Hardware

You can configure a Simulink model running on the target hardware to detect and notify you when a task overrun occurs. A task overrun occurs if the target hardware is still performing one instance of a task when the next instance of that task is scheduled to begin. You can fix overruns by decreasing the frequency with which tasks are scheduled to run, and/or by reducing the number of tasks defined by your model.

To enable overrun detection:

1. Click the **Tools** menu in the model, and select **Run on Target Hardware** and **Options**.
2. In the Run on Target Hardware pane that opens, select the **Enable overrun detection** check box.
3. Use the **Digital output to set on overrun** parameter to specify the pin number of a digital output.
4. Click **OK**.

To create a visual overrun indicator for your board, connect an appropriate resistor in series with an LED between the `GND` and the hardware pin specified by the **Digital output to set on overrun** parameter. Orient the LED so the longer leg (positive) is connected to the digital output pin.

When a task overrun occurs:

- The state of the digital output pin specified by the **Digital output to set on overrun** parameter changes from low (0 Volts) to high (5 Volts).
- The model continues running, but the effective sample time will be longer than specified.

To fix an overrun condition, reduce the processing burden of the model by applying one or more of the following solutions:

- Increase the sample times for the model. For example, increase the values of the **Sample time** parameters in all of your data source blocks.

- Simplify the model.

If you are using External mode, and the preceding solutions do not fix the task overrun condition, consider clearing the **Enable External mode** checkbox in the Run on Target Hardware pane. External mode adds a lightweight server to the model running on the target hardware. This server increases the processing burden upon the target hardware, which can contribute to a task overrun condition.

Troubleshoot Running Models on Arduino Hardware

In this section...

Block Produces Zeros in Simulation

If you simulate a model on your host computer without running it on your target hardware, input blocks produce zeros, and output blocks do nothing. This is the expected behavior.

For example, if you select **Simulation > Run** in a model that contains a Digital Input block and a Digital Output block:

- The block output on the Digital Input block produces zeros.
- The Digital Output block does nothing.

To solve this issue, run your model on the target hardware as described in:

- "Run Model on Arduino Hardware" on page 53-13
- "Run Your Model in External Mode" on page 53-16

"Could not automatically set host COM port"

If you try to run a model on your Arduino hardware and Simulink generates an error message similar to this one: "The call to realtime_make_rtw_hook, during the entry hook generated the following error: Could not automatically set host COM port for your Arduino hardware. This may be due to a disconnected or unrecognized board. If the board is not connected to your host computer, connect it and let the operating system install the board driver."

Resolve Connection Issues

To resolve connection issues:

1. Verify that your Arduino hardware is powered on and connected to your host computer.

2 Try running the model again on your Arduino hardware.

Resolve Driver Issues

If you get the error message while your board is powered on and connected to your host computer, resolve any issues with Arduino drivers in Windows:

1 In the Windows Start menu, select **Devices and Printers**.

2 If you find an **Unknown Device** under **Other Devices** or **COM Ports**, double click the **Unknown Device**.

3 In the **Unknown Device Properties** dialog box that opens, click the **Hardware** tab, and click **Properties**.

4 In the **Unknown device Properties** dialog box that opens, click **Update Driver**.

5 In the **Update Driver Software - Unknown Device** dialog box that opens, click **Browse my computer for driver software**.

6 Select the **Include subfolders** checkbox and click **Browse**.

7 Navigate to the **Installation folder** that Target Installer used when you installed support for your Arduino hardware, and then click **Next**. By default, this folder location is `C:\MATLAB\Targets\`*`releasenumber`*`\arduino-`*`version`*. For example: `C:\MATLAB\Targets\R2012a\arduino-1.0`.

8 If prompted by Windows Security, choose **Install this driver software anyway**, and let Windows complete the process of installing the driver.

9 Try running the model again on your Arduino hardware.

If you get the error message after resolving issues with Arduino drivers, set the host COM port and baud rate manually. The drivers for some Arduino board revisions do not identify the board as an Arduino device in Windows. In that case, set the **COM port number** and **Serial 0 baud rate** manually, as described in "Configure Host COM Port Manually" on page 53-26

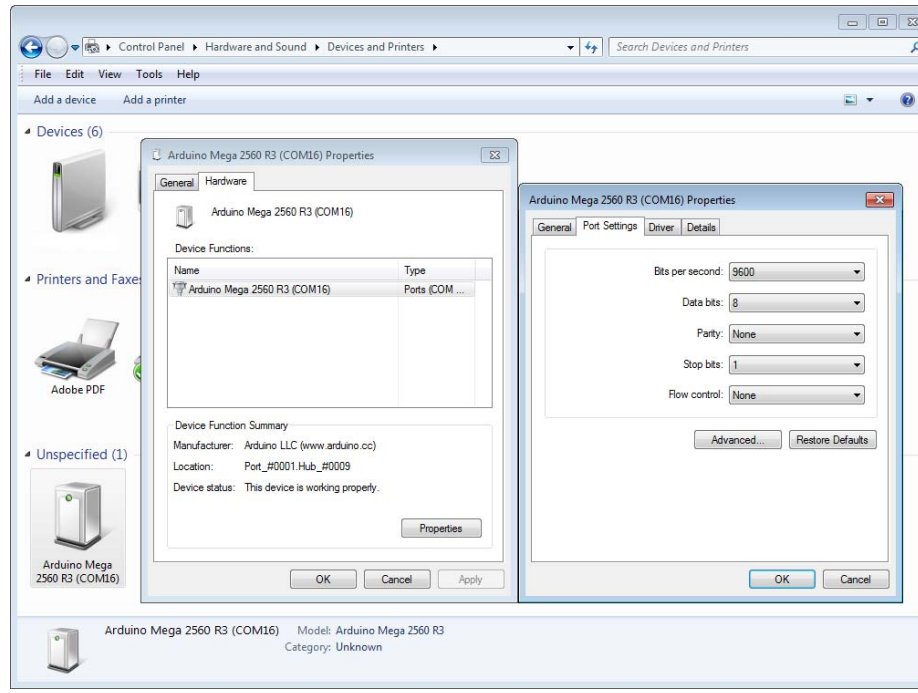
Configure Host COM Port Manually

Simulink software automatically detects the COM port settings of the USB connection between your host computer and the Arduino hardware. Optionally, you can also configure these settings manually.

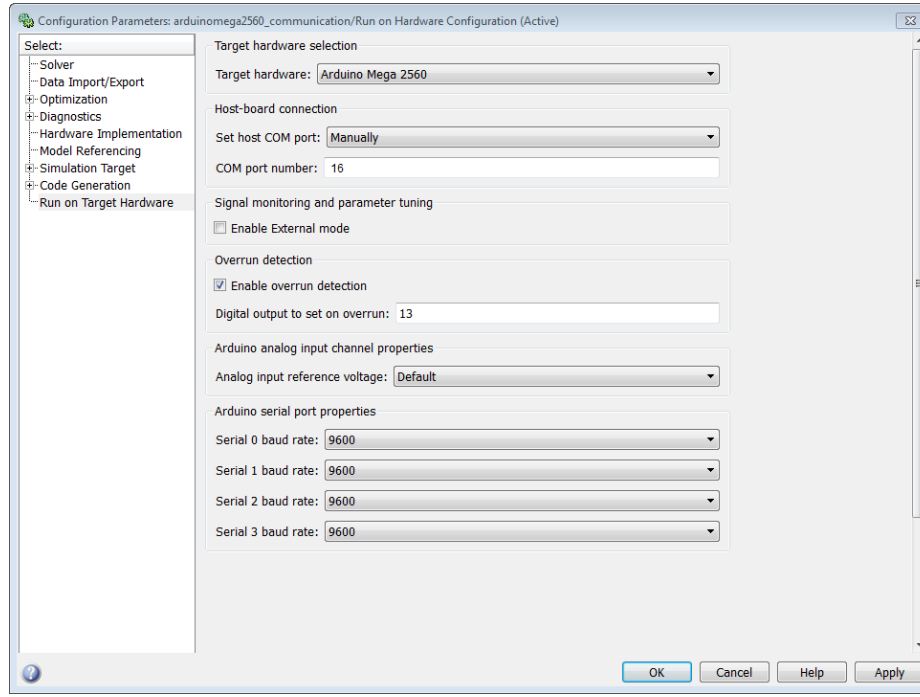
To configure the COM port settings manually:

1. Click the **Tools** menu in the model, and select **Run on Target Hardware > Options**.
2. In the Run on Target Hardware pane, change the **Set host COM port** parameter to `Manually` and leave the Configuration Parameters dialog open.
3. Open **Devices and Printers** in Windows.
4. Double-click **Arduino Uno** or **Arduino Mega 2560** device.
5. In the device properties dialog, click the **Hardware** tab, and then click the **Properties** button.
6. Click the **Port Settings** tab.

   For example, the following image shows an Arduino device in Devices and Printers, the Hardware tab, and the Port Settings tab.



7 In Configuration Parameters, update **COM port number** and **Serial 0 baud rate** to match the Arduino device in Windows.



8 Click **OK** and save the model.

54

Work with BeagleBoard Hardware

Install Support for BeagleBoard Hardware

This topic shows how to add support for BeagleBoard hardware to the Simulink product.

After you complete this process, and replace the firmware on the BeagleBoard hardware, you can run a Simulink model on your BeagleBoard hardware, as described in "Run Model on BeagleBoard Hardware" on page 54-39.

This process downloads and installs the following items on your host computer:

- Third-party software development tools
- A Simulink block library called **Target for Use with BeagleBoard Hardware**.
- Examples

For convenience, this document occasionally refers to BeagleBoard hardware as a "board" or as "target hardware".

Note You can only use this target on a host computer running a version of 32-bit or 64-bit Windows that Simulink software supports.

Repeat this process every six months or so to update to the latest version of the target.

1. Open the **Install or update target** screen in the Target Installer using one of the following methods:
   - In a model, select **Tools > Run on Target Hardware > Install/Update Support Package**.
   - In a MATLAB Command Window, enter `targetinstaller`.
2. Choose to get the support package from the Internet or from a folder.

Note The file size of the support package and other downloads is over 1 GB. Downloading the support package and third-party software can take a while.

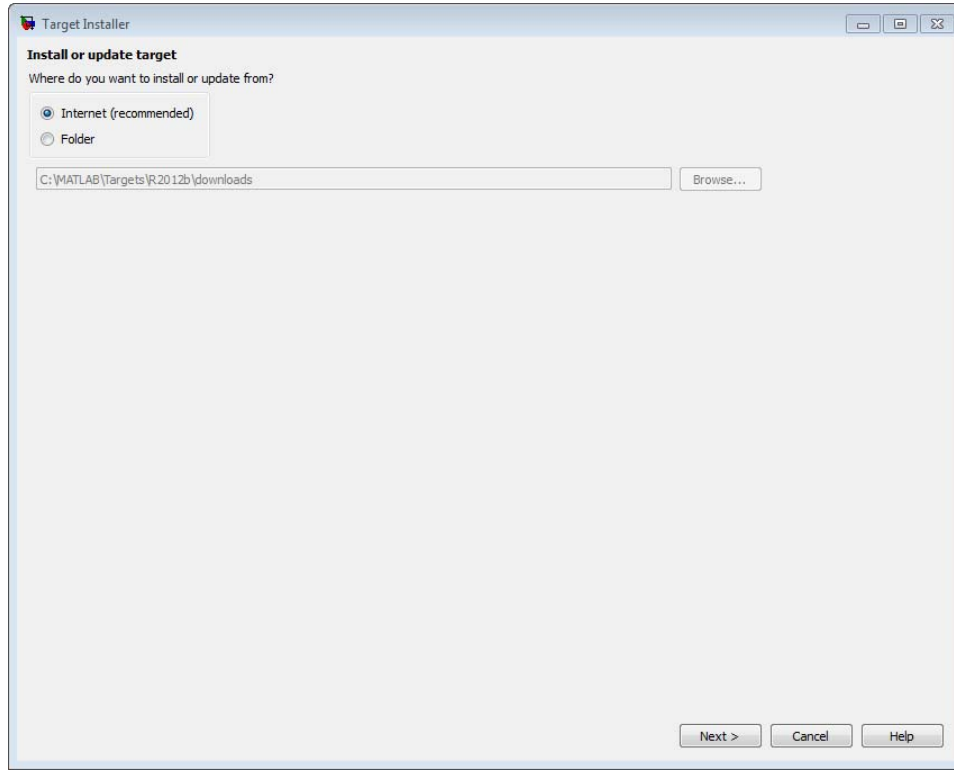
Internet: This option is selected by default. Target Installer downloads and install the support package and third-party software from the Internet.

Folder: Target Installer gets the support package and third-party software installers from the folder specified. If the third-party software installers are not available, Target Installer downloads and installs those from the Internet.

You must have write privileges for this folder. If you use the default folder, having write privileges is typically not an issue. If you change to a new folder for which you do not have write permissions, such as a shared folder on a network, the Target Installer generates an error message.

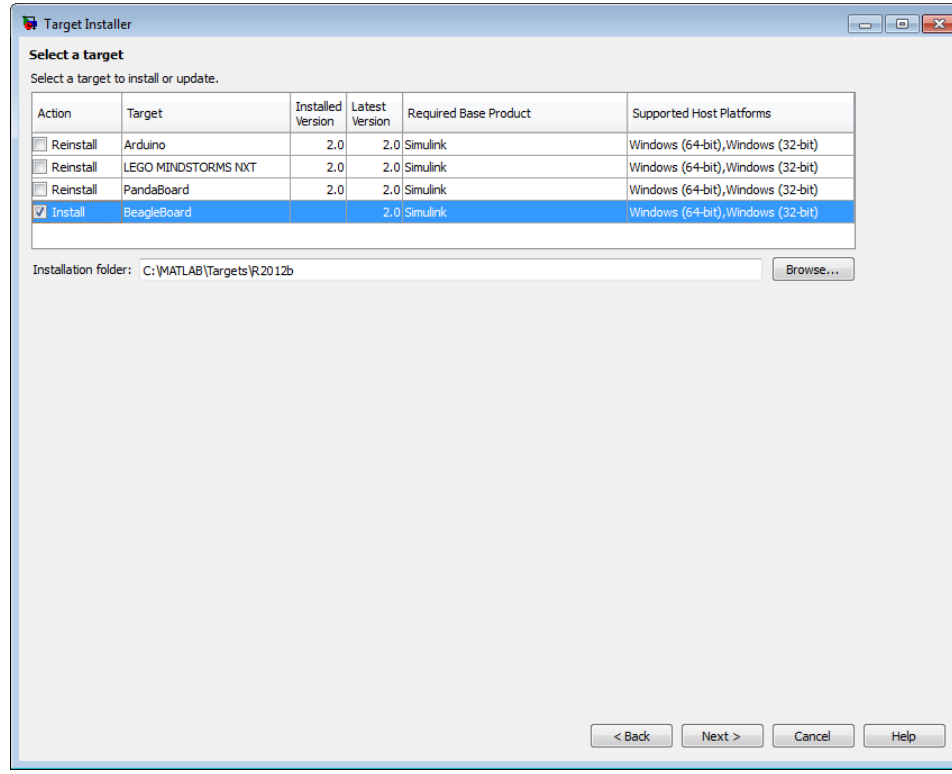
To solve this issue, copy the support package to a folder for which you have write privileges, and point Target Installer to that same folder. For example, copy the support package to `C:\MATLAB\Targets\`*`version`*`\downloads`. If the third-party software installers associated with the support package are available, also copy these.

To locate the support package in a folder, search for a filename that begins with `beagleboard` and ends with `.zip`. For example: `beagleboard_r2012a_v1_0.zip`



3 Select the `BeagleBoard` check box, and click **Next**.

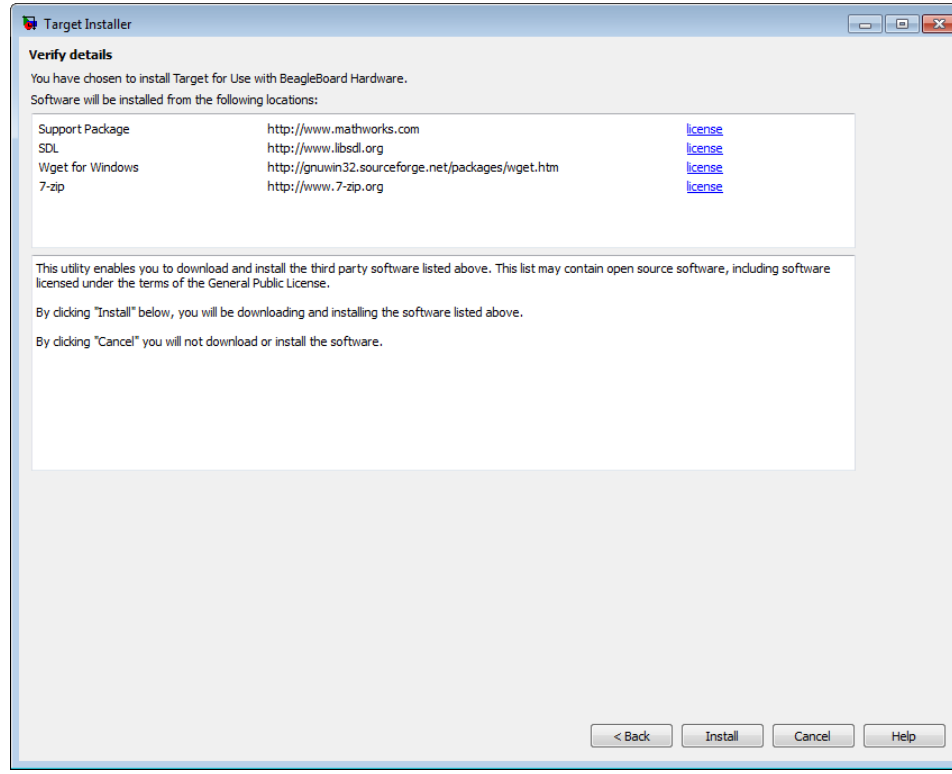
The **Installation folder** parameter tells Target Installer where to install the support package and the third-party software.



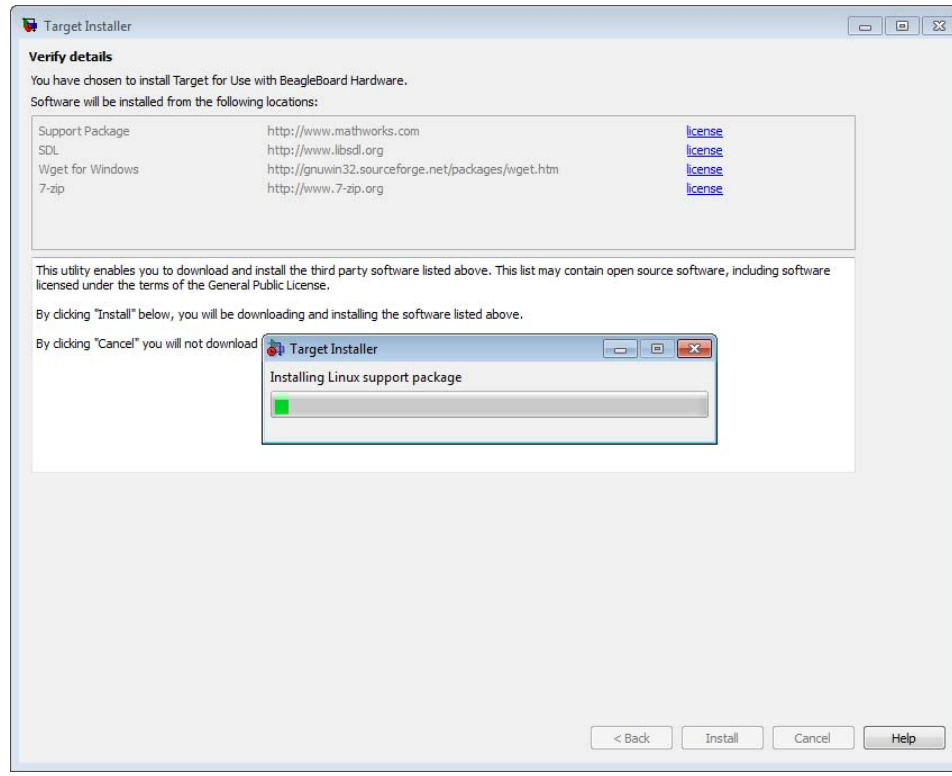
Note You must have write privileges for the Installation folder.

4 Target Installer confirms that you are installing the target, and lists third-party software it will install.

Review the information, including the license agreements, and click **Install**.

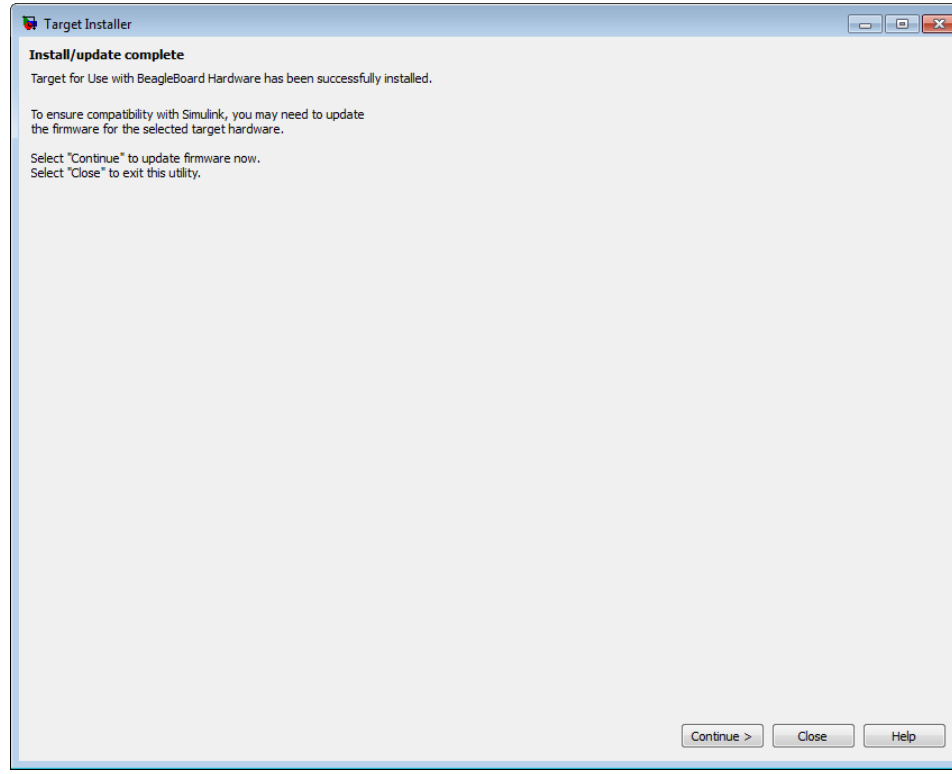


Target Installer displays a progress bar while it downloads and installs the third-party software.



Note If you installed the target previously, Target Installer removes the files from that installation before installing the current target. If Target Installer cannot remove those files automatically, it instructs you to delete the files manually. Close the MATLAB software before removing the files. Then, restart MATLAB software and run Target Installer again.

5 To replace the factory-installed firmware on the BeagleBoard hardware with Ubuntu® Linux, as described in “Replace Firmware on BeagleBoard Hardware” on page 54-9.


Target Installer
Install/update complete
Target for Use with BeagleBoard Hardware has been successfully installed.
To ensure compatibility with Simulink, you may need to update
the firmware for the selected target hardware.
Select "Continue" to update firmware now.
Select "Close" to exit this utility.
Continue >
Close
Help

Replace Firmware on BeagleBoard Hardware

This topic shows how to replace the firmware on the BeagleBoard hardware (the "board") with Ubuntu Linux firmware that can run Simulink models.

Before replacing the firmware, install the target, as described in "Install Support for BeagleBoard Hardware" on page 54-2.

After replacing the firmware, you can run a Simulink model on the BeagleBoard hardware, as described in "Run Model on BeagleBoard Hardware" on page 54-39.

The following steps provide an overview of the firmware replacement process:

1. The Target Installer locates a firmware image on your host computer or downloads new one.
2. The Target Installer uses the host computer to write the firmware image to a microSD or SD memory card.
3. You transfer the microSD or SD memory card to the BeagleBoard hardware.
4. The Target Installer applies the IP settings you choose to the firmware on the BeagleBoard hardware.

Note Target Installer does not use the BeagleBoard hardware to write the firmware image to the memory card.

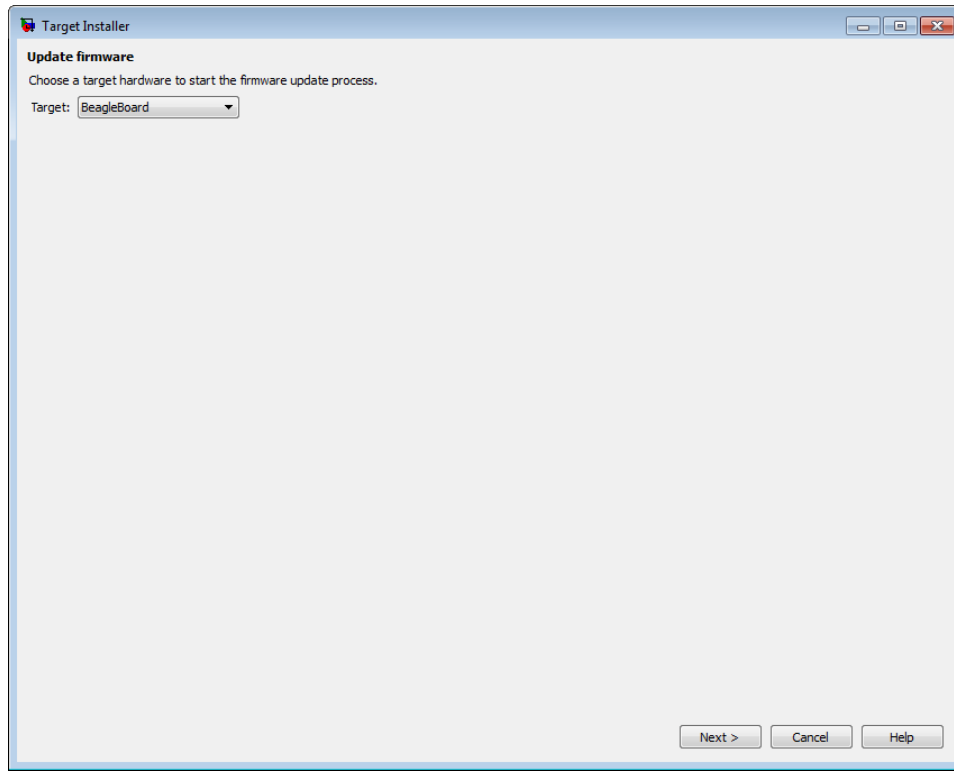
To replace the firmware on your BeagleBoard hardware:

1. Open the **Update firmware** screen in the Target Installer using one of the following methods:

   - Click **Continue** in the **Install/update complete** screen of the Target Installer.
   - In a model, select **Tools > Run on Target Hardware > Update firmware**.

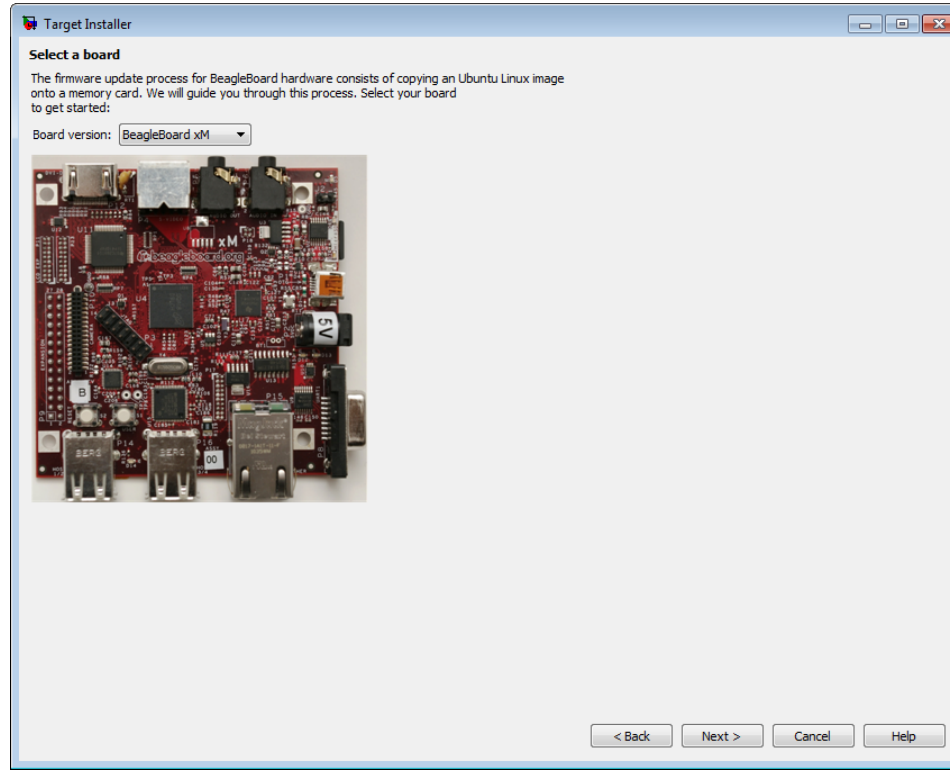
- In a MATLAB Command Window, enter `targetupdater`.

