

**Simulink®**

User's Guide

**R2012a**

**MATLAB®  
& SIMULINK®**

## How to Contact MathWorks



[www.mathworks.com](http://www.mathworks.com) Web  
[comp.soft-sys.matlab](mailto:comp.soft-sys.matlab) Newsgroup  
[www.mathworks.com/contact\\_TS.html](http://www.mathworks.com/contact_TS.html) Technical Support



[suggest@mathworks.com](mailto:suggest@mathworks.com) Product enhancement suggestions  
[bugs@mathworks.com](mailto:bugs@mathworks.com) Bug reports  
[doc@mathworks.com](mailto:doc@mathworks.com) Documentation error reports  
[service@mathworks.com](mailto:service@mathworks.com) Order status, license renewals, passcodes  
[info@mathworks.com](mailto:info@mathworks.com) Sales, pricing, and general information



508-647-7000 (Phone)



508-647-7001 (Fax)



The MathWorks, Inc.  
3 Apple Hill Drive  
Natick, MA 01760-2098

For contact information about worldwide offices, see the MathWorks Web site.

*Simulink® User's Guide*

© COPYRIGHT 1990–2012 by The MathWorks, Inc.

The software described in this document is furnished under a license agreement. The software may be used or copied only under the terms of the license agreement. No part of this manual may be photocopied or reproduced in any form without prior written consent from The MathWorks, Inc.

FEDERAL ACQUISITION: This provision applies to all acquisitions of the Program and Documentation by, for, or through the federal government of the United States. By accepting delivery of the Program or Documentation, the government hereby agrees that this software or documentation qualifies as commercial computer software or commercial computer software documentation as such terms are used or defined in FAR 12.212, DFARS Part 227.72, and DFARS 252.227-7014. Accordingly, the terms and conditions of this Agreement and only those rights specified in this Agreement, shall pertain to and govern the use, modification, reproduction, release, performance, display, and disclosure of the Program and Documentation by the federal government (or other entity acquiring for or through the federal government) and shall supersede any conflicting contractual terms or conditions. If this License fails to meet the government's needs or is inconsistent in any respect with federal procurement law, the government agrees to return the Program and Documentation, unused, to The MathWorks, Inc.

### Trademarks

MATLAB and Simulink are registered trademarks of The MathWorks, Inc. See [www.mathworks.com/trademarks](http://www.mathworks.com/trademarks) for a list of additional trademarks. Other product or brand names may be trademarks or registered trademarks of their respective holders.

### Patents

MathWorks products are protected by one or more U.S. patents. Please see [www.mathworks.com/patents](http://www.mathworks.com/patents) for more information.

## Revision History

November 1990	First printing	New for Simulink 1
December 1996	Second printing	Revised for Simulink 2
January 1999	Third printing	Revised for Simulink 3 (Release 11)
November 2000	Fourth printing	Revised for Simulink 4 (Release 12)
July 2002	Fifth printing	Revised for Simulink 5 (Release 13)
April 2003	Online only	Revised for Simulink 5.1 (Release 13SP1)
April 2004	Online only	Revised for Simulink 5.1.1 (Release 13SP1+)
June 2004	Sixth printing	Revised for Simulink 5.0 (Release 14)
October 2004	Seventh printing	Revised for Simulink 6.1 (Release 14SP1)
March 2005	Online only	Revised for Simulink 6.2 (Release 14SP2)
September 2005	Eighth printing	Revised for Simulink 6.3 (Release 14SP3)
March 2006	Online only	Revised for Simulink 6.4 (Release 2006a)
March 2006	Ninth printing	Revised for Simulink 6.4 (Release 2006a)
September 2006	Online only	Revised for Simulink 6.5 (Release 2006b)
March 2007	Online only	Revised for Simulink 6.6 (Release 2007a)
September 2007	Online only	Revised for Simulink 7.0 (Release 2007b)
March 2008	Online only	Revised for Simulink 7.1 (Release 2008a)
October 2008	Online only	Revised for Simulink 7.2 (Release 2008b)
March 2009	Online only	Revised for Simulink 7.3 (Release 2009a)
September 2009	Online only	Revised for Simulink 7.4 (Release 2009b)
March 2010	Online only	Revised for Simulink 7.5 (Release 2010a)
September 2010	Online only	Revised for Simulink 7.6 (Release 2010b)
April 2011	Online only	Revised for Simulink 7.7 (Release 2011a)
September 2011	Online only	Revised for Simulink 7.8 (Release 2011b)
March 2012	Online only	Revised for Simulink 7.9 (Release 2012a)



## Introduction to Simulink

### Simulink Basics

**1**

<b>Starting Simulink Software</b> .....	<b>1-2</b>
<b>Opening a Model</b> .....	<b>1-4</b>
Introduction .....	1-4
Opening an Existing Model .....	1-4
Opening Models with Different Character Encodings ....	1-4
Avoiding Initial Model Open Delay .....	1-5
<b>Loading a Model</b> .....	<b>1-7</b>
<b>Saving a Model</b> .....	<b>1-8</b>
Introduction .....	1-8
How to Tell If a Model Needs Saving .....	1-8
Techniques for Saving Models .....	1-9
Saving Models in the SLX File Format .....	1-11
Saving Models with Different Character Encodings .....	1-13
Saving a Model in an Earlier Simulink Version .....	1-14
Saving from One Earlier Simulink Version to Another ...	1-15
<b>Using the Model Editor</b> .....	<b>1-16</b>
Editor Overview .....	1-16
Toolbar .....	1-17
Menu Bar .....	1-21
Canvas .....	1-21
Context Menus .....	1-22
Status Bar .....	1-22
<b>Undoing a Command</b> .....	<b>1-25</b>
<b>Zooming Block Diagrams</b> .....	<b>1-26</b>

<b>Panning Block Diagrams</b> .....	<b>1-27</b>
<b>Viewing Command History</b> .....	<b>1-29</b>
<b>Bringing the MATLAB Software Desktop Forward</b> ....	<b>1-30</b>
<b>Copying Models to Third-Party Applications</b> .....	<b>1-31</b>
<b>Updating a Block Diagram</b> .....	<b>1-32</b>
<b>Printing a Block Diagram</b> .....	<b>1-34</b>
About Printing .....	<b>1-34</b>
Print Dialog Box .....	<b>1-34</b>
Specifying Paper Size and Orientation .....	<b>1-36</b>
Positioning and Sizing a Diagram .....	<b>1-36</b>
Tiled Printing .....	<b>1-37</b>
Print Sample Time Legend .....	<b>1-41</b>
Print Command .....	<b>1-41</b>
<b>Generating a Model Report</b> .....	<b>1-44</b>
Model Report Options .....	<b>1-45</b>
<b>Ending a Simulink Session</b> .....	<b>1-47</b>
<b>Summary of Mouse and Keyboard Actions</b> .....	<b>1-48</b>
Model Viewing Shortcuts .....	<b>1-48</b>
Block Editing Shortcuts .....	<b>1-49</b>
Line Editing Shortcuts .....	<b>1-50</b>
Signal Label Editing Shortcuts .....	<b>1-50</b>
Annotation Editing Shortcuts .....	<b>1-51</b>

## How Simulink Works

# 2

<b>Introduction</b> .....	<b>2-2</b>
---------------------------	------------

<b>Modeling Dynamic Systems</b> .....	2-3
Block Diagram Semantics .....	2-3
Creating Models .....	2-4
Time .....	2-5
States .....	2-5
Block Parameters .....	2-9
Tunable Parameters .....	2-9
Block Sample Times .....	2-10
Custom Blocks .....	2-11
Systems and Subsystems .....	2-11
Signals .....	2-16
Block Methods .....	2-16
Model Methods .....	2-18
<b>Simulating Dynamic Systems</b> .....	2-19
Model Compilation .....	2-19
Link Phase .....	2-20
Simulation Loop Phase .....	2-20
Solvers .....	2-22
Zero-Crossing Detection .....	2-24
Algebraic Loops .....	2-40

# Modeling Dynamic Systems

## Creating a Model

### 3

<b>Creating an Empty Model</b> .....	3-2
Creating a Model Template .....	3-2
<b>Populating a Model</b> .....	3-4
About the Library Browser .....	3-4
Opening the Library Browser .....	3-4
Browsing Block Libraries .....	3-5
Searching Block Libraries .....	3-5
Cloning Blocks to Models .....	3-6
<b>Selecting Objects</b> .....	3-7
Selecting an Object .....	3-7

Selecting Multiple Objects .....	3-7
<b>Specifying Block Diagram Colors .....</b>	<b>3-9</b>
How to Specify Block Diagram Colors .....	3-9
Choosing a Custom Color .....	3-10
Defining a Custom Color .....	3-10
Specifying Colors Programmatically .....	3-11
Displaying Sample Time Colors .....	3-12
<b>Connecting Blocks .....</b>	<b>3-15</b>
Automatically Connecting Blocks .....	3-15
Manually Connecting Blocks .....	3-18
Disconnecting Blocks .....	3-23
<b>Aligning, Distributing, and Resizing Groups of Blocks</b>	
Automatically .....	3-24
<b>Annotating Diagrams .....</b>	<b>3-26</b>
How to Annotate Diagrams .....	3-26
Annotations Properties Dialog Box .....	3-27
Annotation Callback Functions .....	3-30
Associating Click Functions with Annotations .....	3-31
Annotations API .....	3-33
Using TeX Formatting Commands in Annotations .....	3-33
Creating Annotations Programmatically .....	3-35
<b>Creating Subsystems .....</b>	<b>3-37</b>
Why Subsystems are Advantageous .....	3-37
Creating Subsystems .....	3-38
Creating a Subsystem by Adding the Subsystem Block ...	3-38
Creating a Subsystem by Grouping Existing Blocks .....	3-38
Executing Subsystems .....	3-40
Model Navigation Commands .....	3-40
Window Reuse .....	3-41
Labeling Subsystem Ports .....	3-41
Controlling Access to Subsystems .....	3-42
Interconverting Subsystems and Block Diagrams .....	3-43
Emptying Subsystems and Block Diagrams .....	3-43
<b>Modeling Control Flow Logic .....</b>	<b>3-44</b>
Equivalent C Language Statements .....	3-44



Modeling Conditional Control Flow Logic .....	3-44
Modeling While and For Loops .....	3-47
<b>Using Callback Functions .....</b>	<b>3-54</b>
About Callback Functions .....	3-54
Tracing Callbacks .....	3-55
Creating Model Callback Functions .....	3-55
Creating Block Callback Functions .....	3-58
Port Callback Parameters .....	3-63
Example Callback Function Tasks .....	3-64
<b>Using Model Workspaces .....</b>	<b>3-67</b>
About Model Workspaces .....	3-67
Simulink.ModelWorkspace Data Object Class .....	3-68
Changing Model Workspace Data .....	3-69
Model Workspace Dialog Box .....	3-71
<b>Resolving Symbols .....</b>	<b>3-76</b>
About Symbol Resolution .....	3-76
Hierarchical Symbol Resolution .....	3-77
Specifying Numeric Values with Symbols .....	3-78
Specifying Other Values with Symbols .....	3-78
Limiting Signal Resolution .....	3-79
Explicit and Implicit Symbol Resolution .....	3-79
<b>Consulting the Model Advisor .....</b>	<b>3-81</b>
About the Model Advisor .....	3-81
Starting the Model Advisor .....	3-82
Overview of the Model Advisor Window .....	3-83
Running Model Advisor Checks .....	3-85
Model Advisor Highlighting .....	3-89
Fixing a Warning or Failure .....	3-91
Reverting Changes Using Restore Points .....	3-95
Viewing and Saving Model Advisor Reports .....	3-97
Running the Model Advisor Programmatically .....	3-101
Model Advisor Limitations .....	3-101
<b>Managing Model Versions .....</b>	<b>3-102</b>
How Simulink Helps You Manage Model Versions .....	3-102
Model File Change Notification .....	3-103
Specifying the Current User .....	3-104
Managing Model Properties .....	3-105

Creating a Model Change History .....	3-112
Version Control Properties .....	3-114
<b>Model Discretizer</b> .....	<b>3-116</b>
What Is the Model Discretizer? .....	3-116
Requirements .....	3-116
How to Discretize a Model from the Model Discretizer	
GUI .....	3-117
Viewing the Discretized Model .....	3-126
How to Discretize Blocks from the Simulink Model .....	3-129
How to Discretize a Model from the MATLAB Command	
Window .....	3-140

## Working with Sample Times

# 4

<b>What Is Sample Time?</b> .....	4-2
<b>How to Specify the Sample Time</b> .....	4-3
Designating Sample Times .....	4-3
Specifying Block-Based Sample Times Interactively .....	4-5
Specifying Port-Based Sample Times Interactively .....	4-6
Specifying Block-Based Sample Times	
Programmatically .....	4-7
Specifying Port-Based Sample Times Programmatically ..	4-7
Accessing Sample Time Information Programmatically ...	4-8
Specifying Sample Times for a Custom Block .....	4-8
Determining Sample Time Units .....	4-8
Changing the Sample Time After Simulation Start	
Time .....	4-8
<b>How to View Sample Time Information</b> .....	4-9
Viewing Sample Time Display .....	4-9
Managing the Sample Time Legend .....	4-10
<b>How to Print Sample Time Information</b> .....	4-13
<b>Types of Sample Time</b> .....	4-14

Discrete Sample Time .....	4-14
Continuous Sample Time .....	4-15
Fixed in Minor Step .....	4-15
Inherited Sample Time .....	4-15
Constant Sample Time .....	4-16
Variable Sample Time .....	4-17
Triggered Sample Time .....	4-18
Asynchronous Sample Time .....	4-18
<b>Determining the Compiled Sample Time of a Block ...</b>	<b>4-20</b>
<b>Managing Sample Times in Subsystems .....</b>	<b>4-21</b>
<b>Managing Sample Times in Systems .....</b>	<b>4-22</b>
Purely Discrete Systems .....	4-22
Hybrid Systems .....	4-25
<b>Resolving Rate Transitions .....</b>	<b>4-28</b>
<b>How Propagation Affects Inherited Sample Times .....</b>	<b>4-29</b>
Process for Sample Time Propagation .....	4-29
Simulink Rules for Assigning Sample Times .....	4-29
<b>Monitoring Backpropagation in Sample Times .....</b>	<b>4-31</b>

## Referencing a Model

# 5

<b>Overview of Model Referencing .....</b>	<b>5-2</b>
About Model Referencing .....	5-2
Referenced Model Advantages .....	5-5
Masking Model Blocks .....	5-6
Model Referencing Demos .....	5-6
Model Referencing Resources .....	5-7
<b>Creating a Model Reference .....</b>	<b>5-8</b>

<b>Converting a Subsystem to a Referenced Model</b> .....	<b>5-12</b>
Conversion Process .....	<b>5-12</b>
Select Subsystems to Convert .....	<b>5-12</b>
Prepare the Model for Conversion .....	<b>5-13</b>
Run a Conversion Tool .....	<b>5-16</b>
Connect the Model Block and Perform Other	
Post-Conversion Tasks .....	<b>5-18</b>
Convert a Masked Subsystem .....	<b>5-19</b>
<b>Referenced Model Simulation Modes</b> .....	<b>5-21</b>
About Referenced Model Simulation Modes .....	<b>5-21</b>
Specifying the Simulation Mode .....	<b>5-23</b>
Mixing Simulation Modes .....	<b>5-23</b>
Using Normal Mode for Multiple Instances of Referenced	
Models .....	<b>5-25</b>
Accelerating a Freestanding or Top Model .....	<b>5-33</b>
<b>Viewing a Model Reference Hierarchy</b> .....	<b>5-35</b>
Displaying Version Numbers .....	<b>5-35</b>
<b>Model Reference Simulation Targets</b> .....	<b>5-37</b>
About Simulation Targets .....	<b>5-37</b>
Building Simulation Targets .....	<b>5-38</b>
Simulation Target Output File Control .....	<b>5-39</b>
Parallel Building for Large Model Reference Hierarchies ..	<b>5-42</b>
<b>Simulink Model Referencing Requirements</b> .....	<b>5-45</b>
About Model Referencing Requirements .....	<b>5-45</b>
Name Length Requirement .....	<b>5-45</b>
Configuration Parameter Requirements .....	<b>5-45</b>
Model Structure Requirements .....	<b>5-50</b>
<b>Parameterizing Model References</b> .....	<b>5-52</b>
Introduction .....	<b>5-52</b>
Global Nontunable Parameters .....	<b>5-53</b>
Global Tunable Parameters .....	<b>5-53</b>
Using Model Arguments .....	<b>5-53</b>
<b>Conditional Referenced Models</b> .....	<b>5-59</b>
Kinds of Conditional Referenced Models .....	<b>5-59</b>
Working with Conditional Referenced Models .....	<b>5-60</b>

Create Conditional Models .....	5-61
Reference Conditional Models .....	5-63
Simulate Conditional Models .....	5-63
Generate Code for Conditional Models .....	5-64
Requirements for Conditional Models .....	5-64
<b>Protecting Referenced Models .....</b>	<b>5-67</b>
About Protected Models .....	5-67
The Model Protection Facility .....	5-68
Model Protection Requirements .....	5-68
Creating a Protected Model .....	5-69
Obtaining Object and Variable Names for a Protected Model .....	5-72
Packaging a Protected Model .....	5-74
Testing a Protected Model .....	5-74
Using a Protected Model .....	5-76
Model Protection Limitations .....	5-77
<b>Inheriting Sample Times .....</b>	<b>5-78</b>
How Sample-Time Inheritance Works for Model Blocks ..	5-78
Conditions for Inheriting Sample Times .....	5-78
Determining Sample Time of a Referenced Model .....	5-79
Blocks That Depend on Absolute Time .....	5-79
Blocks Whose Outputs Depend on Inherited Sample Time .....	5-81
<b>Refreshing Model Blocks .....</b>	<b>5-82</b>
<b>Using S-Functions with Model Referencing .....</b>	<b>5-83</b>
S-Function Support for Model Referencing .....	5-83
Sample Times .....	5-83
S-Functions with Accelerator Mode Referenced Models ...	5-84
Using C S-Functions in Normal Mode Referenced Models .....	5-85
Protected Models .....	5-85
Simulink® Coder™ Considerations .....	5-85
<b>Logging Signals in Referenced Models .....</b>	<b>5-86</b>
<b>Model Referencing Limitations .....</b>	<b>5-87</b>
Introduction .....	5-87

Limitations on All Model Referencing .....	5-87
Limitations on Normal Mode Referenced Models .....	5-90
Limitations on Accelerator Mode Referenced Models .....	5-91
Limitations on PIL Mode Referenced Models .....	5-94

## Creating Conditional Subsystems

# 6

<b>About Conditional Subsystems .....</b>	<b>6-2</b>
<b>Enabled Subsystems .....</b>	<b>6-4</b>
What Are Enabled Subsystems? .....	6-4
Creating an Enabled Subsystem .....	6-5
Blocks that an Enabled Subsystem Can Contain .....	6-10
Using Blocks with Constant Sample Times in Enabled Subsystems .....	6-13
<b>Triggered Subsystems .....</b>	<b>6-17</b>
What Are Triggered Subsystems? .....	6-17
Using Model Referencing Instead of a Triggered Subsystem .....	6-18
Creating a Triggered Subsystem .....	6-19
Blocks That a Triggered Subsystem Can Contain .....	6-20
<b>Triggered and Enabled Subsystems .....</b>	<b>6-21</b>
What Are Triggered and Enabled Subsystems? .....	6-21
Creating a Triggered and Enabled Subsystem .....	6-22
A Sample Triggered and Enabled Subsystem .....	6-23
Creating Alternately Executing Subsystems .....	6-23
<b>Function-Call Subsystems .....</b>	<b>6-26</b>
<b>Conditional Execution Behavior .....</b>	<b>6-28</b>
What Is Conditional Execution Behavior? .....	6-28
Propagating Execution Contexts .....	6-30
Behavior of Switch Blocks .....	6-31
Displaying Execution Contexts .....	6-31
Disabling Conditional Execution Behavior .....	6-32

## Modeling Variant Systems

# 7

<b>Working with Variant Systems</b> .....	7-2
Overview of Variant Systems .....	7-2
Workflow for Implementing Variant Systems .....	7-3
<b>Setting Up Model Variants</b> .....	7-5
Model Variants Block Overview .....	7-5
Example of a Model Variants Block .....	7-7
Configuring the Model Variants Block .....	7-9
Disabling and Enabling Model Variants .....	7-12
Parameterizing Model Variants .....	7-12
Requirements, Limitations, and Tips for Model Variants ..	7-13
Model Variants Demo .....	7-14
<b>Setting Up Variant Subsystems</b> .....	7-15
Variant Subsystem Block Overview .....	7-15
Example of a Variant Subsystem Block .....	7-17
Configuring the Variant Subsystem Block .....	7-20
Disabling and Enabling Subsystem Variants .....	7-23
Variant Subsystem Block Requirements .....	7-23
Variant Subsystem Demo .....	7-24
<b>Setting Up Variant Control</b> .....	7-25
Creating Control Variables .....	7-25
Saving Variant Components .....	7-26
Example Variant Control Variables .....	7-26
Using Enumerated Types for Variant Control Variable Values .....	7-27
<b>Selecting the Active Variant</b> .....	7-29
What Is an Active Variant? .....	7-29
Selecting the Active Variant for Simulation .....	7-29
Checking and Opening the Active Variant .....	7-30
Overriding Variant Conditions .....	7-30

<b>About Variant Objects</b> .....	7-32
What Is a Variant Object? .....	7-32
Creating Variant Objects .....	7-32
Reusing Variant Objects .....	7-33
Variant Condition .....	7-34
<b>Code Generation of Variants</b> .....	7-36
<b>Reference</b> .....	7-37
Custom Storage Classes .....	7-37
Blocks .....	7-37

## Exploring, Searching, and Browsing Models

---

# 8

<b>The Model Explorer: Overview</b> .....	8-2
Introduction to the Model Explorer .....	8-2
Opening the Model Explorer .....	8-2
Model Explorer Components .....	8-3
The Main Toolbar .....	8-4
Adding Objects .....	8-4
Customizing the Model Explorer Interface .....	8-5
Basic Steps for Using the Model Explorer .....	8-6
Focusing on Specific Elements of a Model or Chart .....	8-7
<b>The Model Explorer: Model Hierarchy Pane</b> .....	8-9
What You Can Do with the Model Hierarchy Pane .....	8-9
Simulink Root .....	8-10
Base Workspace .....	8-10
Configuration Preferences .....	8-11
Model Nodes .....	8-11
Displaying Linked Library Subsystems .....	8-12
Displaying Masked Subsystems .....	8-12
Linked Library and Masked Subsystems .....	8-13
Displaying Node Contents .....	8-13
Navigating to the Block Diagram .....	8-13
Working with Configuration Sets .....	8-13
Expanding Model References .....	8-14
Cutting, Copying, and Pasting Objects .....	8-16



<b>The Model Explorer: Contents Pane</b> .....	<b>8-18</b>
Contents Pane Tabs .....	<b>8-18</b>
Data Displayed in the Contents Pane .....	<b>8-21</b>
Link to the Currently Selected Node .....	<b>8-21</b>
Horizontal Scrolling in the Object Property Table .....	<b>8-22</b>
Working with the Contents Pane .....	<b>8-23</b>
Editing Object Properties .....	<b>8-24</b>
<b>The Model Explorer: Controlling Contents Using</b>	
<b>Views</b> .....	<b>8-25</b>
Using Views .....	<b>8-25</b>
Customizing Views .....	<b>8-28</b>
Managing Views .....	<b>8-29</b>
<b>The Model Explorer: Organizing How Data Displays</b> ..	<b>8-35</b>
Layout Options .....	<b>8-35</b>
Sorting Column Contents .....	<b>8-35</b>
Grouping by a Property .....	<b>8-36</b>
Changing the Order of Property Columns .....	<b>8-40</b>
Adding Property Columns .....	<b>8-41</b>
Hiding or Removing Property Columns .....	<b>8-42</b>
Marking Nonexistent Properties .....	<b>8-44</b>
<b>The Model Explorer: Using the Row Filter Option and</b>	
<b>Filtering Contents</b> .....	<b>8-46</b>
Controlling the Set of Objects to Display .....	<b>8-46</b>
Using the Row Filter Option .....	<b>8-46</b>
Filtering Contents .....	<b>8-49</b>
<b>The Model Explorer: Working with Workspace</b>	
<b>Variables</b> .....	<b>8-52</b>
Finding Variables That Are Used by a Model or Block ....	<b>8-52</b>
Finding Blocks That Use a Specific Variable .....	<b>8-55</b>
Finding Unused Workspace Variables .....	<b>8-56</b>
Exporting Workspace Variables .....	<b>8-58</b>
Importing Workspace Variables .....	<b>8-60</b>
<b>The Model Explorer: Search Bar</b> .....	<b>8-61</b>
Searching in the Model Explorer .....	<b>8-61</b>
The Search Bar .....	<b>8-62</b>
Showing and Hiding the Search Bar .....	<b>8-62</b>
Search Bar Controls .....	<b>8-62</b>

Search Options .....	8-64
Search Button .....	8-66
Refining a Search .....	8-66
<b>The Model Explorer: Dialog Pane .....</b>	<b>8-67</b>
What You Can Do with the Dialog Pane .....	8-67
Showing and Hiding the Dialog Pane .....	8-67
Editing Properties in the Dialog Pane .....	8-67
<b>The Finder .....</b>	<b>8-70</b>
Find Model Objects .....	8-70
Filter Options .....	8-72
Search Criteria .....	8-73
<b>The Model Browser .....</b>	<b>8-77</b>
About the Model Browser .....	8-77
Navigating with the Mouse .....	8-79
Navigating with the Keyboard .....	8-79
Showing Library Links .....	8-79
Showing Masked Subsystems .....	8-79
<b>Model Dependency Viewer .....</b>	<b>8-80</b>
About Model Dependency Views .....	8-80
Opening the Model Dependency Viewer .....	8-85
Manipulating a Dependency View .....	8-86
Browsing Dependencies .....	8-92
Saving a Dependency View .....	8-92
Printing a Dependency View .....	8-92
<b>Viewing Linked Requirements in Models and Blocks ..</b>	<b>8-93</b>
Overview of Requirements Features in Simulink .....	8-93
Highlighting Requirements in a Model .....	8-94
Viewing Information About a Requirements Link .....	8-96
Navigating to Requirements from a Model .....	8-97
Filtering Requirements in a Model .....	8-99

<b>About Model Configurations</b> .....	<b>9-2</b>
<b>Multiple Configuration Sets in a Model</b> .....	<b>9-3</b>
<b>Share a Configuration Set Across Models</b> .....	<b>9-4</b>
<b>Share a Configuration Set Across Referenced Models</b> .....	<b>9-6</b>
<b>Manage a Configuration Set</b> .....	<b>9-8</b>
Create a Configuration Set in a Model .....	<b>9-8</b>
Create a Configuration Set in the Base Workspace .....	<b>9-8</b>
Open a Configuration Set in the Configuration Parameters Dialog Box .....	<b>9-9</b>
Activate a Configuration Set .....	<b>9-9</b>
Set Values in a Configuration Set .....	<b>9-10</b>
Copy, Delete, and Move a Configuration Set .....	<b>9-10</b>
Save a Configuration Set .....	<b>9-11</b>
Load a Saved Configuration Set .....	<b>9-12</b>
Copy Configuration Set Components .....	<b>9-12</b>
<b>Manage a Configuration Reference</b> .....	<b>9-14</b>
Create and Attach a Configuration Reference .....	<b>9-14</b>
Resolve a Configuration Reference .....	<b>9-15</b>
Activate a Configuration Reference .....	<b>9-17</b>
Change Parameter Values in a Referenced Configuration Set .....	<b>9-18</b>
Save a Referenced Configuration Set .....	<b>9-19</b>
Load a Saved Referenced Configuration Set .....	<b>9-20</b>
Why is the Build Button Not Available for a Configuration Reference? .....	<b>9-20</b>
<b>About Configuration Sets</b> .....	<b>9-21</b>
What Is a Configuration Set? .....	<b>9-21</b>
What Is a Freestanding Configuration Set? .....	<b>9-22</b>
Model Configuration Preferences .....	<b>9-23</b>

<b>About Configuration References</b> .....	<b>9-24</b>
What Is a Configuration Reference? .....	<b>9-24</b>
Why Use Configuration References? .....	<b>9-24</b>
Unresolved Configuration References .....	<b>9-25</b>
Configuration Reference Limitations .....	<b>9-26</b>
Configuration References for Models with Older Simulation Target Settings .....	<b>9-26</b>
<b>Model Configuration Command Line Interface</b> .....	<b>9-28</b>
Overview .....	<b>9-28</b>
Load and Activate a Configuration Set at the Command Line .....	<b>9-29</b>
Save a Configuration Set at the Command Line .....	<b>9-30</b>
Create a Freestanding Configuration Set at the Command Line .....	<b>9-30</b>
Create and Attach a Configuration Reference at the Command Line .....	<b>9-32</b>
Attach a Configuration Reference to Multiple Models at the Command Line .....	<b>9-32</b>
Get Values from a Referenced Configuration Set .....	<b>9-34</b>
Change Values in a Referenced Configuration Set .....	<b>9-34</b>
Obtain a Configuration Reference Handle .....	<b>9-35</b>
Use refresh When Replacing a Referenced Configuration Set .....	<b>9-36</b>

## Configuring Models for Targets with Multicore Processors

# 10

<b>Introduction</b> .....	<b>10-2</b>
About Configuring Models for Concurrent Execution .....	<b>10-2</b>
Supported Targets .....	<b>10-3</b>
Helpful Terms .....	<b>10-3</b>
Software Requirements .....	<b>10-4</b>
<b>Design Considerations</b> .....	<b>10-5</b>
Modeling for Concurrency .....	<b>10-5</b>
Simulation Limitations .....	<b>10-9</b>

<b>Modeling for Concurrent Execution</b> .....	<b>10-11</b>
Workflow .....	10-11
<b>Configure Your Model</b> .....	<b>10-12</b>
Creating a Concurrent Execution Configuration Set .....	10-12
Creating and Propagating a Configuration Reference .....	10-13
<b>Baseline Analysis Using Configuration Defaults</b> .....	<b>10-17</b>
<b>Customizing Concurrent Execution Settings</b> .....	<b>10-19</b>
Configuring Data Transfer Communications .....	10-19
Configuring Periodic Tasks .....	10-21
Configuring Aperiodic Triggers and Tasks .....	10-22
Mapping Blocks to Tasks .....	10-24
<b>Interpreting Simulation Results</b> .....	<b>10-26</b>
Introduction .....	10-26
Default Configuration .....	10-27
Sample Configured Model with Multiple Target Tasks .....	10-28
How Simulink Determines Data Transfer Requirements ..	10-31
<b>Building and Downloading the Model to a Multicore</b>	
<b>Target</b> .....	<b>10-32</b>
Generating Code .....	10-32
Configuring Embedded Coder for Native Threads	
Example .....	10-42
Build and Download .....	10-43
Profile and Evaluate .....	10-44
<b>Concurrent Execution Example</b> .....	<b>10-45</b>
Modeling Concurrent Execution on Multi-Core Targets .....	10-45
<b>Command-Line Interface</b> .....	<b>10-55</b>

<b>General Considerations when Building Simulink</b>	
<b>Models</b> .....	11-2
Avoiding Invalid Loops .....	11-2
Shadowed Files .....	11-4
Model Building Tips .....	11-6
<b>Modeling a Continuous System</b> .....	11-8
<b>Best-Form Mathematical Models</b> .....	11-11
Series RLC Example .....	11-11
Solving Series RLC Using Resistor Voltage .....	11-12
Solving Series RLC Using Inductor Voltage .....	11-13
<b>Example: Converting Celsius to Fahrenheit</b> .....	11-15
<b>Componentization Guidelines</b> .....	11-17
Componentization .....	11-17
Componentization Techniques .....	11-17
General Componentization Guidelines .....	11-18
Summary of Componentization Techniques .....	11-19
Subsystems Summary .....	11-21
Libraries Summary .....	11-25
Model Referencing Summary .....	11-29

<b>Organize Large Modeling Projects</b> .....	12-2
Tools for Managing Project Files .....	12-2
Getting Started with Your Project .....	12-2
Example Project .....	12-4
<b>Create a New Project</b> .....	12-9
Create a New Project to Manage Existing Files .....	12-9

Open Recent Projects .....	12-13
Change the Project Name, Root, Description, and Startup Folder .....	12-14
<b>Add Files and Discover Required Project Files .....</b>	<b>12-16</b>
Add Files .....	12-16
Discover Required Files .....	12-18
<b>Manage Project Files .....</b>	<b>12-23</b>
Choose Views of Files to Manage .....	12-23
Group and Sort File Views .....	12-24
Work With Project Files .....	12-24
Back Out Changes .....	12-25
Label Files .....	12-26
<b>Create Shortcuts to Set Up Projects and Run Frequent Tasks .....</b>	<b>12-29</b>
Create Shortcuts .....	12-29
Use Shortcuts to Find and Run Frequent Tasks .....	12-30
Automate Startup Tasks with Shortcuts .....	12-31
Automate Shutdown Tasks with Shortcuts .....	12-33
<b>Interface with Source Control from Projects .....</b>	<b>12-34</b>
Set Up Source Control with Projects .....	12-34
Register Model Files with Source Control Tools .....	12-35
Set Up Subversion .....	12-35
Set Up Local Version Control .....	12-37
Add or Change Project Source Control .....	12-39
Write a Source Control Adapter with the SDK .....	12-40
<b>Retrieve and Check Out Files Under Source Control ..</b>	<b>12-42</b>
Retrieve a Working Copy of a Project from Source Control .....	12-42
Check Source Control Status of Project Files .....	12-46
Check Out Files .....	12-46
<b>Review Changes and Commit Modified Files .....</b>	<b>12-48</b>
View Modified Files .....	12-48
Review Changes .....	12-50
Precommit Actions .....	12-50
Commit Modified Files .....	12-52

Resolve Conflicts .....	12-52
<b>Use Templates to Create Standard Project Settings ...</b>	<b>12-54</b>
Use Templates for Standard Project Setup .....	12-54
Create a Template from Your Current Project .....	12-54
View and Validate Templates .....	12-56
Create a New Project Using a Template .....	12-57
Import New Templates .....	12-57
<b>Export Projects .....</b>	<b>12-59</b>
<b>Model Dependencies .....</b>	<b>12-60</b>
What Are Model Dependencies? .....	12-60
Generate Manifests .....	12-61
Command-Line Dependency Analysis .....	12-67
Edit Manifests .....	12-69
Compare Manifests .....	12-72
Export Files in a Manifest .....	12-73
Scope of Dependency Analysis .....	12-75
Best Practices for Dependency Analysis .....	12-78
Use the Model Manifest Report .....	12-79

## Simulating Dynamic Systems

### Running Simulations

# 13

<b>Simulation Basics .....</b>	<b>13-2</b>
<b>Controlling Execution of a Simulation .....</b>	<b>13-3</b>
Starting a Simulation .....	13-3
Pausing or Stopping a Simulation .....	13-5
Using Blocks to Stop or Pause a Simulation .....	13-5
<b>Specifying a Simulation Start and Stop Time .....</b>	<b>13-8</b>
<b>Choosing a Solver .....</b>	<b>13-9</b>



What Is a Solver? .....	13-9
Choosing a Solver Type .....	13-10
Choosing a Fixed-Step Solver .....	13-13
Choosing a Variable-Step Solver .....	13-17
Choosing a Jacobian Method for an Implicit Solver .....	13-24
<b>Interacting with a Running Simulation .....</b>	<b>13-31</b>
<b>Saving and Restoring the Simulation State as the</b>	
<b>SimState .....</b>	<b>13-32</b>
Overview of the SimState .....	13-32
How to Save the SimState .....	13-33
How to Restore the SimState .....	13-35
How to Change the States of a Block within the	
SimState .....	13-37
Using the SimState Interface Checksum Diagnostic .....	13-37
Limitations of the SimState .....	13-38
Using SimState within S-Functions .....	13-38
<b>Diagnosing Simulation Errors .....</b>	<b>13-39</b>
Response to Run-Time Errors .....	13-39
Simulation Diagnostics Viewer .....	13-39
Creating Custom Simulation Error Messages .....	13-41

## Running a Simulation Programmatically

# 14

<b>About Programmatic Simulation .....</b>	<b>14-2</b>
<b>Using the sim Command .....</b>	<b>14-3</b>
Single-Output Syntax for the sim Command .....	14-3
Examples of Implementing the sim Command .....	14-4
Calling sim from within parfor .....	14-5
Backwards Compatible Syntax .....	14-5
<b>Using the set_param Command .....</b>	<b>14-7</b>
Running a Simulation from an S-Function .....	14-7

<b>Running Parallel Simulations</b> .....	14-8
Overview of Calling sim from within parfor .....	14-8
sim in parfor with Rapid Accelerator Mode .....	14-9
Workspace Access Issues .....	14-10
Resolving Workspace Access Issues .....	14-10
Data Concurrency Issues .....	14-12
Resolving Data Concurrency Issues .....	14-12
<b>Error Handling in Simulink Using MSLErrorException</b> ....	14-15
Error Reporting in a Simulink Application .....	14-15
The MSLErrorException Class .....	14-15
Methods of the MSLErrorException Class .....	14-15
Capturing Information about the Error .....	14-15

## Visualizing and Comparing Simulation Results

# 15

<b>About Scope Blocks, Signal Viewers, Signal Logging, and Test Points</b> .....	15-2
What Are Scope Blocks, Signal Viewers, Test Points and Data Logging? .....	15-2
Scope Block and Scope Signal Viewer Differences .....	15-3
Why Use Signal Generators and Signal Viewers Instead of Source Blocks and Scope Blocks? .....	15-4
<b>Signal Viewer Tasks</b> .....	15-6
About Signal Viewers .....	15-6
Attaching a Signal Viewer .....	15-6
Adding Signals to a Signal Viewer .....	15-8
Displaying a Signal Viewer .....	15-9
Zooming In On Graph Regions .....	15-10
How to Save Data to MATLAB Workspace .....	15-10
Plotting the Viewer Data .....	15-11
<b>Scope Signal Viewer Tasks</b> .....	15-12
Adding a Legend to a Scope Signal Viewer .....	15-12
Creating a Multiple Axes Scope Signal Viewer .....	15-12
<b>Scope Signal Viewer Characteristics</b> .....	15-15

Scope Signal Viewer Toolbar .....	15-15
Scope Signal Viewer Context Menu .....	15-16
Scope Signal Viewer Parameters Dialog Box .....	15-17
How a Scope Signal Viewer Determines Trace Color Coding and Line Styles .....	15-20
How Scope Signal Viewer Parameter Settings Can Affect Performance .....	15-21
<b>Signal Generator Tasks</b> .....	<b>15-23</b>
Attaching a Signal Generator. ....	15-23
Removing a Generator .....	15-24
<b>Signal and Scope Manager</b> .....	<b>15-25</b>
About the Signal & Scope Manager .....	15-25
Opening the Signal and Scope Manager .....	15-26
Changing Generator or Viewer Parameters .....	15-27
Adding Signals to a Viewer .....	15-27
Removing a Generator or Viewer from a Simulink Model ..	15-27
Viewing Test Point Data .....	15-27
<b>Signal Selector</b> .....	<b>15-29</b>
About the Signal Selector .....	15-29
Select signals for object .....	15-30
Model Hierarchy .....	15-30
Inputs/Signals List .....	15-30
<b>Inspecting and Comparing Logged Signal Data</b> .....	<b>15-33</b>
Overview .....	15-33
Record or Import Data into the Simulation Data Inspector Tool .....	15-36
Visual Inspection of Signal Data in the Simulation Data Inspector Tool .....	15-42
Comparison of Signal Data .....	15-54
Comparison of One Signal From Multiple Simulations ...	15-56
Comparison of All Logged Signal Data From Multiple Simulations .....	15-59
Create Simulation Data Inspector Report .....	15-63
Export Results in the Simulation Data Inspector Tool ....	15-64
How the Simulation Data Inspector Tool Aligns Signals ..	15-65
How the Simulation Data Inspector Tool Compares Time Series Data .....	15-67
Understanding the Simulation Data Inspector Interface ..	15-68

Limitations of the Simulation Data Inspector Tool .....	15-84
Record and Inspect Signal Data Programmatically .....	15-85

## Analyzing Simulation Results

# 16

<b>Viewing Output Trajectories</b> .....	16-2
Viewing and Exporting Simulation Data .....	16-2
Using the Scope Block .....	16-2
Using Return Variables .....	16-3
Using the To Workspace Block .....	16-3
Using the Simulation Data Inspector Tool .....	16-4
<b>Linearizing Models</b> .....	16-5
About Linearizing Models .....	16-5
Linearization with Referenced Models .....	16-7
Linearization Using the 'v5' Algorithm .....	16-9
<b>Finding Steady-State Points</b> .....	16-11

## Improving Simulation Performance and Accuracy

# 17

<b>About Improving Performance and Accuracy</b> .....	17-2
<b>Speeding Up the Simulation</b> .....	17-3
<b>Comparing Performance</b> .....	17-5
Performance of the Simulation Modes .....	17-5
Measuring Performance .....	17-7
<b>Improving Acceleration Mode Performance</b> .....	17-9
Techniques .....	17-9

C Compilers .....	17-10
-------------------	-------

Improving Simulation Accuracy .....	17-11
-------------------------------------	-------

## Simulink Debugger

# 18

Introduction to the Debugger .....	18-2
------------------------------------	------

Using the Debugger's Graphical User Interface .....	18-3
Displaying the Graphical Interface .....	18-3
Toolbar .....	18-4
Breakpoints Pane .....	18-6
Simulation Loop Pane .....	18-7
Outputs Pane .....	18-8
Sorted List Pane .....	18-9
Status Pane .....	18-10

Using the Debugger's Command-Line Interface .....	18-11
Controlling the Debugger .....	18-11
Method ID .....	18-11
Block ID .....	18-11
Accessing the MATLAB Workspace .....	18-12

Getting Online Help .....	18-13
---------------------------	-------

Starting the Simulink Debugger .....	18-14
Starting from a Model Window .....	18-14
Starting from the Command Window .....	18-14

Starting a Simulation .....	18-16
-----------------------------	-------

Running a Simulation Step by Step .....	18-20
Introduction .....	18-20
Block Data Output .....	18-21
Stepping Commands .....	18-22
Continuing a Simulation .....	18-23

Running a Simulation Nonstop .....	18-25
Debug Pointer .....	18-26
<b>Setting Breakpoints .....</b>	<b>18-28</b>
About Breakpoints .....	18-28
Setting Unconditional Breakpoints .....	18-28
Setting Conditional Breakpoints .....	18-31
<b>Displaying Information About the Simulation .....</b>	<b>18-34</b>
Displaying Block I/O .....	18-34
Displaying Algebraic Loop Information .....	18-36
Displaying System States .....	18-38
Displaying Solver Information .....	18-39
<b>Displaying Information About the Model .....</b>	<b>18-40</b>
Displaying a Models Sorted Lists .....	18-40
Displaying a Block .....	18-41

## Accelerating Models

# 19

<b>What Is Acceleration? .....</b>	<b>19-2</b>
<b>How the Acceleration Modes Work .....</b>	<b>19-3</b>
Overview .....	19-3
Normal Mode .....	19-3
Accelerator Mode .....	19-4
Rapid Accelerator Mode .....	19-5
<b>Code Regeneration in Accelerated Models .....</b>	<b>19-7</b>
Structural Changes That Cause Rebuilds .....	19-7
Determining If the Simulation Will Rebuild .....	19-7
<b>Choosing a Simulation Mode .....</b>	<b>19-10</b>
Simulation Mode Tradeoffs .....	19-10
Comparing Modes .....	19-11
Decision Tree .....	19-13

<b>Designing Your Model for Effective Acceleration</b> .....	<b>19-15</b>
Selecting Blocks for Accelerator Mode .....	<b>19-15</b>
Selecting Blocks for Rapid Accelerator Mode .....	<b>19-16</b>
Controlling S-Function Execution .....	<b>19-16</b>
Accelerator and Rapid Accelerator Mode Data Type Considerations .....	<b>19-17</b>
Behavior of Scopes and Viewers with Rapid Accelerator Mode .....	<b>19-17</b>
Factors Inhibiting Acceleration .....	<b>19-18</b>
<b>Performing Acceleration</b> .....	<b>19-21</b>
Customizing the Build Process .....	<b>19-21</b>
Running Acceleration Mode from the User Interface .....	<b>19-22</b>
Making Run-Time Changes .....	<b>19-24</b>
<b>Interacting with the Acceleration Modes</b>	
<b>Programmatically</b> .....	<b>19-25</b>
Why Interact Programmatically? .....	<b>19-25</b>
Building Accelerator Mode MEX-files .....	<b>19-25</b>
Controlling Simulation .....	<b>19-25</b>
Simulating Your Model .....	<b>19-26</b>
Customizing the Acceleration Build Process .....	<b>19-27</b>
<b>Using the Accelerator Mode with the Simulink</b>	
<b>Debugger</b> .....	<b>19-28</b>
Advantages of Using Accelerator Mode with the Debugger .....	<b>19-28</b>
How to Run the Debugger .....	<b>19-28</b>
When to Switch Back to Normal Mode .....	<b>19-29</b>
<b>Capturing Performance Data</b> .....	<b>19-30</b>
What Is the Profiler? .....	<b>19-30</b>
How the Profiler Works .....	<b>19-30</b>
Enabling the Profiler .....	<b>19-32</b>
How to Save Simulink Profiler Results .....	<b>19-35</b>

# Managing Blocks

## Working with Blocks

### 20

<b>About Blocks</b> .....	20-2
What Are Blocks? .....	20-2
Block Data Tips .....	20-2
Virtual Blocks .....	20-2
<b>Adding Blocks</b> .....	20-4
Ways to Add Blocks .....	20-4
Adding Blocks by Browsing or Searching with the Library Browser .....	20-5
Copying Blocks from a Model .....	20-5
Adding Frequently Used Blocks .....	20-6
Adding Blocks Programmatically .....	20-8
<b>Editing Blocks</b> .....	20-9
Copying and Moving Blocks from One Window to Another .....	20-9
Moving Blocks in a Model .....	20-10
Copying Blocks in a Model .....	20-13
Deleting Blocks .....	20-14
<b>Block Properties Dialog Box</b> .....	20-15
General Pane .....	20-15
Block Annotation Pane .....	20-17
Callbacks Pane .....	20-19
Creating Block Annotations Programmatically .....	20-21
<b>Changing a Block's Appearance</b> .....	20-22
Changing a Block's Orientation .....	20-22
Resizing a Block .....	20-25
Displaying Parameters Beneath a Block .....	20-26
Using Drop Shadows .....	20-26
Manipulating Block Names .....	20-26
Specifying a Block's Color .....	20-28
<b>Displaying Port Values</b> .....	20-29