2 Choose the `BeagleBoard` option and click **Next**.

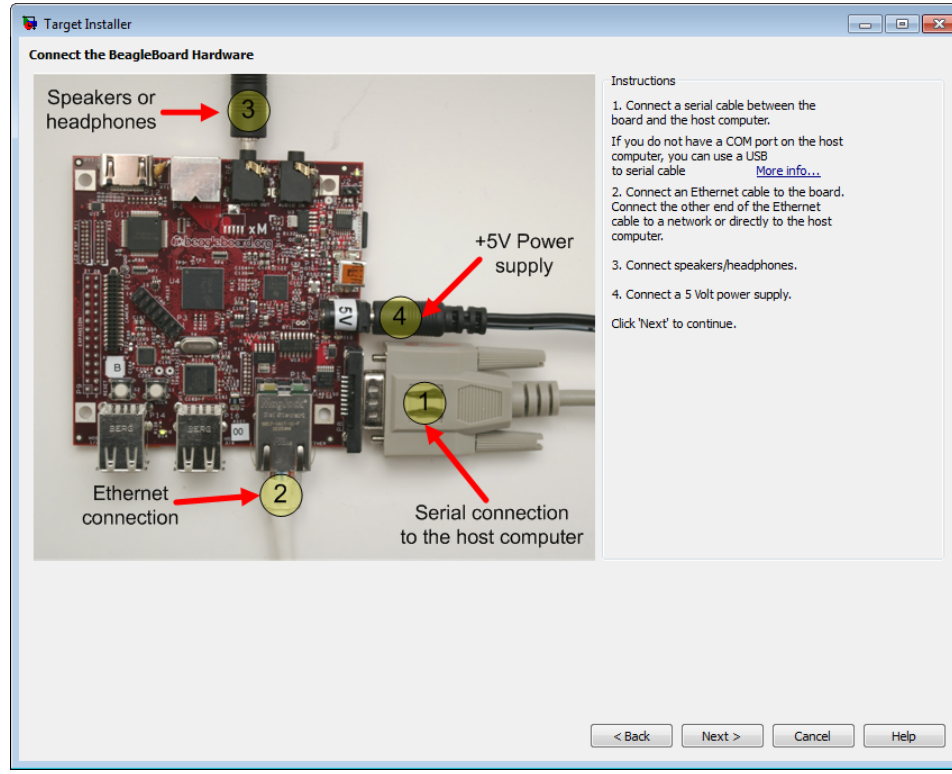


3 Choose your board version and click **Next**. This action enables the Target Installer to display instructions that are specific to your hardware.

Note The images in this topic only apply to the BeagleBoard xM hardware. If you are using the BeagleBoard Bx or Cx hardware, refer to the images in the Target Installer.



4 Make the connections shown and click **Next**.



5 Choose to get the firmware image from the Internet or from a folder.

Note The file size of the firmware image is approximately 1 GB. Depending on your connection, downloading the firmware can take from 2 to 60 minutes, or more.

Internet: This option is selected by default. When you click **Download**, Target Installer checks the **Download folder** for a valid firmware image:

- If a firmware image is not present, Target Installer downloads a firmware image from the Internet, and saves it to the download folder.

- If a firmware image is present, Target Installer uses the firmware image already present in the download folder, and does not download a new firmware image from the Internet.

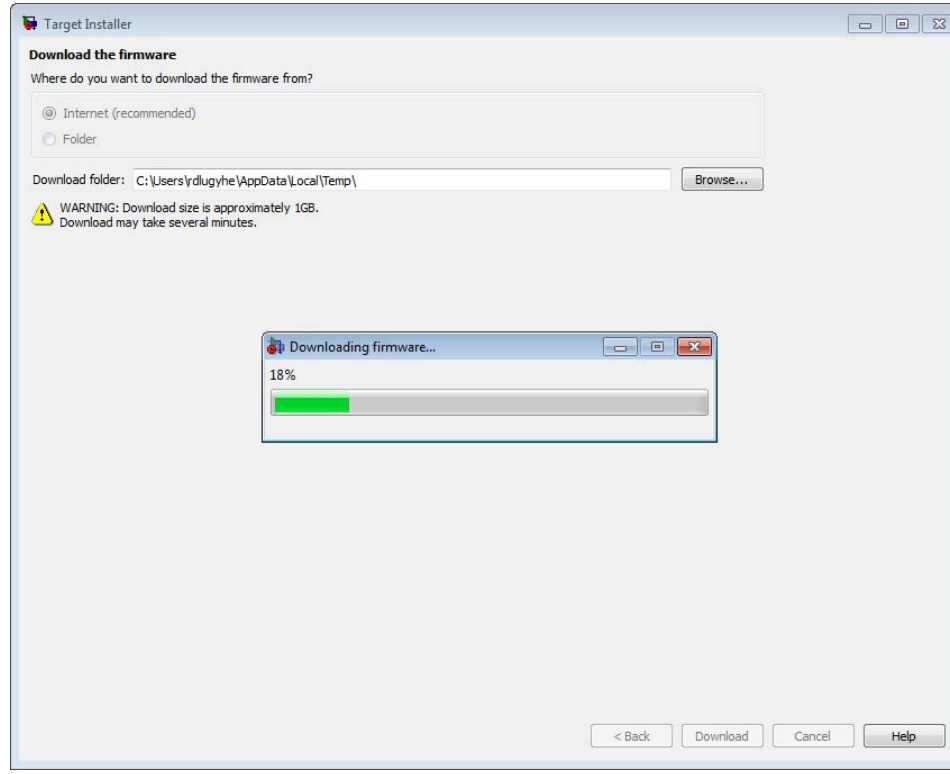
Folder: When you click **Download**, Target Installer checks the **Download folder** for a valid firmware image:

- If a firmware image is not present, Target Installer displays an error message that the image file is missing. To solve this issue, copy the firmware image from another location to the download folder, or choose the **Internet** option instead.
- If a firmware image is present, Target Installer continues the firmware installation process.

You must have write privileges for the download folder. If you use the default download folder, having write privileges is typically not an issue. If you change to a new download folder for which you do not have write permissions, such as a shared folder on a network, the Target Installer generates an error message: "Error: Download the firmware. The download folder is not writable. Choose a folder for which you have write permissions".

To solve this issue, copy the firmware image to a folder for which you have write privileges. For example, copy the firmware image from the shared folder on the network to the `C:\Users\`*`username`*`\AppData\Local\Temp` folder. Then, update the **Download location** to the same folder, and click **Download** again.

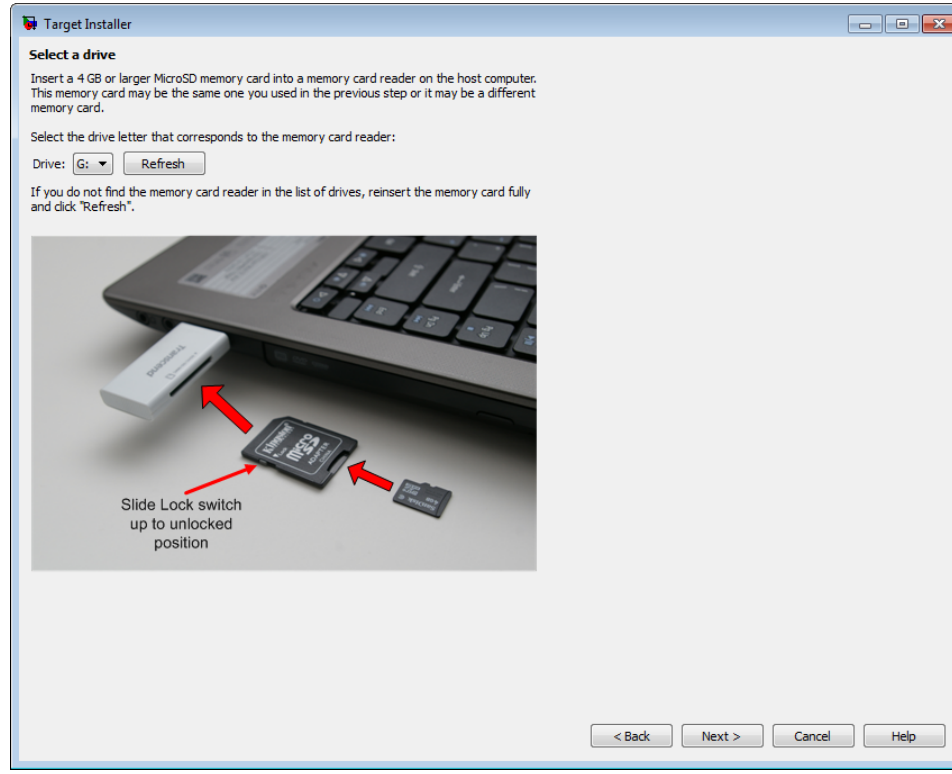
To locate the firmware image in a folder, search for a filename that begins with `beagleboard_ubuntu`. For example: `beagleboard_ubuntu_11_04_r4_12_08_2011.img.7z`



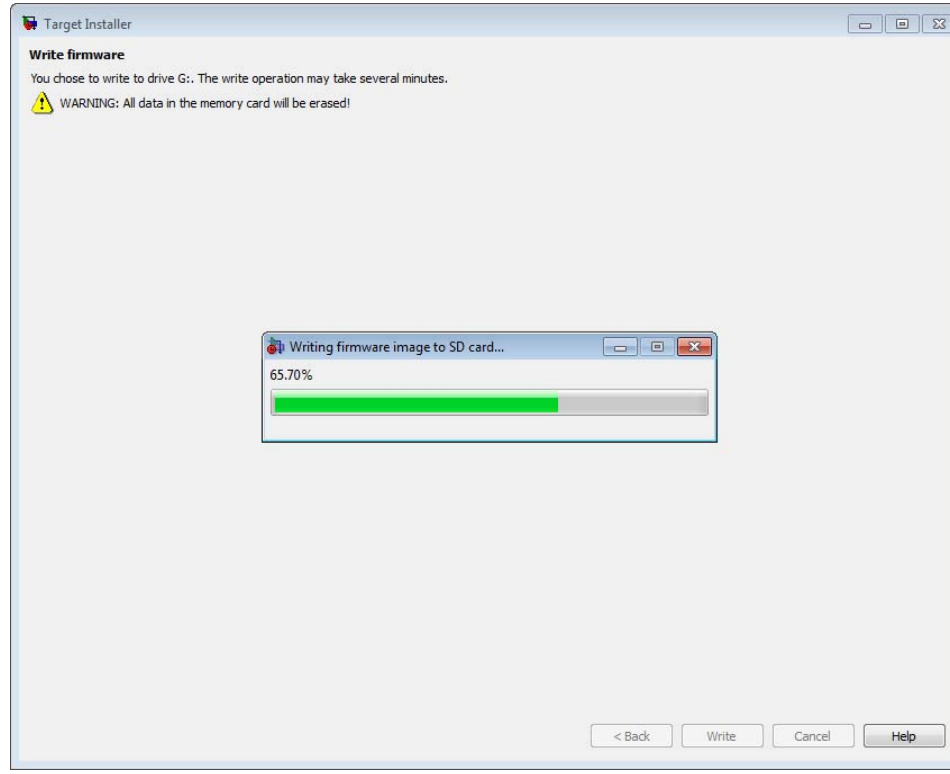
6 Insert the microSD or SD memory card into a media card reader connected to your host computer. Windows assigns a drive letter to the memory card.

7 Target Installer does not automatically detect the drive letter of the memory card. It displays a drive letter for each device with removable storage.

- If only one drive letter is available, click **Next**.
- If no drive letters are available, check that the memory card is fully inserted, and click **Refresh**.
- If multiple drive letters are available, open the Windows Start menu, choose **Computer**, and look for the memory card under **Devices with Removable Storage**.

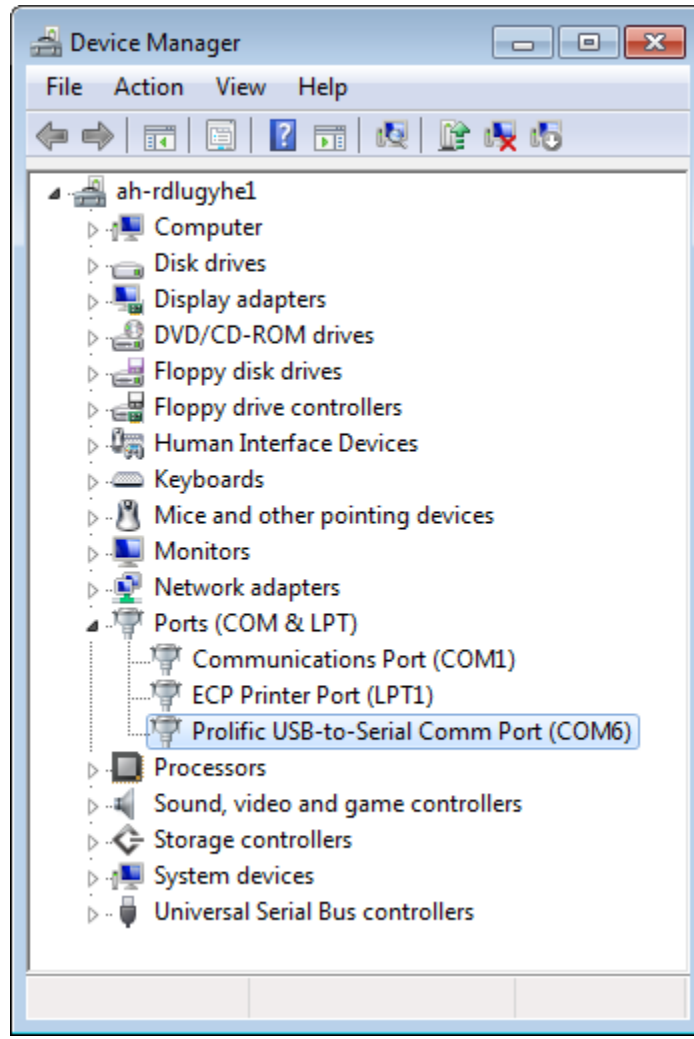


8 Click **Write**. Target Installer overwrites all previous data on the memory card with the firmware. This process takes several minutes to complete.



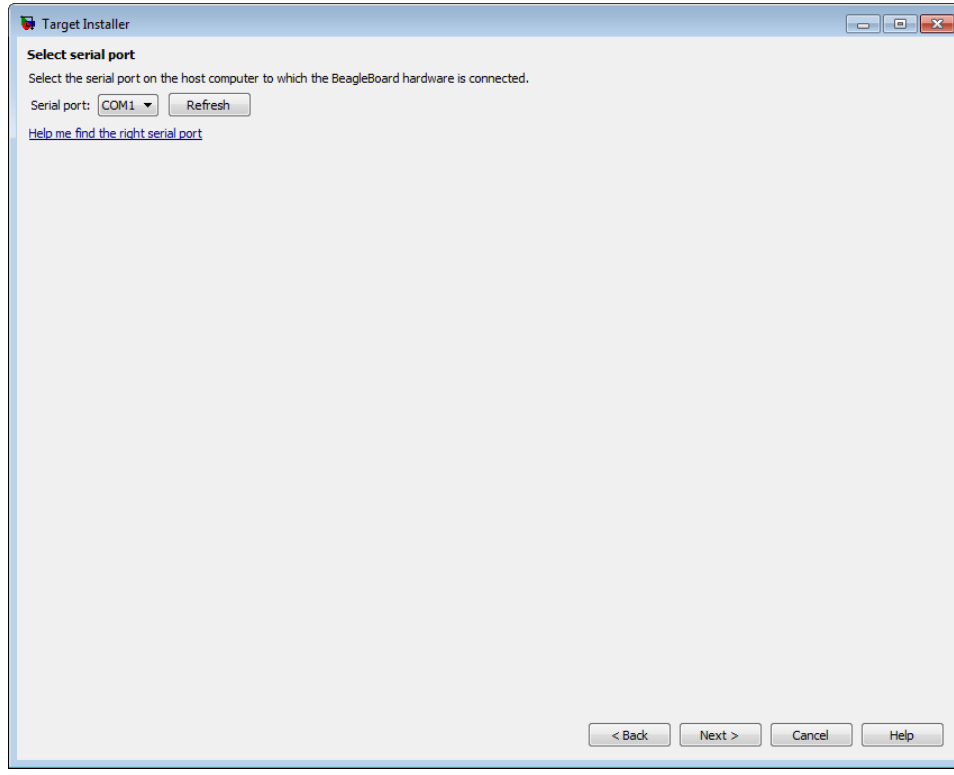
9 Get the COM port of the serial connection in Windows. From the Windows Start menu, choose search programs and files for "Device Manager". Open Device Manager, expand **Ports (COM & LPT)**, and identify the COM port of the serial connection to the BeagleBoard hardware.

For example, the following image shows a DB9 serial port called "Communications Port" using COM1, and a USB-to-serial adapter called "Prolific USB-to-Serial Comm Port" using COM6.



Note Some USB-to-serial adapters do not appear in the list of serial connections immediately after you install the software drivers. To solve this issue, disconnect/reconnect the adapter, or reboot your host computer.

10 Target Installer does not automatically choose the COM port of the serial connection. After you get the COM port of the serial connection from Windows Device Manager, return to Target Installer, set **Serial port** to the COM port, and click **Next**.

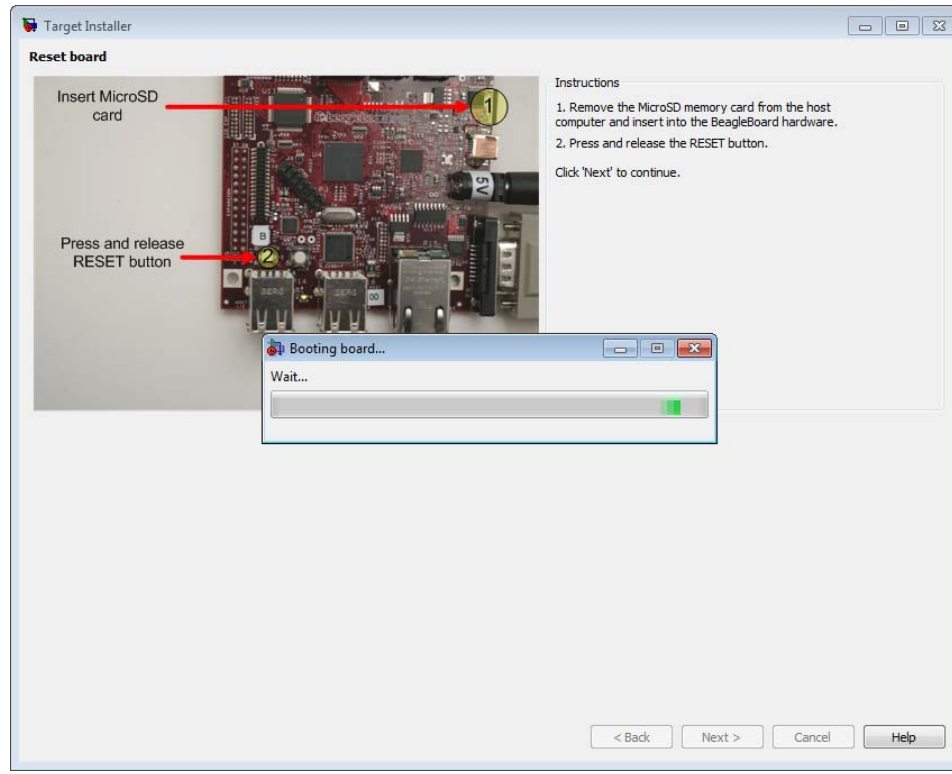


11 Insert the memory card into the BeagleBoard hardware, and follow the instructions for resetting your board:

- For the BeagleBoard xM hardware, press and release the RESET button.
- For the BeagleBoard Bx/Cx hardware, hold down the USER button while you press and release the RESET button.

Click **Next**. When the Target Installer detects a reset, it displays progress booting the board.

If the Target Installer does not display any progress, click **Back**. On the **Select serial port** screen. Verify that you selected the correct COM port, and close any other applications, such as PuTTY, that might using the serial connection.



12 If your board is connected to a network with DHCP services, such as an office LAN or a home network connected to the Internet, select **Automatically get IP address**, give the board a unique name, and click **Configure**. DHCP is a network service that automatically configures the IP settings of Ethernet devices connected to a network.

If your board is directly connected to an Ethernet port on your computer, or connected to an isolated network without DHCP services, select **Manually enter IP address**, give the board a unique name, enter static IP settings for the board, and click **Configure**.

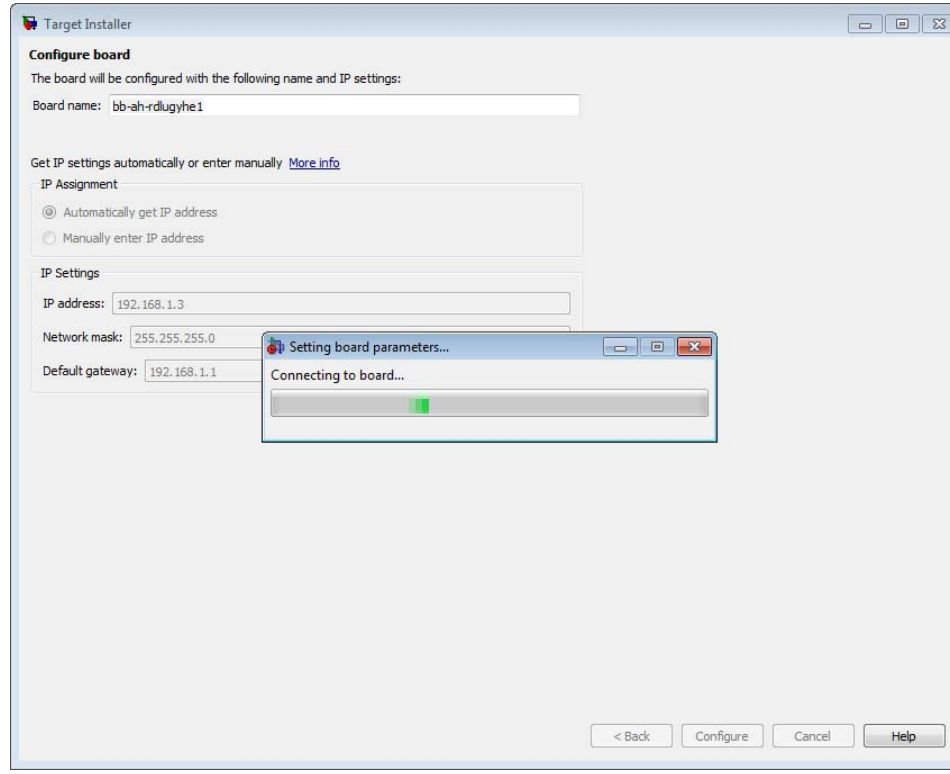
To enter static IP settings for your board, follow these guidelines:

- The value of the subnet mask must be the same for all devices on the network.
- The value of the IP address must be unique for each device on the network.

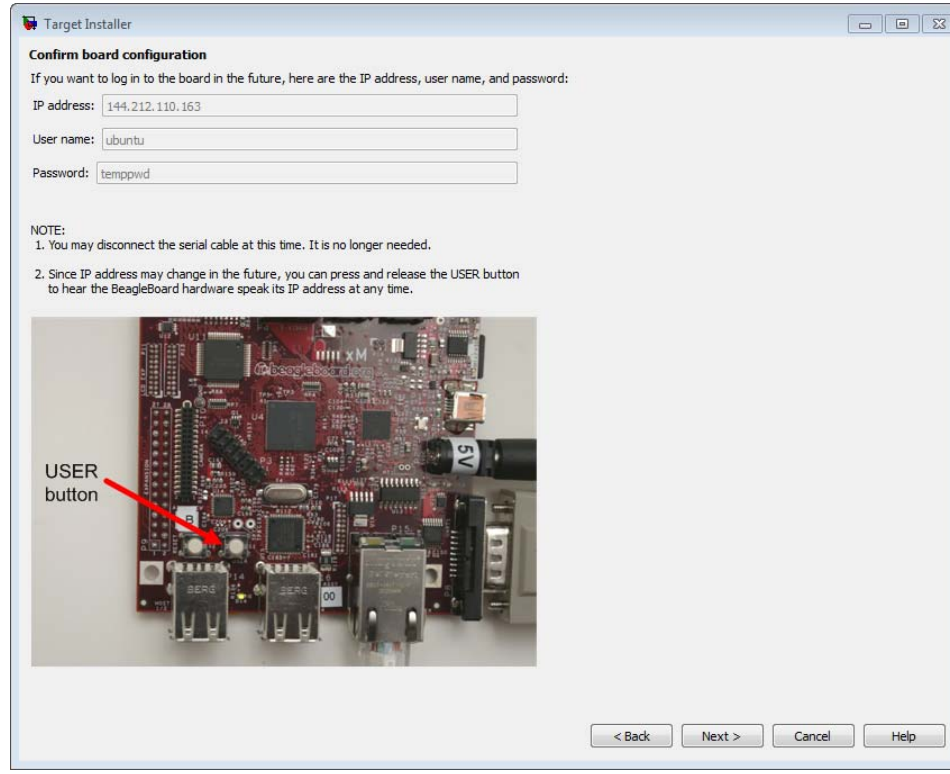
For example, if the Ethernet port on your host computer has a network mask of `255.255.255.0` and a static IP address of `192.168.1.1`, set:

- **Network mask** to use the same network mask value, `255.255.255.0`.
- **IP address** to an unused IP address, between `192.168.1.2` and `192.168.1.254`.

When you click **Configure**, the Target Installer opens a serial connection and applies the settings to the board.



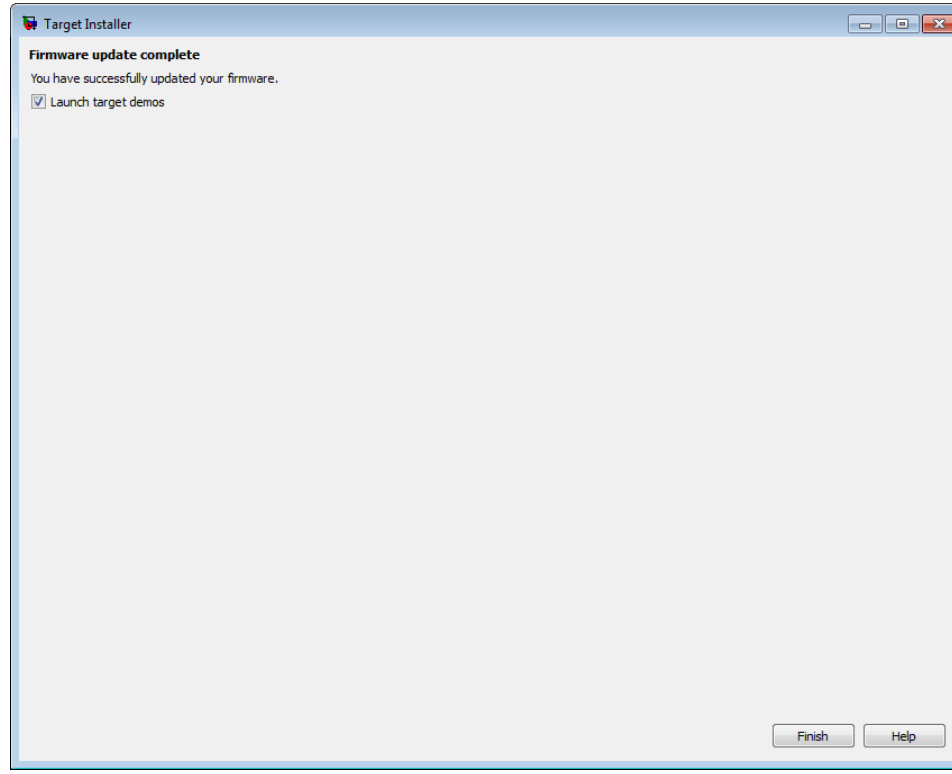
13 Make a note of the board information. Then, click **Next**.



14 Click **Finish**. If **Launch target examples** is enabled, the Target Installer opens the example page for BeagleBoard hardware.

Note To reopen the examples later, enter the following text in a MATLAB Command Window:

```
demo simulink 'Target for Use with Beagleboard'
```


Target Installer
Firmware update complete
You have successfully updated your firmware.
Launch target demos
Finish
Help

Choose the Type of Serial Cable

This topic shows you how to choose a serial cable for connecting your host computer to the BeagleBoard hardware.

Two types of cables are available for this purpose:

- DB9 null modem M/F cable
- USB to DB9 male adapter cable

DB9 null modem M/F cable:

- If your host computer has a DB9 male serial connector similar to the one in the following image, you can use a DB9 null modem M/F cable.

- To find the appropriate cable online, search for “DB9 low profile null modem M-F cable”.

USB to DB9 male adapter cable:

- If your host computer has a USB port, you can use a USB to DB9 male adapter cable.
- To find the appropriate cable online, search for "USB to RS-232 DB9 Serial Adapter”.
- Some USB-to-serial adapters do not appear in the list of serial connections immediately after you install the software drivers. To solve this issue, disconnect and reconnect the adapter, or reboot your host computer.
- To avoid issues with the software/driver quality, we recommend choosing an adapter that has good customer feedback ratings, or using the DB9 null modem M/F cable instead.

Connect to Serial Port on BeagleBoard Hardware

This topic shows you how to configure and open a command line session with the target hardware.

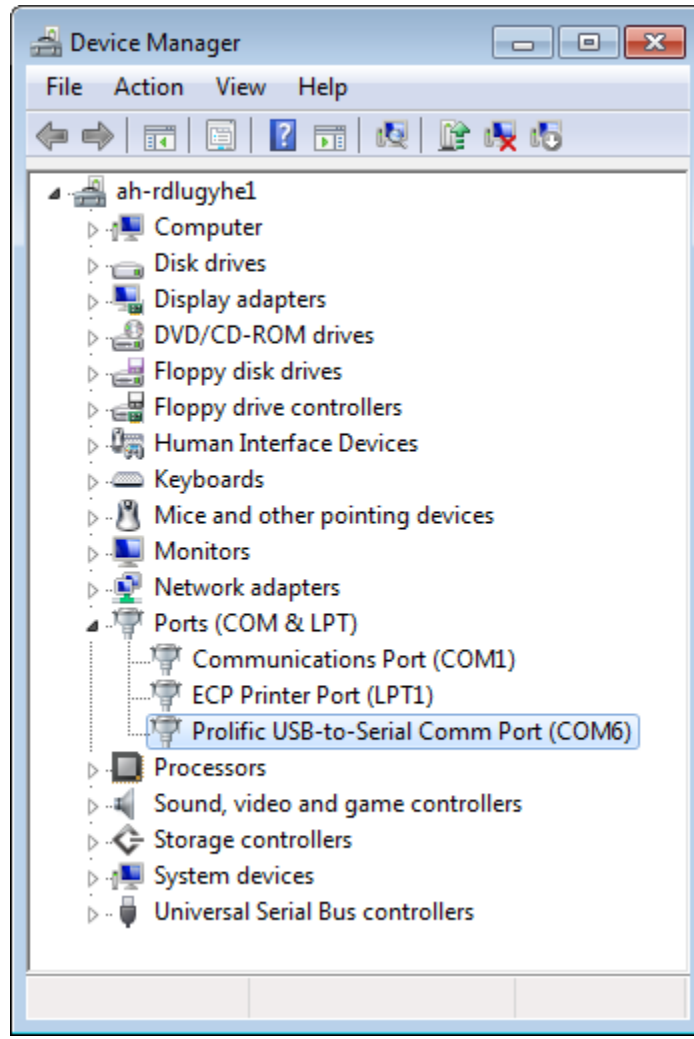
This is an optional task that you can use to:

- View the standard output while the board boots.
- Get or set the IP address, as described in "Get IP Address of BeagleBoard Hardware" on page 54-34 topic.

To open a serial connection to your board:

1. Connect a serial cable from your host computer to the female DB9 connector on the board.
2. Identify the COM port for your serial connection. In Windows 7, use the "search programs and files" feature in the Start menu to find "Device Manager". Open Device Manager, and expand **Ports (COM & LPT)** to see the list of serial connections.

   For example, the following image shows that the DB9 serial port called "Communications Port" uses COM1. Similarly, the image shows that the USB-to-serial adapter called "Prolific USB-to-Serial Comm Port" uses COM6.

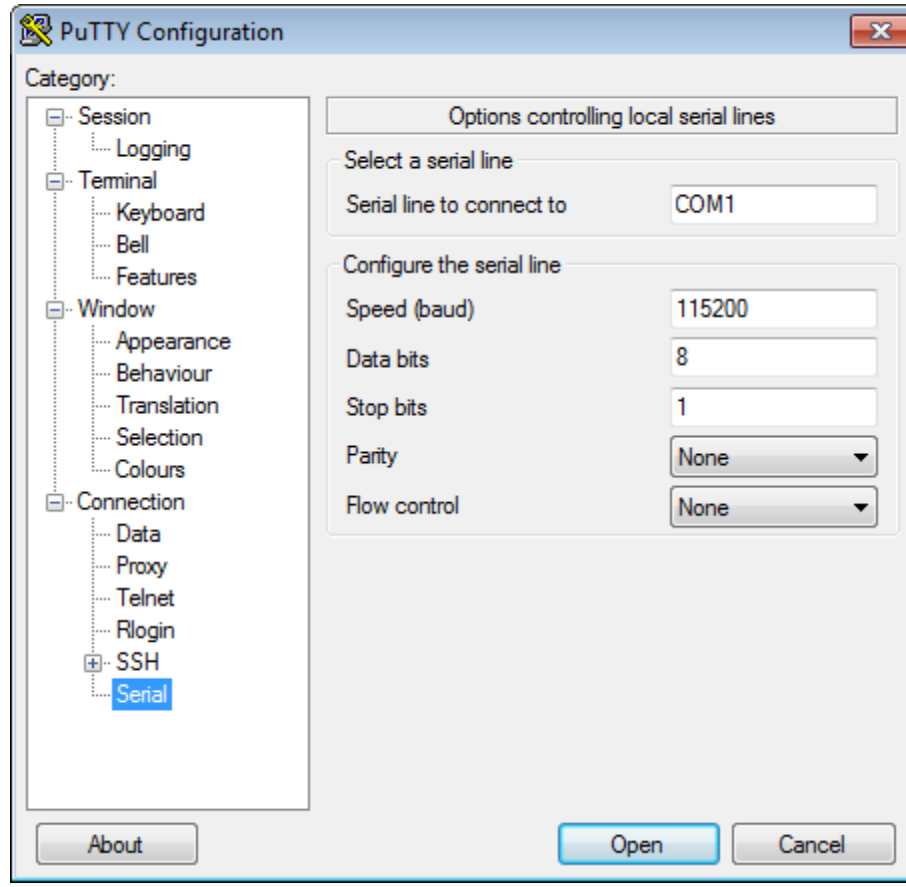


Note If you have trouble locating the COM port number, search the Windows "Help and Support" for "Device Manager".

3 In the MATLAB Command Window, start PuTTY by entering:

```
h = beagle;
system(['"' fullfile(h.PutilsFolder, 'putty.exe') '" -serial &'], '-runAsAdmin');
```

4 In the PuTTY dialog box that opens, select the **Serial** category.

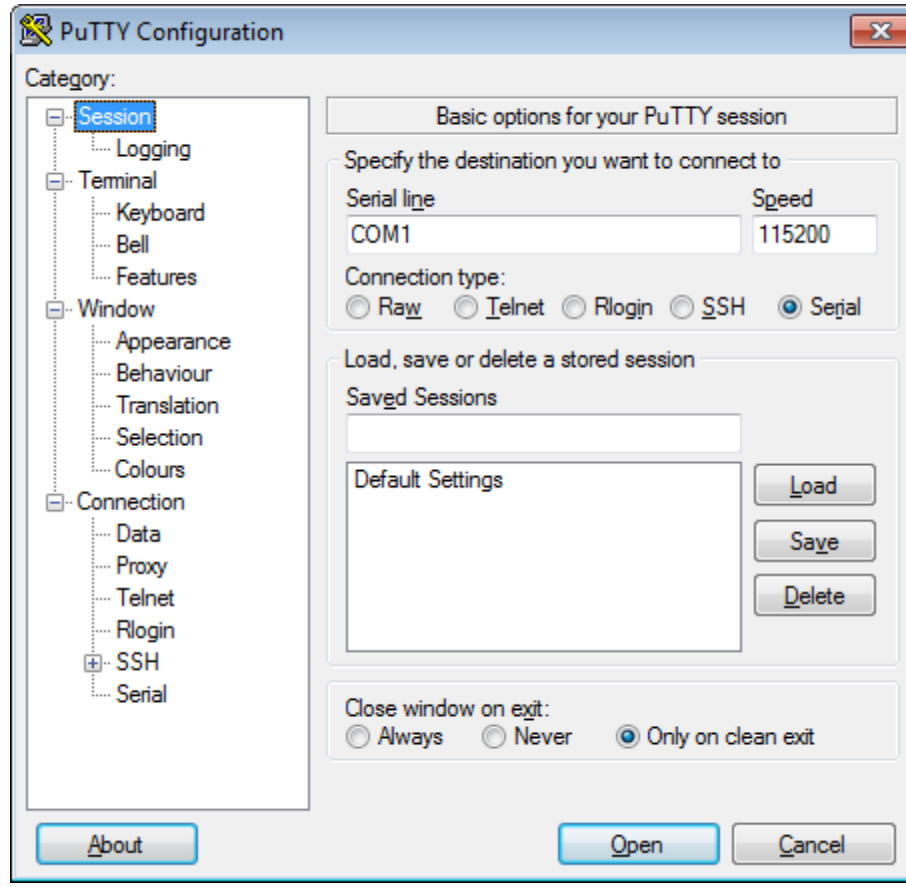


5 Set the following values:

- **Serial line to connect to**: If you are using your computer's built-in serial port, try `COM1`. Otherwise, use the Device Manager in Windows to determine the COM port number.
- **Speed (baud)**: `115200`

- **Flow control**: `None`

6 In the PuTTY dialog box, select the **Session** category.



7 Set the **Connection type** parameter to `Serial`, enter a new name for **Saved Sessions**, click **Save**, and click **Open**.

Note Do not save the serial settings to **Default Settings**. The **Default Settings** must remain configured to use SSH in order to run your Simulink model on the BeagleBoard hardware. Otherwise, trying to run the model on BeagleBoard hardware produces an error message similar to this one:

```
>> [status, message] = h.connect()
Error using linkfoundation.util.beagleboard/connect (line 125)
SSH connection to host 144.212.110.44 failed:
FATAL ERROR: Network error: Connection refused
```

8. When a terminal window opens, press the **Enter** key on your keyboard. The terminal window displays the Linux command line.

9. When you are finished, enter `logout` on the Linux command line, and close PuTTY to end the serial connection.

See Also

- "Get IP Address of BeagleBoard Hardware" on page 54-34
- For more information about PuTTY, see: http://www.chiark.greenend.org.uk/~sgtatham/putty/

Configure Network Connection with BeagleBoard Hardware

You can configure the IP settings of the BeagleBoard hardware by running Linux shell commands directly on the BeagleBoard hardware (the “board”).

To inspect and reconfigure the IP settings on a board that already has the new firmware, follow the procedure in this section that starts with “To configure the board to use DHCP or static IP settings”.

To configure the IP settings while you are replacing the firmware on your BeagleBoard hardware, see “Replace Firmware on BeagleBoard Hardware” on page 54-9.

You may need to reconfigure the IP settings if your board:

- Has unknown IP settings.
- Is unreachable using a network connection.
- Is being moved to a network or direct Ethernet connection that uses static IP settings.
- Is being moved from a network that used static IP settings to one that uses DHCP services.

When you complete the procedure in this topic, the board should be able to communicate over the network to which it is connected.

Before starting the procedure in this topic, it helps to understand the conditions under which networks use DHCP or static IP settings:

- If your board is connected to a network with DHCP services, such as an office LAN or a home network connected to the Internet, configure the board to use DHCP services. DHCP is a network service that automatically configures the IP settings of Ethernet devices connected to a network.
- If your board is directly connected to an Ethernet port on your computer, or connected to an isolated network without DHCP services, configure the board to use static IP settings.

To configure the board to use DHCP or static IP settings:

1. Open a serial command line session, as described in "Connect to Serial Port on BeagleBoard Hardware" on page 54-25

   Alternatively, if your board is connected to a monitor, keyboard, and mouse, you can log in to the Ubuntu desktop and open a terminal window.

2. Display the contents of the /etc/network/interfaces file. Enter:

   ```
   cat /etc/network/interfaces
   ```

   If the board is configured to use DHCP services (the default configuration), `dhcp` appears at the end of the following line:

   ```
   iface eth0 inet dhcp
   ```

   If the board is configured to use static IP settings, `static` appears at the end of the following line:

   ```
   iface eth0 inet static
   ```

3. Create a backup of the /etc/network/interfaces file. Enter:

   ```
   sudo cp /etc/network/interfaces /etc/network/interfaces.backup
   ```

   Enter the root password when prompted (default: `temppwd`).

4. Change the permissions of /etc/network/interfaces so you can edit the file. Enter:

   ```
   sudo chmod 777 /etc/network/interfaces
   ```

   Enter the root password when prompted (default: `temppwd`).

5. Edit `interfaces` using a simple editor called nano. Enter:

   ```
   nano interfaces
   ```

6. Edit the last word of line that starts with `iface eth0 inet`.

   To use DHCP services, edit the line to say:

```
iface eth0 inet dhcp
```

To use static IP settings, edit the line to say:

```
iface eth0 inet static
```

7 For static IP settings, add lines for `address`, `netmask`, and `gateway`. For example:

```
iface eth0 inet static
    address 192.168.1.2
    netmask 255.255.255.0
    gateway 192.168.1.1
```

Note For static IP settings:

- The value of the subnet mask must be the same for all devices on the network.
- The value of the IP address must be unique for each device on the network.

For example, if the Ethernet port on your host computer has a network mask of `255.255.255.0` and a static IP address of `192.168.1.1`, set:

- `netmask` to use the same network mask value, `255.255.255.0`.
- `address` to an unused IP address, between `192.168.1.2` and `192.168.1.254`.

---

8 Tell nano to exit and save the changes:

Press **Ctrl+x**.

Enter `Y` to save the modified buffer.

For "File Name to Write: interfaces", press Enter.

The nano editor confirms that it "Wrote # lines" and returns control to the command line.

9 Restore the original file permissions. Enter:

```
sudo chmod u=rw,g=r,o=r interfaces
```

Enter the root password when prompted. (default: `temppwd`)

10 Test the IP settings by logging in to the board over a telnet session.

Note You can use the `ifconfig` command to temporarily change the IP settings. Rebooting the board removes the `ifconfig` settings and restores the `/etc/network/interfaces` settings.

To change the IP settings temporarily, open a Linux command line, and enter `ifconfig`, the device id, a valid IP address, `netmask`, and the appropriate network mask. For example:

```
ifconfig eth0 192.168.45.12 netmask 255.255.255.0
```

Related Examples

- "Run Model on BeagleBoard Hardware" on page 54-39
- "Get IP Address of BeagleBoard Hardware" on page 54-34

Get IP Address of BeagleBoard Hardware

You can get the IP address of the BeagleBoard hardware (the "board") by listening to the audio output, or by using the Linux command line. This is an optional task that you can use to:

- Preparing a model to run on a board that is different from the previous one you used.
- Opening a telnet session with a board whose IP settings you do not know.
- Configuring the UDP Send block.

When you prepare a model to run on a board, your model Configuration Parameters reuse the IP settings of the previous board you used. If you are working with a different board on the same network, get the IP address of the your new board, and update the **Host name** parameter in the Configuration Parameters. For more information, see "Run Model on BeagleBoard Hardware" on page 54-39.

If Ethernet port on the BeagleBoard hardware board has an IP address, the audio output on the board can read the IP address out loud. For example the board can say "My IP address is one hundred and forty four point two one two point one one zero point two zero six."

To listen your board's IP address using headphones or speakers:

1. Plug headphones or speakers into the AUDIO OUT jack on the board.
2. Press the USER button on the board.
3. Write down the IP address as the board reads it out over the headphones or speakers.

The Linux command line on the board can provide the IP address of the Ethernet port.

To get your board's IP address command line session:

1. Open a serial command line session on your board, as described in "Connect to Serial Port on BeagleBoard Hardware" on page 54-25.

If your board is connected to a monitor, keyboard, and mouse, you can also log in to the Ubuntu desktop and open a terminal window.

2. At the Linux command line, enter `ifconfig`.

3. Locate the IP address following `inet addr` in the command line output. For example, locate `inet addr:144.212.110.206` on line 9 of the following output:

```
omap login: ubuntu
Password:
Last login: Wed Nov 23 15:40:36 EST 2011 from ah-rdlugyhe1.dhcp.mathworks.com on pts/1
Welcome to Ubuntu 11.04 (GNU/Linux 3.0.4-x3 armv7l)

 * Documentation:  https://help.ubuntu.com/
ubuntu@omap:~$ ifconfig
eth0      Link encap:Ethernet  HWaddr d2:a7:db:b3:c4:81
          inet addr:144.212.110.206  Bcast:144.212.110.255  Mask:255.255.255.0
          inet6 addr: fe80::d0a7:dbff:feb3:c481/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST  MTU:1488  Metric:1
          RX packets:125537 errors:0 dropped:0 overruns:0 frame:0
          TX packets:76 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:18103491 (18.1 MB)  TX bytes:7670 (7.6 KB)

lo        Link encap:Local Loopback
          inet addr:127.0.0.1  Mask:255.0.0.0
          inet6 addr: ::1/128 Scope:Host
          UP LOOPBACK RUNNING  MTU:16436  Metric:1
          RX packets:4 errors:0 dropped:0 overruns:0 frame:0
          TX packets:4 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:0
          RX bytes:240 (240.0 B)  TX bytes:240 (240.0 B)

ubuntu@omap:~$
```

Related Examples

- "Connect to Serial Port on BeagleBoard Hardware" on page 54-25
- "Run Model on BeagleBoard Hardware" on page 54-39
- "Configure Network Connection with BeagleBoard Hardware" on page 54-30

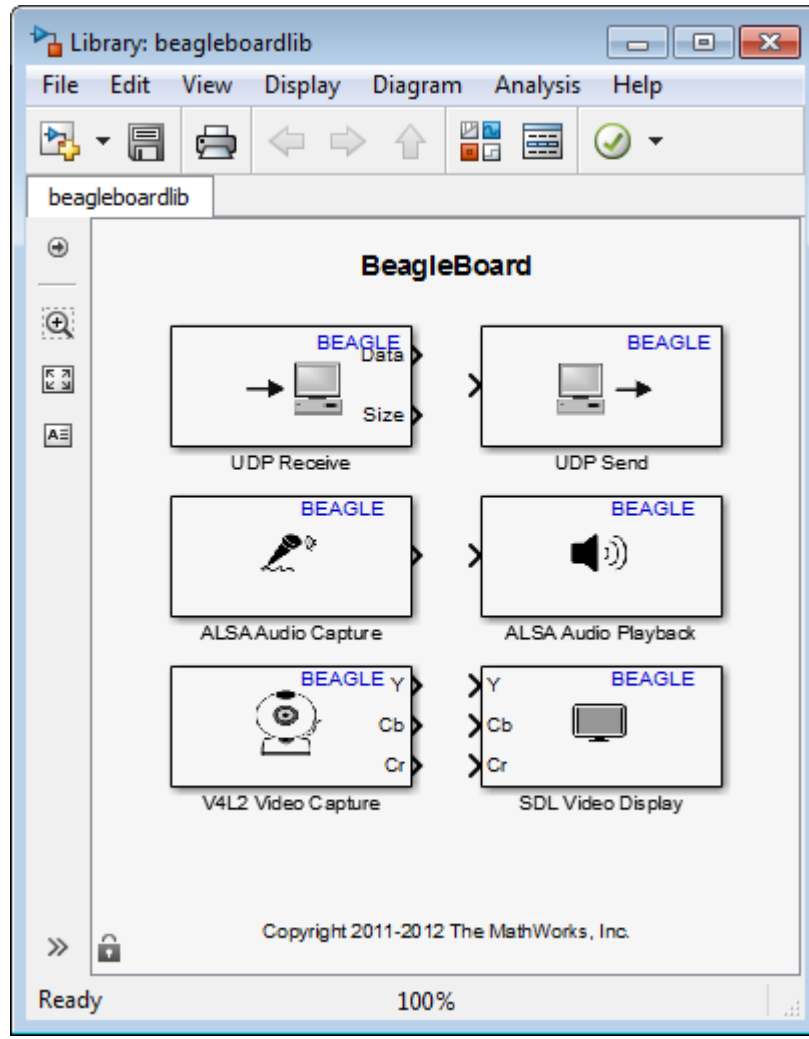
Open Block Library for BeagleBoard Hardware

This block library provides support for protocols and APIs available on BeagleBoard hardware (the “board”).

To open the block library from the MATLAB Command Window, enter:

```
beagleboardlib
```

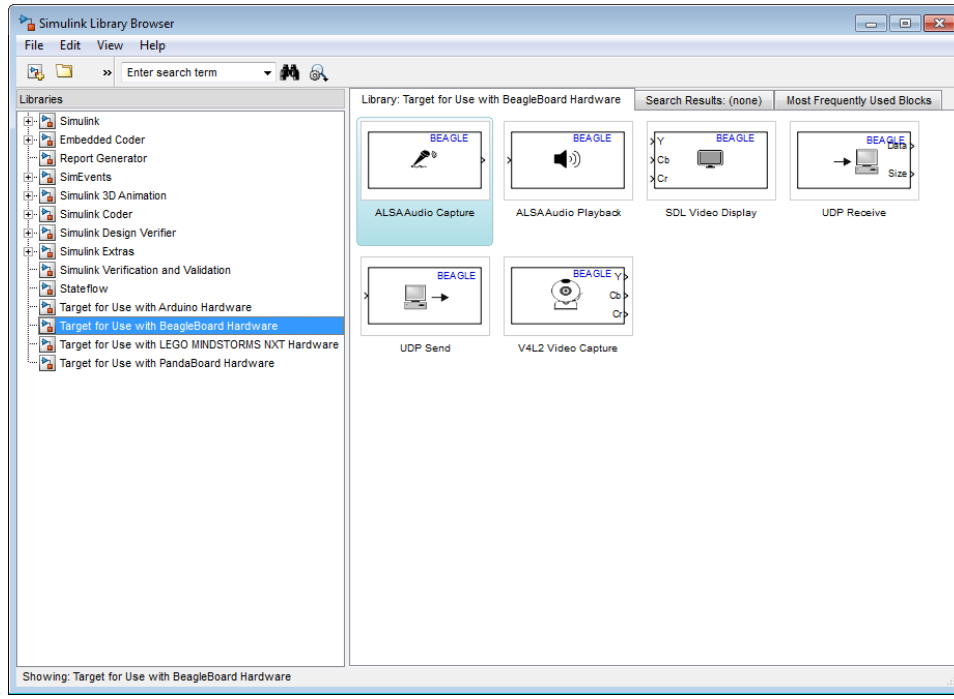
The following block library opens.



To open the block library from the Simulink Library Browser:

1 Open the Simulink Library Browser by entering `simulink` in the MATLAB Command Window, or by clicking the following icon on the MATLAB toolbar.

2 In the Simulink Library Browser, click **Target for Use with BeagleBoard Hardware**.



Run Model on BeagleBoard Hardware

This example shows how to prepare, configure, and run a simple model on your BeagleBoard hardware (the "board").

Before starting this procedure:

- Connect your board to the network and to a power supply.
- Create or open a Simulink model.

To prepare and run the model:

1. Use **File > Save As** to create a working copy of your model. Keep the original model as a backup copy.
2. In your model, select **ToolsRun on Target HardwarePrepare to Run**. This action changes the model Configuration Parameters.
3. In the Run on Target Hardware pane that opens, set the **Target hardware** parameter to `BeagleBoard`.
4. If you have changed boards since the last time you updated the firmware or ran a model, update the **Host name**, **User name**, and **Password** parameters.
5. Select **Tools > Run on Target Hardware > Run**. This action automatically downloads and runs your model on the board.

Note Pressing RESET or cycling the power on the BeagleBoard hardware during this step can cause the ssh utility to hang.

Warning **Avoid using the RESET button to stop a running model and reboot the board. Doing so can corrupt operating system and program files. To fix corrupt files, replace the firmware as described in "Replace Firmware on BeagleBoard Hardware" on page 54-9.**

Running a new or updated model on the board:

- Automatically stops a running model with the same name.

- Does not stop running models that have other names.

To stop a model running on the board, enter the following commands in the MATLAB Command Window:

```
h=beagle;
h.stop('modelName');
```

For example, to stop the sumdiff model, enter:

```
h=beagle;
h.stop('sumdiff');
```

To restart a model that was previously running on the board, or to run multiple instances of a model, enter the following commands in the MATLAB Command Window:

```
h=beagle;
h.run('modelName');
```

Note You do not need to enter `h=beagle;` multiple times if a previous instance of `h` is available in the MATLAB Workspace.

For example, to restart the sumdiff model you stopped in the previous example, enter:

```
h.run('sumdiff');
```

Prepare Models That Use Model Reference

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*. The model that contains a referenced model is its *parent model*. When you run parent model on your target hardware, the submodel effectively replaces the Model block that references it. For more information, see "Overview of Model Referencing" on page 6-2.

To run on target hardware, the parent model and the submodels must have the same Configuration Parameter settings.

For each Model block:

- Select **Tools > Run on Target Hardware > Prepare to Run**.
- Apply the same Configuration Parameters settings to the submodel as you applied to the parent model.

If the model and Model blocks have different settings, the software generates an error when you try to run the model on the target hardware.

See Also

- "Create the Simple Model"
- "Configure Network Connection with BeagleBoard Hardware" on page 54-30
- "Tune and Monitor Model Running on BeagleBoard Hardware" on page 54-42
- "Overview of Model Referencing" on page 6-2

Tune and Monitor Model Running on BeagleBoard Hardware

In this section...

About External Mode

You can use External mode to tune parameters and monitor a model running on your target hardware.

External mode enables you to tune model parameters and evaluate the effects of different parameter values on model results in real-time, in order to find the optimal values to achieve desired performance. This process is called *parameter tuning*.

External mode accelerates parameter tuning because you do not have to re-run the model each time you change parameters. External mode also lets you develop and validate your model using the actual data and hardware for which it is designed. This software-hardware interaction is not available solely by simulating a model.

The following list provides an overview of the parameter tuning process with External mode:

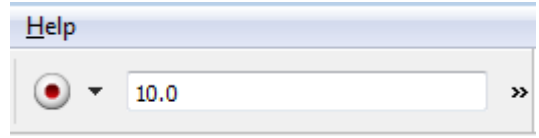
- In the model on your host computer, you enable External mode in the Configuration Parameters.
- In the model on your host computer, you tell Simulink software to run your model on the target hardware.
- Simulink software runs the model on the target hardware.
- You use the model on the host computer as a user interface for interacting with the model running on the target hardware:

  - When open blocks and apply new parameter values on the host computer, External mode updates the corresponding values on target hardware.
  - If your model contains blocks for viewing data, such as Scope or Display blocks, External mode sends the corresponding data from the target hardware to those blocks on the host computer.
- You determine the optimal parameter values by adjusting parameter values on the host computer and observing data/outputs from the target hardware.
- When you are finished, you save the new parameter values, disable External mode, and save the model.

Run Your Simulink Model in External Mode

1. Create a network connection between the BeagleBoard hardware and your host computer. See "Configure Network Connection with BeagleBoard Hardware" on page 54-30

2. In the model, set the **Simulation stop time** parameter, located on the model toolbar, as shown here.



   - To run the model for an indefinite period, enter `inf`.
   - To run the model for a finite period, enter a number of seconds. For example, entering `120` runs the model on the hardware for 2 minutes.

3. Select **Tools > Run on Target Hardware > Options**.

4. In the Run on Target Hardware pane that opens, select **Enable External mode**.

5. Click **OK**, and then save the changes your model.

6. In your model, select **Tools > Run on Target Hardware > Run**.

   After several minutes, Simulink starts running your model on the board.

7 While the model is running in External mode, you can change parameter values in the model on your host computer and observe the corresponding changes in the model running on the hardware.

If your model contains blocks from the Simulink Sinks block library, the sink blocks in the model on your host computer display the values generated by the model running on the hardware.

If your model does not contain a sink block to which External mode can send data, the MATLAB Command Window displays a warning message. For example:

```
Warning: No data has been selected for uploading.
> In C:\Program Files (x86)\MATLAB\R2012a Student1\toolbox\
realtime\realtime\+realtime\extModeAutoConnect.p>
extModeAutoConnect at 17
In C:\Program Files (x86)\MATLAB\R2012a Student1\toolbox\
realtime\realtime\sl_customization.p>myRunCallback at 149
```

You can disregard this warning, or you can add a sink block to the model.

Note To use External mode with the Run on Target Hardware feature, only use the External mode settings described in this topic.

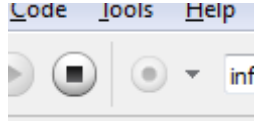
If you have Simulink Coder or Embedded Coder software, do not use other External mode-related items that appear that in the Tools menu or the Configuration Parameters dialog.

Note External mode increases the processing burden of the model running on the board. If the software reports an overrun, clear the **Enable External mode** checkbox in the Run on Target Hardware pane.

Note If you have the Embedded Coder or Simulink Coder products, you can use External mode with a model that contains Model blocks (uses the “Model reference”).

Stop External Mode

To stop the model running in External mode, click the Stop button located on the model toolbar, as shown here.



This action stops the process for the model running on the BeagleBoard hardware, and stops the model simulation running on your host computer.

If it is set to a finite period, the **Simulation stop time** parameter stops External mode when the period elapses.

Detect and Fix Task Overruns on BeagleBoard Hardware

You can configure a model running on the target hardware to detect and notify you of when task overrun occurs.

Standard scheduling works well when a processor is moderately loaded but may fail if the processor becomes overloaded. When a task is required to perform extra processing and takes longer than normal to execute, it may be scheduled to execute before a previous instance of the same task has completed. The result is a task overrun.

To enable overrun detection:

1. In your model, click **Tools > Run on Target Hardware > Options**.
2. In the Run on Target Hardware pane that opens, select the **Enable overrun detection** check box.
3. Click **OK**.

When a task overrun occurs, the command prompt on the host machine repeatedly prints an "Overrun" error message, such as "Overrun — rate for subrate task 1 is too fast", until the model stops.

To fix an overrun condition:

- Simplify the model.
- Increase the sample times for the model and the blocks in it. For example, change the **Sample time** parameter in all of your data source blocks, such as blocks for input devices, from `0.1` to `0.2`.

Note External mode increases the processing burden of the model running on your board. If the software reports an overrun, clear the **Enable External mode** checkbox in the Run on Target Hardware pane.

55

Work with LEGO MINDSTORMS NXT Hardware

Install Support for LEGO MINDSTORMS NXT Hardware

This example shows how to add support for LEGO MINDSTORMS NXT hardware to the Simulink product.

This process downloads and installs:

- Third-party software development tools on your host computer.
- A Simulink block library called **Target for Use with LEGO MINDSTORMS NXT Hardware**.
- Examples

For convenience, this document occasionally refers to LEGO MINDSTORMS NXT hardware as an "NXT brick" or as "target hardware".