Port Value Data Tips .....	20-29
Setting Port Value Data Tip Options .....	20-30
Enabling Port Value Display .....	20-31
Controlling the Port Value Display .....	20-31
Displayed Value When No Data Is Available .....	20-32
Port Value Display Limitations .....	20-33
<b>Controlling and Displaying the Sorted Order .....</b>	<b>20-35</b>
What Is Sorted Order? .....	20-35
Displaying the Sorted Order .....	20-35
Sorted Order Notation .....	20-36
How Simulink Determines the Sorted Order .....	20-46
Assigning Block Priorities .....	20-48
Rules for Block Priorities .....	20-49
Block Priority Violations .....	20-52
<b>Accessing Block Data During Simulation .....</b>	<b>20-53</b>
About Block Run-Time Objects .....	20-53
Accessing a Run-Time Object .....	20-53
Listening for Method Execution Events .....	20-54
Synchronizing Run-Time Objects and Simulink Execution .....	20-55
<b>Configuration a Block for Code Generation .....</b>	<b>20-57</b>

## Working with Block Parameters

# 21

<b>About Block Parameters .....</b>	<b>21-2</b>
<b>Setting Block Parameters .....</b>	<b>21-4</b>
Displaying a Block Parameter Dialog Box .....	21-4
<b>Specifying Parameter Values .....</b>	<b>21-6</b>
About Parameter Values .....	21-6
Using Workspace Variables in Parameter Expressions ...	21-6
Resolving Variable References in Block Parameter Expressions .....	21-7

Using Parameter Objects to Specify Parameter Values ...	21-7
Determining Parameter Data Types .....	21-8
<b>Checking Parameter Values .....</b>	<b>21-9</b>
About Value Checking .....	21-9
Blocks That Perform Parameter Range Checking .....	21-9
Specifying Ranges for Parameters .....	21-10
Performing Parameter Range Checking .....	21-11
<b>Using Tunable Parameters .....</b>	<b>21-13</b>
About Tunable Parameters .....	21-13
Tuning a Block Parameter .....	21-13
<b>Inlining Parameters .....</b>	<b>21-14</b>
About Inlined Parameters .....	21-14
Specifying Some Parameters as Noninline .....	21-14
<b>Using Structure Parameters .....</b>	<b>21-16</b>
About Structure Parameters .....	21-16
Defining Structure Parameters .....	21-17
Referencing Structure Parameters .....	21-17
Structure Parameter Arguments .....	21-18
Tunable Structure Parameters .....	21-19
Parameter Structure Limitations .....	21-20

## Working with Lookup Tables

# 22

<b>About Lookup Table Blocks .....</b>	<b>22-2</b>
<b>Anatomy of a Lookup Table .....</b>	<b>22-4</b>
<b>Lookup Tables Block Library .....</b>	<b>22-5</b>
<b>Guidelines for Choosing a Lookup Table .....</b>	<b>22-7</b>
Data Set Dimensionality .....	22-7
Data Set Numeric and Data Types .....	22-7

Data Accuracy and Smoothness .....	22-8
Dynamics of Table Inputs .....	22-8
Efficiency of Performance .....	22-8
Summary of Lookup Table Block Features .....	22-10
<b>Entering Breakpoints and Table Data .....</b>	<b>22-11</b>
Entering Data in a Block Parameter Dialog Box .....	22-11
Entering Data in the Lookup Table Editor .....	22-13
Entering Data Using Inports of the Lookup Table Dynamic Block .....	22-16
<b>Characteristics of Lookup Table Data .....</b>	<b>22-18</b>
Sizes of Breakpoint Data Sets and Table Data .....	22-18
Monotonicity of Breakpoint Data Sets .....	22-19
Representation of Discontinuities in Lookup Tables .....	22-20
Formulation of Evenly Spaced Breakpoints .....	22-22
<b>Methods for Estimating Missing Points .....</b>	<b>22-23</b>
About Estimating Missing Points .....	22-23
Interpolation Methods .....	22-23
Extrapolation Methods .....	22-24
Rounding Methods .....	22-25
Example Output for Lookup Methods .....	22-26
<b>Lookup Table Editor .....</b>	<b>22-28</b>
When to Use the Lookup Table Editor .....	22-28
Layout of the Lookup Table Editor .....	22-28
Browsing Lookup Table Blocks .....	22-29
Editing Table Values .....	22-30
Working with Table Data of Standard Format .....	22-32
Working with Table Data of Nonstandard Format .....	22-36
Importing Data from an Excel Spreadsheet .....	22-53
Adding and Removing Rows and Columns in a Table .....	22-55
Displaying N-Dimensional Tables in the Editor .....	22-56
Plotting Lookup Tables .....	22-57
Editing Custom Lookup Table Blocks .....	22-61
<b>Example of a Logarithm Lookup Table .....</b>	<b>22-63</b>
<b>Examples for Prelookup and Interpolation Blocks .....</b>	<b>22-66</b>

<b>Tips to Optimize Generated Code for Lookup Table</b>	
<b>Blocks</b> .....	22-67
Remove Code That Checks for Out-of-Range Inputs .....	22-67
Optimize Breakpoint Spacing in Lookup Tables .....	22-69
<b>Updating Your Model to Use Current Lookup Table</b>	
<b>Blocks</b> .....	22-71
Comparison of Blocks with Current Versions .....	22-71
Compatibility of Models with Older Versions of Lookup Table Blocks .....	22-72
How to Update Your Model .....	22-73
What to Expect from the Model Advisor Check .....	22-74
<b>Lookup Table Glossary</b> .....	22-77

## Working with Block Masks

# 23

<b>What Are Masks?</b> .....	23-2
<b>Why Use a Mask?</b> .....	23-3
<b>Masked Subsystem Example</b> .....	23-5
<b>Roadmap for Masking Blocks</b> .....	23-8
<b>Mask Terminology</b> .....	23-10
<b>Creating a Block Mask</b> .....	23-11
Introduction .....	23-11
Opening the Mask Editor .....	23-12
Defining a Mask Icon .....	23-13
Defining Mask Initialization .....	23-16
Understanding Mask Parameters .....	23-19
Defining Mask Parameters .....	23-21
Defining Mask Documentation .....	23-26
Using a Block Mask .....	23-29

<b>Masking a Model Block</b> .....	<b>23-32</b>
Special Considerations for Masking a Model Block .....	<b>23-32</b>
Specifying the Model Name .....	<b>23-32</b>
Workspace for Variables .....	<b>23-33</b>
<b>Masks on Blocks in User Libraries</b> .....	<b>23-34</b>
About Masks and User-Defined Libraries .....	<b>23-34</b>
Masking a Block for Inclusion in a User Library .....	<b>23-34</b>
Masking a Block that Resides in a User Library .....	<b>23-34</b>
Masking a Block Copied from a User Library .....	<b>23-35</b>
<b>Masking Blocks and Promoting Parameters</b> .....	<b>23-36</b>
Masking Built-In Blocks Directly and Within Subsystems .....	<b>23-36</b>
Promoting Block Parameters to the Mask .....	<b>23-36</b>
Creating a Simplified Custom Interface for a Built-In Block .....	<b>23-40</b>
Creating a Simplified Custom Interface for Multiple Parameters in a Subsystem .....	<b>23-44</b>
Rules for Promoting Parameters .....	<b>23-47</b>
<b>Operating on Existing Masks</b> .....	<b>23-50</b>
Changing a Block Mask .....	<b>23-50</b>
Viewing Mask Parameters .....	<b>23-50</b>
Looking Under a Block Mask .....	<b>23-50</b>
Removing and Caching a Mask .....	<b>23-51</b>
Restoring a Cached Mask .....	<b>23-52</b>
Permanently Deleting a Mask .....	<b>23-52</b>
<b>Roadmap for Dynamic Masks</b> .....	<b>23-53</b>
<b>Calculating Values Used Under the Mask</b> .....	<b>23-54</b>
<b>Controlling Masks Programmatically</b> .....	<b>23-57</b>
Using the get_param and set_param Commands .....	<b>23-57</b>
Predefined Masked Dialog Box Parameters .....	<b>23-58</b>
Notes on Mask Parameter Storage .....	<b>23-61</b>
<b>Creating Dynamic Mask Dialog Boxes</b> .....	<b>23-63</b>
About Dynamic Masked Dialog Boxes .....	<b>23-63</b>
Show parameter .....	<b>23-64</b>

Enable parameter .....	23-64
Setting Masked Block Dialog Box Parameters .....	23-64
Setting Nested Masked Block Parameters .....	23-66
<b>Creating Dynamic Masked Subsystems .....</b>	<b>23-68</b>
Allow library block to modify its contents .....	23-68
Creating Self-Modifying Masks for Library Blocks .....	23-68
<b>Understanding Mask Code Execution .....</b>	<b>23-72</b>
Partitioning MATLAB Code .....	23-72
Drawing Commands Execution .....	23-72
Initialization Command Execution .....	23-73
Mask Parameters Dialog Box Callback Code Execution ..	23-74
<b>Debugging Masks That Use MATLAB Code .....</b>	<b>23-75</b>

## Creating Custom Blocks

# 24

<b>When to Create Custom Blocks .....</b>	<b>24-2</b>
<b>Types of Custom Blocks .....</b>	<b>24-3</b>
MATLAB Function Blocks .....	24-3
Subsystem Blocks .....	24-4
S-Function Blocks .....	24-4
<b>Comparison of Custom Block Functionality .....</b>	<b>24-7</b>
Custom Block Considerations .....	24-7
Modeling Requirements .....	24-10
Speed and Code Generation Requirements .....	24-13
<b>Expanding Custom Block Functionality .....</b>	<b>24-17</b>
<b>Tutorial: Creating a Custom Block .....</b>	<b>24-18</b>
How to Design a Custom Block .....	24-18
Defining Custom Block Behavior .....	24-20
Deciding on a Custom Block Type .....	24-21

Placing Custom Blocks in a Library .....	24-26
Adding a Graphical User Interface to a Custom Block ....	24-28
Adding Block Functionality Using Block Callbacks .....	24-37
<b>Custom Block Examples .....</b>	<b>24-43</b>
Creating Custom Blocks from Masked Library Blocks ....	24-43
Creating Custom Blocks from MATLAB Functions .....	24-43
Creating Custom Blocks from S-Functions .....	24-44

## Working with Block Libraries

# 25

<b>About Block Libraries and Linked Blocks .....</b>	<b>25-2</b>
Block Libraries .....	25-2
Benefits of Block Libraries .....	25-2
Library Browser .....	25-2
Linked Blocks .....	25-2
 <b>Creating and Working with Linked Blocks .....</b>	 <b>25-4</b>
About Linked Blocks .....	25-4
Creating a Linked Block .....	25-4
Updating a Linked Block .....	25-5
Modifying Linked Blocks .....	25-6
Finding a Linked Block's Prototype .....	25-7
Finding Linked Blocks in a Model .....	25-7
 <b>Working with Library Links .....</b>	 <b>25-8</b>
Displaying Library Links .....	25-8
Locking Links to Blocks in a Library .....	25-9
Disabling Links to Library Blocks .....	25-11
Restoring Disabled or Parameterized Links .....	25-12
Checking and Setting Link Status Programmatically ....	25-16
Breaking a Link to a Library Block .....	25-18
Fixing Unresolved Library Links .....	25-19
 <b>Creating Block Libraries .....</b>	 <b>25-21</b>
Creating a Library .....	25-21
Creating a Sublibrary .....	25-22
Modifying and Locking Libraries .....	25-22

Making Backward-Compatible Changes to Libraries . . . . .	25-23
---	-------

<b>Adding Libraries to the Library Browser . . . . .</b>	<b>25-36</b>
How to Display a Library in the Library Browser . . . . .	25-36
Example of a Minimal slblocks.m File . . . . .	25-36
Adding More Descriptive Information in slblocks.m . . . . .	25-37

## Using the MATLAB Function Block

# 26

<b>Introduction to MATLAB Function Blocks . . . . .</b>	<b>26-3</b>
What Is a MATLAB Function Block? . . . . .	26-3
Why Use MATLAB Function Blocks? . . . . .	26-6

### Creating an Example Model That Uses a MATLAB

<b>Function Block . . . . .</b>	<b>26-7</b>
Adding a MATLAB Function Block to a Model . . . . .	26-7
Programming the MATLAB Function Block . . . . .	26-8
Building the Function and Checking for Errors . . . . .	26-10
Defining Inputs and Outputs . . . . .	26-12

### Debugging a MATLAB Function Block . . . . .

How Debugging Affects Simulation Speed . . . . .	26-14
Enabling and Disabling Debugging . . . . .	26-14
Debugging the Function in Simulation . . . . .	26-14
Watching Function Variables During Simulation . . . . .	26-18
Checking for Data Range Violations . . . . .	26-20
Debugging Tools . . . . .	26-20

### MATLAB Function Block Editor . . . . .

Customizing the MATLAB Function Block Editor . . . . .	26-23
MATLAB Function Block Editor Tools . . . . .	26-23
Editing and Debugging MATLAB Function Block Code . . . . .	26-24
Ports and Data Manager . . . . .	26-27

### Working with MATLAB Function Reports . . . . .

About MATLAB Function Reports . . . . .	26-46
Location of MATLAB Function Reports . . . . .	26-46



Opening MATLAB Function Reports .....	26-47
Description of MATLAB Function Reports .....	26-47
Viewing Your MATLAB Function Code .....	26-47
Viewing Call Stack Information .....	26-49
Viewing the Compilation Summary Information .....	26-49
Viewing Error and Warning Messages .....	26-49
Viewing Variables in Your MATLAB Code .....	26-51
Keyboard Shortcuts for the MATLAB Function Report ...	26-57
Report Limitations .....	26-58
<b>Typing Function Arguments .....</b>	<b>26-60</b>
About Function Arguments .....	26-60
Specifying Argument Types .....	26-60
Inheriting Argument Data Types .....	26-62
Built-In Data Types for Arguments .....	26-63
Specifying Argument Types with Expressions .....	26-64
Specifying Simulink® Fixed Point™ Data Properties .....	26-64
<b>Sizing Function Arguments .....</b>	<b>26-69</b>
Specifying Argument Size .....	26-69
Inheriting Argument Sizes from Simulink .....	26-69
Specifying Argument Sizes with Expressions .....	26-70
<b>Parameter Arguments in MATLAB Function Block</b>	
<b>Functions .....</b>	<b>26-72</b>
<b>Resolving Signal Objects for Output Data .....</b>	<b>26-73</b>
Implicit Signal Resolution .....	26-73
Eliminating Warnings for Implicit Signal Resolution in the Model .....	26-73
Disabling Implicit Signal Resolution for a MATLAB Function Block .....	26-74
Forcing Explicit Signal Resolution for an Output Data Signal .....	26-74
<b>Working with Structures and Bus Signals .....</b>	<b>26-75</b>
About Structures in MATLAB Function Blocks .....	26-75
Example of Structures in a MATLAB Function Block ....	26-76
How Structure Inputs and Outputs Interface with Bus Signals .....	26-78
Rules for Defining Structures in MATLAB Function Blocks .....	26-79

Workflow for Creating Structures in MATLAB Function	
Blocks .....	26-79
Indexing Substructures and Fields .....	26-81
Assigning Values to Structures and Fields .....	26-81
Working with Structure Parameters in MATLAB Function	
Blocks .....	26-83
Limitations of Structures and Buses in MATLAB Function	
Blocks .....	26-85

### **Using Variable-Size Data in MATLAB Function**

<b>Blocks</b> .....	26-86
What Is Variable-Size Data? .....	26-86
How MATLAB Function Blocks Implement Variable-Size	
Data .....	26-86
Enabling Support for Variable-Size Data .....	26-86
Declaring Variable-Size Inputs and Outputs .....	26-87
Declaring Variable-Size Data Locally .....	26-87
Simple Example: Defining and Using Variable-Size Data in	
MATLAB Function Blocks .....	26-87

### **Using Enumerated Data in MATLAB Function**

<b>Blocks</b> .....	26-95
Enumerated Data in MATLAB Function Blocks .....	26-95
When to Use Enumerated Data .....	26-96
Simple Example: Defining and Using Enumerated Types in	
MATLAB Function Blocks .....	26-97
Using Enumerated Data in MATLAB Function Blocks ...	26-101
How to Define Enumerated Data Types for MATLAB	
Function Blocks .....	26-101
How to Add Enumerated Data to MATLAB Function	
Blocks .....	26-102
How to Instantiate Enumerated Data in MATLAB Function	
Blocks .....	26-104
Operations on Enumerated Data .....	26-104
Limitations of Enumerated Types .....	26-105

### **Using Global Data with the MATLAB Function**

<b>Block</b> .....	26-106
When Do You Need to Use Global Data? .....	26-106
Using Global Data with the MATLAB Function Block ....	26-106
Choosing How to Store Global Data .....	26-107
How to Use Data Store Memory Blocks .....	26-109
How to Use Simulink.Signal Objects .....	26-111

Using Data Store Diagnostics to Detect Memory Access	
Issues .....	26-113
Limitations of Using Shared Data in MATLAB Function	
Blocks .....	26-114
<b>Working with Frame-Based Signals .....</b>	<b>26-115</b>
About Frame-Based Signals .....	26-115
Supported Types for Frame-Based Data .....	26-115
Adding Frame-Based Data in MATLAB Function Blocks ..	26-116
Examples of Frame-Based Signals in MATLAB Function	
Blocks .....	26-117
<b>Creating Custom Block Libraries with MATLAB</b>	
<b>Function Blocks .....</b>	<b>26-121</b>
When to Use MATLAB Function Block Libraries .....	26-121
How to Create Custom MATLAB Function Block	
Libraries .....	26-121
Example: Creating a Custom Signal Processing Filter Block	
Library .....	26-122
Code Reuse with Library Blocks .....	26-133
Debugging MATLAB Function Library Blocks .....	26-137
Properties You Can Specialize Across Instances of Library	
Blocks .....	26-138
<b>Using Traceability in MATLAB Function Blocks .....</b>	<b>26-139</b>
Extent of Traceability in MATLAB Function Blocks .....	26-139
Traceability Requirements .....	26-139
Basic Workflow for Using Traceability .....	26-140
Tutorial: Using Traceability in a MATLAB Function	
Block .....	26-141
<b>Including MATLAB Source Code as Comments in the</b>	
<b>Generated Code .....</b>	<b>26-144</b>
How to Include MATLAB Code as Comments in the	
Generated Code .....	26-145
Location of Comments in Generated Code .....	26-145
Including MATLAB Function Help Text in the Function	
Banner .....	26-148
Limitations of MATLAB Source Code as Comments .....	26-148
<b>Enhancing Readability of Generated Code for MATLAB</b>	
<b>Function Blocks .....</b>	<b>26-150</b>

Requirements for Using Readability Optimizations . . . . .	26-150
Converting If-Elseif-Else Code to Switch-Case Statements . . . . .	26-150
Example of Converting Code for If-Elseif-Else Decision Logic to Switch-Case Statements . . . . .	26-153

**Speeding Up Simulation with the Basic Linear Algebra**

<b>Subprograms (BLAS) Library</b> . . . . .	26-159
How MATLAB Function Blocks Use the BLAS Library . . .	26-159
When to Disable BLAS Library Support . . . . .	26-159
How to Disable BLAS Library Support . . . . .	26-160
Supported Compilers . . . . .	26-160

**Controlling Run-Time Checks . . . . . 26-161**

Types of Run-Time Checks . . . . .	26-161
When to Disable Run-Time Checks . . . . .	26-161
How to Disable Run-Time Checks . . . . .	26-162

**Tutorial: Integrating MATLAB Code with a Simulink**

<b>Model for Tracking a Moving Object</b> . . . . .	26-163
Learning Objectives . . . . .	26-163
Tutorial Prerequisites . . . . .	26-164
Example: The Kalman Filter . . . . .	26-164
Files for the Tutorial . . . . .	26-167
Tutorial Steps . . . . .	26-169
Best Practices Used in This Tutorial . . . . .	26-189
Key Points to Remember . . . . .	26-189
Where to Learn More . . . . .	26-190

**Tutorial: Integrating MATLAB Code with a Simulink**

<b>Model for Filtering an Audio Signal</b> . . . . .	26-192
Learning Objectives . . . . .	26-192
Tutorial Prerequisites . . . . .	26-193
Example: The LMS Filter . . . . .	26-194
Files for the Tutorial . . . . .	26-196
Tutorial Steps . . . . .	26-198

<b>Working with Data Types</b> .....	27-2
About Data Types .....	27-2
Data Types Supported by Simulink .....	27-3
Fixed-Point Data .....	27-4
Enumerations .....	27-6
Bus Objects .....	27-6
Block Support for Data and Numeric Signal Types .....	27-7
Creating Signals of a Specific Data Type .....	27-7
Specifying Block Output Data Types .....	27-8
Using the Data Type Assistant .....	27-15
Displaying Port Data Types .....	27-28
Data Type Propagation .....	27-28
Data Typing Rules .....	27-29
Typecasting Signals .....	27-30
Validating a Floating-Point Embedded Model .....	27-30
Tutorial: Validating a Single-Precision Model .....	27-31
<b>Working with Data Objects</b> .....	27-37
About Data Object Classes .....	27-37
About Data Object Methods .....	27-38
Using the Model Explorer to Create Data Objects .....	27-40
About Object Properties .....	27-42
Changing Object Properties .....	27-42
Handle Versus Value Classes .....	27-44
Comparing Data Objects .....	27-46
Saving and Loading Data Objects .....	27-46
Using Data Objects in Simulink Models .....	27-46
Creating Persistent Data Objects .....	27-47
Data Object Wizard .....	27-47
<b>Define Level-2 Data Classes Using MATLAB Class</b>	
<b>Syntax</b> .....	27-53
<b>Supported Property Types</b> .....	27-57
<b>Upgrade Level-1 Data Classes to Level-2</b> .....	27-58

<b>New Infrastructure for Extending Simulink Data</b>	
<b>Classes</b> .....	27-60
Disadvantages of Level-1 Data Class Infrastructure .....	27-60
Features of Level-2 Data Class Infrastructure .....	27-60
Other Differences between Level-1 and Level-2 Data	
Classes .....	27-61
<b>Define Level-1 Data Classes Using Data Class</b>	
<b>Designer</b> .....	27-62
About Packages and Data Classes .....	27-62
Define Level-1 Data Classes .....	27-63
Working with Classes .....	27-66
Enumerated Property Types .....	27-75
Enabling Custom Storage Classes .....	27-78
<b>Associating User Data with Blocks</b> .....	27-79
<b>Design Minimum and Maximum</b> .....	27-80
Use of Design Minimum and Maximum .....	27-80
Valid Values for Design Minimum and Maximum .....	27-80

## Enumerations and Modeling

# 28

<b>About Simulink Enumerations</b> .....	28-2
<b>Defining Simulink Enumerations</b> .....	28-3
Basic Workflow for Defining a Simulink Enumeration ...	28-3
Creating a Simulink Enumeration Class .....	28-3
Customizing a Simulink Enumeration .....	28-5
Saving an Enumeration in a MATLAB File .....	28-7
Changing and Reloading Enumerations .....	28-7
Importing Enumerations Defined Externally to	
MATLAB .....	28-8
<b>Using Enumerated Data in Simulink Models</b> .....	28-10
Simulating with Enumerations .....	28-10
Specifying Enumerations as Data Types .....	28-12

Getting Information About Enumerations .....	28-13
Enumeration Value Display .....	28-13
Instantiating Enumerations .....	28-15
Enumerated Values in Computation .....	28-18
<b>Simulink Constructs that Support Enumerations .....</b>	<b>28-21</b>
Overview .....	28-21
Block Support .....	28-21
Class Support .....	28-23
Logging Enumerated Data .....	28-23
Importing Enumerated Data .....	28-23
<b>Simulink Enumeration Limitations .....</b>	<b>28-24</b>
Enumerations and Scopes .....	28-24
Enumerated Types for Switch Blocks .....	28-24
Nonsupport of Enumerations .....	28-24