Note You can only use this target on a host computer running 32-bit or 64-bit version of Windows that Simulink supports.

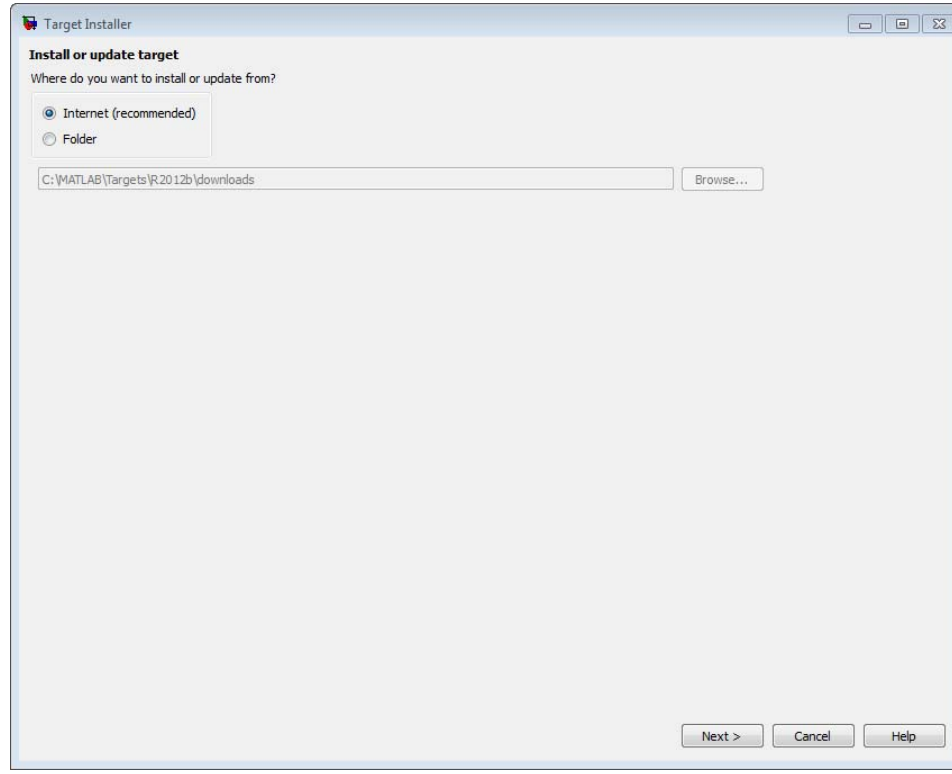
Repeat this process every six months or so to update the third-party tools, the block library, or firmware to the latest versions.

1. Open the **Install or update target** screen in the Target Installer using one of the following methods:

   - In a model, select **Tools > Run on Target Hardware > Install/Update Support Package**.
   - In a MATLAB Command Window, enter `targetinstaller`.

2. Target Installer prompts "Where do you want to install or update from?"

   Keep the default, **Internet**, and click **Next**.



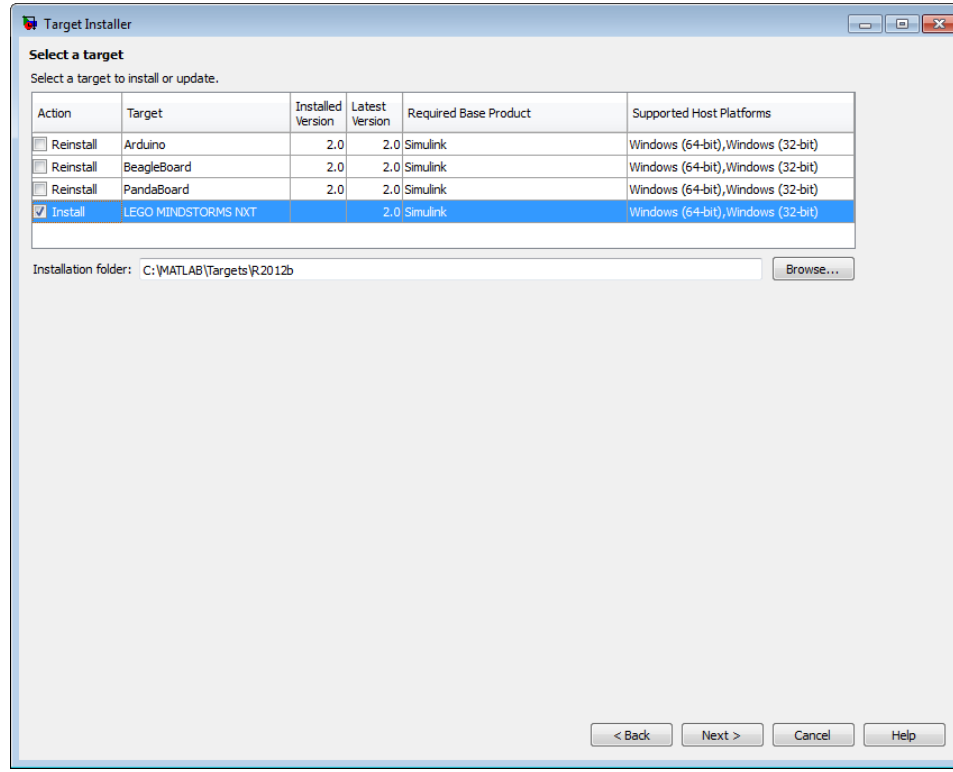
Note If you choose the **Folder** option, place the support package zip file in a folder for which you have write privileges. Otherwise, the Target Installer cannot complete the installation process.

If the support package in a read-only folder, copy the support package zip file to a writable folder before continuing. For example, copy `legomindstormsnxt_r20*.zip` from a read-only network drive to the `C:\MATLAB\Targets\R20*\downloads` folder on your host computer.

Note If you are choosing the **Folder** option because you do not have Internet access, the support package folder must also contain installers for the required third-party software.

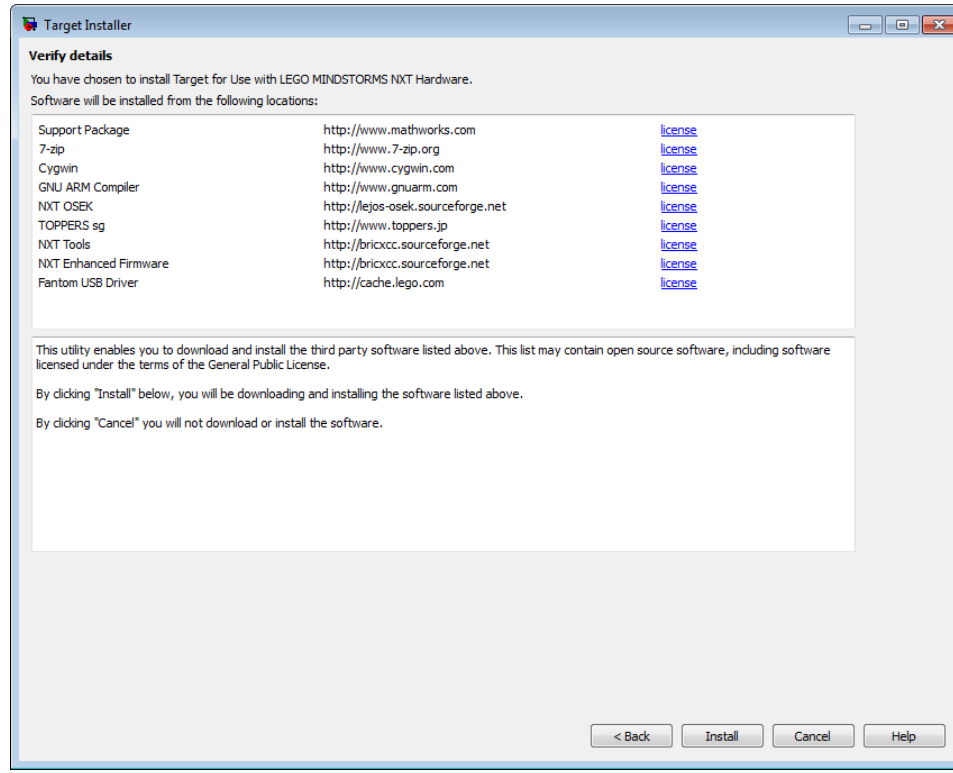
3 Select the `LEGO MINDSTORMS NXT` checkbox and click **Next**.

The **Installation folder** parameter tells Target Installer where to install the support package and the third-party software. Set the **Installation folder** parameter to a local hard drive. Do not use a mapped network drive because doing so causes the Cygwin installation to fail during the target installation process.

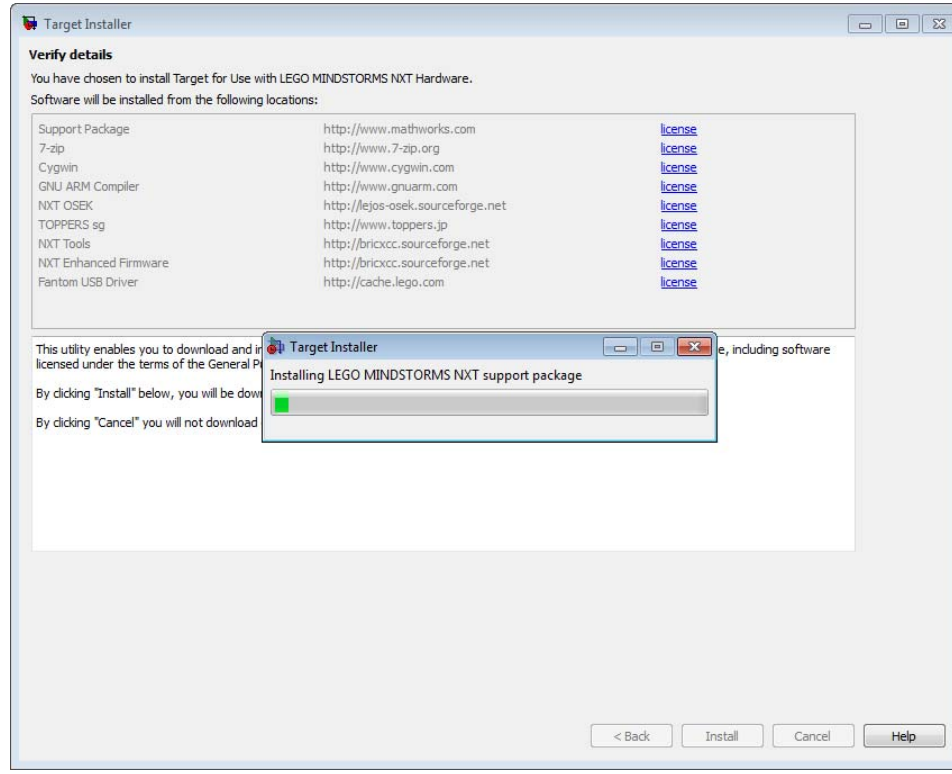


4 Target Installer states that you have chosen to install the support package for LEGO MINDSTORMS NXT and lists third-party software it will install.

Review the information, and click **Install**.



Target Installer displays a progress bar while it downloads and installs the third-party software.



Note If you installed the target previously, Target Installer removes the files from that installation before installing the current target. If Target Installer cannot remove those files automatically, it instructs you to delete the files manually. Close the MATLAB software before removing the files. Then, restart MATLAB software and run Target Installer again.

5 The Target Installer finishes installing the target and displays the following screen.

If your NXT brick still has its factory-installed firmware, click **Continue >** and complete the process described in “Replace Firmware on NXT Brick” on page 55-7. Otherwise, click **Close**.

Replace Firmware on NXT Brick

This topic shows how to replace the firmware on the NXT brick with enhanced firmware that can run Simulink models. The enhanced firmware can run

When you complete this process, and install the target for use with LEGO MINDSTORMS NXT hardware, you can run a Simulink model on NXT brick, as described in "Run Model on NXT Brick" on page 55-14.

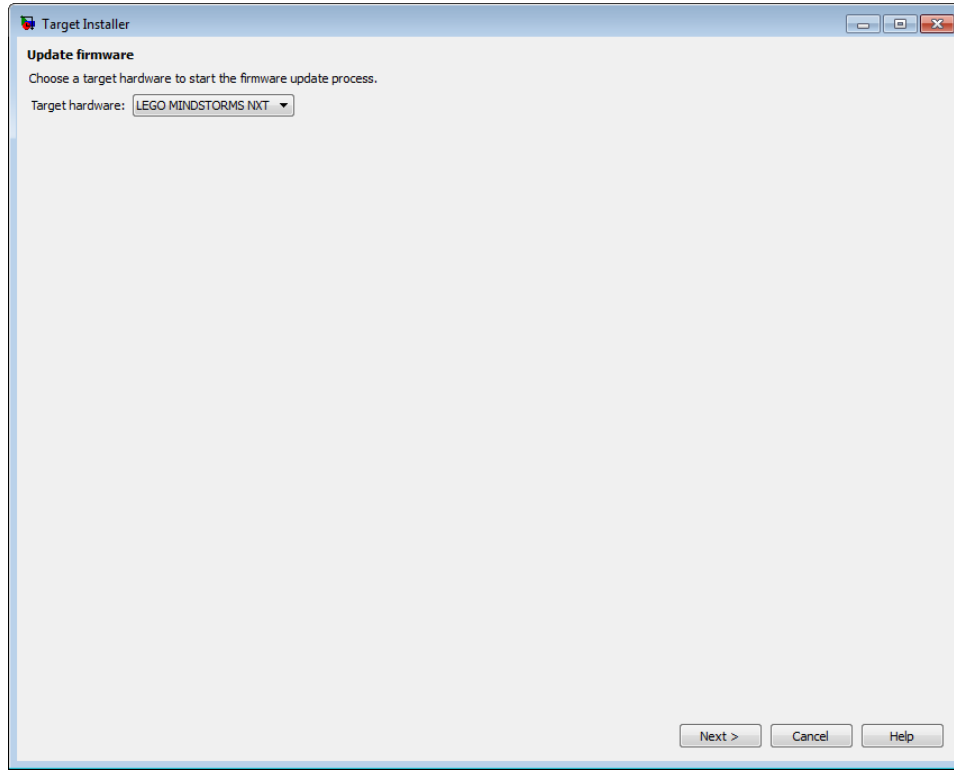
Repeat this process every six months or so to replace the firmware with the latest version.

Warning **This process completely erases the memory on the NXT brick.**

1. Open the **Update firmware** screen in the Target Installer using one of the following methods:

   - Click **Continue >** in the **Install/update complete** screen of the Target Installer.
   - In a model, select **Tools** > **Run on Target Hardware** > **Update firmware**.
   - In a MATLAB Command Window, enter `targetupdater`.

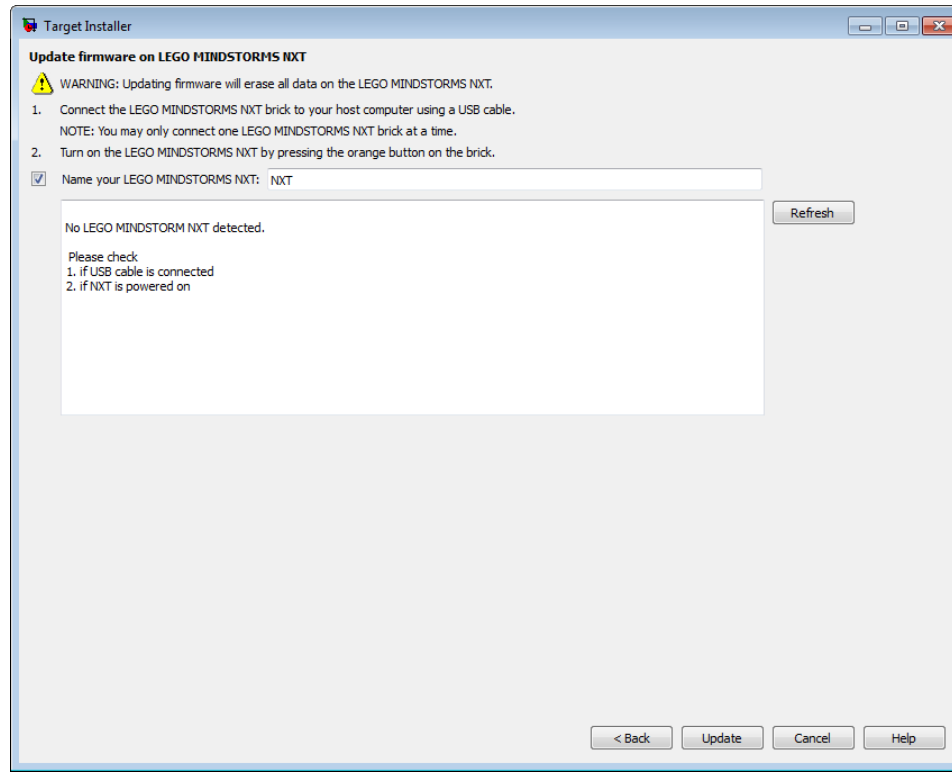
2. Choose `LEGO MINDSTORMS NXT` and click **Next**.



3 Connect the NXT brick to your host computer with a USB cable.

Turn the NXT brick on by pressing its orange button.

Enter a unique name for the **Name your LEGO MINDSTORMS NXT** parameter, and click **Next**.



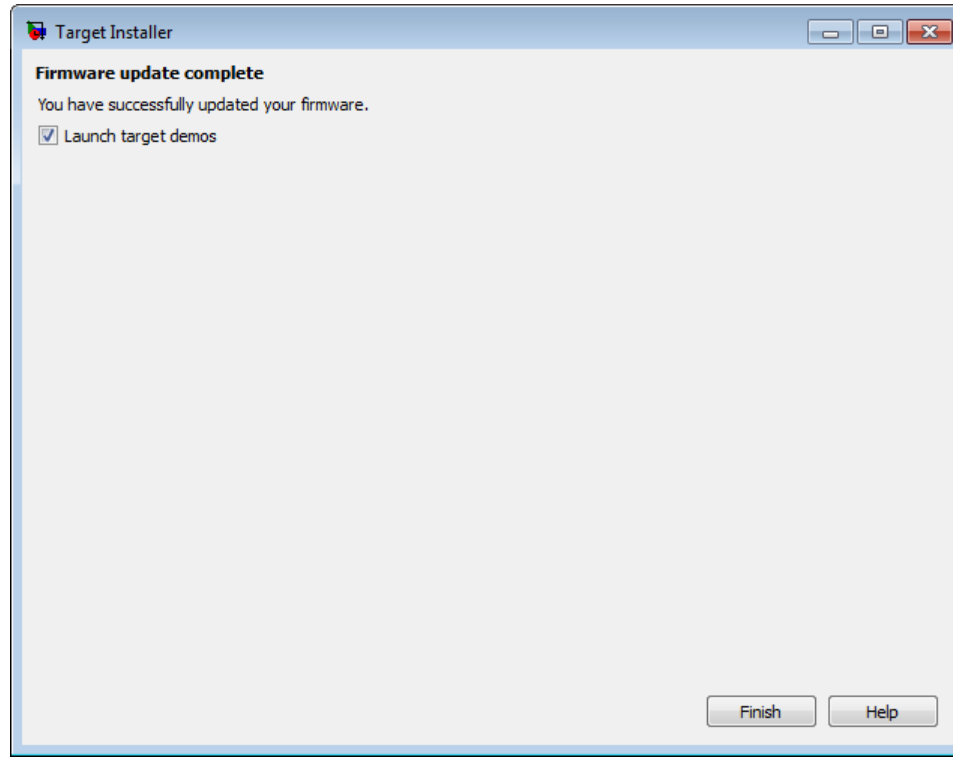
During the firmware update, the NXT brick emits a faint ticking sound and the LCD goes blank. The USB connection to the host computer can disconnect and reconnect multiple times.

When the firmware process is complete, the NXT brick displays the default screen including `My Files`.

4 Click **Finish** and review the examples.

Note To reopen the examples later, enter the following text in a MATLAB Command Window:

```
demo simulink 'Target for Use with LEGO'
```



Open Block Library for LEGO MINDSTORMS NXT Hardware

The block library for LEGO MINDSTORMS NXT hardware is a collection of blocks that provides drivers for LEGO MINDSTORMS NXT sensors and hardware.

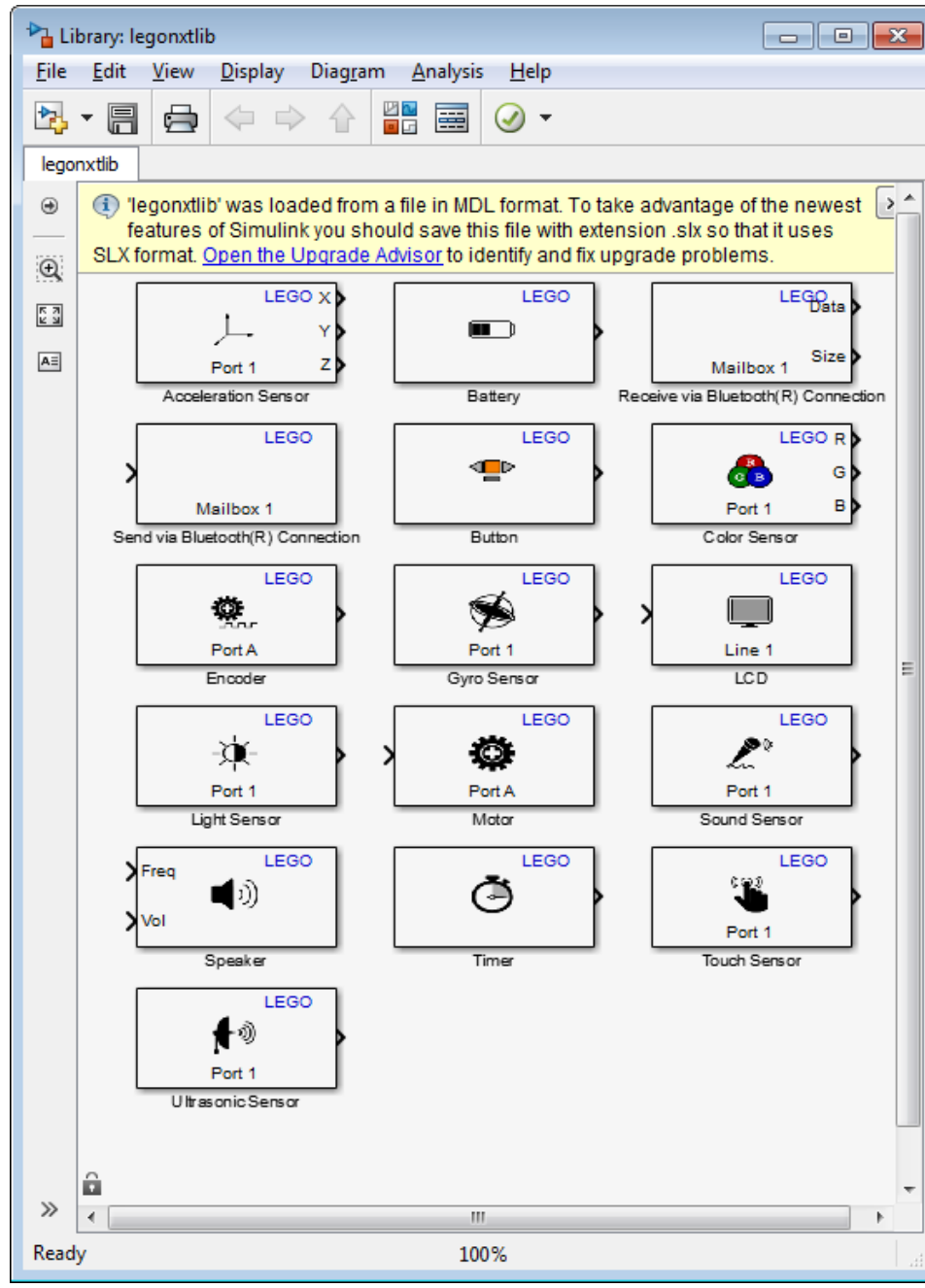
There are two ways to open the block library for LEGO MINDSTORMS NXT hardware:

- The MATLAB Command Window. This approach is quick, but doesn't display the other Simulink block libraries that are available.
- The Simulink Library Browser. This approach takes a few more steps, but displays all of the Simulink block libraries that are available.

1 In the MATLAB Command Window, enter:

```
legonxtlib
```

The block library for LEGO MINDSTORMS NXT hardware opens.


Library: legonxtlib
File Edit View Display Diagram Analysis Help
legonxtlib
'legonxtlib' was loaded from a file in MDL format. To take advantage of the newest features of Simulink you should save this file with extension .slx so that it uses SLX format. Open the Upgrade Advisor to identify and fix upgrade problems.
LEGO X Y Z Port 1 Acceleration Sensor
LEGO Battery
LEGO Data Size Mailbox 1 Receive via Bluetooth(R) Connection
LEGO Mailbox 1 Send via Bluetooth(R) Connection
LEGO Button
LEGO R G B Port 1 Color Sensor
LEGO Port A Encoder
LEGO Port 1 Gyro Sensor
LEGO Line 1 LCD
LEGO Port 1 Light Sensor
LEGO Port A Motor
LEGO Port 1 Sound Sensor
LEGO Freq Vol Speaker
LEGO Timer
LEGO Port 1 Touch Sensor
LEGO Port 1 Ultrasonic Sensor
Ready
100%

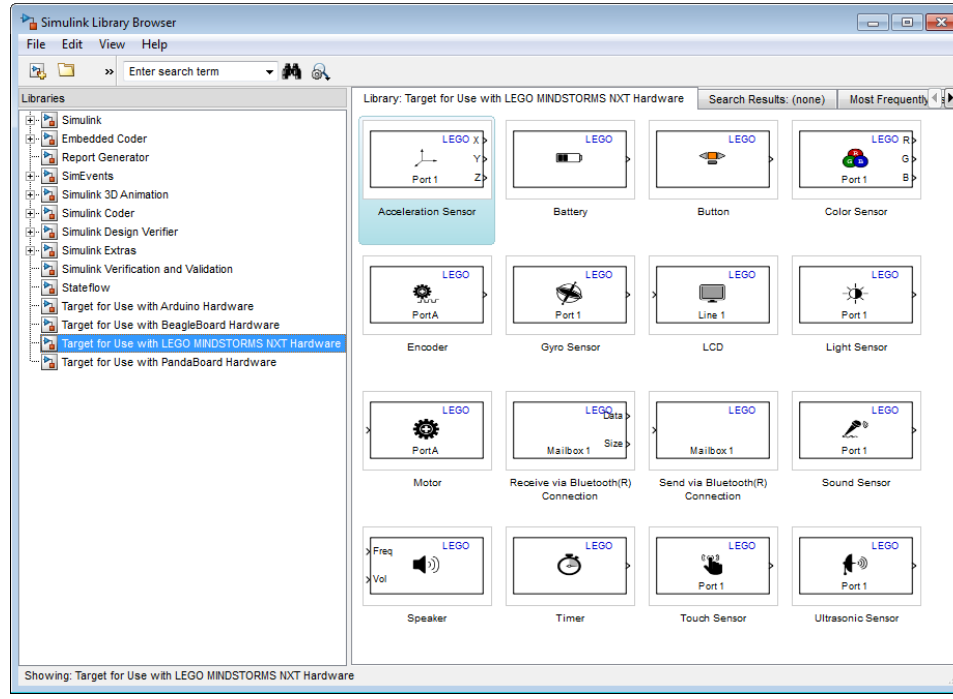
2 In the MATLAB Command Window, enter:

```
simulink
```

Or, in the MATLAB Toolbar, click the following icon.

Simulink Library Browser opens.

3 In the Simulink Library Browser, click **Target for Use with LEGO MINDSTORMS NXT Hardware**.



Run Model on NXT Brick

This topic shows how to configure and run a model on NXT brick.

Before starting this procedure, create or open a Simulink model.

1. Connect your NXT brick to the host computer using a USB cable or a Bluetooth® device. Simulink software uses this connection to download the model to the NXT hardware when you run the model.

   For more information about using a Bluetooth device, see "Set Up A Bluetooth Connection" on page 55-31.

2. Use **File > Save As** to create a working copy of your model. Keep the original model as a backup copy.

3. In your model, select **Tools > Run on Target Hardware > Prepare to Run**. This action changes the model Configuration Parameters.

4. In the Run on Target Hardware pane that opens, set the **Target hardware** parameter to `LEGO MINDSTORMS NXT`.

5. Set the **Connection type** parameter to `USB connection` or `Bluetooth connection`.

6. Turn the NXT brick on by pressing the orange button. The LCD displays LEGO and MINDSTORMS splash screens, and then **My Files**.

   Note The NXT brick automatically powers down after several minutes of inactivity. If this happens, turn the power back on.

7. Select **Tools > Run on Target Hardware > Run**. This action automatically downloads and runs your model on the NXT brick.

   When the NXT hardware starts running the model, the LCD displays "I am running ...", or it displays the input values and labels of any LCD blocks in the model.

Note To restart a model while it is running, press the left-arrow button on the NXT brick.

To restart a model that is stopped, use the orange button on the NXT brick to select My Files > Software Files, and then select your model.

To stop the model, press the grey button on the NXT brick.

Prepare Models That Use Model Reference

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*. The model that contains a referenced model is its *parent model*. When you run parent model on your target hardware, the submodel effectively replaces the Model block that references it. For more information, see "Overview of Model Referencing" on page 6-2.

To run on target hardware, the parent model and the submodels must have the same Configuration Parameter settings.

For each Model block:

- Select **Tools > Run on Target Hardware > Prepare to Run**.
- Apply the same Configuration Parameters settings to the submodel as you applied to the parent model.

If the model and Model blocks have different settings, the software generates an error when you try to run the model on the target hardware.

Tune Parameters and Monitor Data in a Model Running on NXT Brick

In this section...

About External Mode

This topic explains how the *External mode* feature enables you to tune parameters and monitor data in a model running on your target hardware.

When you enable External mode and choose the **Run** command, Simulink embeds light-weight client/server code in your model and then runs your model on the target hardware. If you tune parameters in the model on your host computer, External mode updates the corresponding parameter values in the model running on the target hardware. You can use sink blocks, such as Display or Scope blocks, to monitor data from the model running on the target hardware. External mode sends data from the sink blocks on the target hardware to the corresponding sink blocks on your host computer, where you can view or log the data.

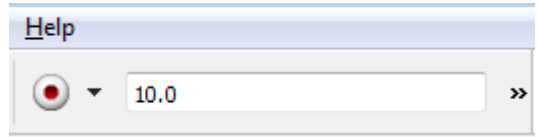
External mode accelerates parameter tuning. When you develop an algorithm, you must typically try a range of parameter values in order to find the optimal settings. Without External mode, you must re-run the model on the target hardware to evaluate the effects of each change. With External mode, you can adjust parameter values, monitor data, and evaluate the results until you find the optimal value, without re-running the model.

External mode increases the processing burden of the model running on the NXT brick. If the model running on the hardware reports an overrun, you can disable External mode or fix the issue as described in "Detect and Fix Task Overruns on NXT Brick" on page 55-22.

Run Your Simulink Model in External Mode

Before running your model in External mode, set up a Bluetooth connection between the NXT hardware and your Windows computer, as described in "Set Up A Bluetooth Connection" on page 55-31

1. In the model, set the **Simulation stop time** parameter, located on the model toolbar, as shown here.



   - To run the model for an indefinite period, enter `inf`.
   - To run the model for a finite period, enter a number of seconds. For example, entering `120` runs the model on the hardware for 2 minutes.

2. Select **Tools** > **Run on Target Hardware** > **Options**.

3. In the Run on Target Hardware pane that opens, select **Enable External mode**.

Note This action disables the **Enable communication between two NXT bricks** parameter. External mode requires exclusive use of the Bluetooth device on the NXT brick.

---

4. Click **OK**, and then save the changes your model.

5. In your model, select **Tools** > **Run on Target Hardware** > **Run**.

   After several minutes, Simulink starts running your model on the NXT brick.

6. While the model is running in External mode, you can change parameter values in the model on your host computer and observe the corresponding changes in the model running on the hardware.

If your model contains blocks from the Simulink Sinks block library, the sink blocks in the model on your host computer display the values generated by the model running on the hardware.

If your model does not contain a sink block to which External mode can send data, the MATLAB Command Window displays an error message. For example:

```
Warning: No data has been selected for uploading.
> In C:\Program Files (x86)\MATLAB\R2012a Student1\toolbox\
realtime\realtime\+realtime\extModeAutoConnect.p>
extModeAutoConnect at 17
In C:\Program Files (x86)\MATLAB\R2012a Student1\toolbox\
realtime\realtime\sl_customization.p>myRunCallback at 149
```

You can disregard this warning, or you can add a sink block to the model.

Note To use External mode with the Run on Target Hardware feature, only use the External mode settings described in this topic.

If you have Simulink Coder or Embedded Coder software, do not use other External mode-related items that appear that in the Tools menu or the Configuration Parameters dialog.

Note If you have the Embedded Coder or Simulink Coder products, you can use External mode with a model that contains Model blocks (uses the "Model reference").

Stop External Mode

To stop the model running in External mode, click the Stop button located on the model toolbar, as shown here.

This action turns off the power of the NXT brick, and stops the model simulation running on your host computer.

If it is set to a finite period, the **Simulation stop time** parameter stops External mode when the period elapses.

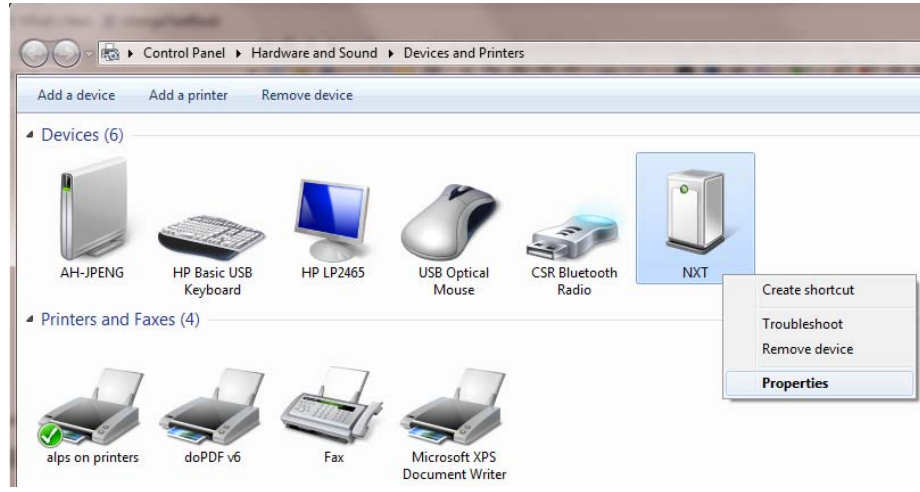
Set COM Port Number Manually

By default, Run on Target Hardware automatically gets the COM port number of the NXT brick when you use External mode. However, you have the option of setting the COM port number manually.

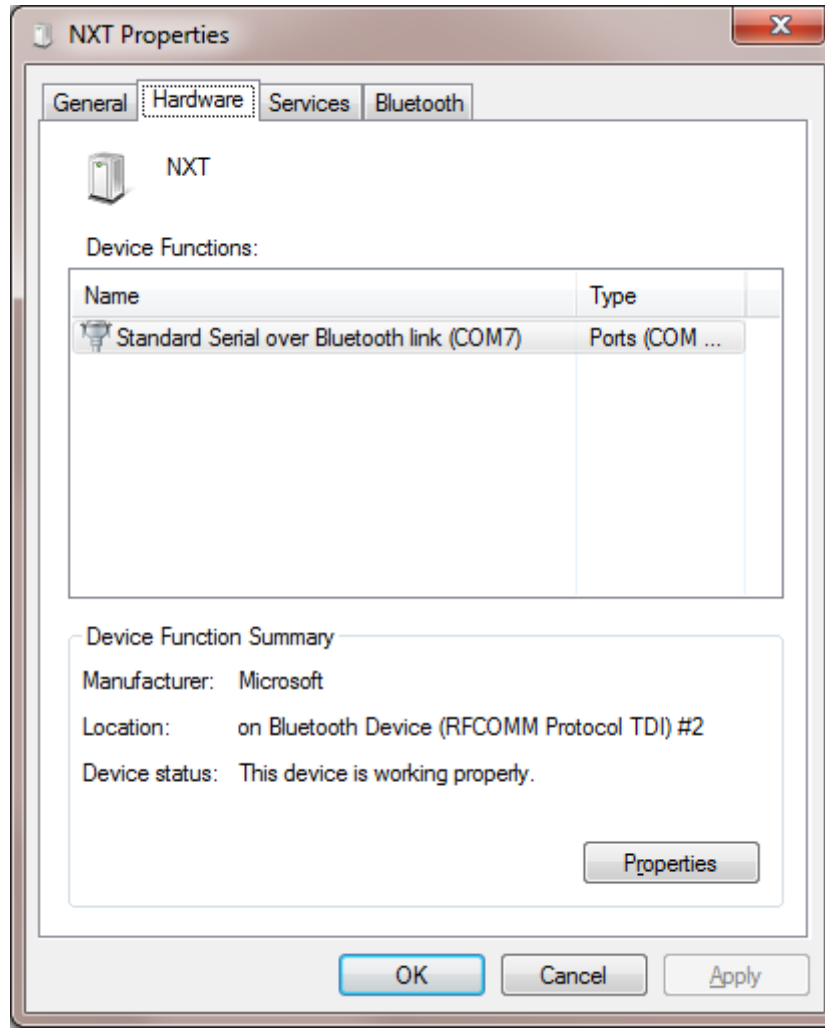
1. In Windows, locate the NXT brick under **Control Panel > Hardware and Sound > Devices and Printers**.

   The NXT brick uses the name you assigned to it during the firmware update process. By default, that name is "NXT". If you changed that name during the firmware update, the Windows device label shows that new name.

2. Right-click the NTX brick and select **Properties**.



3. In the Properties dialog box, select the Hardware tab and make a note of the COM port number.



4 In your model, select the **Tools > Run on Target Hardware > Options** menu item.

5 In the Run on Target Hardware pane that opens, change the **Set host COM port** parameter to `Manually`.

6 In the **COM port number** parameter, enter the COM port number you noted earlier.

Detect and Fix Task Overruns on NXT Brick

You can configure a model running on the target hardware to detect and notify you of when task overrun occurs.

Standard scheduling works well when a processor is moderately loaded but may fail if the processor becomes overloaded. When a task is required to perform extra processing and takes longer than normal to execute, it may be scheduled to execute before a previous instance of the same task has completed. The result is a task overrun.

To enable overrun detection:

1. In your model, click **Tools**, **Run on Target Hardware** and **Options**.
2. In the Run on Target Hardware pane that opens, select the **Enable overrun detection** check box.
3. Click **OK**.

When a task overrun occurs, the LCD on the NXT brick displays an "Overrun!" error message until you stop the model.

To fix an overrun condition:

- Simplify the model.
- Increase the sample times for the model and the blocks in it. For example, change the **Sample time** parameter in all of your data sources, such as the sensor blocks, from `0.1` to `0.2`.

Note External mode increases the processing burden of the model running on the NXT brick. If the software reports an overrun, clear the **Enable External mode** checkbox in the Run on Target Hardware pane.

Exchange Data Between Two NXT Bricks

In this section...

This topic explains how to exchange data between two separate NXT Intelligent Bricks ("NXT bricks") over a Bluetooth connection.

If, instead, you are looking for information about exchanging data between your host computer and an NXT brick, see "Tune Parameters and Monitor Data in a Model Running on NXT Brick" on page 55-16.

Tips for Use Bluetooth Blocks

Here are some tips for using the Send via Bluetooth Connection block and Receive via Bluetooth Connection block:

- Use two separate models, one for each NXT brick.
- You can only use the Bluetooth blocks for connecting two NXT bricks.
- For each Send via Bluetooth Connection block in one model, use a corresponding Receive via Bluetooth Connection block in the other model. Set the **Mailbox** parameter in both blocks to the same number.
- For each Receive via Bluetooth Connection block in a model, use a unique Mailbox number.
- A model can contain no more than five Receive via Bluetooth Connection blocks.

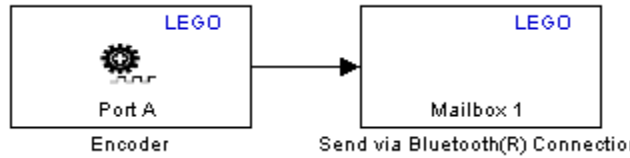
Add Bluetooth Blocks to your Models

Add Bluetooth blocks to your models and configure them:

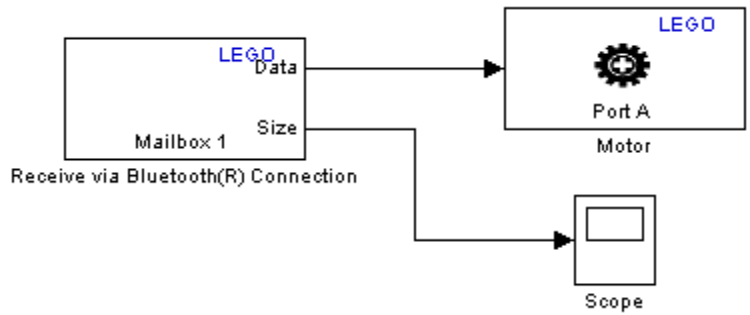
1. Open `legonxtlib`.

2 Open two models. One for each NXT brick.

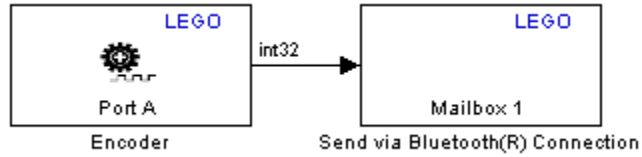
3 Add a Send via Bluetooth Connection block to a model, and connect it to the data source, as shown in the following example.



4 Add a Receive via Bluetooth Connection block to the other model, and connect it to the data sinks, as shown in the following example.



5 In the model that contains the Send via Bluetooth Connection block, select the **Display > Signals & Ports > Port Data Types** menu item. Then, select **Simulation > Update Diagram Ctrl+D**. Observe the data type that appears above the connector attached to the Send via Bluetooth Connection block. For example “int32” in the following example.

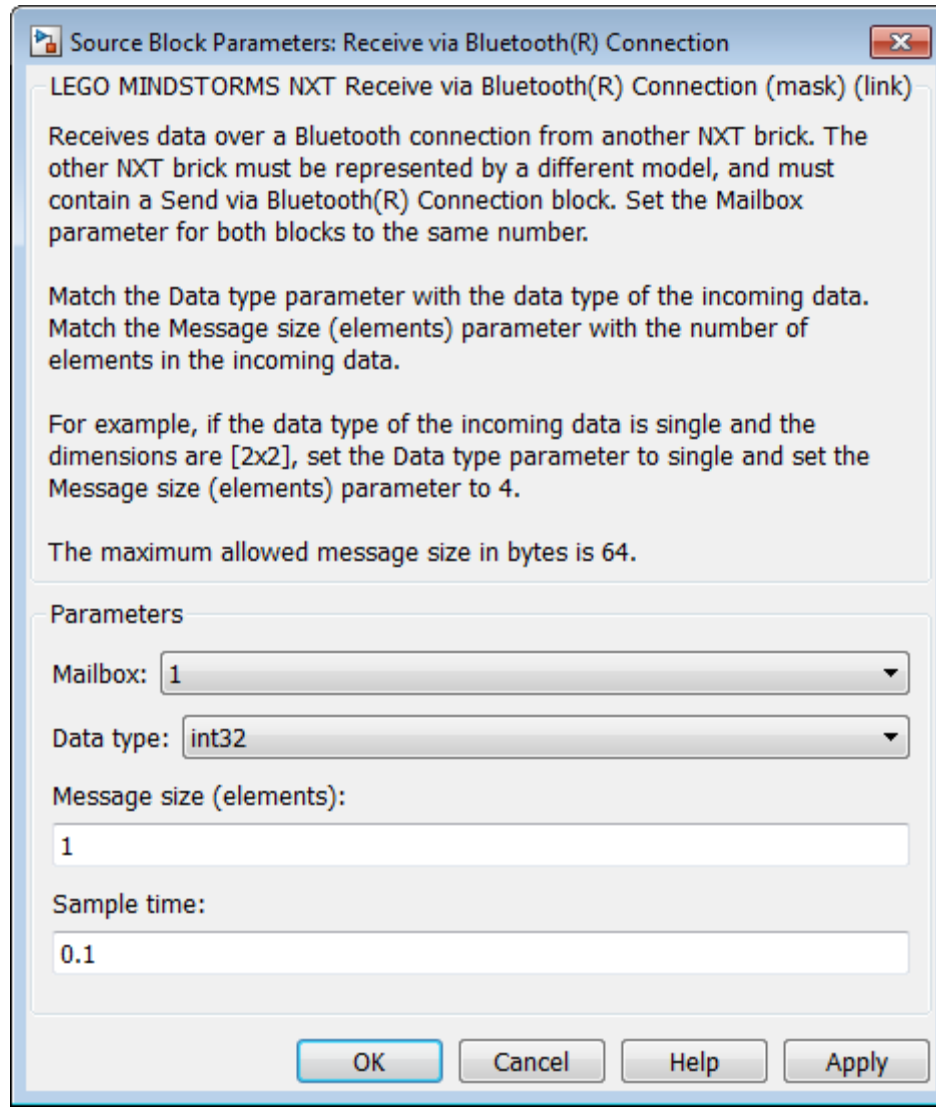


6. Open the Receive via Bluetooth Connection block in the other model. Apply the data type from the previous step to the **Data type** parameter in the Receive via Bluetooth Connection block.

7. In the model that contains the Send via Bluetooth Connection block, select the **Display > Signals & Ports > Signal Dimensions** menu item. Then, select **Simulation > Update Diagram Ctrl+D**.

   - If the signal dimensions are greater than 1, the connector attached to the Send via Bluetooth Connection block displays the signal dimension. Multiply the signal dimensions to get the value you will apply to the **Message size** parameter. For example, if the signal dimensions are 2x10, the set **Message size** to 10.
   - If the signal is one-dimensional, the connector attached to the Send via Bluetooth Connection block does not display a signal dimension. For a one-dimensional signal, set **Message size** to 1.

8. In the model that contains the Receive via Bluetooth Connection block, apply the signal dimension from the previous step to the **Signal dimension** parameter in the Receive via Bluetooth Connection block.



9 Save all of your changes and leave the models open.

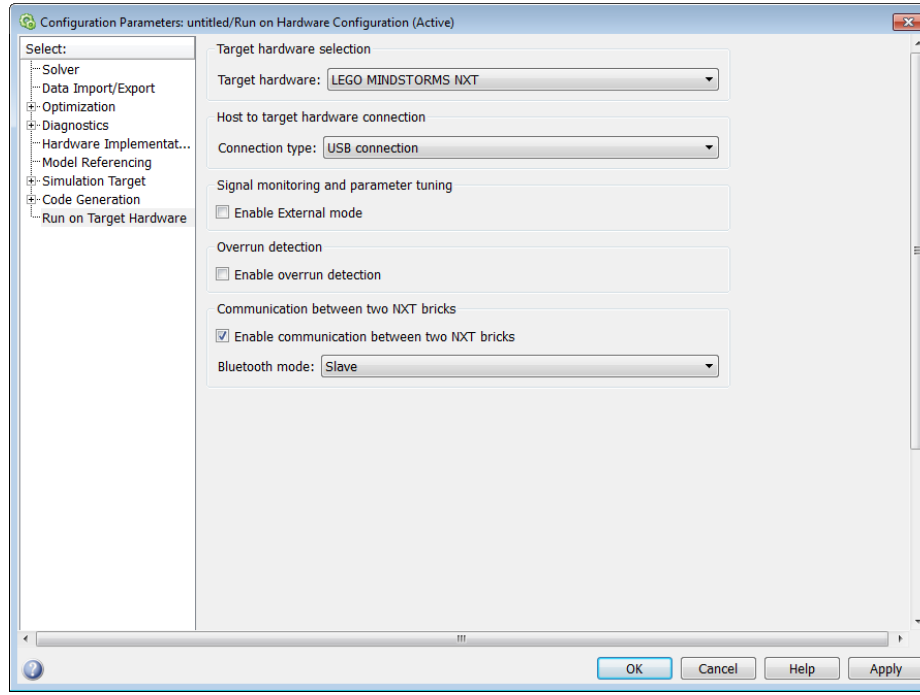
Configure Bluetooth Slave

Using your models, configure the NXT brick to operate as a slave Bluetooth node. You can make this choice arbitrarily, without regard to which device is sending or receiving data.

To configure an NXT brick as a slave Bluetooth node:

1. Open one model and select **Tools > Run on Target Hardware > Options**.
2. In the Run on Target Hardware pane that opens, select the **Enable communication between two NXT bricks** check box, and set **Bluetooth mode** to `Slave`.

Note This action disables the **External mode** parameter. Enabling communication between two NXT bricks requires exclusive use of the Bluetooth device on the NXT brick.



3 Click **OK**. This saves and closes the Configuration Parameters.

4 In your model, select **Tools > Run on Target Hardware > Run** to run your model on the NXT brick.

   This process can take a couple of minutes. When the download completes, the NXT brick automatically runs the application.

5 When Simulink software finishes downloading the application to the slave NXT brick, the LCD displays “Waiting...”.

   Observe the number on the second line of the LCD. The first 12 digits of this number are the *Slave Bluetooth address*, which you will use as you configure the Bluetooth master in the next procedure.

Configure Bluetooth Master

Configure the other NXT brick as a master Bluetooth node:

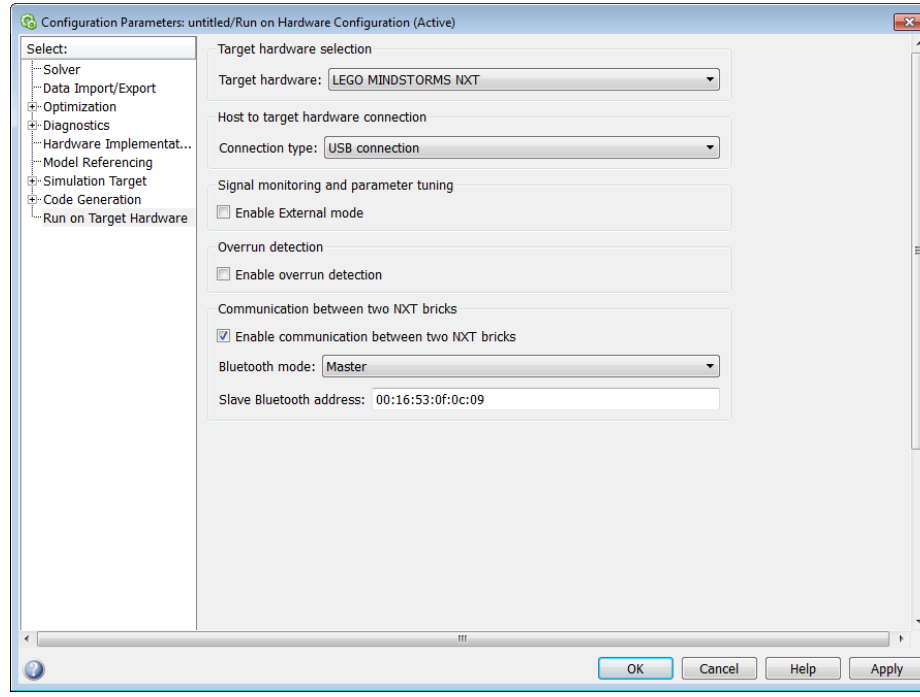
1 Open one model and select **Tools** > **Run on Target Hardware** > **Options**.

2 In the Run on Target Hardware pane that opens, select the **Enable communication between two NXT bricks** check box, and set **Bluetooth mode** to `Master`.

Note This action disables the **External mode** parameter. Enabling communication between two NXT bricks requires exclusive use of the Bluetooth device on the NXT brick.

---

3 Enter the 12-digit **Slave Bluetooth address**, inserting a colon between each pair of digits. For example, if the slave NXT brick displays `00165312926900`, enter `00:16:53:12:92:69`. Disregard the last two digits, `00`.



4 Click **OK**. This saves and closes the Configuration Parameters.

5 In your model, select **Tools > Run on Target Hardware > Run** to run your model on the NXT brick.

   This process can take a couple of minutes. When the download completes, the NXT brick automatically runs the application and connects to the Bluetooth slave.

6 On the Bluetooth master, turn the wheel back and forth. Observe the direction and speed of the wheel on the Bluetooth slave.

Set Up A Bluetooth Connection

This topic shows you how to set up a Bluetooth connection between your Windows host computer and the NXT hardware.

You may need to create a Bluetooth connection between your Windows host computer and the NXT hardware for either of these purposes:

- To enable External mode, as described in "Tune Parameters and Monitor Data in a Model Running on NXT Brick" on page 55-16.
- To download the model to the NXT hardware. You do so by setting the **Connection type** to `Bluetooth connection`, as described in "Run Model on NXT Brick" on page 55-14.

This procedure requires a Bluetooth device on your host computer that is compatible with the NTX's built-in Bluetooth device. Details for adding a Bluetooth device vary from one of version of Windows to another. If needed, search Microsoft help for additional information.

Note Some Bluetooth devices do not support connections with the NXT brick. For this reason, MathWorks recommends using the 9847 Bluetooth Dongle specified on the LEGO MINDSTORMS NXT Web site.

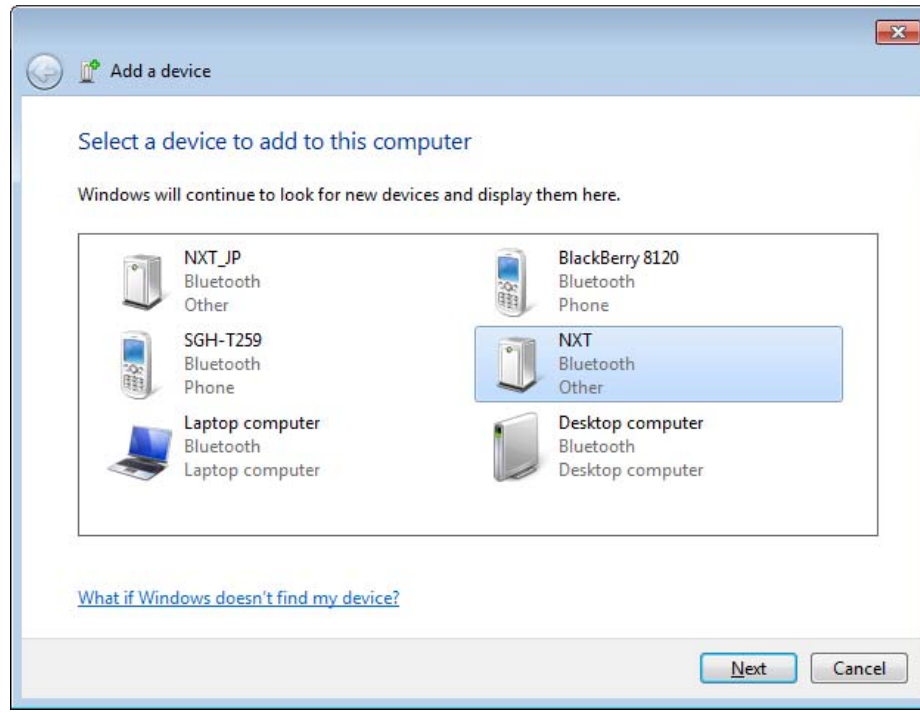
Set up a Bluetooth on your Windows host:

1. Connect a supported Bluetooth dongle to your Windows host computer. Let Windows automatically find and install the appropriate drivers.
2. Turn the NXT brick on, and verify that the small Bluetooth icon is visible in the upper-left corner of the LCD. The icon looks like a capital-B composed of two triangles.

   If the Bluetooth symbol is not visible, press the right arrow on the NXT brick four times. Then, select **Bluetooth > On/Off > On**.
3. In Windows 7, open **Control Panel > Devices and Printers** to check whether the NXT brick has already been added to Devices.

4 If the NXT brick is not among the devices, click **Add a device**.

5 In the **Add a device** wizard that opens, select your NXT Bluetooth device, and click **Next.**

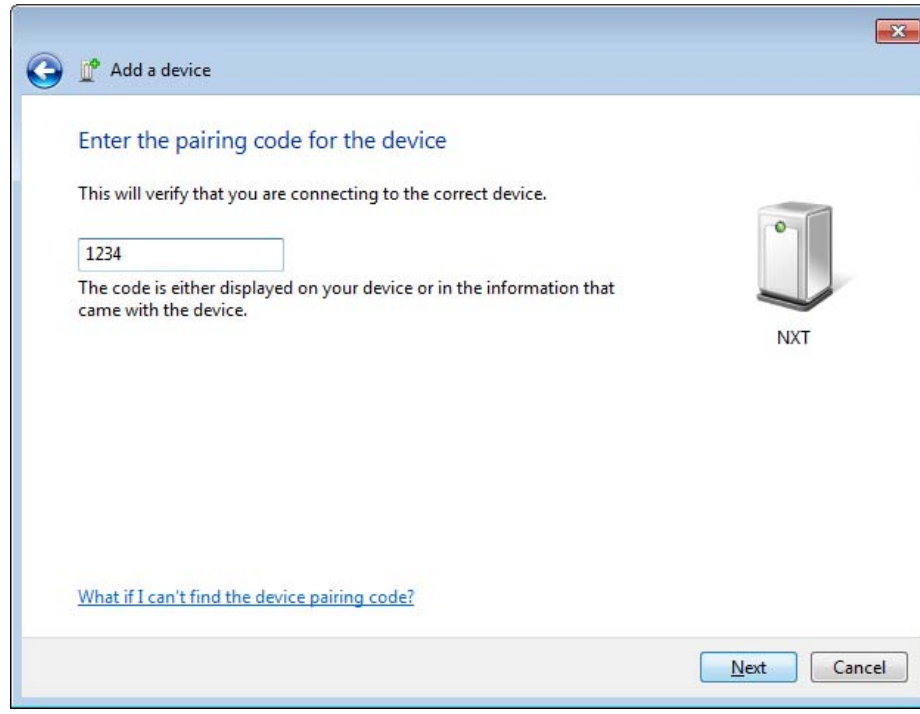


Note All of the NXT bricks operating within Bluetooth range appear in the list of devices. To avoid confusion, assign a unique name to your NXT brick, as described in “Replace Firmware on NXT Brick” on page 55-7.