## Importing and Exporting Simulation Data

# 29

<b>Using Simulation Data .....</b>	<b>29-3</b>
Working with Simulation Data .....	29-3
<b>Exporting Simulation Data .....</b>	<b>29-4</b>
Simulation Data .....	29-4
Approaches for Exporting Signal Data .....	29-4
Enabling Simulation Data Export .....	29-6
Viewing Logged Simulation Data With the Simulation Data Inspector .....	29-7
<b>Selecting the Data Format for Exported Simulation     Data .....</b>	<b>29-8</b>
Data Format for Block-Based Exported Data .....	29-8
Data Format for Model-Based Exported Data .....	29-8
Signal Logging Format .....	29-8
Logged Data Store Format .....	29-9
State and Output Data Format .....	29-9

<b>Specifying the Amount of Exported Data</b> .....	<b>29-14</b>
Decimation .....	<b>29-14</b>
Limit Data Points to Last .....	<b>29-14</b>
<b>Specifying Which Samples to Export for Models with</b>	
<b>Variable-Step Solvers</b> .....	<b>29-16</b>
Output Options .....	<b>29-16</b>
Refining Output .....	<b>29-16</b>
Producing Additional Output .....	<b>29-17</b>
Producing Specified Output Only .....	<b>29-18</b>
<b>Exporting Signal Data Using Signal Logging</b> .....	<b>29-19</b>
Signal Logging .....	<b>29-19</b>
Signal Logging Workflow .....	<b>29-19</b>
Signal Logging Limitations .....	<b>29-20</b>
<b>Configuring a Signal for Signal Logging</b> .....	<b>29-21</b>
Enabling Logging for a Signal .....	<b>29-21</b>
Specifying a Logging Name .....	<b>29-23</b>
Limiting the Data Logged for a Signal .....	<b>29-25</b>
<b>Viewing the Signal Logging Configuration</b> .....	<b>29-27</b>
Approaches for Viewing the Signal Logging	
Configuration .....	<b>29-27</b>
Using the Model Editor to View the Signal Logging	
Configuration .....	<b>29-28</b>
Using the Signal Logging Selector to View the Signal	
Logging Configuration .....	<b>29-30</b>
Using the Model Explorer to View the Signal Logging	
Configuration .....	<b>29-33</b>
<b>Enabling Signal Logging for a Model</b> .....	<b>29-34</b>
Enabling and Disabling Logging Globally for a Model ....	<b>29-34</b>
Specifying the Signal Logging Data Format .....	<b>29-34</b>
Specifying a Name for the Signal Logging Data .....	<b>29-37</b>
<b>Overriding Signal Logging Settings</b> .....	<b>29-38</b>
Benefits of Overriding Signal Logging Settings .....	<b>29-38</b>
Two Interfaces for Overriding Signal Logging Settings ...	<b>29-38</b>
Scope of Signal Logging Setting Overrides .....	<b>29-39</b>
Signal Logging Selector .....	<b>29-39</b>



Command-Line Interface for Overriding Signal Logging Settings .....	29-45
<b>Accessing Signal Logging Data .....</b>	<b>29-50</b>
Viewing Signal Logging Data .....	29-50
The Signal Logging Object .....	29-51
Viewing Logged Signal Data with the Simulation Data Inspector .....	29-51
Programmatically Accessing Logged Signal Data Saved in Dataset Format .....	29-52
Programmatically Accessing Logged Signal Data Saved in ModelDataLogs Format .....	29-53
<b>Importing Signal Data in Simulink .....</b>	<b>29-61</b>
Techniques for Importing Signal Data .....	29-61
Guidelines for Specifying Time and Signal Values for Imported Data .....	29-61
<b>Importing Data to Model a Continuous Plant .....</b>	<b>29-64</b>
Sharing Simulation Data Across Models .....	29-64
Example of Importing Data to Model a Continuous Plant .....	29-64
<b>Importing Data to Test a Discrete Algorithm .....</b>	<b>29-67</b>
Specify a Signal-Only Structure .....	29-67
Example of Importing Data to Test a Discrete Algorithm ..	29-67
<b>Importing Data to Create an Input Test Case .....</b>	<b>29-68</b>
Guidelines for Importing a Test Case .....	29-68
Example of Test Case Data .....	29-68
Using a From Workspace Block to Import an Input Test Case .....	29-69
Using a Signal Builder Block to Import an Input Test Case .....	29-70
<b>Importing Signal Logging Data .....</b>	<b>29-72</b>
<b>Importing Data to Root-Level Input Ports .....</b>	<b>29-74</b>
Root-Level Input Ports .....	29-74
Enabling Data Import .....	29-74
Input Data .....	29-74

Importing Bus Data .....	29-77
<b>Importing MATLAB timeseries Data .....</b>	<b>29-78</b>
Specifying the Time Dimension .....	29-78
Models with Multiple Root Inport Blocks .....	29-79
<b>Importing Structures of MATLAB timeseries Objects for Bus Signals to a Root-Level Input Port .....</b>	<b>29-80</b>
Defining a Structure of MATLAB timeseries Objects for a Bus Signal .....	29-80
When to Use a Structure of MATLAB timeseries Objects Instead of a Simulink.TsArray Object .....	29-81
How to Use a Structure of MATLAB timeseries Objects to Import Bus Signals .....	29-82
<b>Importing Simulink.Timeseries and Simulink.TsArray Data to a Root-Level Input Port .....</b>	<b>29-85</b>
Alternative to Using MATLAB timeseries Data .....	29-85
Simulink.TsArray Data .....	29-85
<b>Importing Data Arrays to a Root-Level Input Port ....</b>	<b>29-86</b>
Data Array Format .....	29-86
Specifying the Input Expression .....	29-86
<b>Importing MATLAB Time Expression Data .....</b>	<b>29-88</b>
Specifying the Input Expression .....	29-88
<b>Importing Data Structures to a Root-Level Input Port .....</b>	<b>29-89</b>
Data Structures .....	29-89
One Structure for All Ports or a Structure for Each Port ..	29-90
Specifying Signal Data .....	29-90
Specifying Time Data .....	29-91
Examples of Specifying Signal and Time Data .....	29-92
<b>Importing and Exporting States .....</b>	<b>29-94</b>
State Information .....	29-94
Saving State Information .....	29-94
Importing Initial States .....	29-99
Importing and Exporting State Information for Referenced Models .....	29-101

<b>About Data Stores</b> .....	<b>30-2</b>
Local and Global Data Stores .....	<b>30-2</b>
When to Use a Data Store .....	<b>30-3</b>
Creating Data Stores .....	<b>30-3</b>
Accessing Data Stores .....	<b>30-4</b>
Workflow for Configuring Data Stores .....	<b>30-5</b>
Using Data Stores with Buses and Arrays of Buses .....	<b>30-5</b>
<b>Defining Data Stores with Data Store Memory</b>	
<b>Blocks</b> .....	<b>30-8</b>
Creating the Data Store .....	<b>30-8</b>
Specifying Data Store Memory Block Attributes .....	<b>30-8</b>
<b>Defining Data Stores with Signal Objects</b> .....	<b>30-12</b>
Creating the Data Store .....	<b>30-12</b>
Local and Global Data Stores .....	<b>30-12</b>
Specifying Signal Object Data Store Attributes .....	<b>30-12</b>
<b>Accessing Data Stores with Simulink Blocks</b> .....	<b>30-14</b>
Writing to a Data Store .....	<b>30-14</b>
Reading from a Data Store .....	<b>30-14</b>
Accessing a Global Data Store .....	<b>30-15</b>
Accessing Specific Bus and Matrix Elements .....	<b>30-16</b>
<b>Data Store Examples</b> .....	<b>30-22</b>
Overview .....	<b>30-22</b>
Local Data Store Example .....	<b>30-22</b>
Global Data Store Example .....	<b>30-23</b>
<b>Logging Data Stores</b> .....	<b>30-25</b>
Logging Local and Global Data Store Values .....	<b>30-25</b>
Supported Data Types, Dimensions, and Complexity for Logging Data Stores .....	<b>30-25</b>
Data Store Logging Limitations .....	<b>30-26</b>
Logging Data Stores Created with a Data Store Memory Block .....	<b>30-26</b>
Logging Icon for the Data Store Memory Block .....	<b>30-27</b>

Logging Data Stores Created with a Simulink.Signal Object .....	30-27
Accessing Data Store Logging Data .....	30-28
<b>Ordering Data Store Access</b> .....	<b>30-30</b>
About Data Store Access Order .....	30-30
Ordering Access Using Function Call Subsystems .....	30-30
Ordering Access Using Block Priorities .....	30-31
<b>Using Data Store Diagnostics</b> .....	<b>30-33</b>
About Data Store Diagnostics .....	30-33
Detecting Access Order Errors .....	30-33
Detecting Multitasking Access Errors .....	30-36
Detecting Duplicate Name Errors .....	30-38
Data Store Diagnostics in the Model Advisor .....	30-40
<b>Data Stores and Software Verification</b> .....	<b>30-41</b>

## Managing Signals

### Working with Signals

# 31

<b>Signal Basics</b> .....	<b>31-2</b>
About Signals .....	31-2
Creating Signals .....	31-3
Signal Line Styles .....	31-4
Signal Properties .....	31-5
Testing Signals .....	31-6
<b>Signal Types</b> .....	<b>31-8</b>
Summary of Signal Types .....	31-8
Control Signals .....	31-9
Composite (Bus) Signals .....	31-9
<b>Virtual Signals</b> .....	<b>31-11</b>
About Virtual Signals .....	31-11
Mux Signals .....	31-11

<b>Signal Values</b> .....	<b>31-15</b>
Signal Data Types .....	<b>31-15</b>
Signal Dimensions, Size, and Width .....	<b>31-15</b>
Complex Signals .....	<b>31-16</b>
Initializing Signal Values .....	<b>31-16</b>
Viewing Signal Values .....	<b>31-17</b>
Displaying Signal Values in Model Diagrams .....	<b>31-17</b>
Exporting Signal Data .....	<b>31-18</b>
<b>Signal Names and Labels</b> .....	<b>31-19</b>
Signal Names .....	<b>31-19</b>
Signal Labels .....	<b>31-22</b>
<b>Signal Label Propagation</b> .....	<b>31-24</b>
About Signal Label Propagation .....	<b>31-24</b>
Propagated Signal Label Format .....	<b>31-24</b>
Blocks That Support Signal Label Propagation .....	<b>31-25</b>
Display Propagated Signal Labels .....	<b>31-26</b>
How Simulink Propagates Signal Labels .....	<b>31-27</b>
<b>Signal Dimensions</b> .....	<b>31-34</b>
About Signal Dimensions .....	<b>31-34</b>
Simulink Blocks that Support Multidimensional Signals ..	<b>31-35</b>
<b>Determining Output Signal Dimensions</b> .....	<b>31-36</b>
About Signal Dimensions .....	<b>31-36</b>
Determining the Output Dimensions of Source Blocks ...	<b>31-36</b>
Determining the Output Dimensions of Nonsource Blocks .....	<b>31-37</b>
Signal and Parameter Dimension Rules .....	<b>31-37</b>
Scalar Expansion of Inputs and Parameters .....	<b>31-38</b>
<b>Displaying Signal Sources and Destinations</b> .....	<b>31-41</b>
About Signal Highlighting .....	<b>31-41</b>
Highlighting Signal Sources .....	<b>31-41</b>
Highlighting Signal Destinations .....	<b>31-42</b>
Removing Highlighting .....	<b>31-43</b>
Resolving Incomplete Highlighting to Library Blocks ....	<b>31-43</b>
<b>Signal Ranges</b> .....	<b>31-45</b>
About Signal Ranges .....	<b>31-45</b>

Blocks That Allow Signal Range Specification .....	31-45
Specifying Ranges for Signals .....	31-46
Checking for Signal Range Errors .....	31-47
<b>Initializing Signals and Discrete States .....</b>	<b>31-52</b>
About Initialization .....	31-52
Using Block Parameters to Initialize Signals and Discrete States .....	31-53
Using Signal Objects to Initialize Signals and Discrete States .....	31-53
Using Signal Objects to Tune Initial Values .....	31-54
Example: Using a Signal Object to Initialize a Subsystem Output .....	31-56
Initialization Behavior Summary for Signal Objects .....	31-57
<b>Working with Test Points .....</b>	<b>31-59</b>
What Is a Test Point? .....	31-59
Designating a Signal as a Test Point .....	31-59
Displaying Test Point Indicators .....	31-61
<b>Displaying Signal Attributes .....</b>	<b>31-63</b>
Port/Signal Displays Menu .....	31-63
Port Data Types .....	31-64
Design Ranges .....	31-64
Signal Dimensions .....	31-65
Signal Resolution Indicators .....	31-66
Wide Nonscalar Lines .....	31-67
<b>Working with Signal Groups .....</b>	<b>31-68</b>
About Signal Groups .....	31-68
Signal Builder Window .....	31-68
Creating Signal Group Sets .....	31-74
Editing Waveforms .....	31-102
Signal Builder Time Range .....	31-108
Exporting Signal Group Data .....	31-109
Printing, Exporting, and Copying Waveforms .....	31-109
Simulating with Signal Groups .....	31-110
Simulation Options Dialog Box .....	31-111

<b>About Composite Signals</b> .....	32-2
Composite Signal Terminology .....	32-2
Types of Simulink Buses .....	32-3
View Information about Buses .....	32-3
Buses and Muxes .....	32-8
Bus Objects .....	32-8
Bus Code .....	32-9
<b>Creating and Accessing a Bus</b> .....	32-10
<b>Nesting Buses</b> .....	32-12
Circular Bus Definitions .....	32-13
<b>Bus-Capable Blocks</b> .....	32-14
<b>Using Bus Objects</b> .....	32-15
About Bus Objects .....	32-15
Bus Object Capabilities .....	32-16
Associating Bus Objects with Simulink Blocks .....	32-16
<b>Using the Bus Editor</b> .....	32-18
Introduction .....	32-18
Opening the Bus Editor .....	32-19
Displaying Bus Objects .....	32-21
Creating Bus Objects .....	32-23
Creating Bus Elements .....	32-26
Nesting Bus Definitions .....	32-29
Changing Bus Entities .....	32-33
Exporting Bus Objects .....	32-39
Importing Bus Objects .....	32-40
Closing the Bus Editor .....	32-41
<b>Filtering Displayed Bus Objects</b> .....	32-42
Filtering by Name .....	32-43
Filtering by Relationship .....	32-44
Changing Filtered Objects .....	32-47
Clearing the Filter .....	32-47

<b>Customizing Bus Object Import and Export</b> .....	<b>32-49</b>
Prerequisites for Customization .....	<b>32-50</b>
Writing a Bus Object Import Function .....	<b>32-50</b>
Writing a Bus Object Export Function .....	<b>32-51</b>
Registering Customizations .....	<b>32-52</b>
Changing Customizations .....	<b>32-53</b>
<b>Using the Bus Object API</b> .....	<b>32-55</b>
<b>Virtual and Nonvirtual Buses</b> .....	<b>32-56</b>
Introduction .....	<b>32-56</b>
Creating Nonvirtual Buses .....	<b>32-56</b>
Nonvirtual Bus Sample Times .....	<b>32-57</b>
Automatic Bus Conversion .....	<b>32-58</b>
Explicit Bus Conversion .....	<b>32-58</b>
<b>Connecting Buses to Inports and Outports</b> .....	<b>32-59</b>
Connecting Buses to Root Level Inports .....	<b>32-59</b>
Connecting Buses to Root Level Outports .....	<b>32-59</b>
Connecting Buses to Nonvirtual Inports .....	<b>32-59</b>
Connecting Buses to Model, Stateflow, and MATLAB Function Blocks .....	<b>32-61</b>
Connecting Multi-Rate Buses to Referenced Models .....	<b>32-62</b>
<b>Specifying Initial Conditions for Bus Signals</b> .....	<b>32-63</b>
Bus Signal Initialization .....	<b>32-63</b>
Creating Initial Condition (IC) Structures .....	<b>32-65</b>
Three Ways to Initialize Bus Signals Using Block Parameters .....	<b>32-70</b>
Setting Diagnostics to Support Bus Signal Initialization ..	<b>32-74</b>
<b>Combining Buses into an Array of Buses</b> .....	<b>32-75</b>
What Is an Array of Buses? .....	<b>32-75</b>
Benefits of an Array of Buses .....	<b>32-77</b>
Blocks That Support Arrays of Buses .....	<b>32-78</b>
Array of Buses Limitations .....	<b>32-79</b>
Defining an Array of Buses .....	<b>32-81</b>
Using an Array of Buses in a Model .....	<b>32-84</b>
Generated Code for an Array of Buses .....	<b>32-87</b>
Converting a Model to Use an Array of Buses .....	<b>32-88</b>



<b>Buses and Libraries</b> .....	<b>32-92</b>
<b>Avoiding Mux/Bus Mixtures</b> .....	<b>32-93</b>
Introduction .....	<b>32-93</b>
Using Diagnostics for Mux/Bus Mixtures .....	<b>32-94</b>
Using the Model Advisor for Mux/Bus Mixtures .....	<b>32-98</b>
Correcting Buses Used as Muxes .....	<b>32-99</b>
Bus to Vector Block Compatibility Issues .....	<b>32-101</b>
Avoiding Mux/Bus Mixtures When Developing Models ...	<b>32-102</b>
<b>Buses in Generated Code</b> .....	<b>32-103</b>
<b>Composite Signal Limitations</b> .....	<b>32-104</b>

## Working with Variable-Size Signals

# 33

<b>Variable-Size Signal Basics</b> .....	<b>33-2</b>
About Variable-Size Signals .....	<b>33-2</b>
Creating Variable-Size Signals .....	<b>33-2</b>
How Variable-Size Signals Propagate .....	<b>33-3</b>
Empty Signals .....	<b>33-4</b>
Subsystem Initialization of Variable-Size Signals .....	<b>33-4</b>
<b>Simulink Models Using Variable-Size Signals</b> .....	<b>33-6</b>
Demo of Variable-Size Signal Generation and Operations .....	<b>33-6</b>
Demo of Variable-Size Signal Length Adaptation .....	<b>33-10</b>
Demo of Mode-Dependent Variable-Size Signals .....	<b>33-13</b>
<b>S-Functions Using Variable-Size Signals</b> .....	<b>33-19</b>
Demo of Level-2 MATLAB S-Function with Variable-Size Signals .....	<b>33-19</b>
Demo of C S-Function with Variable-Size Signals .....	<b>33-20</b>
<b>Simulink Block Support for Variable-Size Signals</b> ....	<b>33-22</b>
Simulink Block Data Type Support .....	<b>33-22</b>
Conditionally Executed Subsystem Blocks .....	<b>33-22</b>

Switching Blocks .....	33-23
Variable-Size Signal Limitations .....	33-25

# Customizing Simulink Environment and Printed Models

## Customizing the Simulink User Interface

### 34

<b>Adding Items to Model Editor Menus .....</b>	<b>34-2</b>
About Adding Items to the Model Editor Menus .....	34-2
Code Example .....	34-2
Defining Menu Items .....	34-4
Registering Menu Customizations .....	34-9
Callback Info Object .....	34-10
Debugging Custom Menu Callbacks .....	34-10
About Menu Tags .....	34-10
<b>Disabling and Hiding Model Editor Menu Items .....</b>	<b>34-13</b>
About Disabling and Hiding Model Editor Menu Items ...	34-13
Example: Disabling the New Model Command on the Simulink Editor's File Menu .....	34-13
Creating a Filter Function .....	34-13
Registering a Filter Function .....	34-14
<b>Disabling and Hiding Dialog Box Controls .....</b>	<b>34-15</b>
About Disabling and Hiding Controls .....	34-15
Example: Disabling a Button on a Simulink Dialog Box ..	34-16
Writing Control Customization Callback Functions .....	34-17
Dialog Box Methods .....	34-17
Dialog Box and Widget IDs .....	34-18
Registering Control Customization Callback Functions ...	34-19
<b>Customizing the Library Browser .....</b>	<b>34-21</b>
Reordering Libraries .....	34-21
Disabling and Hiding Libraries .....	34-21
Customizing the Library Browser's Menu .....	34-22

<b>Registering Customizations</b> .....	34-24
About Registering User Interface Customizations .....	34-24
Customization Manager .....	34-24

## PrintFrame Editor

# 35

<b>PrintFrame Editor Overview</b> .....	35-2
About the Print Frame Editor .....	35-2
What PrintFrames Are .....	35-3
Starting the PrintFrame Editor .....	35-6
Getting Help for the PrintFrame Editor .....	35-7
Closing the PrintFrame Editor .....	35-7
Print Frame Process .....	35-7
<b>Designing the Print Frame</b> .....	35-8
Before You Begin .....	35-8
Variable and Static Information .....	35-8
Single Use or Multiple Use Print Frames .....	35-8
<b>Specifying the Print Frame Page Setup</b> .....	35-9
<b>Creating Borders (Rows and Cells)</b> .....	35-11
First Steps .....	35-11
Adding and Removing Rows .....	35-11
Adding and Removing Cells .....	35-12
Resizing Rows and Cells .....	35-12
Print Frame Size .....	35-12
<b>Adding Information to Cells</b> .....	35-14
Procedure for Adding Information to Cells .....	35-14
Text Information .....	35-15
Variable Information .....	35-15
Multiple Entries in a Cell .....	35-16
<b>Changing Information in Cells</b> .....	35-18
Aligning the Information in a Cell .....	35-18
Editing Text Strings .....	35-18

Removing and Copying Entries .....	35-19
Changing the Font Characteristics .....	35-20
<b>Saving and Opening Print Frames .....</b>	<b>35-22</b>
Saving a Print Frame .....	35-22
Opening a Print Frame .....	35-22
<b>Printing Block Diagrams with Print Frames .....</b>	<b>35-23</b>
<b>Example .....</b>	<b>35-26</b>
About the Example .....	35-26
Create the Print Frame .....	35-27
Print the Block Diagram with the Print Frame .....	35-30

## Running Models on Target Hardware

### About the Run on Target Hardware Feature

**36**

### Work with BeagleBoard Hardware

**37**

Install Target for Use with BeagleBoard Hardware ...	37-2
<b>Replace the Firmware on the BeagleBoard</b>	
Hardware .....	37-9
<b>Open a Serial Command Line Session with the</b>	
<b>BeagleBoard Hardware .....</b>	<b>37-24</b>
See Also .....	37-28
<b>Connect the BeagleBoard Hardware to a Network and</b>	
<b>Configure IP Settings .....</b>	<b>37-29</b>

<b>Get the IP Address of the BeagleBoard Hardware</b> . . . .	<b>37-33</b>
<b>Open the Block Library for BeagleBoard Hardware</b> . .	<b>37-36</b>
<b>Run a Model on BeagleBoard Hardware</b> . . . . .	<b>37-38</b>
Prepare Models That Use Model Reference . . . . .	<b>37-39</b>
See Also . . . . .	<b>37-40</b>
<b>Tune Parameters and Monitor Data in a Model Running on BeagleBoard Hardware</b> . . . . .	<b>37-41</b>
About External Mode . . . . .	<b>37-41</b>
Run Your Simulink Model in External Mode . . . . .	<b>37-42</b>
Stop External Mode . . . . .	<b>37-43</b>
<b>Detect and Fix Task Overruns on BeagleBoard Hardware</b> . . . . .	<b>37-45</b>

## **Work with LEGO MINDSTORMS NXT Hardware**

# **38**

<b>Install Target for Use with LEGO MINDSTORMS NXT Hardware</b> . . . . .	<b>38-2</b>
<b>Replace the Firmware on the NXT Brick</b> . . . . .	<b>38-7</b>
<b>Open the Block Library for LEGO MINDSTORMS NXT Hardware</b> . . . . .	<b>38-11</b>
<b>Run a Model on LEGO MINDSTORMS NXT Hardware</b> . . . . .	<b>38-14</b>
Prepare Models That Use Model Reference . . . . .	<b>38-15</b>
<b>Remotely Control and Monitor a Model Running on LEGO MINDSTORMS NXT Hardware</b> . . . . .	<b>38-16</b>
About External Mode . . . . .	<b>38-16</b>
Set up Bluetooth on Windows . . . . .	<b>38-17</b>
Run Your Simulink Model in External Mode . . . . .	<b>38-21</b>

Stop External Mode .....	38-23
Set the COM Port Number Manually .....	38-23

**Detect and Fix Task Overruns on LEGO MINDSTORMS**

NXT Hardware .....	38-27
--------------------	-------

**Exchange Data Between Two NXT Bricks .....**

Tips for Use Bluetooth Blocks .....	38-28
Add Bluetooth Blocks to your Models .....	38-29
Configure a Bluetooth Slave .....	38-34
Configure a Bluetooth Master .....	38-35

**Examples**

**A**

Simulink Basics .....	A-2
How Simulink Works .....	A-3
Creating a Model .....	A-4
Executing Commands From Models .....	A-5
Working with Lookup Tables .....	A-6
Creating Block Masks .....	A-7
Creating Custom Simulink Blocks .....	A-8
Working with Blocks .....	A-9

**Index**

# Introduction to Simulink

---

- Chapter 1, “Simulink Basics”
- Chapter 2, “How Simulink Works”





# Simulink Basics


---

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

- “Starting Simulink Software” on page 1-2
- “Opening a Model” on page 1-4
- “Loading a Model” on page 1-7
- “Saving a Model” on page 1-8
- “Using the Model Editor” on page 1-16
- “Undoing a Command” on page 1-25
- “Zooming Block Diagrams” on page 1-26
- “Panning Block Diagrams” on page 1-27
- “Viewing Command History” on page 1-29
- “Bringing the MATLAB Software Desktop Forward” on page 1-30
- “Copying Models to Third-Party Applications” on page 1-31
- “Updating a Block Diagram” on page 1-32
- “Printing a Block Diagram” on page 1-34
- “Generating a Model Report” on page 1-44
- “Ending a Simulink Session” on page 1-47
- “Summary of Mouse and Keyboard Actions” on page 1-48

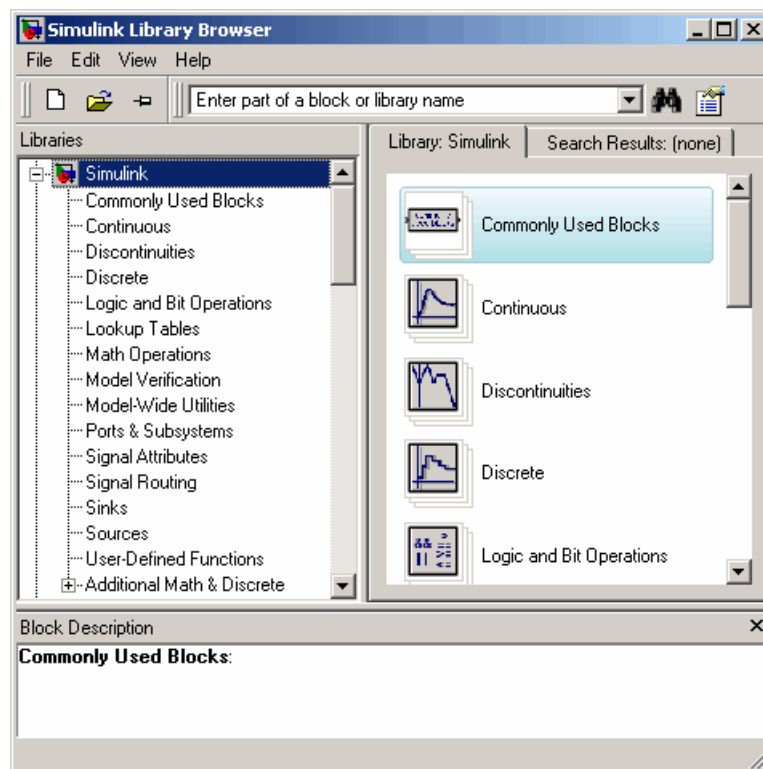
## Starting Simulink Software

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

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

The Library Browser appears. It displays a tree-structured view of the Simulink block libraries installed on your system. You build models by copying blocks from the Library Browser into a model window (see “Editing Blocks” on page 20-9).

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



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

## Opening a Model

### In this section...

“Introduction” on page 1-4

“Opening an Existing Model” on page 1-4

“Opening Models with Different Character Encodings” on page 1-4

“Avoiding Initial Model Open Delay” on page 1-5

### Introduction

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

### Opening an Existing Model

To open an existing model diagram, either:

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

---

**Note** If you have an earlier version of the Simulink software, and you want to open a model that was created in a later version, you must first use the later version to save the model in a format compatible with the earlier version. You can then open the model in the earlier version. See “Saving a Model in an Earlier Simulink Version” on page 1-14 for details.

---

### Opening Models with Different Character Encodings

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

configured to support another character encoding, for example, `US_ASCII`, the Simulink software displays a warning for SLX files. For MDL files, you might see a warning or an error message, depending on whether it can or cannot encode the model, using the current character encoding, respectively. The warning or error message specifies the encoding of the current session and the encoding used to create the model. To avoid corrupting the model (see “Saving Models with Different Character Encodings” on page 1-13) and ensure correct display of the model’s text, you should:

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

You can now safely edit and save the model.

## Avoiding Initial Model Open Delay

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

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

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

```
matlab -r load_simulink
```

## Loading a Model

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

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

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

## Saving a Model

In this section...
“Introduction” on page 1-8
“How to Tell If a Model Needs Saving” on page 1-8
“Techniques for Saving Models” on page 1-9
“Saving Models in the SLX File Format” on page 1-11
“Saving Models with Different Character Encodings” on page 1-13
“Saving a Model in an Earlier Simulink Version” on page 1-14
“Saving from One Earlier Simulink Version to Another” on page 1-15

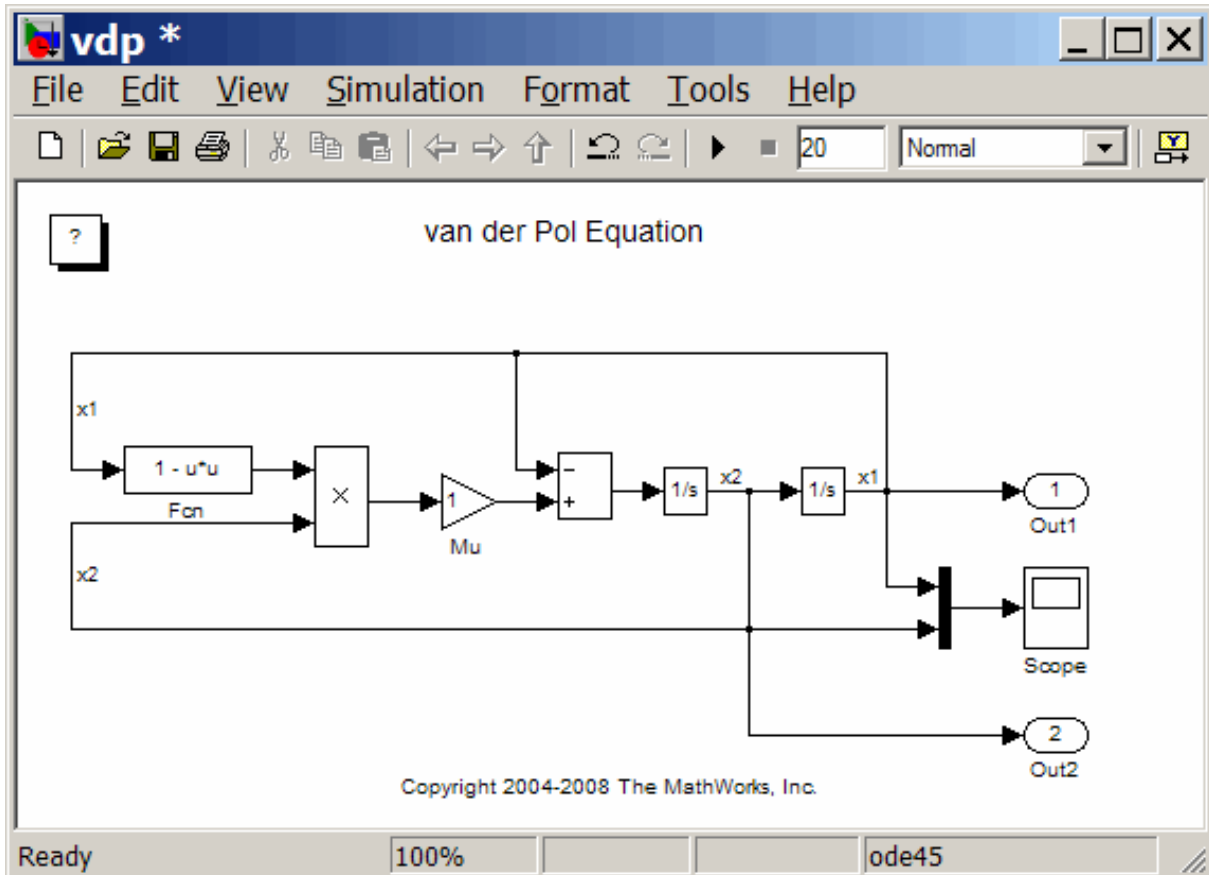
### Introduction

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

### How to Tell If a Model Needs Saving

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





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

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

## Techniques for Saving Models

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

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

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

If you are saving a model whose model file was previously saved, use the **Save** command to replace the file's contents or the **Save As** command to save the model with a new name or location. You can also use the **Save As** command to save the model in a format compatible with previous releases of the Simulink product (see "Saving a Model in an Earlier Simulink Version" on page 1-14).

The Simulink software follows this procedure while saving a model:

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

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

## Saving Models in the SLX File Format

You can save your model file in the SLX format, 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. 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.

To save new models and libraries in the SLX model file format, set the Simulink preference “File format for new models and libraries”, or enter at the command line:

```
set_param(0, 'ModelFileFormat', 'slx');
```

To save an existing model in the SLX file format, 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`, e.g., `mymodel.mdl.R2010a`.

If you convert an MDL file to SLX file format, the file contains the same information as the MDL 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.

---

**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.

---

<b>Operations with Possible Compatibility Considerations when using SLX</b>	<b>What Happens</b>	<b>Action</b>
Hard-coded references to file names with extension <code>.mdl</code> .	Scripts cannot find or process models saved with new file extension <code>.slx</code> .	Make your code work with both the <code>.mdl</code> and <code>.slx</code> extension. Use functions like <code>which</code> and <code>what</code> 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 <code>.slx</code> as a binary file format with third-party source control tools. Also recommended for <code>.mdl</code> files. See “Register Model Files with Source Control Tools” on page 12-35.
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. Use documented APIs (such as `get_param`, `find_system`, and `Simulink.MDLInfo`) to operate on model data.

## Saving Models with Different Character Encodings

- “MDL Files and Character Encodings” on page 1-13
- “SLX Files and Character Encodings” on page 1-14

### MDL Files and Character Encodings

When you save a model, the current character encoding is used to encode the text stored in the model's .mdl 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's name, leaving the original model file unchanged. The Simulink software also displays an error message that specifies the line and column number of the first character which cannot be represented.

To recover from this error, either:

- Save the model in SLX format (see “Saving Models in the SLX File Format” on page 1-11)
- 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
- If you share models across locales, continue to use MDL for R2012a, because MDL detects models that contain characters unsupported in the current locale.

## **Saving a Model in an Earlier Simulink Version**

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

To save a model in an earlier format:

- 1** Select **Save** from the **File** menu. This saves a copy in the latest version of Simulink. This step is necessary to avoid compatibility problems.
- 2** Select **Save As** from the **File** menu.  
  
The **Save As** dialog box is displayed.
- 3** Select a format from the **Save as type** list in the dialog box.

- 4 Click the **Save** button.

When saving a model in an earlier version's format, the model is saved in the earlier format regardless of whether the model contains blocks and features that were introduced after that version. If the model does contain blocks or use features that postdate the earlier version, the model might not give correct results when run by the earlier version. In addition, Simulink converts blocks that postdate an earlier version into empty masked Subsystem blocks colored yellow. For example, if you save a model that contains Polynomial blocks to Release R2007b, Simulink will convert the Polynomial blocks into empty masked Subsystem blocks and will color them yellow. Simulink also removes any unsupported functionality of the model.

## **Saving from One Earlier Simulink Version to Another**

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

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

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

- 3 Use **Save as** to save the model in the earlier version of Simulink.
- 4 Start the earlier Simulink version and use it to open the saved model.
- 5 Use **Save** to save the model in the earlier version.

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

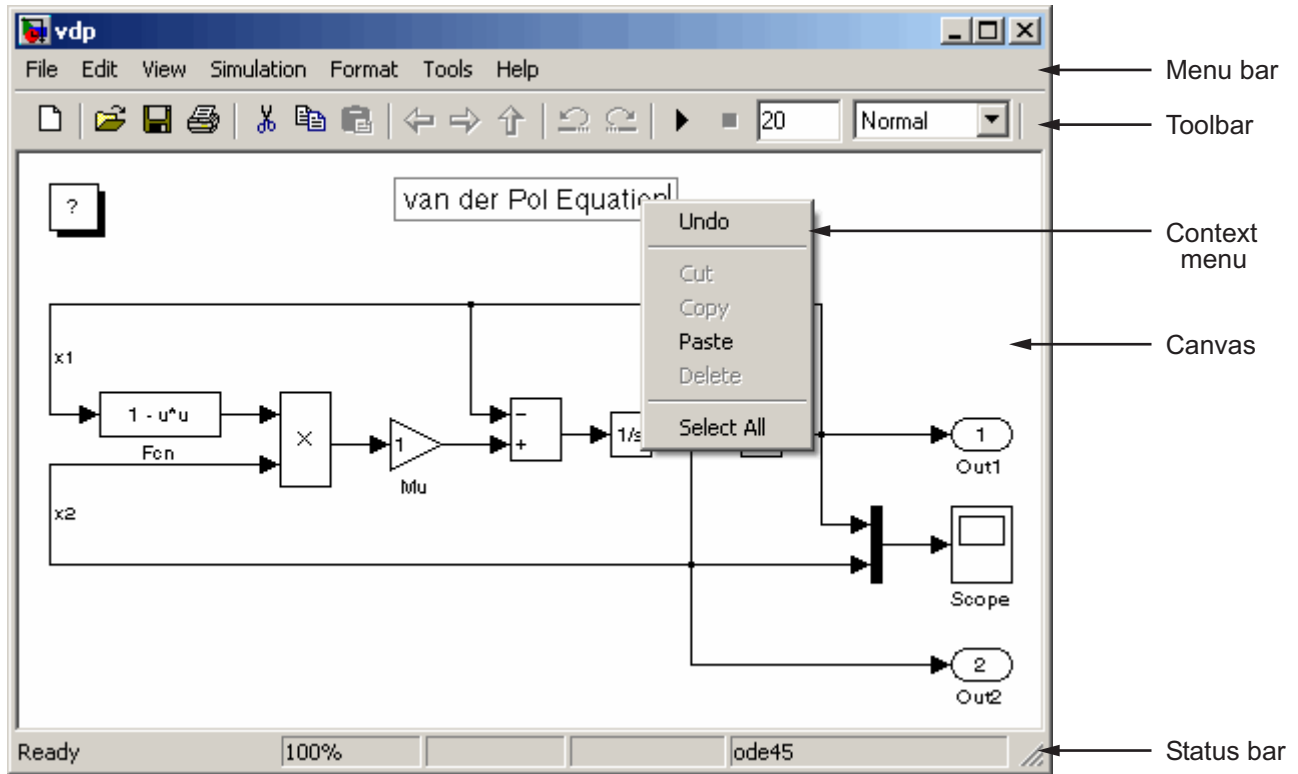
## Using the Model Editor

<b>In this section...</b>
“Editor Overview” on page 1-16
“Toolbar” on page 1-17
“Menu Bar” on page 1-21
“Canvas” on page 1-21
“Context Menus” on page 1-22
“Status Bar” on page 1-22

### **Editor Overview**

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

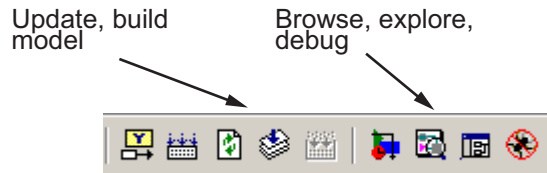
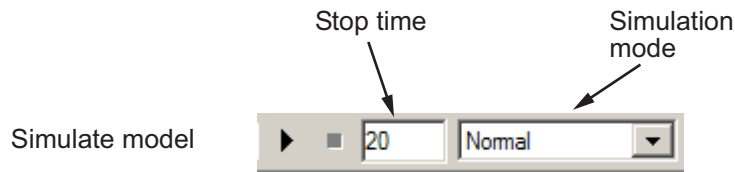
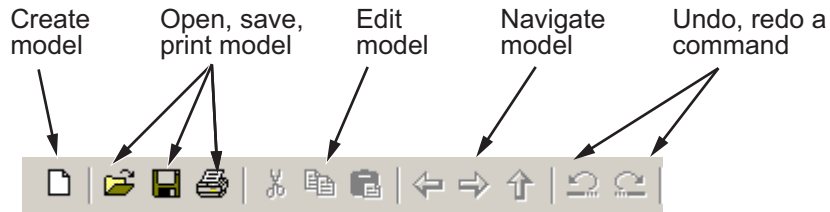




The Model Editor includes the following components.

## Toolbar

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
















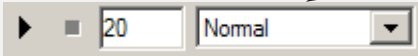





## Using the Toolbar







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

## Button Reference

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

Button	Usage
	Create a new model (see “Creating an Empty Model” on page 3-2).
	Open a model (see “Opening a Model” on page 1-4).
	Save the current model (see “Saving a Model” on page 1-8).
	Print the current model (see “Printing a Block Diagram” on page 1-34).
	Cut the diagram object selected in the editor window to the system clipboard .
	Copy the selected diagram object to the system clipboard.
	Paste a diagram object from the system clipboard into the current diagram.
	Go back to the subsystem previously displayed in this editor window. This button works only in window reuse mode (see “Viewing Command History” on page 1-29).
	Go forward to the subsystem displayed after the subsystem currently displayed in this editor window. This button works only in window reuse mode.
	Go to the parent of the subsystem currently displayed in the editor window (see “Model Navigation Commands” on page 3-40).
	Undo the last editor command (see “Undoing a Command” on page 1-25).
	Redo the last undone command.

Button	Usage
	<p>Start simulating the model displayed in this editor window (see “Starting a Simulation” on page 13-3).</p> <hr/> <p><b>Note</b> The controls to the right of this button enable you to set the end time of the simulation and the simulation mode, respectively.</p> <p>Enter simulation stop time here! <span style="margin-left: 200px;">Select simulation mode here!</span></p> 
	<p>Pause the current simulation (see “Pausing or Stopping a Simulation” on page 13-5).</p> <hr/> <p><b>Note</b> This button replaces the <b>Start</b> button while a simulation is in progress.</p>
	<p>Stop the current simulation.</p>
	<p>Display block outputs as tool tips during simulation (see “Displaying Port Values” on page 20-29).</p>
	<p>Build the RTW target for this model.</p> <hr/> <p><b>Note</b> This button is enabled only if the Simulink Coder™ is installed on your system (see “Initiate the Build Process” for more information).</p>
	<p>Refresh Model blocks residing in this model (see “Refreshing Model Blocks” on page 5-82).</p>

Button	Usage
	Update this model's diagram (see "Updating a Block Diagram" on page 1-32).
	Build the selected subsystem.  <b>Note</b> This button is enabled only if you have selected a subsystem and the Simulink Coder is installed on your system (see "Generate Code and Executables from Subsystems" for more information).
	Open the Library Browser (see "Library Browser").
	Open the Model Explorer (see "The Model Explorer: Overview" on page 8-2).
	Open the Model Browser (see "The Model Browser" on page 8-77).
	Open the Simulink Debugger (see Chapter 18, "Simulink Debugger").

## Menu Bar

The Simulink menu bar contains commands for creating, editing, viewing, printing, and simulating models. The menu commands apply to the model displayed in the editor. See Chapter 3, "Creating a Model" and Chapter 13, "Running Simulations" for more information.

## Canvas

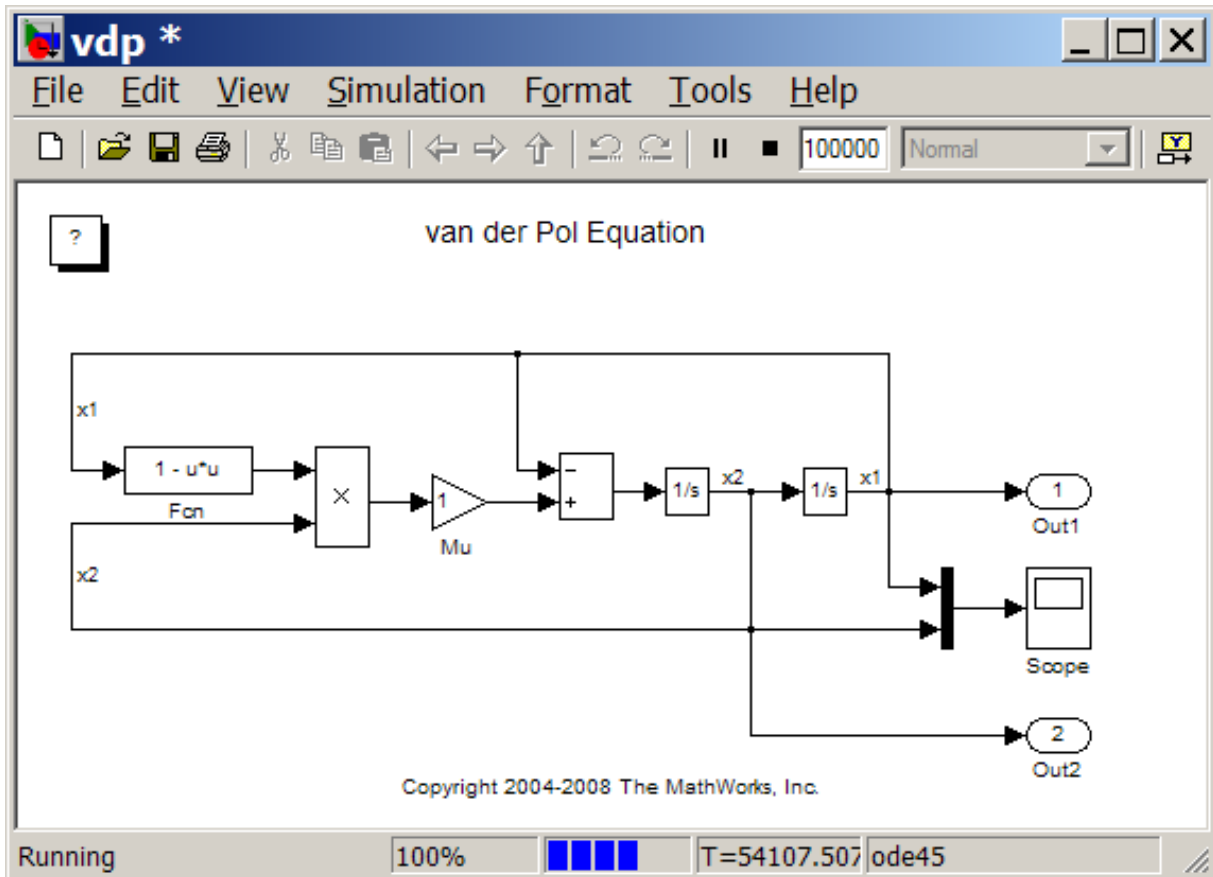
The canvas displays the model's block diagram. The canvas allows you to edit the block diagram. You can use your system's mouse and keyboard to create and connect blocks, select and move blocks, edit block labels, display block dialog boxes, and so on. See Chapter 20, "Working with Blocks" for more information.