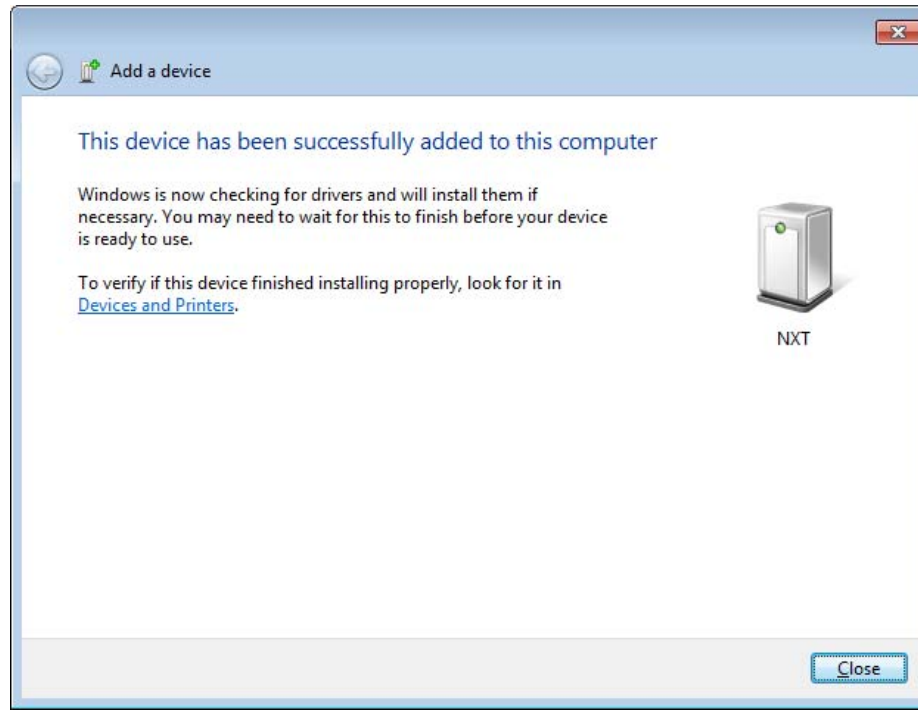
6 When the LCD on the NXT brick displays the default passkey, 1234, promptly press the orange button on the NXT brick.

Note If the NXT times out during this step, return to Windows, select the NXT Bluetooth device, and click **Next**.

7 In the **Add a device** dialog box, enter the passkey, 1234, as the pairing code. Click **Next**.



8 When you see confirmation that the device has been added, click **Close**. The next time you turn on both devices, the Bluetooth connection between your host computer and the NXT brick will be available.



If you have trouble with the Bluetooth connection, try removing the device from Devices and Printers and repeating this process.

56

Work with PandaBoard Hardware

Install Support for PandaBoard Hardware

You can add support for PandaBoard hardware to Simulink product, using the following process. After you complete this process, and replace the firmware on the PandaBoard hardware, you can run a Simulink model on your PandaBoard hardware, as described in "Run Model on PandaBoard Hardware" on page 56-38.

Using this installation process, you download and install the following items on your host computer:

- Third-party software development tools
- A Simulink block library called Target for Use with PandaBoard Hardware.
- Examples

For convenience, these instructions occasionally refer to PandaBoard hardware as a "board" or as "target hardware".

Note You can use this target only on a host computer running a version of 32-bit or 64-bit Windows that Simulink software supports.

---

1. Open the **Install or update target** screen in the Target Installer, using one of the following methods:

   - In a model, select **Tools > Run on Target Hardware > Install/Update Support Package**.
   - In a MATLAB Command Window, enter `targetinstaller`.

2. Choose whether to get the support package from the Internet or from a folder.

Note The file size of the support package and other downloads is over 1 GB. Downloading the support package and third-party software can take a while.

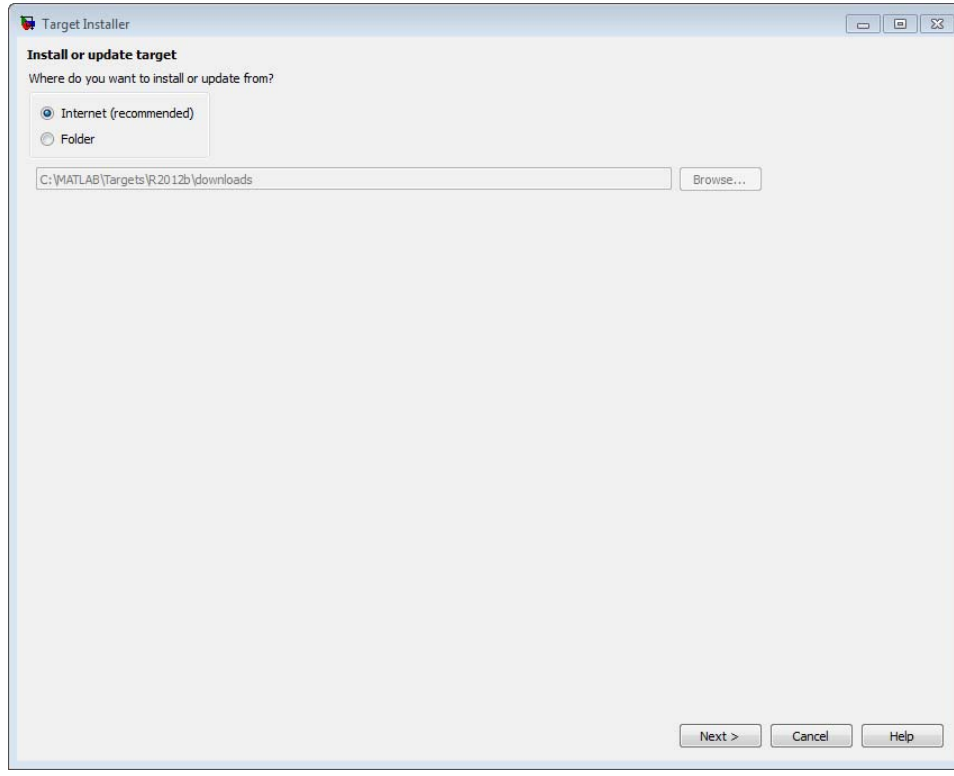
Internet: This option is selected by default. Target Installer downloads and install the support package and third-party software from the Internet.

Folder: Target Installer gets the support package from the folder specified. If you choose Folder, you must have write privileges for the folder specified.

- Installing from the default folder — If you use the default folder, having write privileges is typically not an issue.
- Installing from the folder without write permission — You may want to install from a different folder for which you do not have write permissions, such as a shared folder on a network. If so, Target Installer generates an error message.

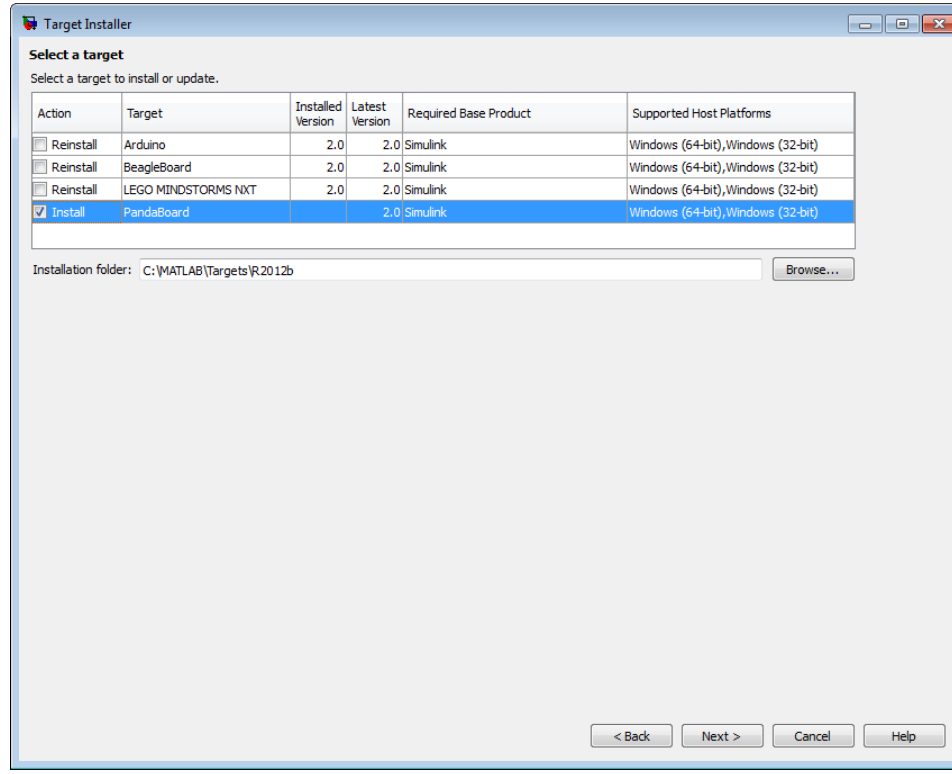
  To resolve this issue, copy the support package to a folder for which you have write privileges, and point Target Installer to that same folder. For example, copy the support package to `C:\MATLAB\Targets\`*`version`*`\downloads`.

  To locate the support package in a folder, search for a filename that begins with `pandaboard` and ends with `.zip`. For example: `pandaboard_r2012a_v1_0.zip`



3 Select the `PandaBoard` check box, and click **Next**.

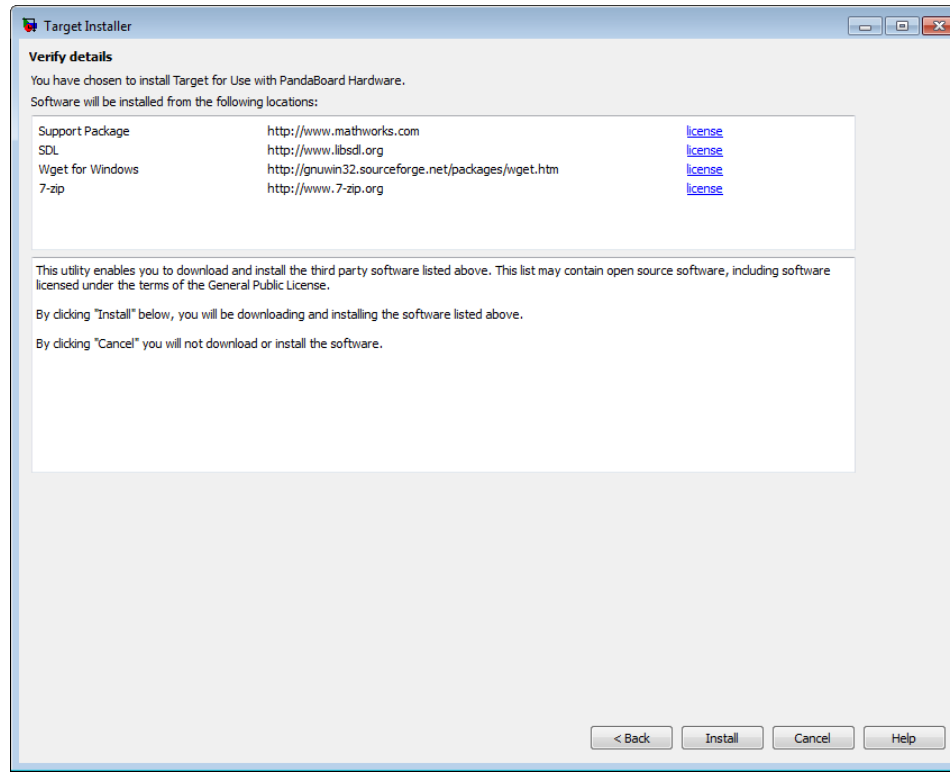
The **Installation folder** parameter specifies where Target Installer puts the target files.



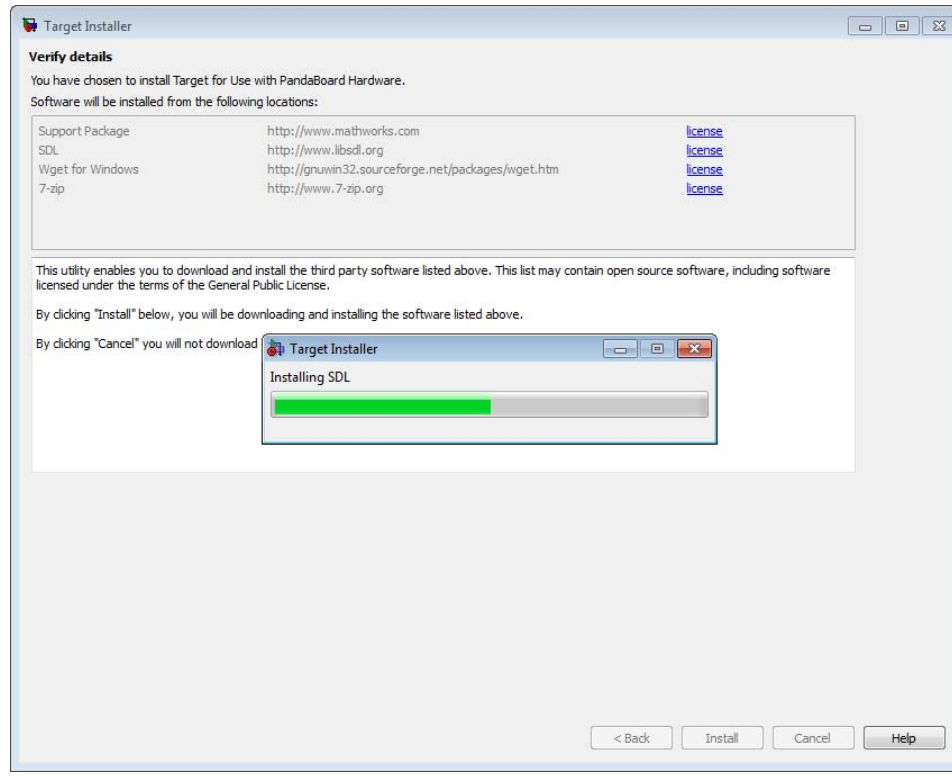
Note You must have write privileges for the Installation folder.

4 Target Installer confirms that you are installing the target, and lists third-party software it will install.

Review the information, including the license agreements, and click **Install**.

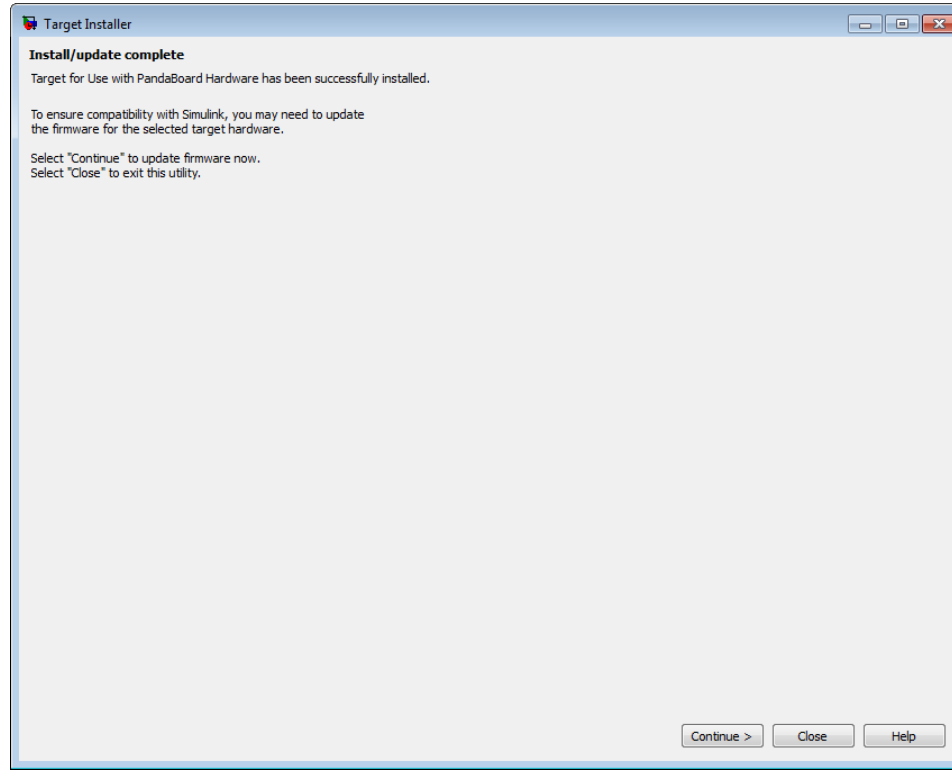


Target Installer displays a progress bar while it downloads and installs the third-party software.



Note If you installed the target previously, Target Installer removes the files from that installation before installing the current target. If Target Installer cannot remove those files automatically, it instructs you to delete the files manually. Close the MATLAB software before removing the files. Then, restart MATLAB software and run Target Installer again.

5 Click **Continue** to replace the factory-installed firmware on the PandaBoard hardware with Ubuntu Linux, as described in "Replace Firmware on PandaBoard Hardware" on page 56-9.


Target Installer
Install/update complete
Target for Use with PandaBoard Hardware has been successfully installed.
To ensure compatibility with Simulink, you may need to update
the firmware for the selected target hardware.
Select "Continue" to update firmware now.
Select "Close" to exit this utility.
Continue >
Close
Help

Replace Firmware on PandaBoard Hardware

This topic shows how to replace the firmware on the PandaBoard hardware (the "board") with a Linaro.org build of Ubuntu Linux firmware that can run Simulink models.

Before replacing the firmware, install the target, as described in "Install Support for PandaBoard Hardware" on page 56-2.

After replacing the firmware, you can run a Simulink model on the PandaBoard hardware, as described in "Run Model on PandaBoard Hardware" on page 56-38.

The following steps provide an overview of the firmware replacement process:

1. The Target Installer locates a firmware image on your host computer or downloads new one.
2. The Target Installer uses the host computer to write the firmware image to a microSD or SD memory card.
3. You transfer the microSD or SD memory card to the PandaBoard hardware.
4. The Target Installer applies the IP settings you choose to the firmware on the PandaBoard hardware.

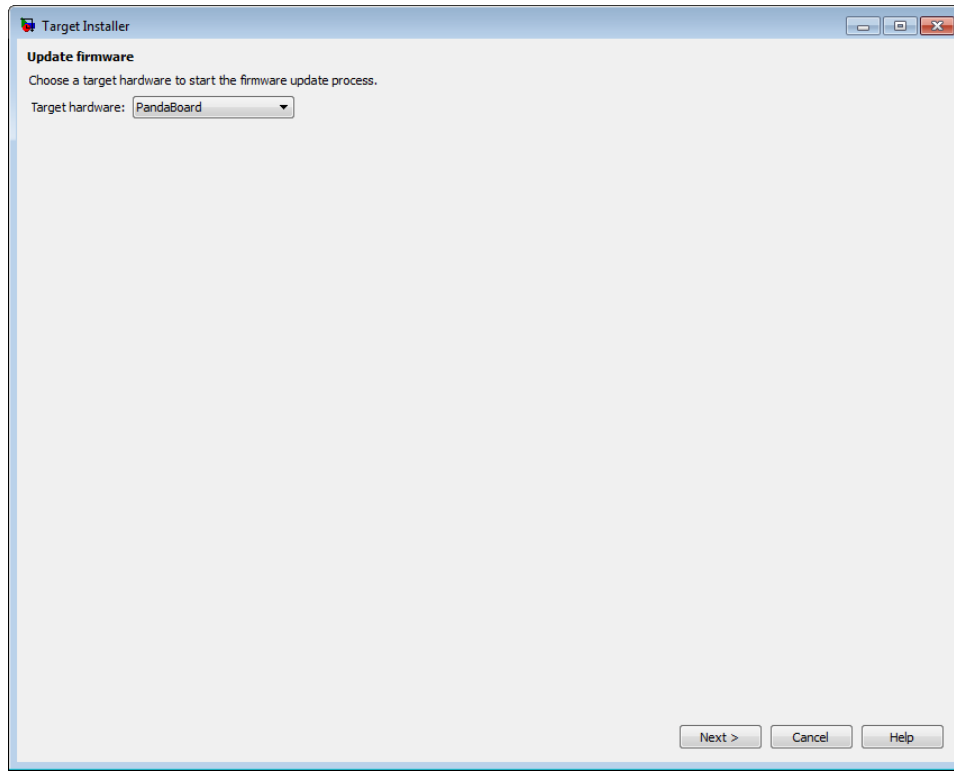
Note Target Installer does not use the PandaBoard hardware to write the firmware image to the memory card.

To replace the firmware on your PandaBoard hardware:

1. Open the **Update firmware** screen in the Target Installer using one of the following methods:
   - Click **Continue** in the **Install/update complete** screen of the Target Installer.
   - In a model, select **Tools > Run on Target Hardware > Update firmware**.

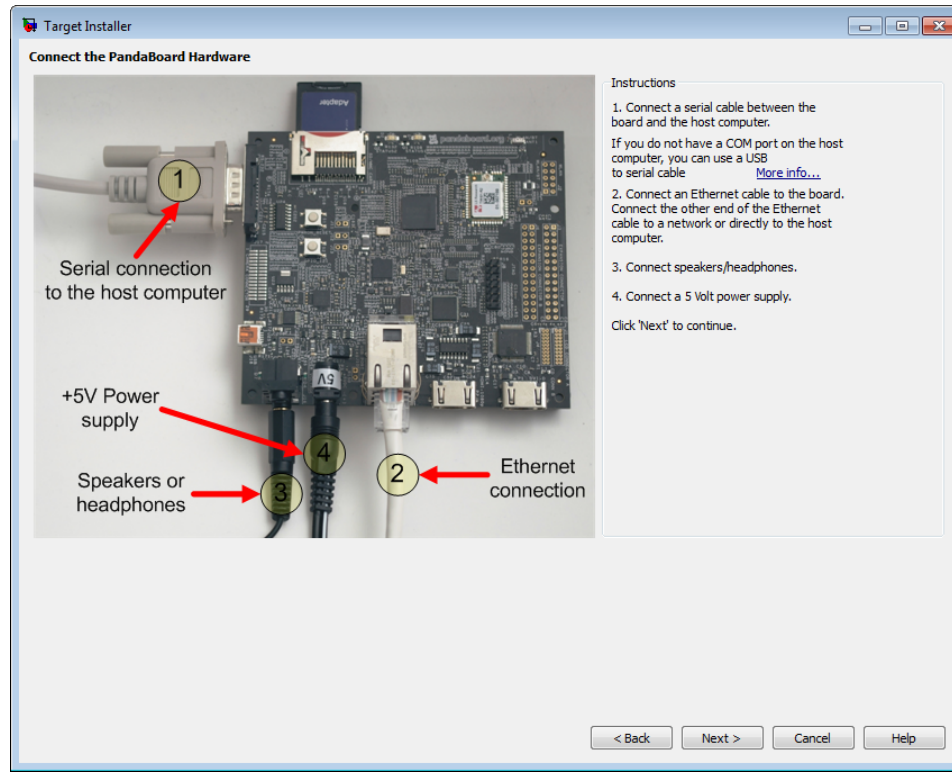
- In a MATLAB Command Window, enter `targetupdater`.

2 Choose the `PandaBoard` option and click **Next**.



3 Make the connections shown and click **Next**.

Note For "3. Speakers or headphones", use the lower jack (closest to the board).



4 Choose to get the firmware image from the Internet or from a folder.

Note The file size of the firmware image is approximately 1 GB. Depending on your connection, downloading the firmware can take from 2 to 60 minutes, or more.

Internet: This option is selected by default. When you click **Download**, Target Installer checks the **Download folder** for a valid firmware image:

- If a firmware image is not present, Target Installer downloads a firmware image from the Internet, and saves it to the download folder.

- If a firmware image is present, Target Installer uses the firmware image already present in the download folder, and does not download a new firmware image from the Internet.

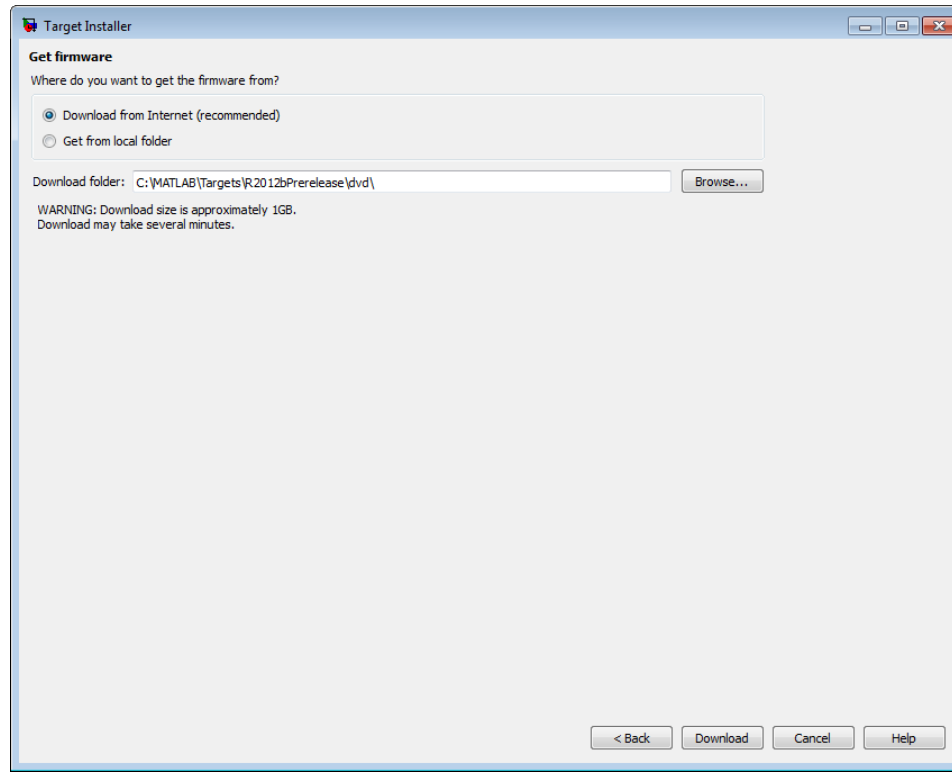
Folder: When you click **Download**, Target Installer checks the **Download folder** for a valid firmware image:

- If a firmware image is not present, Target Installer displays an error message that the image file is missing. To solve this issue, copy the firmware image from another location to the download folder, or choose the **Internet** option instead.
- If a firmware image is present, Target Installer continues the firmware installation process.

You must have write privileges for the download folder. If you use the default download folder, having write privileges is typically not an issue. If you change to a new download folder for which you do not have write permissions, such as a shared folder on a network, the Target Installer generates an error message: "Error: Download the firmware. The download folder is not writable. Choose a folder for which you have write permissions".

To solve this issue, copy the firmware image to a folder for which you have write privileges. For example, copy the firmware image from the shared folder on the network to the `C:\Users\`*`username`*`\AppData\Local\Temp` folder. Then, update the **Download location** to the same folder, and click **Download** again.

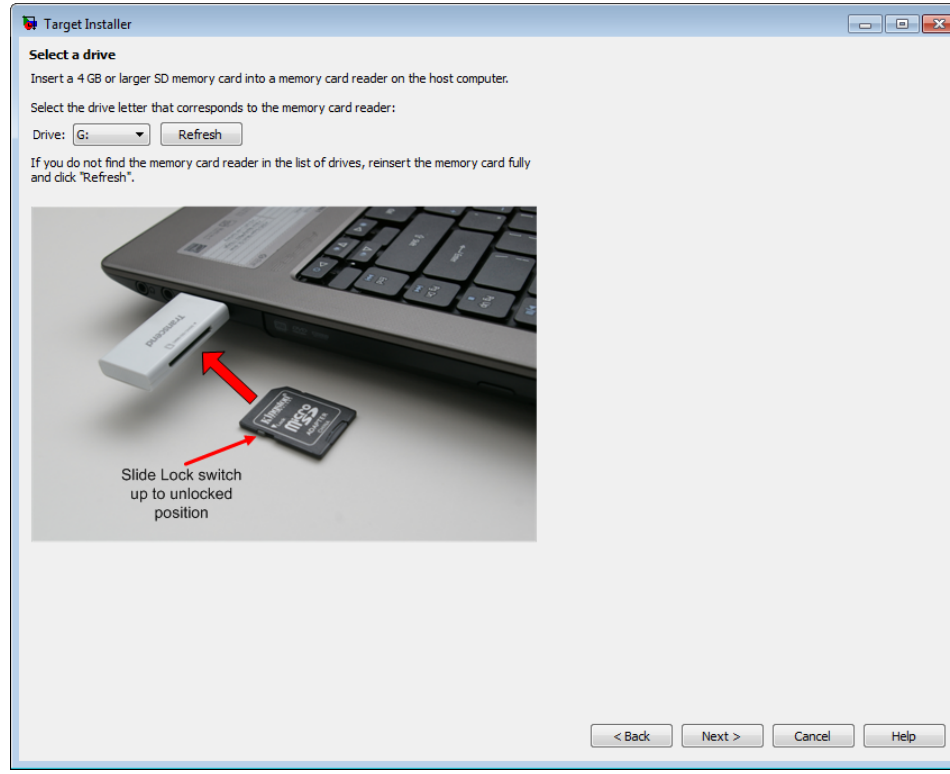
To locate the firmware image in a folder, search for a filename that begins with `pandaboard` and ends with `.img` or `.7z` . For example: `pandaboard_ubuntu_11_10_3_1_1_04_14_2012.img`



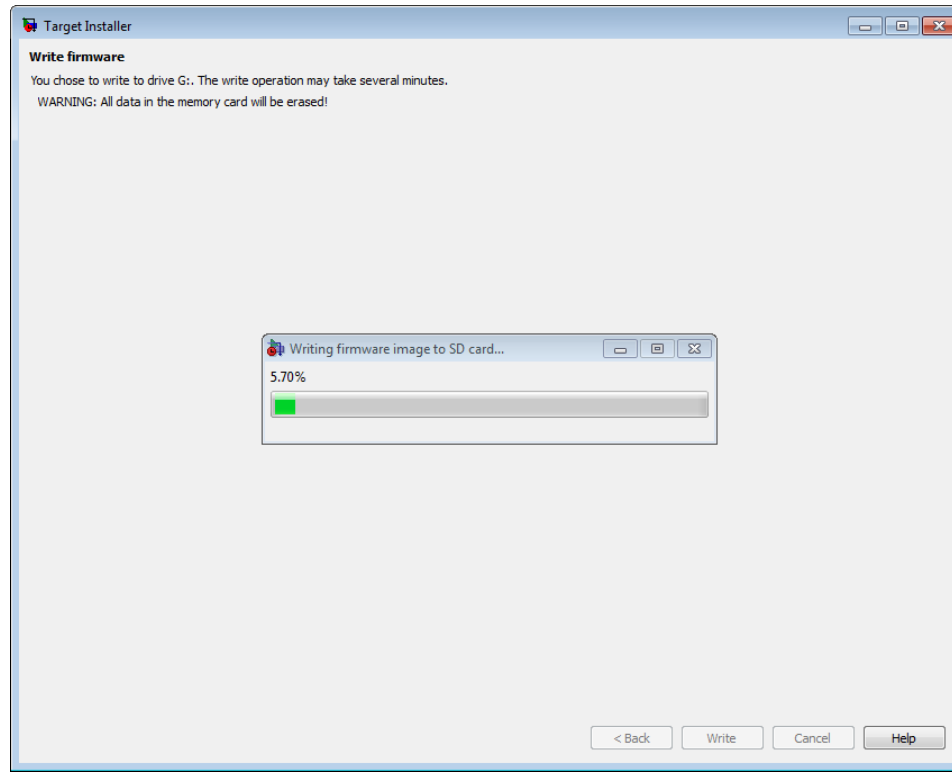
5 Insert the microSD or SD memory card into a media card reader connected to your host computer. Windows assigns a drive letter to the memory card.