## **Context Menu**

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

## **Status Bar**

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



Status Messages

Zoom Level

Progress Bar

Current Simulation Time

Solver

The status bar includes the following areas:

- status message

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

- zoom level

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

- progress bar

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

- current simulation time
- current solver

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



## Undoing a Command

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

- Adding, deleting, or moving a block
- Adding, deleting, or moving a line
- Adding, deleting, or moving a model annotation
- Editing a block name
- Creating a subsystem (see “Undoing Subsystem Creation” on page 3-40 for more information)

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

## Zooming Block Diagrams

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

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

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

## Panning Block Diagrams

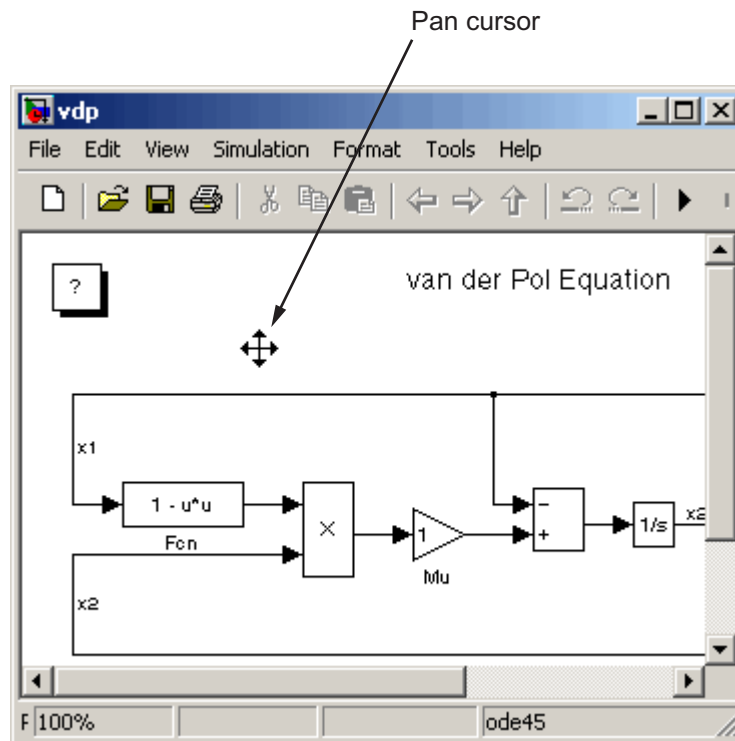
You can use your keyboard alone (see “Model Viewing Shortcuts” on page 1-48 ) or in combination with your mouse to pan model diagrams that are too large to fit in the Model Editor’s window. To use the keyboard and the mouse, position the mouse over the diagram, hold down the **p** or **q** key on the keyboard, then hold down the left mouse button.

---

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

---

A pan cursor appears.



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

## Viewing Command History

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

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

---

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

---

## **Bringing the MATLAB Software Desktop Forward**

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

## Copying Models to Third-Party Applications

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

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

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

With this setting, the MATLAB software selects the figure format for you, and uses the metafile format whenever possible.

- d** Click **OK**.
- 2** Click **OK**.
- 3** Open the vdp model.
- 4** In the Model Editor, select **Edit > Copy Model to Clipboard**.
- 5** Open a document in Microsoft Word and paste the contents of the clipboard.

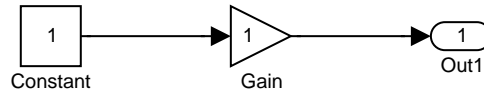
## Updating a Block Diagram

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

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

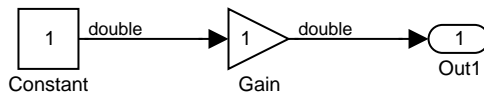
For example:

- 1 Create the following model.



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

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



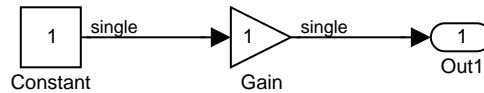
- 3 Set the **Output data type** parameter of the Constant block (see Constant) to `single`.



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

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

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



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

## Printing a Block Diagram

In this section...
“About Printing” on page 1-34
“Print Dialog Box” on page 1-34
“Specifying Paper Size and Orientation” on page 1-36
“Positioning and Sizing a Diagram” on page 1-36
“Tiled Printing” on page 1-37
“Print Sample Time Legend” on page 1-41
“Print Command” on page 1-41

### About Printing

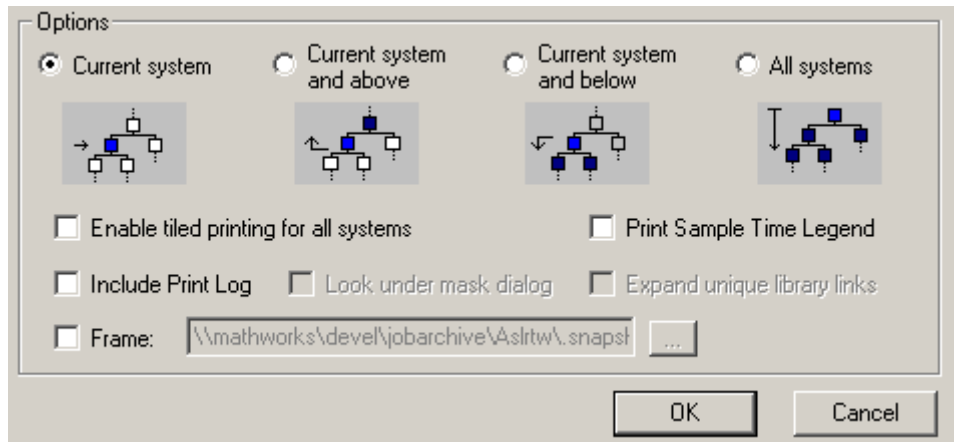
You can print a block diagram by selecting **Print** from the **File** menu or by using the print command in the MATLAB software Command Window.

### Print Dialog Box

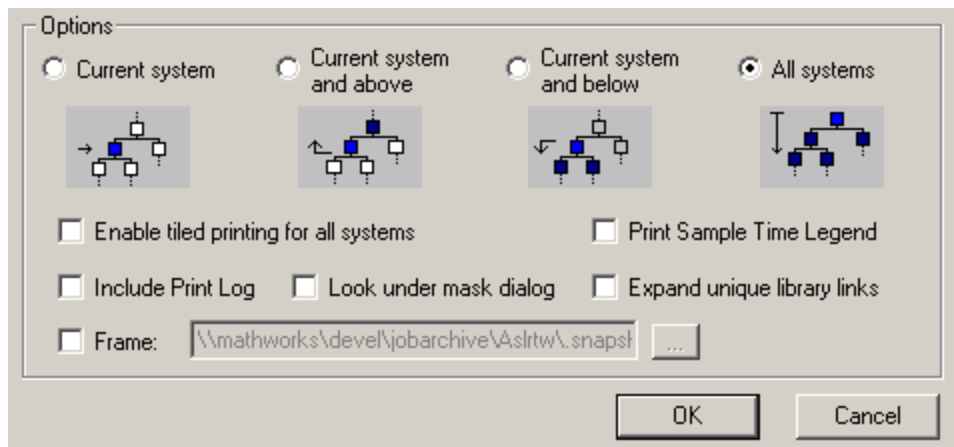
When you select the **Print** menu item, the **Print** dialog box appears. The **Print** dialog box enables you to selectively print systems within your model. Using the dialog box, you can print

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

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



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



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

Selecting the **Expand unique library links** check box prints the contents of library blocks when those blocks are systems. Only one copy is printed regardless of how many copies of the block are contained in the model. For more information about libraries, see Chapter 25, “Working with Block Libraries”.

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

Selecting the **Enable tiled printing for all systems** check box overrides the tiled-print settings for individual subsystems in a model. See “Tiled Printing” on page 1-37 for more information.

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

## Specifying Paper Size and Orientation

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

## Positioning and Sizing a Diagram

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

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

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

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

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

## Tiled Printing

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

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

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

## Enabling Tiled Printing

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

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

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

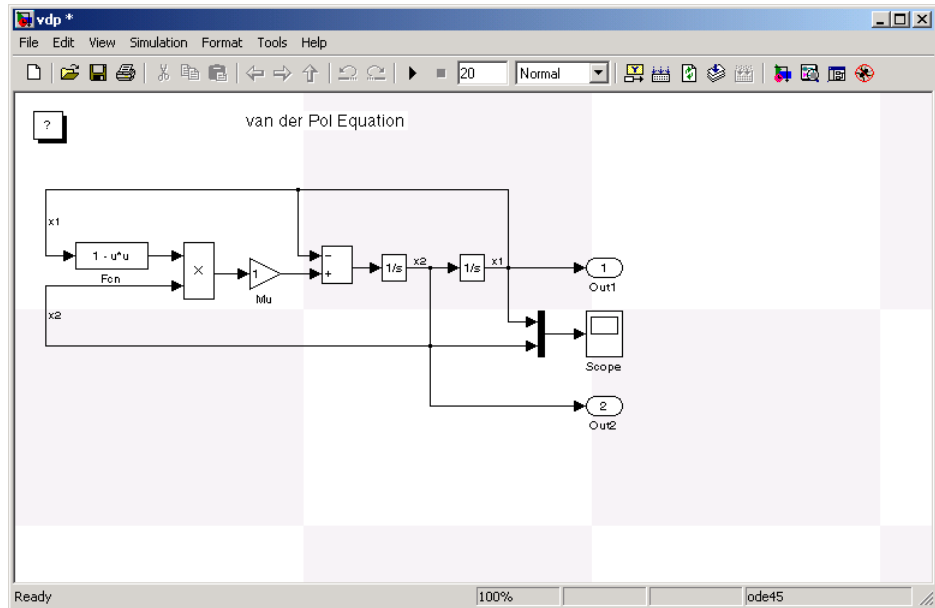
open the f14 demo model and enable tiled printing for the **Controller** subsystem.

To enable tiled printing for all systems in your model, select the **Enable tiled printing for all systems** check box on the **Print** dialog box (see "Print Dialog Box" on page 1-34). If you select this option, the Simulink software overrides the individual tiled-print settings for all systems in your model.

## Displaying Page Boundaries

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

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



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

## Specifying Tiled Print Settings

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

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

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

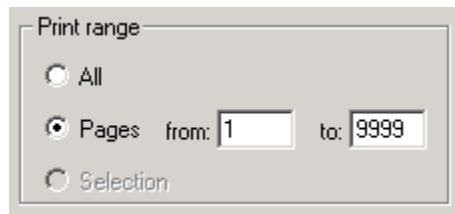
vector of form [left top right bottom]. Each element specifies the size of the margin at a particular edge of the page. The value of the `PaperUnits` parameter is used to determine its units of measurement. Each margin is 0.5 inches by default. By decreasing the margin sizes, you can increase the printable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

## Printing Tiled Pages

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

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

- On a computer running the Microsoft Windows operating system, you can specify a range of tiled page numbers to be printed using the **Print range** portion of the **Print** dialog box. This field is accessible if you select both the **Current system** and **Enable tiled printing for all systems** options (see “Print Dialog Box” on page 1-34).



- On all platforms, you can specify a range of tiled page numbers to be printed using the print command at the MATLAB software prompt. The print command's `tileall` option enables tiled printing for the system, and its `pages` option indicates the range of tiled page numbers to be printed (see “Print Command” on page 1-41). For example, the following commands

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

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



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

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

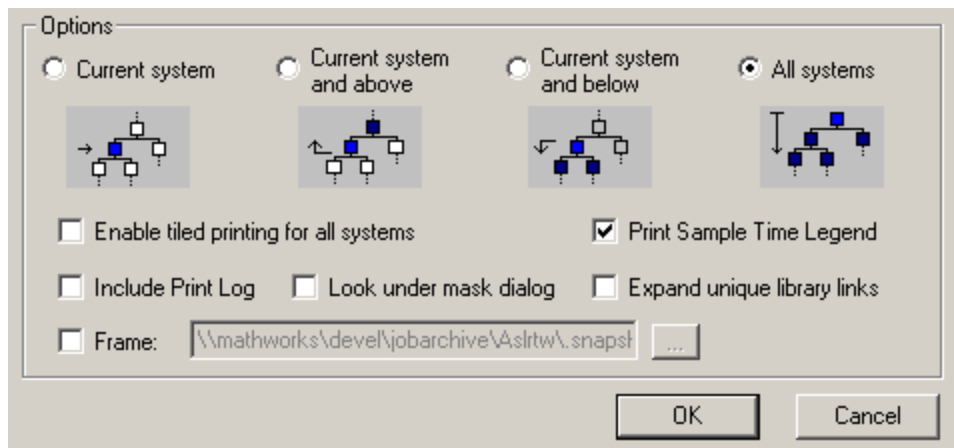
---

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

---

## Print Sample Time Legend

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



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

## Print Command

The format of the print command is

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

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

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

`tileall` specifies the tiled printing option (see “Tiled Printing” on page 1-37).

`p` is a two-element vector specifying the range of tiled page numbers to be printed. The vector must be preceded by the `pages` switch identifier. This option is valid only when you enable tiled printing using the `tileall` switch. For an example of its usage, see “Printing Tiled Pages” on page 1-40.

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

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

```
print -suntitled
```

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

```
print -sSub1
```

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

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

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

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

To print the currently selected subsystem, enter

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

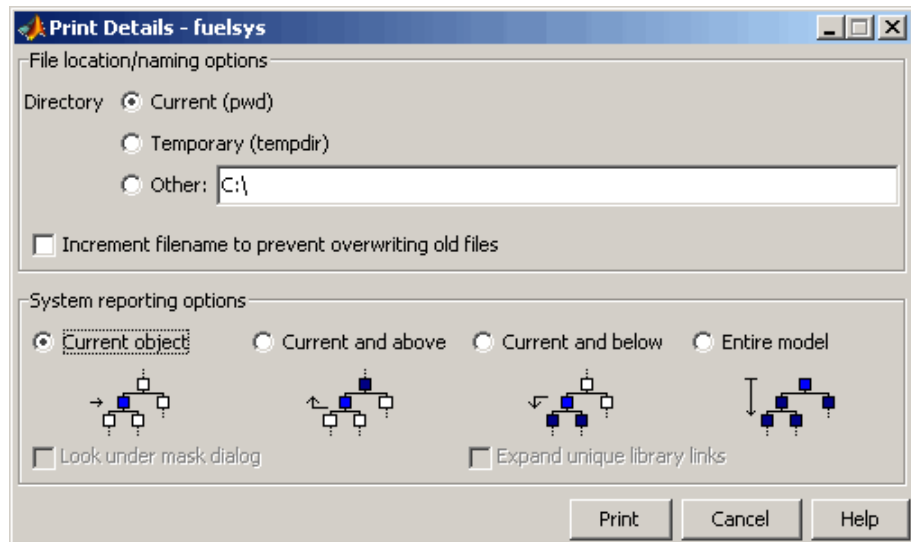
## Generating a Model Report

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

To generate a report for the current model:

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

The **Print Details** dialog box appears.

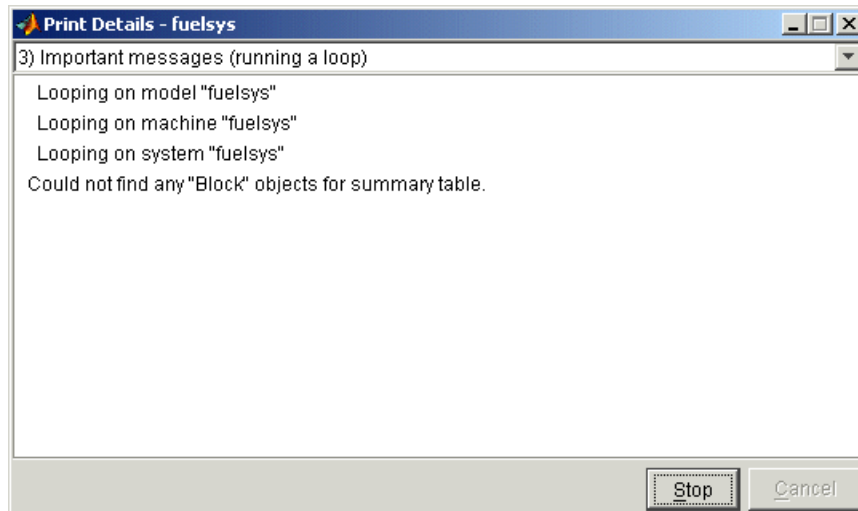


The dialog box allows you to select various report options (see “Model Report Options” on page 1-45).

- 2 Select the desired report options on the dialog box.
- 3 Select **Print**.

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

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



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

## Model Report Options

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

### Directory

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

### **Increment filename to prevent overwriting old files**

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

### **Current object**

Include only the currently selected object in the report.

### **Current and above**

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

### **Current and below**

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

### **Entire model**

Include the entire model in the report.

### **Look under mask dialog**

Include the contents of masked subsystems in the report.

### **Expand unique library links**

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

## Ending a Simulink Session

Terminate a Simulink software session by closing all Simulink windows.

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

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

## Summary of Mouse and Keyboard Actions

In this section...
“Model Viewing Shortcuts” on page 1-48
“Block Editing Shortcuts” on page 1-49
“Line Editing Shortcuts” on page 1-50
“Signal Label Editing Shortcuts” on page 1-50
“Annotation Editing Shortcuts” on page 1-51

### Model Viewing Shortcuts

The following table lists keyboard shortcuts for viewing models.

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



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

## Block Editing Shortcuts

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

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

## Line Editing Shortcuts

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

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

## Signal Label Editing Shortcuts

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

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

## Annotation Editing Shortcuts

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

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



# How Simulink Works

---

- “Introduction” on page 2-2
- “Modeling Dynamic Systems” on page 2-3
- “Simulating Dynamic Systems” on page 2-19

## Introduction

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

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

# Modeling Dynamic Systems

**In this section...**

“Block Diagram Semantics” on page 2-3

“Creating Models” on page 2-4

“Time” on page 2-5

“States” on page 2-5

“Block Parameters” on page 2-9

“Tunable Parameters” on page 2-9

“Block Sample Times” on page 2-10

“Custom Blocks” on page 2-11

“Systems and Subsystems” on page 2-11

“Signals” on page 2-16

“Block Methods” on page 2-16

“Model Methods” on page 2-18

## 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 an equation is the notion of parameters, which are the coefficients found within the equation.

### **Creating Models**

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



## Time

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

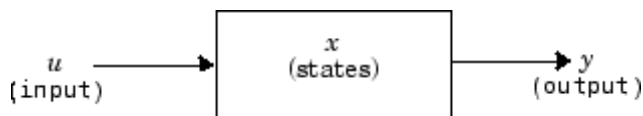
## States

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

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

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

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



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

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

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

### Working with States

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

- The `model` command displays information about the states defined by a model, including the total number of states defined by the model, the block that defines each state, and the initial value of each state.
- The Simulink debugger displays the value of a state at each time step during a simulation, and the Simulink debugger's `states` command displays information about the model's current states (see Chapter 18, "Simulink Debugger").
- The **Data Import/Export** pane of a model's Configuration Parameters dialog box (see Chapter 29, "Importing and Exporting Simulation Data") allows you to specify initial values for a model's states, and to record the values of the states at each time step during simulation as an array or structure variable in the MATLAB workspace.
- The Block Parameters dialog box (and the `ContinuousStateAttributes` parameter) allows you to give names to states for those blocks (such as the Integrator) that employ continuous states. This can simplify analyzing data logged for states, especially when a block has multiple states.

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

## **Continuous States**

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

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

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

## **Discrete States**

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

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

## **Modeling Hybrid Systems**

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

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

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 Chapter 21, “Working with Block Parameters” and Chapter 25, “Working with Block Libraries” for more information.

## Tunable Parameters

Many block parameters are tunable. A *tunable parameter* is a parameter whose value can be changed without recompiling the model (see “Model Compilation” on page 2-19 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 Chapter 21, “Working with Block Parameters” and “Using Tunable Parameters” on page 21-13 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  $[T_s, T_o]$  where  $T_s$  is the time interval or period between consecutive sample times and  $T_o$  is an initial offset to the sample time. In contrast, the sample times for nondiscrete blocks are represented by ordered pairs that use zero, a negative integer, or infinity to represent a specific type of sample time (see “How to View Sample Time Information” on page 4-9). For example, continuous blocks have a nominal sample time of  $[0, 0]$  and are used to model systems in which the states change continuously (e.g., a car accelerating). Whereas you indicate the sample time type of an inherited block symbolically as  $[-1, 0]$  and Simulink then determines the actual value based upon the context of the inherited block within the model.

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

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

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

## Custom Blocks

You can create libraries of custom blocks that you can then use in your models. You can create a custom block either graphically or programmatically. To create a custom block graphically, you draw a block diagram representing the block's behavior, wrap this diagram in an instance of the Simulink Subsystem block, and provide the block with a parameter dialog, using the Simulink block mask facility. To create a block programmatically, you create a MATLAB file or a MEX-file that contains the block's system functions (see *Developing S-Functions*). The resulting file is called an S-function. You then associate the S-function with instances of the Simulink S-Function block in your model. You can add a parameter dialog to your S-Function block by wrapping it in a Subsystem block and adding the parameter dialog to the Subsystem block. See Chapter 24, "Creating Custom Blocks" for more information.

## Systems and Subsystems

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

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

## Virtual Subsystems

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

## **Nonvirtual Subsystems**

Nonvirtual subsystems, 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 Chapter 6, “Creating 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 Output 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<sup>®</sup> 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 output values via the `Output when disabled` parameter on the output 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 Chapter 31, “Working with Signals”.

## Block Methods

Blocks represent multiple equations. These equations are represented as block methods. These block methods are evaluated (executed) during the

execution of a block diagram. The evaluation of these block methods is performed within a simulation loop, where each cycle through the simulation loop represents the evaluation of the block diagram at a given point in time.

## Method Types

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

- **Outputs**

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

- **Update**

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

- **Derivatives**

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

## Method Naming Convention

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

`BlockType.MethodType`

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

`Gain.Outputs`

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

`g1.Outputs`

### **Model Methods**

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

# Simulating Dynamic Systems

## In this section...

“Model Compilation” on page 2-19

“Link Phase” on page 2-20

“Simulation Loop Phase” on page 2-20

“Solvers” on page 2-22

“Zero-Crossing Detection” on page 2-24

“Algebraic Loops” on page 2-40

## Model Compilation

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

- Evaluates the model’s block parameter expressions to determine their values.
- Determines signal attributes, e.g., name, data type, numeric type, and dimensionality, not explicitly specified by the model and checks that each block can accept the signals connected to its inputs.
- A process called attribute propagation is used to determine unspecified attributes. This process entails propagating the attributes of a source signal to the inputs of the blocks that it drives.
- Performs block reduction optimizations.
- Flattens the model hierarchy by replacing virtual subsystems with the blocks that they contain (see “Solvers” on page 2-22).
- Determines the block sorted order (see “Controlling and Displaying the Sorted Order” on page 20-35 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 4-29).

### **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 “Assigning Block Priorities” on page 20-48). The output methods of higher priority blocks are executed before those of lower priority blocks. The priorities are honored only if they are consistent with its block sorting rules.

### **Simulation Loop Phase**

Once the Link Phase completes, the simulation enters the simulation loop phase. In this phase, the Simulink engine successively computes the states and outputs of the system at intervals from the simulation start time to the finish time, using information provided by the model. The successive time points at which the states and outputs are computed are called time steps. The length of time between steps is called the step size. The step size depends on the type of solver (see “Solvers” on page 2-22) used to compute the system’s continuous states, the system’s fundamental sample time (see “Managing Sample Times in Systems” on page 4-22), and whether the system’s continuous states have discontinuities (see “Zero-Crossing Detection” on page 2-24).



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

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

## Loop Iteration

At each time step, the Simulink Engine:

### 1 Computes the model's outputs.

The Simulink Engine initiates this step by invoking the Simulink model Outputs method. The model Outputs method in turn invokes the model system Outputs method, which invokes the Outputs methods of the blocks that the model contains in the order specified by the Outputs method execution lists generated in the Link phase of the simulation (see "Solvers" on page 2-22).

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

### 2 Computes the model's states.

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

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

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

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

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

A technique called zero-crossing detection is used to detect discontinuities in continuous states. See “Zero-Crossing Detection” on page 2-24 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 13-10).

## 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 13-10).

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

---

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

---

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

### **Minor Time Steps**

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

### **Shape Preservation**

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

### **Zero-Crossing Detection**

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

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

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

Two algorithms are provided in the Simulink software: Nonadaptive and Adaptive. For information about these techniques, see “Zero-Crossing Algorithms” on page 2-34.

### **Demonstrating Effects of Excessive Zero-Crossing Detection**

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

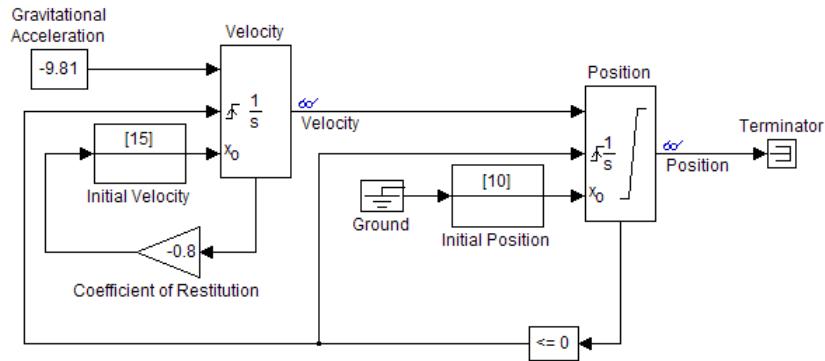
- The `sldemo_bounce_two_integrators` demo demonstrates how excessive zero crossings can cause a simulation to halt before the intended completion time unless you use the adaptive algorithm.
- The `sldemo_bounce` demo uses a better model design than `sldemo_bounce_two_integrators`.
- The `sldemo_doublebounce`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

## The Bounce Demo with Two Integrators.

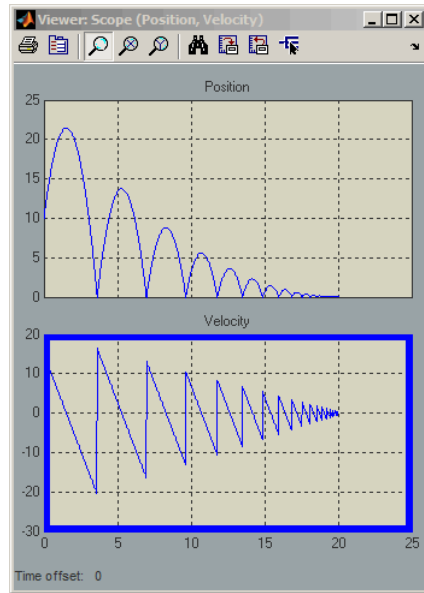


### Bouncing Ball Model

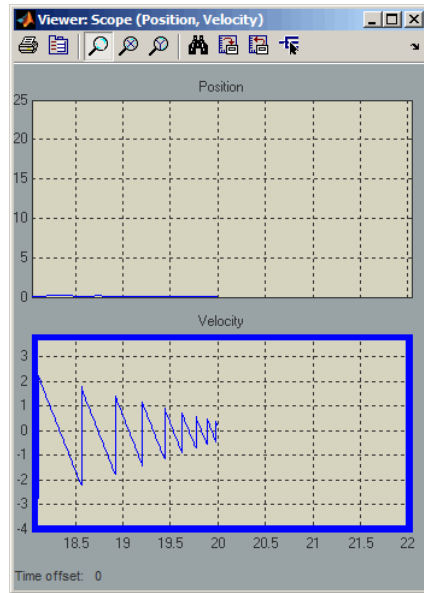
Two separate Integrators are less efficient than a single Second-Order Integrator for simulating a bouncing ball. [Click here to see sldemo\\_bounce for the recommended modeling approach.](#)



- 1 At the MATLAB command prompt, type `sldemo_bounce_two_integrators` to load the demo.
- 2 Once the block diagram appears, navigate to the Configuration Parameters dialog box. Confirm that the **Algorithm** parameter is set to **Nonadaptive**.
- 3 Set the **Stop time** to 20 s.
- 4 Run the model by clicking the **Start simulation** button.
- 5 After the simulation completes, click the scope window to see the results.  
You may need to click on **Autoscale** to view the results in their entirety.



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

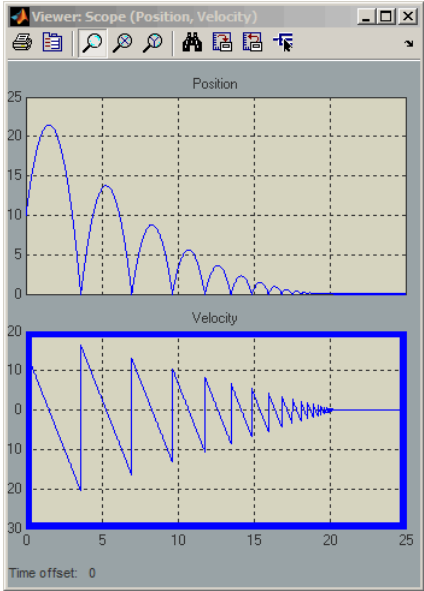


- 7 Change the simulation **Stop time** to 25 seconds, and run the simulation again.
- 8 This time the simulation halts with an error shortly after it passes the simulated 20 second time point.

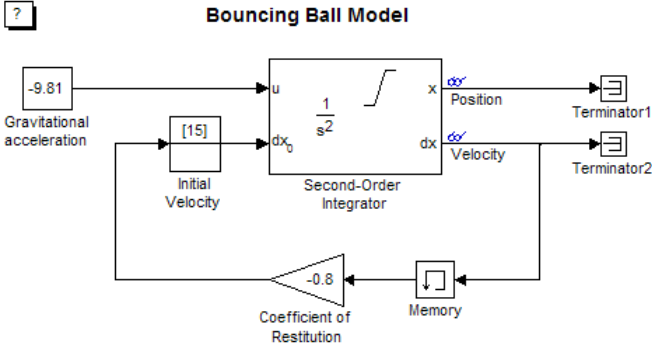
Excessive chattering as the ball repeatedly approaches zero velocity has caused the simulation to exceed the default limit of 1000 for the number of consecutive zero crossings allowed. Although this limit can be increased by adjusting the **Number of consecutive zero crossings parameter** in the Configuration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

- 9 Navigate to the Configuration Parameters dialog box. From the **Algorithm** pull down menu, select the **Adaptive** algorithm.
- 10 Run the simulation again.
- 11 This time the simulation runs to completion because the adaptive algorithm prevented an excessive number of zero crossings from occurring.

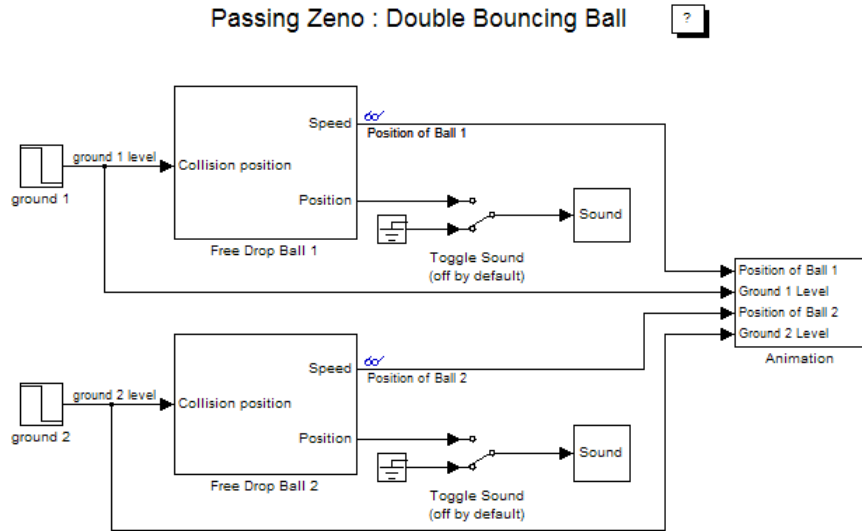




**Bounce Demo with a Second-Order Integrator.**



## The Double-Bounce Demo.



- 1 At the MATLAB command prompt, type `sldemo_doublebounce` to load the demo. The model and an animation window open. In the animation window, two balls are resting on two platforms.
- 2 In the animation window, click the **Nonadaptive** button to run the demo using the nonadaptive algorithm. This is the default setting used by the Simulink software for all models.
- 3 The ball on the right is given a larger initial velocity and has Consequently, the two balls hit the ground and recoil at different times.
- 4 The simulation halts after 14 seconds because the ball on the left exceeded the number of zero crossings limit. The ball on the right is left hanging in mid air.
- 5 An error message dialog opens. Click **OK** to close it.
- 6 Click on the **Adaptive** button to run the simulation with the adaptive algorithm.

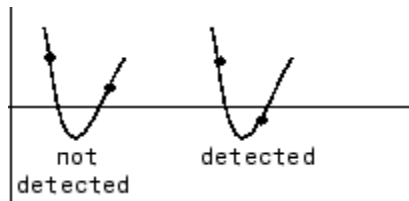
- 7 Notice that this time the simulation runs to completion, even after the ground shifts out from underneath the ball on the left at 20 seconds.

### How the Simulator Can Miss Zero-Crossing Events

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

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

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



### Preventing Excessive Zero Crossings

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

<b>Make this change...</b>	<b>How to make this change...</b>	<b>Rational for making this change...</b>
Increase the number of allowed zero crossings	Increase the value of the <b>Number of consecutive zero crossings</b> option on the <b>Solver</b> pane in the Configuration Parameters dialog box.	This may give your model enough time to resolve the zero crossing.
Relax the <b>Signal threshold</b>	Select <b>Adaptive</b> from the <b>Algorithm</b> pull down and increase the value of the <b>Signal threshold</b> option on the <b>Solver</b> 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 <b>Signal threshold</b> may reduce accuracy.
Use the <b>Adaptive Algorithm</b>	Select <b>Adaptive</b> from the <b>Algorithm</b> pull down on the <b>Solver</b> 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 <b>Time tolerance</b> and the <b>Signal threshold</b> .

Make this change...	How to make this change...	Rational for making this change...
Disable zero-crossing detection for a specific block	<ol style="list-style-type: none"> <li><b>1</b> Clear the <b>Enable zero-crossing detection</b> check box on the block's parameter dialog box.</li> <li><b>2</b> Select Use local settings from the <b>Zero-crossing control</b> pull down on the <b>Solver</b> pane of the Configuration Parameters dialog box.</li> </ol>	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 <b>Zero-crossing control</b> pull down on the <b>Solver</b> 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 <b>Maximum order</b> pull down on the <b>Solver</b> pane of the Configuration Parameters dialog box.	For more information, see "Maximum order".
Reduce the maximum step size	Enter a value for the <b>Max step size</b> option on the <b>Solver</b> pane of the Configuration Parameters dialog box.	This can insure the solver takes steps small enough to resolve the zero crossing. However, reducing the step size can increase simulation time, and

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

### Zero-Crossing Algorithms

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

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

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

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

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

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

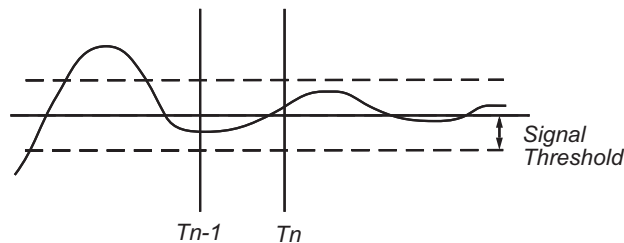
- The zero crossing error is exceeded. This is determined by the value specified in the **Signal threshold** option in the Solver pane of the Configuration Parameters dialog box. This can also be set with the `ZCThreshold` command. The default is Auto, but you can enter any real number greater than zero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

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

## Understanding Signal Threshold

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

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



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

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

## How Blocks Work with Zero-Crossing Detection

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

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

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

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



<b>Block</b>	<b>Description of Zero Crossing</b>
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 6-17.
Enabled and Triggered Subsystem	Two: one for the enable port and one for the trigger port. See the Triggered and Enabled Subsystem block for details: “Triggered and Enabled Subsystems” on page 6-21

---

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

---

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

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

Simulink blocks that define their own state events are considered to have *intrinsic zero crossings*. Use the Hit Crossing block to receive explicit notification of a zero-crossing event. See “Blocks That Register Zero Crossings” on page 2-36 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?” on page 2-40
- “Problems Caused by Algebraic Loops” on page 2-44
- “Identifying Algebraic Loops in Your Model” on page 2-44
- “What If I Have an Algebraic Loop in My Model?” on page 2-47
- “Simulink Algebraic Loop Solver” on page 2-50
- “Removing Algebraic Loops” on page 2-52
- “Additional Techniques to Help the Algebraic Loop Solver” on page 2-54
- “Changing Block Priorities Does Not Remove Algebraic Loops” on page 2-55
- “Artificial Algebraic Loops” on page 2-55

### What Is an Algebraic Loop?

- “Algebraic Loops in Simulink” on page 2-40
- “Mathematical Definition of an Algebraic Loop” on page 2-42
- “Meaning of Algebraic Loops in Physical Systems” on page 2-43

**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.

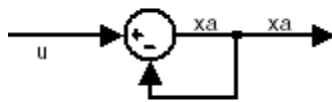
**2** Click the **Help** button in the block parameter dialog box.

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:

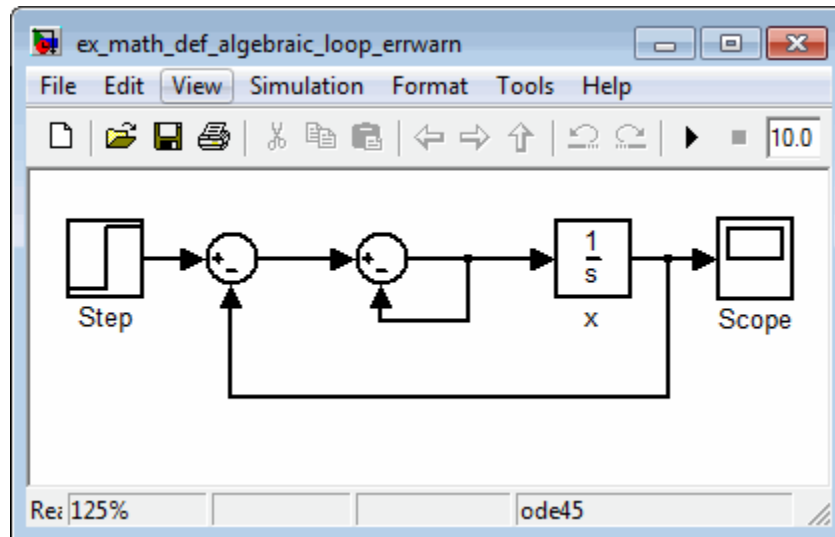
$$\begin{aligned}\dot{\mathbf{x}} &= \mathbf{f}(\mathbf{x}, \mathbf{x}_a, t) \\ 0 &= \mathbf{g}(\mathbf{x}, \mathbf{x}_a, t),\end{aligned}$$

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

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



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 2-52, 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 2-44
- “Highlighting Algebraic Loops Using the Algebraic Loop Diagnostic” on page 2-45
- “Highlighting Algebraic Loops Using the `ashow` Debugger Command” on page 2-46

**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 Model Editor when updating or simulating a model:

- 1 Open the `sldemo_hydcyl` demo model:

```
sldemo_hydcyl
```

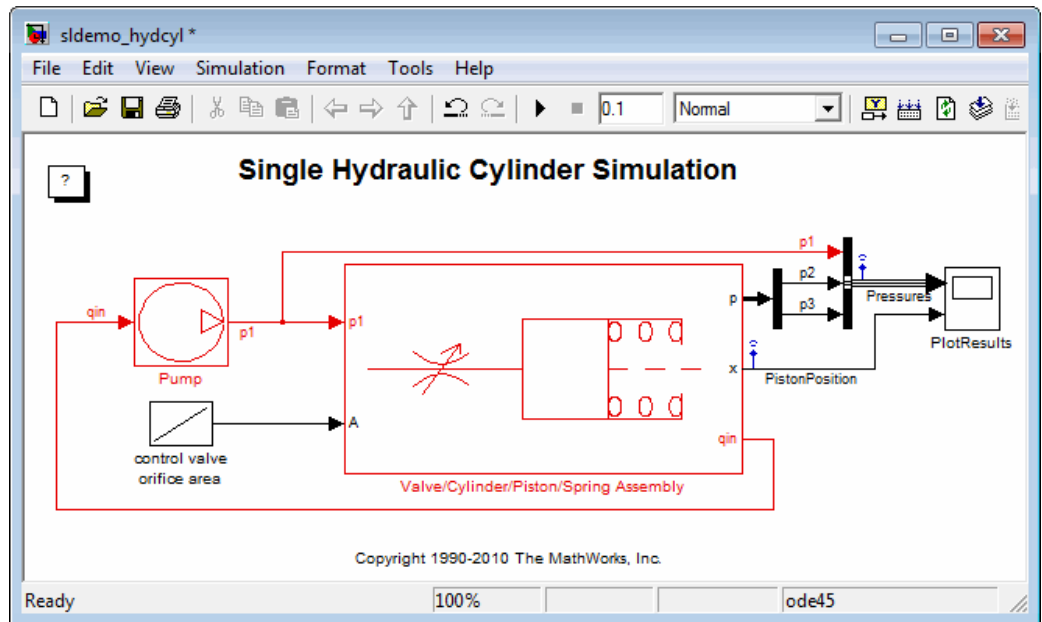
- 2 Open the Configuration Parameters dialog box by selecting **Simulation > Configuration Parameters**.
- 3 On the **Diagnostics** pane, set the **Algebraic loop** parameter to `error`.

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



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

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

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

### Highlighting Algebraic Loops 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` demo model.

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

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

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

- 4** In the MATLAB Command Window, type:

```
ashow
```

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

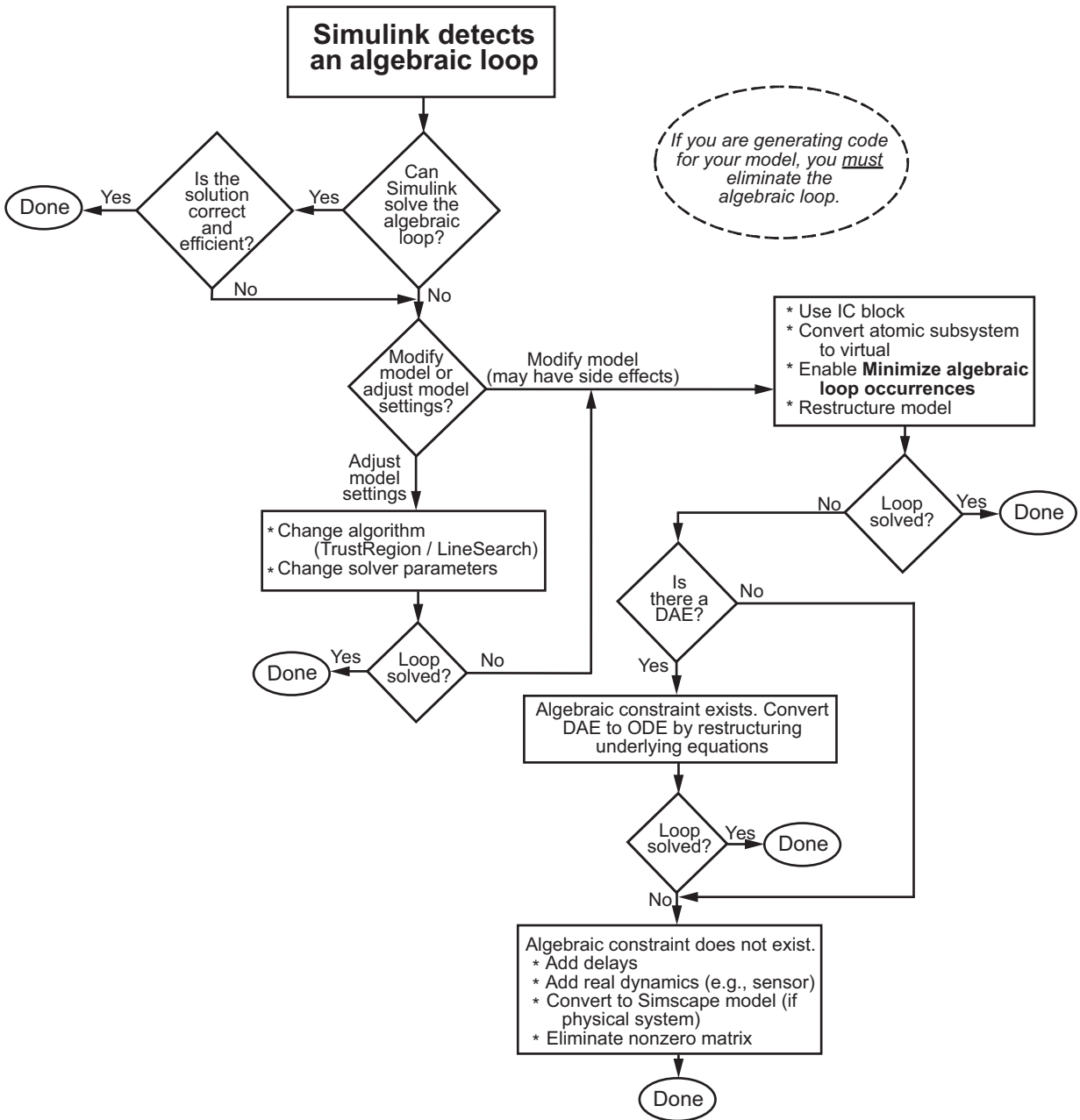
```
- sldemo_hydcyl/Valve//Cylinder//Piston//Spring Assembly/Control Valve Flow/IC
- sldemo_hydcyl/Valve//Cylinder//Piston//Spring Assembly/Control Valve Flow/signed sqrt
- sldemo_hydcyl/Valve//Cylinder//Piston//Spring Assembly/Control Valve Flow/Product
- sldemo_hydcyl/Valve//Cylinder//Piston//Spring 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 variable)
- sldemo_hydcyl/Pump/Sum1
- sldemo_hydcyl/Pump/leakage (algebraic variable)
```

- 6** In the Simulink Debugger window, 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 Algebraic Loop Solver