6 Target Installer does not automatically detect the drive letter of the memory card. It displays a drive letter for each device with removable storage.

- If only one drive letter is available, click **Next**.
- If no drive letters are available, check that the memory card is fully inserted, and click **Refresh**.
- If multiple drive letters are available, open the Windows Start menu, choose **Computer**, and look for the memory card under **Devices with Removable Storage**.

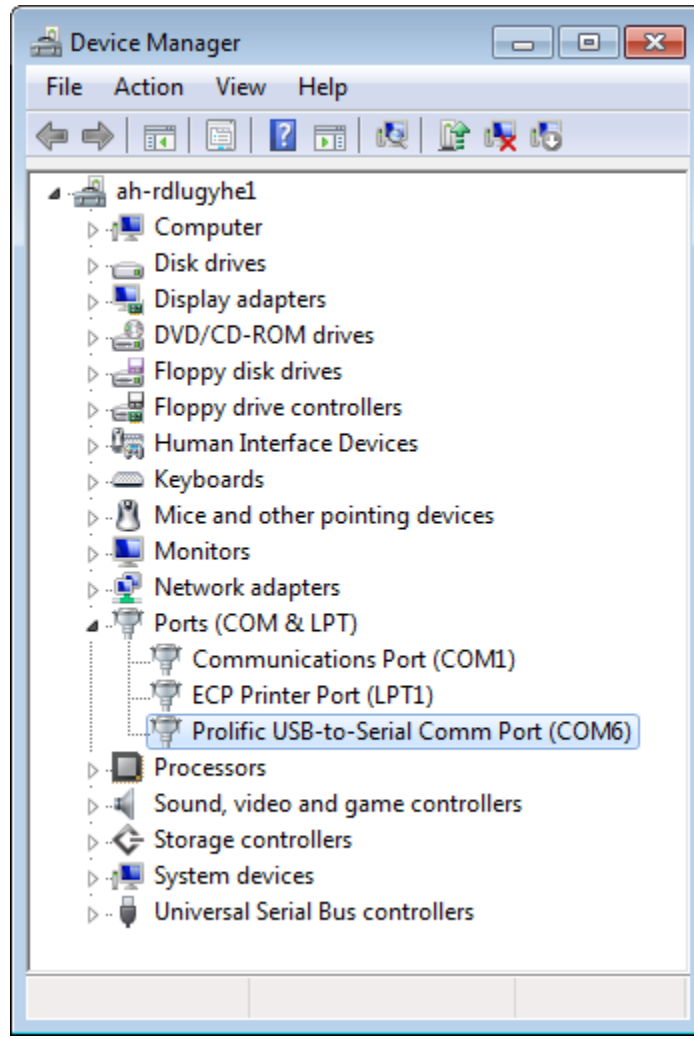


7 Click **Write**. Target Installer overwrites all previous data on the memory card with the firmware. This process takes several minutes to complete.



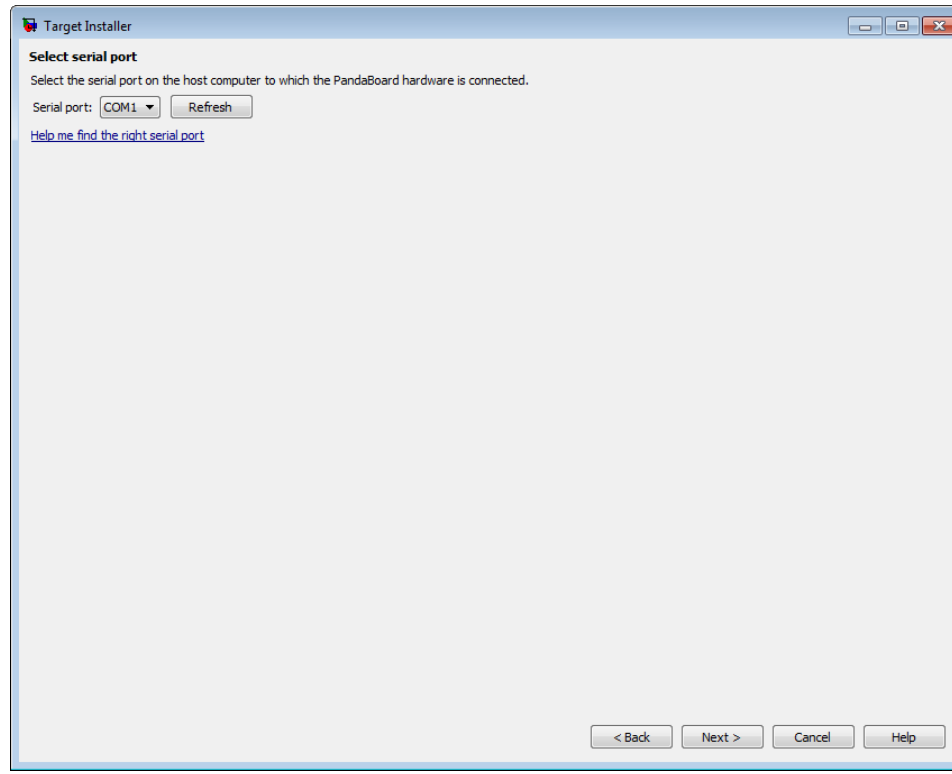
8 Get the COM port of the serial connection in Windows. From the Windows Start menu, choose search programs and files for "Device Manager". Open Device Manager, expand **Ports (COM & LPT)**, and identify the COM port of the serial connection to the PandaBoard hardware.

For example, the following image shows a DB9 serial port called "Communications Port" using COM1, and a USB-to-serial adapter called "Prolific USB-to-Serial Comm Port" using COM6.



Note Some USB-to-serial adapters do not appear in the list of serial connections immediately after you install the software drivers. To solve this issue, disconnect/reconnect the adapter, or reboot your host computer.

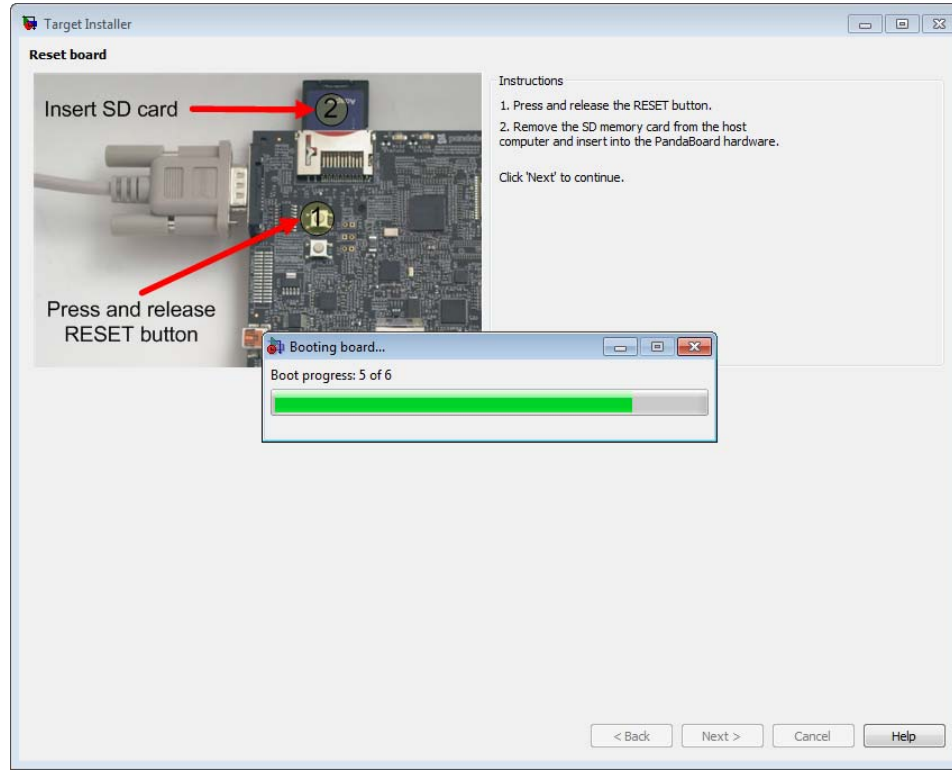
9 Target Installer does not automatically choose the COM port of the serial connection. After you get the COM port of the serial connection from Windows Device Manager, return to Target Installer, set **Serial port** to the COM port, and click **Next**.



10 Press and release the RESET button. Then, insert the memory card into the PandaBoard hardware.

Click **Next**. When the Target Installer detects a reset, it displays progress booting the board.

If the Target Installer does not display any progress, click **< Back**. On the **Select serial port** screen. Verify that you selected the correct COM port, and close any other applications, such as PuTTY, that might using the serial connection.



11 If your board is connected to a network with DHCP services, such as an office LAN or a home network connected to the Internet, select **Automatically get IP address**, give the board a unique name, and click **Configure**. DHCP is a network service that automatically configures the IP settings of Ethernet devices connected to a network.

If your board is directly connected to an Ethernet port on your computer, or connected to an isolated network without DHCP services, select **Manually enter IP address**, give the board a unique name, enter static IP settings for the board, and click **Configure**.

To enter static IP settings for your board, follow these guidelines:

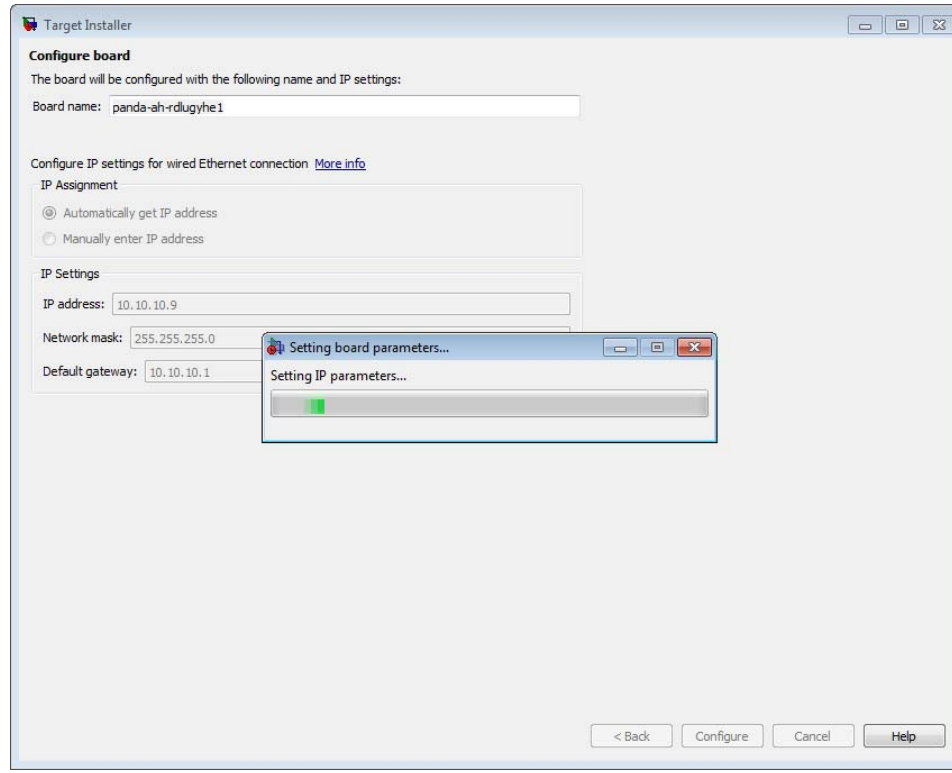
- The value of the subnet mask must be the same for all devices on the network.

- The value of the IP address must be unique for each device on the network.

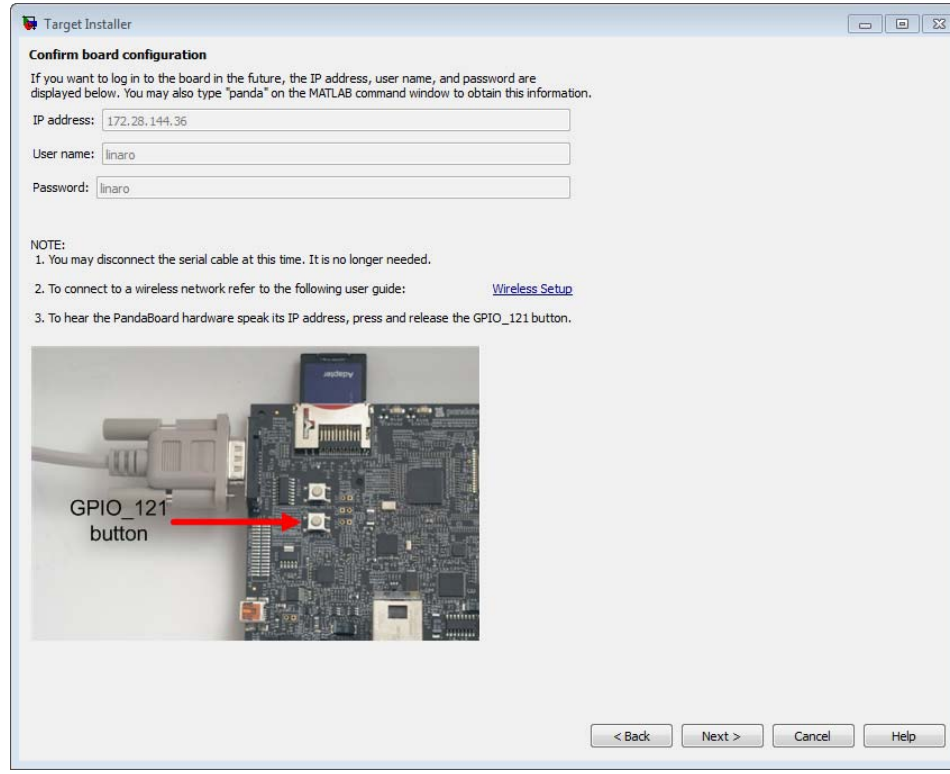
For example, if the Ethernet port on your host computer has a network mask of `255.255.255.0` and a static IP address of `192.168.1.1`, set:

- **Network mask** to use the same network mask value, `255.255.255.0`.
- **IP address** to an unused IP address, between `192.168.1.2` and `192.168.1.254`.

When you click **Configure**, the Target Installer opens a serial connection and applies the settings to the board.



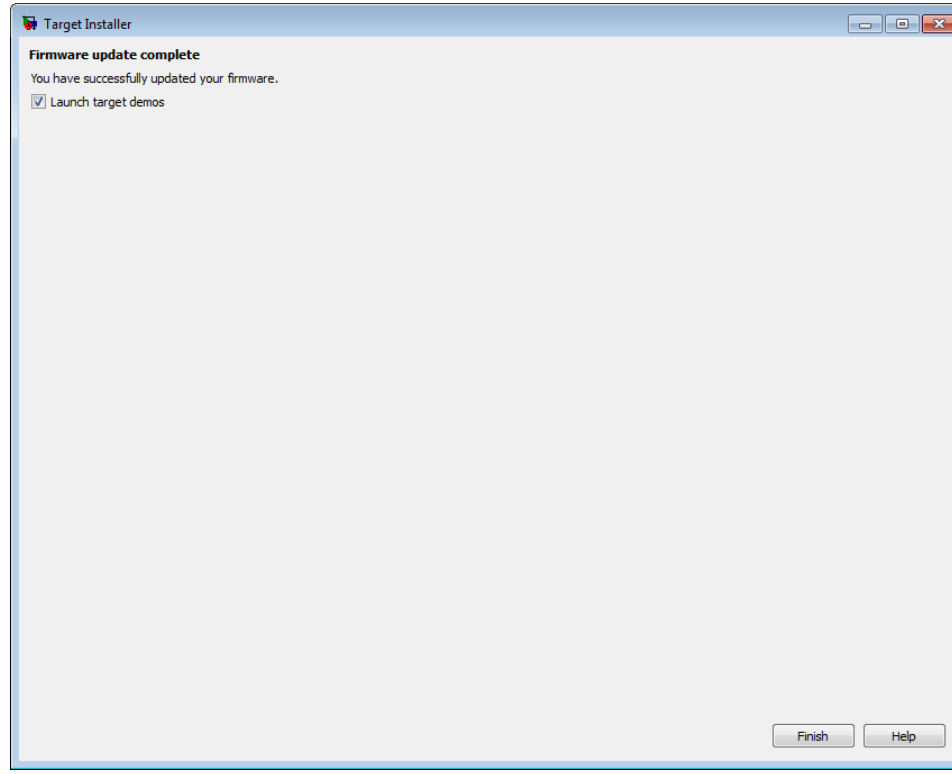
12 Make a note of the values for **IP address**, **User name**, and **Password**. Then, click **Next**.



13 Click **Finish**. If **Launch target examples** is enabled, the Target Installer opens the example page for PandaBoard hardware.

Note To reopen the examples later, enter the following text in a MATLAB Command Window:

```
demo simulink 'Target for Use with Pandaboard'
```


Target Installer
Firmware update complete
You have successfully updated your firmware.
Launch target demos
Finish
Help

Choose the Type of Serial Cable

This topic shows you how to choose a serial cable for connecting your host computer to the PandaBoard hardware.

Two types of cables are available for this purpose:

- DB9 null modem M/F cable
- USB to DB9 male adapter cable

DB9 null modem M/F cable:

- If your host computer has a DB9 male serial connector similar to the one in the following image, you can use a DB9 null modem M/F cable.

- To find the appropriate cable online, search for “DB9 low profile null modem M-F cable”.

USB to DB9 male adapter cable:

- If your host computer has a USB port, you can use a USB to DB9 male adapter cable.
- To find the appropriate cable online, search for "USB to RS-232 DB9 Serial Adapter”.
- Some USB-to-serial adapters do not appear in the list of serial connections immediately after you install the software drivers. To solve this issue, disconnect and reconnect the adapter, or reboot your host computer.
- To avoid issues with the software/driver quality, we recommend choosing an adapter that has good customer feedback ratings, or using the DB9 null modem M/F cable instead.

Connect to Serial Port on PandaBoard Hardware

This topic shows you how to configure and open a command line session with the target hardware.

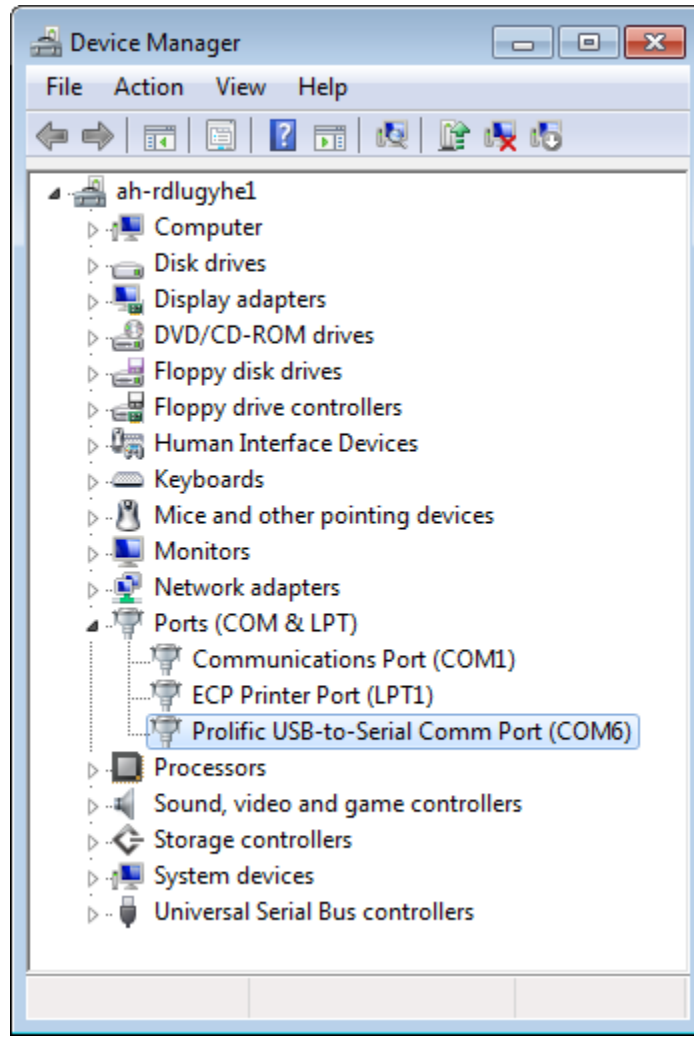
This is an optional task that you can use to:

- View the standard output while the board boots.
- Get or set the IP address, as described in "Get IP Address of PandaBoard Hardware" on page 56-32 topic.

To open a serial connection to your board:

1. Connect a serial cable from your host computer to the female DB9 connector on the board.
2. Identify the COM port for your serial connection. In Windows 7, use the "search programs and files" feature in the Start menu to find "Device Manager". Open Device Manager, and expand **Ports (COM & LPT)** to see the list of serial connections.

   For example, the following image shows that the DB9 serial port called "Communications Port" uses COM1. Similarly, the image shows that the USB-to-serial adapter called "Prolific USB-to-Serial Comm Port" uses COM6.

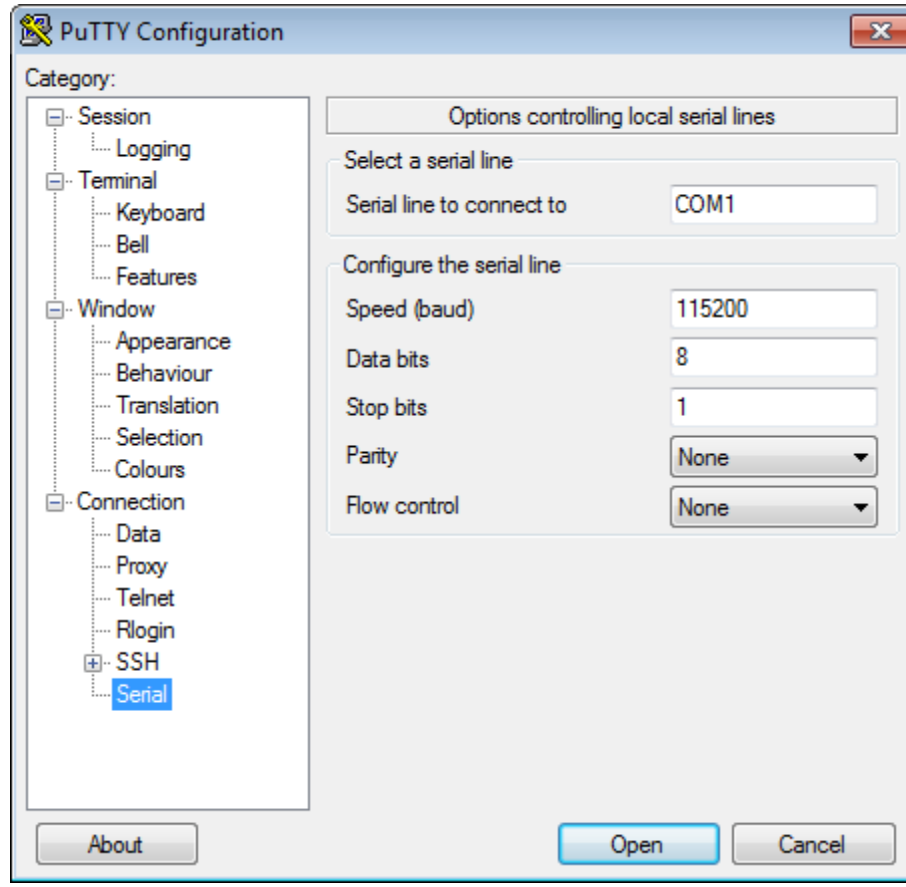


Note If you have trouble locating the COM port number, search the Windows "Help and Support" for "Device Manager".

3 In the MATLAB Command Window, start PuTTY by entering:

```
h = panda;
system(['"' fullfile(h.PutilsFolder, 'putty.exe') '" -serial &'], '-runAsAdmin');
```

4 In the PuTTY dialog box that opens, select the **Serial** category.

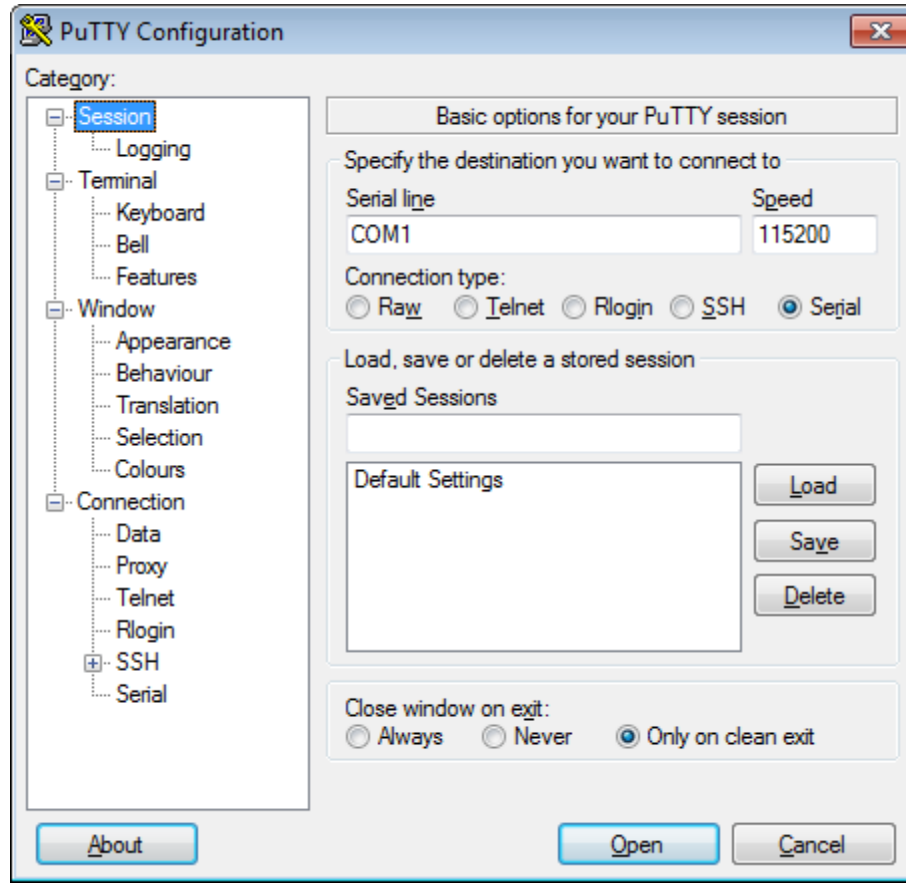


5 Set the following values:

- **Serial line to connect to**: If you are using your computer's built-in serial port, try `COM1`. Otherwise, use the Device Manager in Windows to determine the COM port number.
- **Speed (baud)**: `115200`

- **Flow control**: `None`

6 In the PuTTY dialog box, select the **Session** category.



7 Set the **Connection type** parameter to `Serial`, enter a new name for **Saved Sessions**, click **Save**, and click **Open**.

Note Do not save the serial settings to **Default Settings**. The **Default Settings** must remain configured to use SSH in order to run your Simulink model on the BeagleBoard hardware. Otherwise, trying to run the model on BeagleBoard hardware produces an error message similar to this one:

```
>> [status, message] = h.connect()
Error using linkfoundation.util.pandaboard/connect (line 125)
SSH connection to host 144.212.110.44 failed:
FATAL ERROR: Network error: Connection refused
```

8. When a terminal window opens, press the **Enter** key on your keyboard. The terminal window displays the Linux command line.

9. When you are finished, enter `logout` on the Linux command line, and close PuTTY to end the serial connection.

See Also

- "Get IP Address of PandaBoard Hardware" on page 56-32
- For more information about PuTTY, see: http://www.chiark.greenend.org.uk/~sgtatham/putty/

Configure Network Connection with PandaBoard Hardware

You can configure the IP settings of the PandaBoard hardware by running Linux shell commands directly on the PandaBoard hardware (the "board").

To inspect and reconfigure the IP settings on a board that already has the new firmware, follow the procedure in this section that starts with "To configure the board to use DHCP or static IP settings".

To configure the IP settings while you are replacing the firmware on your PandaBoard hardware, see "Replace Firmware on PandaBoard Hardware" on page 56-9.

You may need to reconfigure the IP settings if your board:

- Has unknown IP settings.
- Is unreachable using a network connection.
- Is being moved to a network or direct Ethernet connection that uses static IP settings.
- Is being moved from a network that used static IP settings to one that uses DHCP services.

When you complete the procedure in this topic, the board should be able to communicate over the network to which it is connected.

Before starting the procedure in this topic, it helps to understand the conditions under which networks use DHCP or static IP settings:

- If your board is connected to a network with DHCP services, such as an office LAN or a home network connected to the Internet, configure the board to use DHCP services. DHCP is a network service that automatically configures the IP settings of Ethernet devices connected to a network.
- If your board is directly connected to an Ethernet port on your computer, or connected to an isolated network without DHCP services, configure the board to use static IP settings.

To configure the board to use DHCP or static IP settings:

1. Open a serial command line session, as described in "Connect to Serial Port on PandaBoard Hardware" on page 56-23

   Alternatively, you can use a terminal window after accessing the Linux desktop as described in:

   - "Access the Linux Desktop Directly Using Desktop Computer Peripherals" on page 56-46
   - "Access the Linux Desktop Remotely Using VNC" on page 56-48

2. Display the contents of the /etc/network/interfaces file. Enter:

   ```
   cat /etc/network/interfaces
   ```

   If the board is configured to use DHCP services (the default configuration), `dhcp` appears at the end of the following line:

   ```
   iface eth0 inet dhcp
   ```

   If the board is configured to use static IP settings, `static` appears at the end of the following line:

   ```
   iface eth0 inet static
   ```

3. Create a backup of the /etc/network/interfaces file. Enter:

   ```
   sudo cp /etc/network/interfaces /etc/network/interfaces.backup
   ```

   If prompted, enter the root password (default: `linaro`).

4. Change the permissions of /etc/network/interfaces so you can edit the file. Enter:

   ```
   sudo chmod 777 /etc/network/interfaces
   ```

   If prompted, enter the root password (default: `linaro`).

5. Edit `interfaces` using a simple editor called nano. Enter:

   ```
   nano /etc/network/interfaces
   ```

6 Edit the last word of line that starts with `iface eth0 inet`.

To use DHCP services, edit the line to say:

```
iface eth0 inet dhcp
```

To use static IP settings, edit the line to say:

```
iface eth0 inet static
```

7 For static IP settings, add lines for `address`, `netmask`, and `gateway`. For example:

```
iface eth0 inet static
    address 192.168.1.2
    netmask 255.255.255.0
    gateway 192.168.1.1
```

Note For static IP settings:

- The value of the subnet mask must be the same for all devices on the network.
- The value of the IP address must be unique for each device on the network.

For example, if the Ethernet port on your host computer has a network mask of `255.255.255.0` and a static IP address of `192.168.1.1`, set:

- `netmask` to use the same network mask value, `255.255.255.0`.
- `address` to an unused IP address, between `192.168.1.2` and `192.168.1.254`.

---

8 Tell nano to exit and save the changes:

Press **Ctrl+x**.

Enter `Y` to save the modified buffer.

For "File Name to Write: interfaces", press Enter.

The nano editor confirms that it "Wrote # lines" and returns control to the command line.

9. Restore the original file permissions. Enter:

```
sudo chmod u=rw,g=r,o=r /etc/network/interfaces
```

If prompted, enter the root password (default: `linaro`).

10. Test the IP settings by logging in to the board over a telnet session.

Note You can use the `ifconfig` command to temporarily change the IP settings. Rebooting the board removes the `ifconfig` settings and restores the `/etc/network/interfaces` settings.

To change the IP settings temporarily, open a Linux command line, and enter `ifconfig`, the device id, a valid IP address, `netmask`, and the appropriate network mask. For example:

```
ifconfig eth0 192.168.45.12 netmask 255.255.255.0
```

Related Examples

- "Run Model on PandaBoard Hardware" on page 56-38
- "Get IP Address of PandaBoard Hardware" on page 56-32

Get IP Address of PandaBoard Hardware

You can get the IP address of the PandaBoard hardware (the "board") by listening to the audio output, or by using the Linux command line. This is an optional task that you can use to:

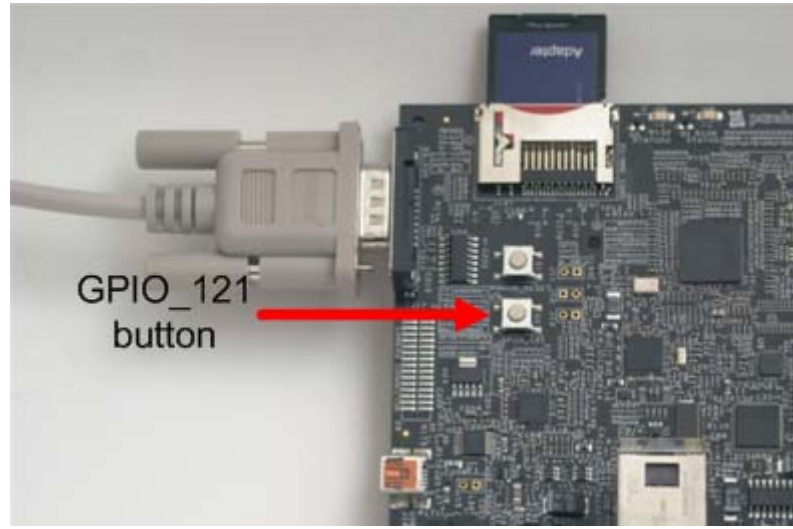
- Preparing a model to run on a board that is different from the previous one you used.
- Opening a telnet session with a board whose IP settings you do not know.
- Configuring the UDP Send block.

When you prepare a model to run on a board, your model Configuration Parameters reuse the IP settings of the previous board you used. If you are working with a different board on the same network, get the IP address of the your new board, and update the **Host name** parameter in the Configuration Parameters. For more information, see "Run Model on PandaBoard Hardware" on page 56-38.

If Ethernet port on the PandaBoard hardware board has an IP address, the audio output on the board can read the IP address out loud. For example the board can say "My IP address is one hundred and forty four point two one two point one one zero point two zero six."

To listen your board's IP address using headphones or speakers:

1. Plug headphones or speakers into the AUDIO OUT jack on the board.
2. Press the GPIO_121 button on the board.



3 Write down the IP address as the board reads it out over the headphones or speakers.

The Linux command line on the board can provide the IP address of the Ethernet port.

To get your board's IP address using a command line session:

1 Open a serial command line session on your board, as described in "Connect to Serial Port on PandaBoard Hardware" on page 56-23.

   Alternatively, you can use a terminal window after accessing the Linux desktop as described in:

   - "Access the Linux Desktop Directly Using Desktop Computer Peripherals" on page 56-46
   - "Access the Linux Desktop Remotely Using VNC" on page 56-48

2 At the Linux command line, enter `ifconfig`.

3 Locate the IP address following `inet addr` in the command line output. For example, locate `inet addr:172.28.144.36` on line 3 of the following output:

```
root@panda-ah-rdlugyhe1:~# ifconfig
eth0      Link encap:Ethernet  HWaddr 0a:40:27:be:3b:0a
          inet addr:172.28.144.36  Bcast:172.28.144.255  Mask:255.255.255.0
          inet6 addr: fe80::840:27ff:febe:3b0a/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST  MTU:1488  Metric:1
          RX packets:15137 errors:0 dropped:0 overruns:0 frame:0
          TX packets:1080 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:5118973 (5.1 MB)  TX bytes:144806 (144.8 KB)

lo        Link encap:Local Loopback
          inet addr:127.0.0.1  Mask:255.0.0.0
          inet6 addr: ::1/128 Scope:Host
          UP LOOPBACK RUNNING  MTU:16436  Metric:1
          RX packets:0 errors:0 dropped:0 overruns:0 frame:0
          TX packets:0 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:0
          RX bytes:0 (0.0 B)  TX bytes:0 (0.0 B)

wlan0     Link encap:Ethernet  HWaddr 0a:00:27:be:3b:0a
          UP BROADCAST MULTICAST  MTU:1500  Metric:1
          RX packets:0 errors:0 dropped:0 overruns:0 frame:0
          TX packets:0 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:0 (0.0 B)  TX bytes:0 (0.0 B)

root@panda-ah-rdlugyhe1:~#
```

Related Examples

- "Connect to Serial Port on PandaBoard Hardware" on page 56-23
- "Run Model on PandaBoard Hardware" on page 56-38
- "Get IP Address of PandaBoard Hardware" on page 56-32

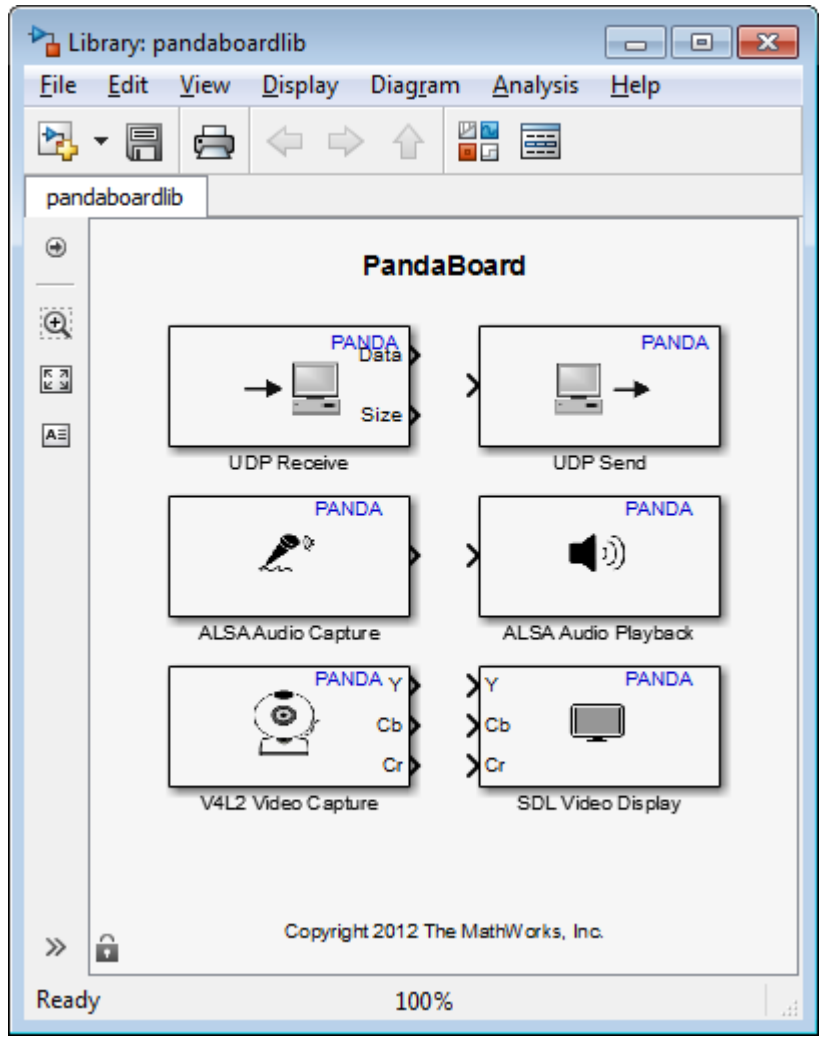
Open Block Library for PandaBoard Hardware

This block library provides support for protocols and APIs available on PandaBoard hardware (the “board”).

To open the block library from the MATLAB Command Window, enter:

```
pandaboardlib
```

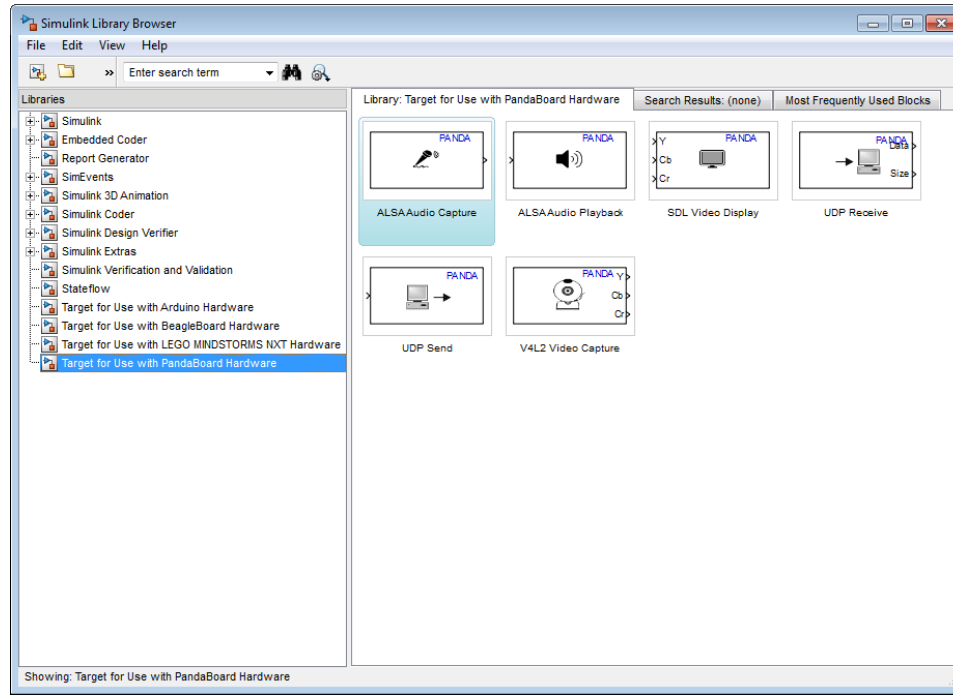
The following block library opens.



To open the block library from the Simulink Library Browser:

1 Open the Simulink Library Browser by entering `simulink` in the MATLAB Command Window, or by clicking the following icon on the MATLAB toolbar.

2 In the Simulink Library Browser, click **Target for Use with PandaBoard Hardware**.



Run Model on PandaBoard Hardware

This example shows how to prepare, configure, and run a simple model on your PandaBoard hardware (the "board").

Before starting this procedure:

- Connect your board to the network and to a power supply.
- Create or open a Simulink model.

To prepare and run the model:

1. Use **File > Save As** to create a working copy of your model. Keep the original model as a backup copy.
2. In your model, select **Tools > Run on Target Hardware > Prepare to Run**. This action changes the model Configuration Parameters.
3. In the Run on Target Hardware pane that opens, set the **Target hardware** parameter to `PandaBoard`.
4. If you have changed boards since the last time you updated the firmware or ran a model, update the **Host name**, **User name**, and **Password** parameters.
5. Select **Tools > Run on Target Hardware > Run**. This action automatically downloads and runs your model on the board.

Note Pressing RESET or cycling the power on the PandaBoard hardware during this step can cause the ssh utility to hang.

Warning **Avoid using the RESET button to stop a running model and reboot the board. Doing so can corrupt operating system and program files. To fix corrupt files, replace the firmware as described in "Replace Firmware on PandaBoard Hardware" on page 56-9.**

Running a new or updated model on the board:

- Automatically stops a running model with the same name.

- Does not stop running models that have other names.

To stop a model running on the board, enter the following commands in the MATLAB Command Window:

```
h=panda;
h.stop('modelName');
```

For example, to stop the sumdiff model, enter:

```
h=panda;
h.stop('sumdiff');
```

To restart a model that was previously running on the board, or to run multiple instances of a model, enter the following commands in the MATLAB Command Window:

```
h=panda;
h.run('modelName');
```

Note You do not need to enter `h=panda;` multiple times if a previous instance of `h` is available in the MATLAB Workspace.

For example, to restart the sumdiff model you stopped in the previous example, enter:

```
h.run('sumdiff');
```

Prepare Models That Use Model Reference

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*. The model that contains a referenced model is its *parent model*. When you run parent model on your target hardware, the submodel effectively replaces the Model block that references it. For more information, see “Overview of Model Referencing” on page 6-2.

To run on target hardware, the parent model and the submodels must have the same Configuration Parameter settings.

For each Model block:

- Select **Tools > Run on Target Hardware > Prepare to Run**.
- Apply the same Configuration Parameters settings to the submodel as you applied to the parent model.

If the model and Model blocks have different settings, the software generates an error when you try to run the model on the target hardware.

See Also

- "Create the Simple Model"
- "Configure Network Connection with PandaBoard Hardware" on page 56-28
- "Tune and Monitor Model Running on PandaBoard Hardware" on page 56-41
- "Overview of Model Referencing" on page 6-2

Tune and Monitor Model Running on PandaBoard Hardware

In this section...

About External Mode

You can use External mode to tune parameters and monitor a model running on your target hardware.

External mode enables you to tune model parameters and evaluate the effects of different parameter values on model results in real-time, in order to find the optimal values to achieve desired performance. This process is called *parameter tuning*.

External mode accelerates parameter tuning because you do not have to re-run the model each time you change parameters. External mode also lets you develop and validate your model using the actual data and hardware for which it is designed. This software-hardware interaction is not available solely by simulating a model.

The following list provides an overview of the parameter tuning process with External mode:

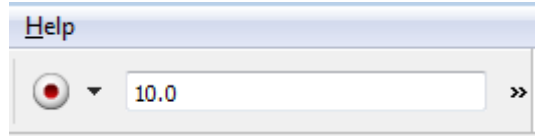
- In the model on your host computer, you enable External mode in the Configuration Parameters.
- In the model on your host computer, you tell Simulink software to run your model on the target hardware.
- Simulink software runs the model on the target hardware.
- You use the model on the host computer as a user interface for interacting with the model running on the target hardware:

  - When open blocks and apply new parameter values on the host computer, External mode updates the corresponding values on target hardware.
  - If your model contains blocks for viewing data, such as Scope or Display blocks, External mode sends the corresponding data from the target hardware to those blocks on the host computer.
- You determine the optimal parameter values by adjusting parameter values on the host computer and observing data/outputs from the target hardware.
- When you are finished, you save the new parameter values, disable External mode, and save the model.

Run Your Simulink Model in External Mode

1. Create a network connection between the PandaBoard hardware and your host computer. See "Configure Network Connection with PandaBoard Hardware" on page 56-28

2. In the model, set the **Simulation stop time** parameter, located on the model toolbar, as shown here.



   - To run the model for an indefinite period, enter `inf`.
   - To run the model for a finite period, enter a number of seconds. For example, entering `120` runs the model on the hardware for 2 minutes.

3. Select **Tools > Run on Target Hardware > Options**.

4. In the Run on Target Hardware pane that opens, select **Enable External mode**.

5. Click **OK**, and then save the changes your model.

6. In your model, select **Tools > Run on Target Hardware > Run**.

   After several minutes, Simulink starts running your model on the board.

7 While the model is running in External mode, you can change parameter values in the model on your host computer and observe the corresponding changes in the model running on the hardware.

   If your model contains blocks from the Simulink Sinks block library, the sink blocks in the model on your host computer display the values generated by the model running on the hardware.

   If your model does not contain a sink block to which External mode can send data, the MATLAB Command Window displays a warning message. For example:

```
Warning: No data has been selected for uploading.
> In C:\Program Files (x86)\MATLAB\R2012a Student1\toolbox\
realtime\realtime\+realtime\extModeAutoConnect.p>
extModeAutoConnect at 17
In C:\Program Files (x86)\MATLAB\R2012a Student1\toolbox\
realtime\realtime\sl_customization.p>myRunCallback at 149
```

   You can disregard this warning, or you can add a sink block to the model.

Note To use External mode with the Run on Target Hardware feature, only use the External mode settings described in this topic.

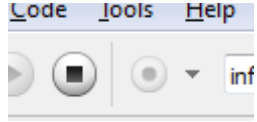
If you have Simulink Coder or Embedded Coder software, do not use other External mode-related items that appear that in the Tools menu or the Configuration Parameters dialog.

Note External mode increases the processing burden of the model running on the board. If the software reports an overrun, clear the **Enable External mode** checkbox in the Run on Target Hardware pane.

Note If you have the Embedded Coder or Simulink Coder products, you can use External mode with a model that contains Model blocks (uses the “Model reference”).

Stop External Mode

To stop the model running in External mode, click the Stop button located on the model toolbar, as shown here.



This action stops the process for the model running on the PandaBoard hardware, and stops the model simulation running on your host computer.

If it is set to a finite period, the **Simulation stop time** parameter stops External mode when the period elapses.

Detect and Fix Task Overruns on PandaBoard Hardware

You can configure a model running on the target hardware to detect and notify you of when task overrun occurs.

Standard scheduling works well when a processor is moderately loaded but may fail if the processor becomes overloaded. When a task is required to perform extra processing and takes longer than normal to execute, it may be scheduled to execute before a previous instance of the same task has completed. The result is a task overrun.

To enable overrun detection:

1. In your model, click **Tools > Run on Target Hardware > Options**.
2. In the Run on Target Hardware pane that opens, select the **Enable overrun detection** check box.
3. Click **OK**.

When a task overrun occurs, the command prompt on the host machine repeatedly prints an "Overrun" error message, such as "Overrun — rate for subrate task 1 is too fast", until the model stops.

To fix an overrun condition:

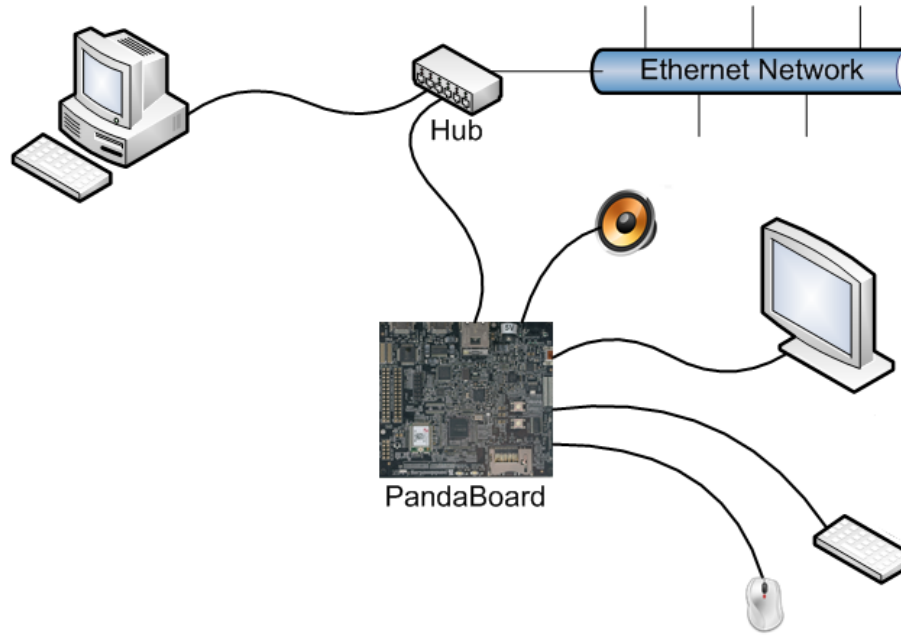
- Simplify the model.
- Increase the sample times for the model and the blocks in it. For example, change the **Sample time** parameter in all of your data source blocks, such as blocks for input devices, from `0.1` to `0.2`.

Note External mode increases the processing burden of the model running on your board. If the software reports an overrun, clear the **Enable External mode** checkbox in the Run on Target Hardware pane.

Access the Linux Desktop Directly Using Desktop Computer Peripherals

You can access the Linux desktop on the PandaBoard hardware using hardware peripherals such as a monitor, keyboard, and mouse.

You can use this approach to connect the PandaBoard hardware to a wireless network, as described in "Configure Wi-Fi on PandaBoard Hardware" on page 56-50.



If you do not have hardware peripherals, you can access the Linux desktop as described in "Access the Linux Desktop Remotely Using VNC" on page 56-48.

To connect to the PandaBoard hardware to the hardware peripherals:

1. Connect a computer monitor to the HDMI output, labelled `P2` on the PandaBoard hardware.

2 Connect the USB keyboard and USB mouse to the USB ports on the PandaBoard hardware.

Note To connect additional USB devices, use a powered USB hub.

3 You can connect computer speakers to the lower of the two 3.5 mm audio connectors, labelled `J16` on the PandaBoard hardware.

4 You can connect a network cable to the Ethernet port.

5 Connect the PandaBoard hardware to the power supply.

6 Log in to the Linux desktop using the username and password. The default user name and password is `linaro`.

Access the Linux Desktop Remotely Using VNC

You can remotely access the Linux desktop on the PandaBoard hardware from another computer. This capability uses a client-server graphical desktop sharing system called Virtual Network Computing (VNC).

The PandaBoard firmware distributed by MathWorks has a built-in VNC server called *x11vnc*. To remotely interact with the PandaBoard hardware, you can run a VNC client on a remote computer, open a VNC connection with x11vnc on the PandaBoard hardware.

To open a VNC session from MATLAB:

1. Create a physical network connection between your host computer and the PandaBoard hardware.
2. In the MATLAB Command Window, enter:

```
h = panda
h.connect
h.execute('export DISPLAY=:0.0; xhost +; x11vnc&', true)
h.execute('pidof x11vnc', true);
```

The MATLAB Command Window displays the status of the VNC server running on the PandaBoard hardware. For example:

```
h =

  realtime.internal.LinuxServices
  Package: realtime.internal

  Properties:
        HostName: '172.28.144.36'
        UserName: 'linaro'
        Password: 'linaro'
        BuildDir: '/home/linaro'
    PutilsFolder: 'C:\Program Files\MATLAB\R2012b\toolbox\idelink\foundation\hostapps'

  Methods
```

```
ans =

     0

access control disabled, clients can connect from any host

ans =

     0

>>
```

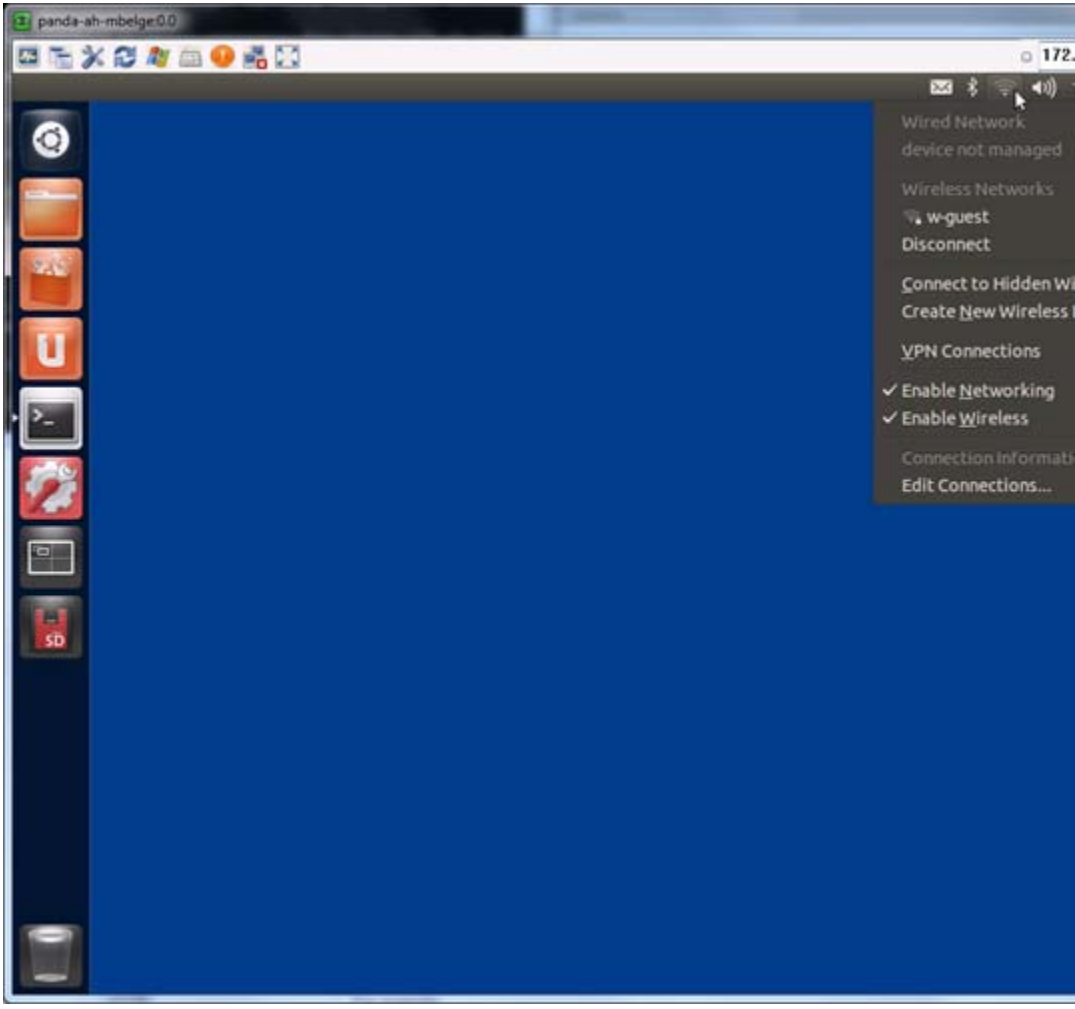
3 Open the VNC viewer and connect to the HostName IP address of the PandaBoard.

Configure Wi-Fi on PandaBoard Hardware

PandaBoard has built-in 802.11b/g/n wireless networking.

To configure the PandaBoard hardware for wireless network connection, use the Network Manager in the Linux desktop:

1. Access the Linux desktop running on the PandaBoard hardware as described in either of the following topics:
   - “Access the Linux Desktop Directly Using Desktop Computer Peripherals” on page 56-46
   - “Access the Linux Desktop Remotely Using VNC” on page 56-48
2. On the Linux desktop, open the Network manager, and select a wireless network.



3 If prompted, enter the wireless network password, and click **Connect**.

A

Examples

Use this list to find examples in the documentation.

Simulink Basics

How Simulink Works

Creating a Model

Executing Commands From Models

Working with Lookup Tables

Creating Block Masks

Creating Custom Simulink Blocks

"Create a Custom Block" on page 27-18

Working with Blocks

"Make Backward-Compatible Changes to Libraries" on page 28-22

Data Management

Code Generation for Variable-Size Data

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