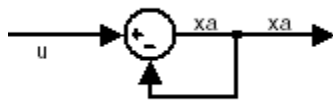
- “How the Algebraic Loop Solver Works” on page 2-50
- “Trust-Region and Line-Search Algorithms in the Algebraic Loop Solver” on page 2-51
- “Limitations of the Algebraic Loop Solver” on page 2-51

**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

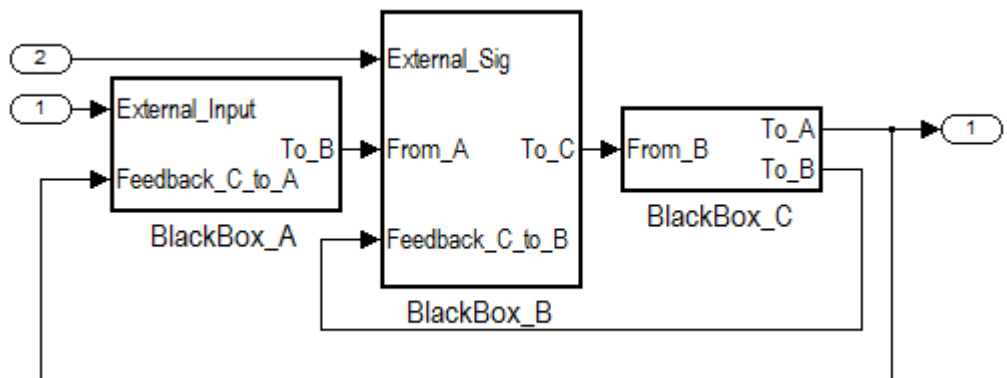
## Removing Algebraic Loops

### 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:

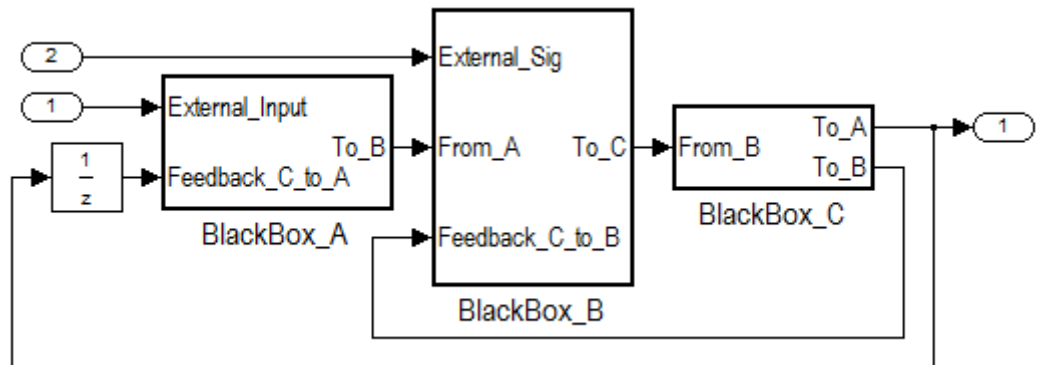
- Add a unit delay between BlackBox\_A and BlackBox\_C
- Add a unit delay between BlackBox\_B and BlackBox\_C



- Add unit delays to both algebraic loops

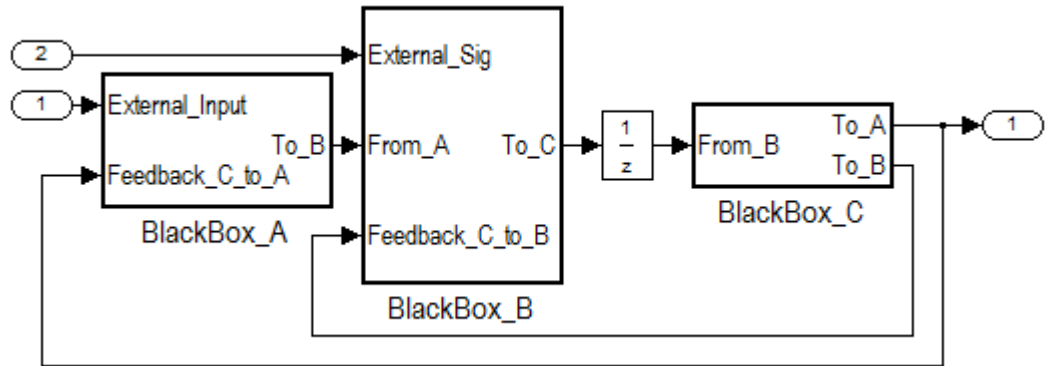
### Add a unit delay between BlackBox\_A and BlackBox\_C

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.



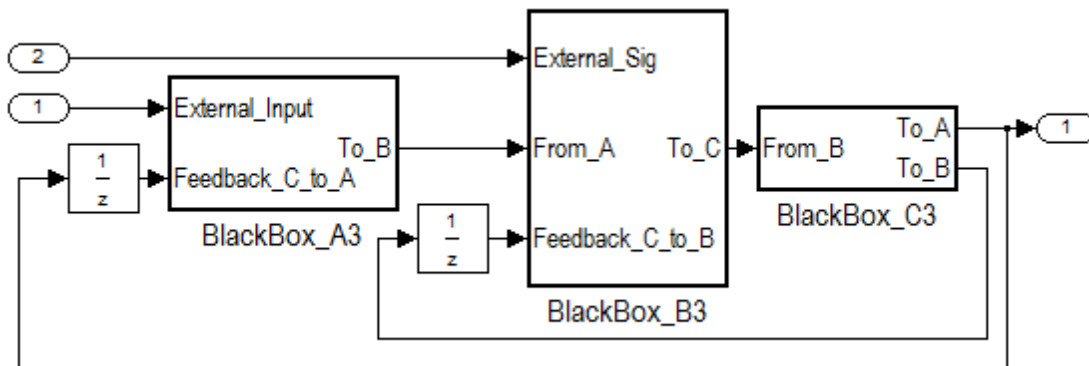
### Add a unit delay between BlackBox\_B and BlackBox\_C

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 2-55

### **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.

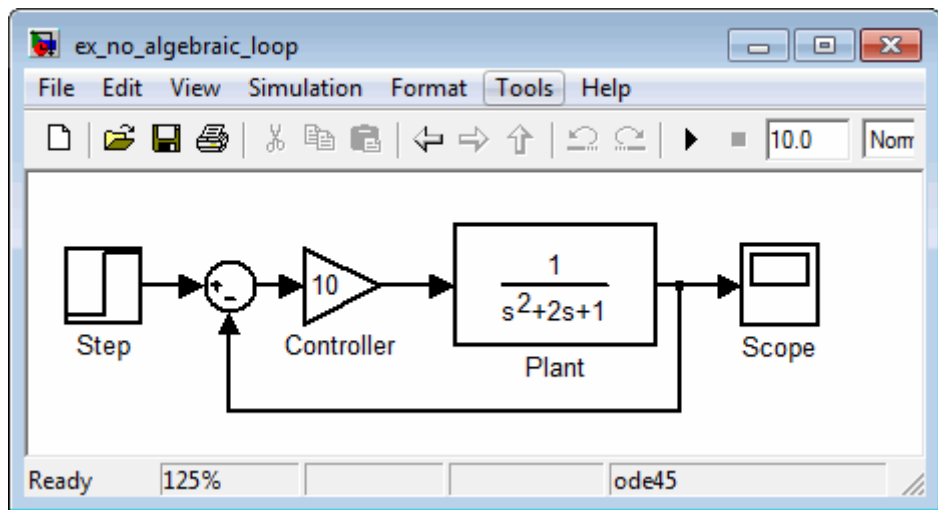
### **Artificial Algebraic Loops**

- “What Is an Artificial Algebraic Loop?” on page 2-56
- “Eliminating Artificial Algebraic Loops Caused by Atomic Subsystems” on page 2-57
- “Bundled Signals That Create Artificial Algebraic Loops” on page 2-58
- “Model and Block Parameters for Diagnosing and Eliminating Artificial Algebraic Loops” on page 2-61

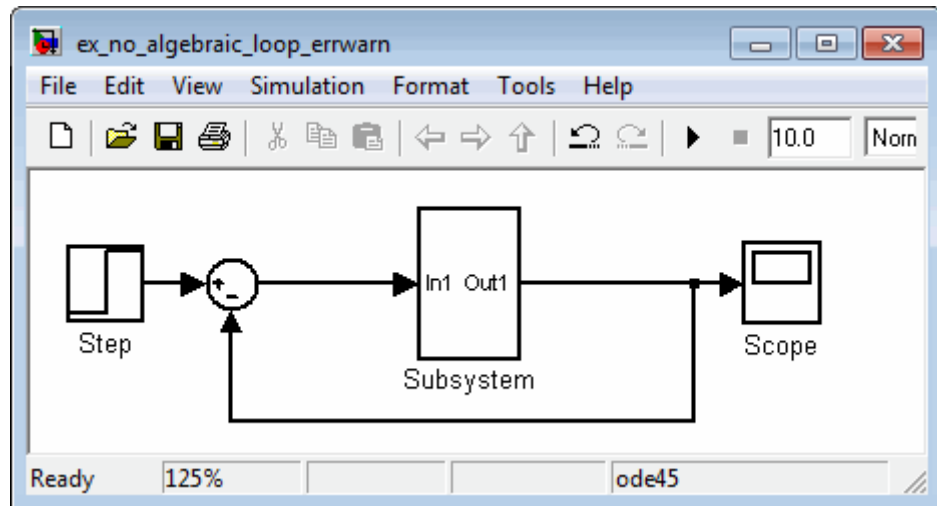
- “Block Reduction and Artificial Algebraic Loops” on page 2-62
- “How Simulink Eliminates Artificial Algebraic Loops” on page 2-67
- “When Simulink Cannot Eliminate Artificial Algebraic Loops” on page 2-72
- “Managing Large Models with Artificial Algebraic Loops” on page 2-74

**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  $q_1$  is the rate of the fluid flow into the tank from the pump.
- Output  $h_2$  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:

Parameters

A:

$$\begin{bmatrix} -c_2 & c_1 \\ 0 & -c_1 \end{bmatrix}$$

B:

$$\begin{bmatrix} 0 & 1 \end{bmatrix}'$$

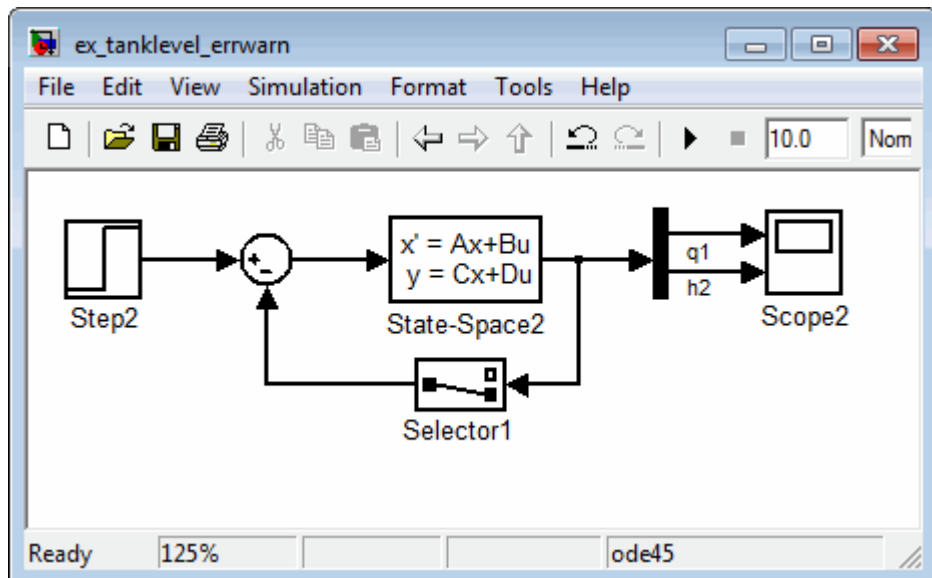
C:

$$\begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}$$

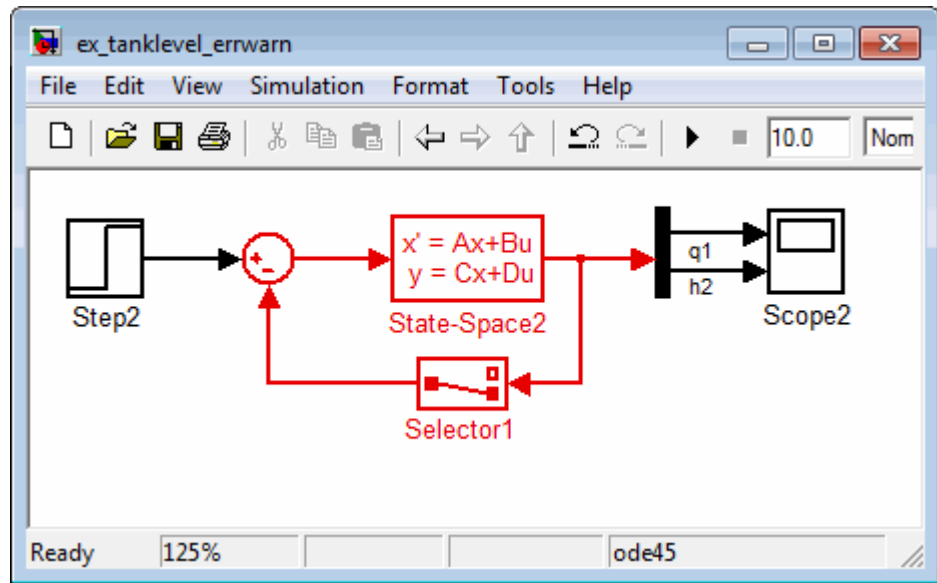
D:

$$\begin{bmatrix} 1 & 0 \end{bmatrix}'$$

- The output from the State-Space block is a vector that contains  $q_1$  and  $h_2$ .



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:

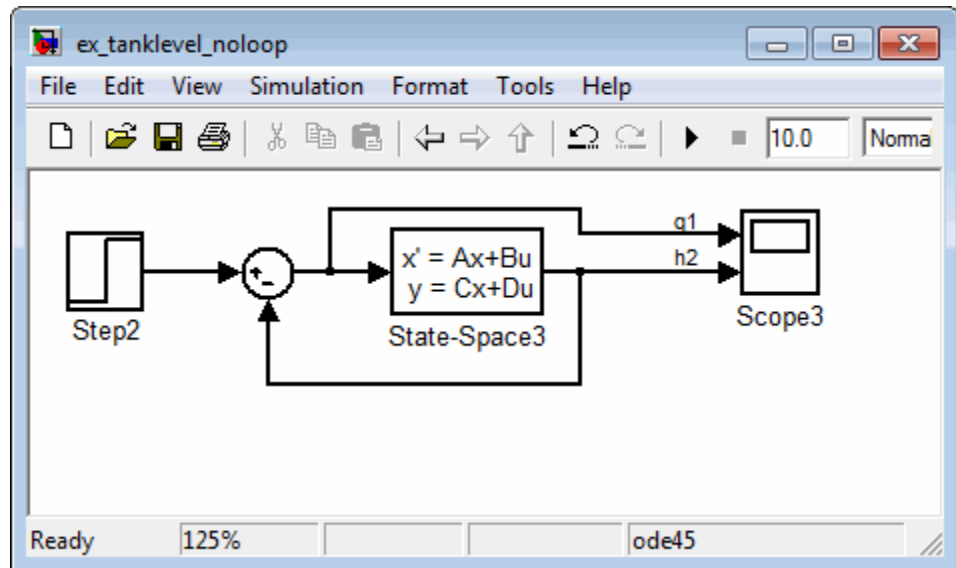
- 1 Change the C and D matrices as follows:

Parameters	
A:	<input type="text" value="[-c2 c1 ; 0 -c1]"/>
B:	<input type="text" value="[ 0 1 ]'"/>
C:	<input type="text" value="[1 0]"/>
D:	<input type="text" value="0"/>



- 2 Pass  $q_1$  directly to the Scope instead of through the State-Space block.

Now, the input ( $q_1$ ) 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.

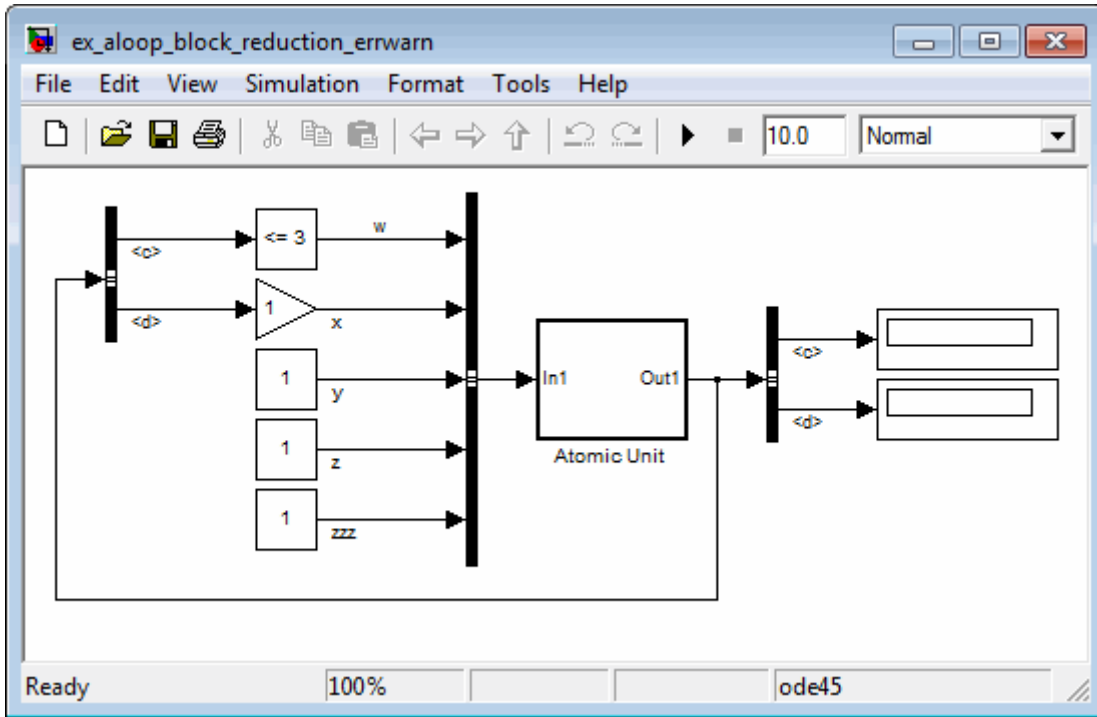
The **Minimize algebraic loop** parameter is in the Configuration Parameters dialog box, on the main **Diagnostics** pane. The diagnostic actions for this parameter are:

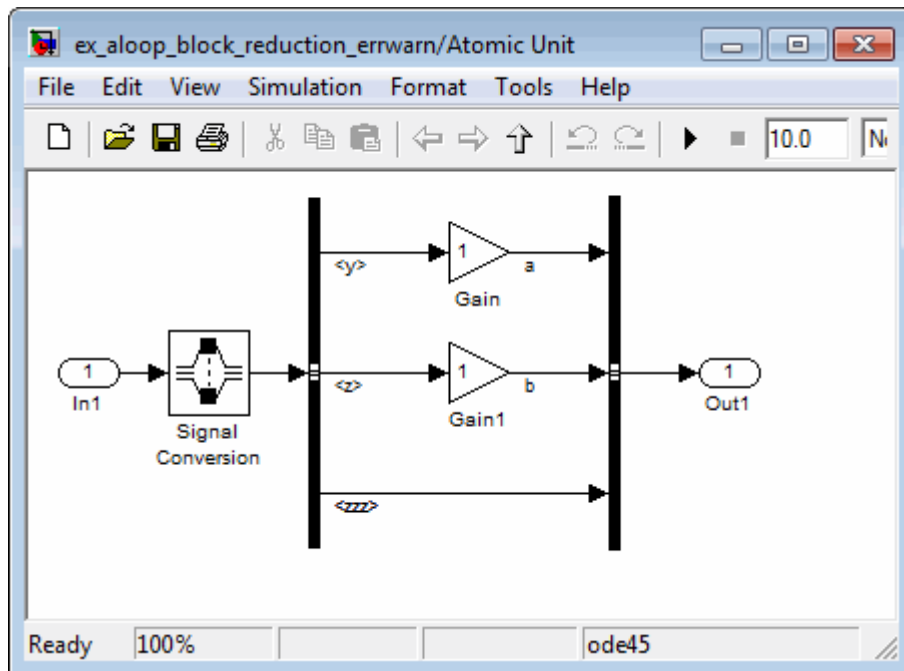
Setting	Simulation Response
none	Simulink takes no action.
warning	Simulink displays a warning that the <b>Minimize algebraic loop occurrences</b> parameter has no effect.
error	Simulink terminates the simulation and displays an error that the <b>Minimize algebraic loop occurrences</b> parameter has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

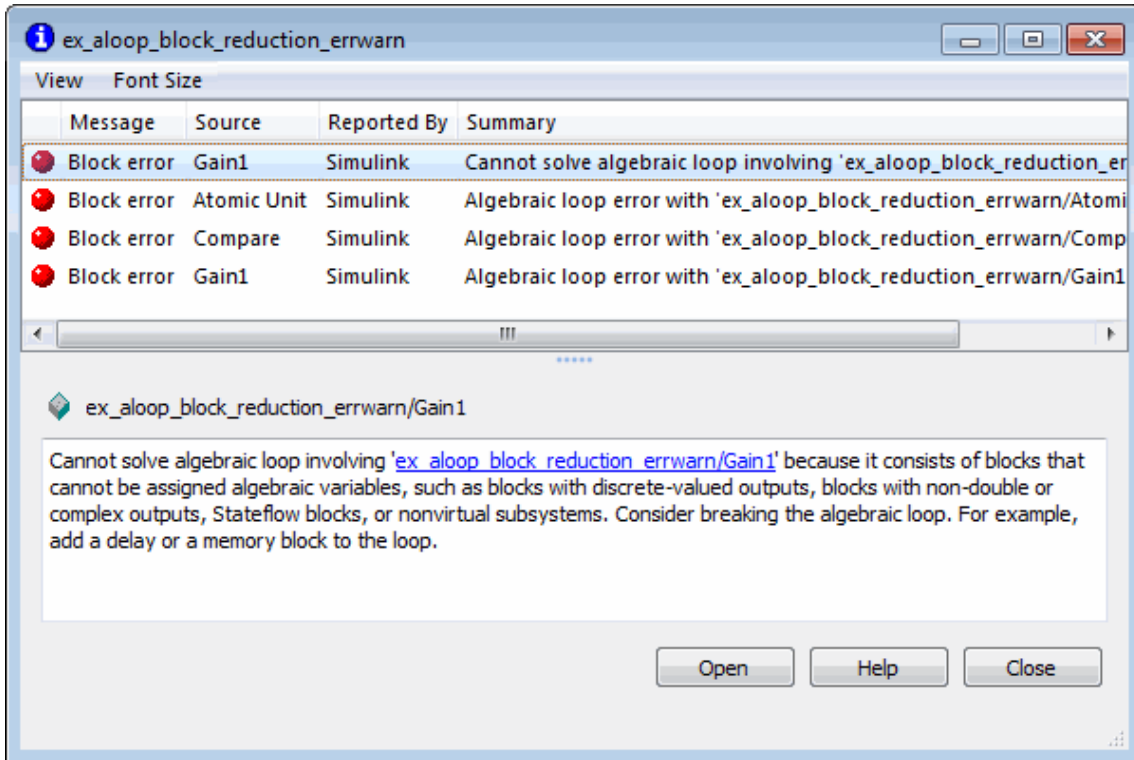
Enabling block reduction may also help Simulink solve artificial algebraic loops.

Consider the following example model.

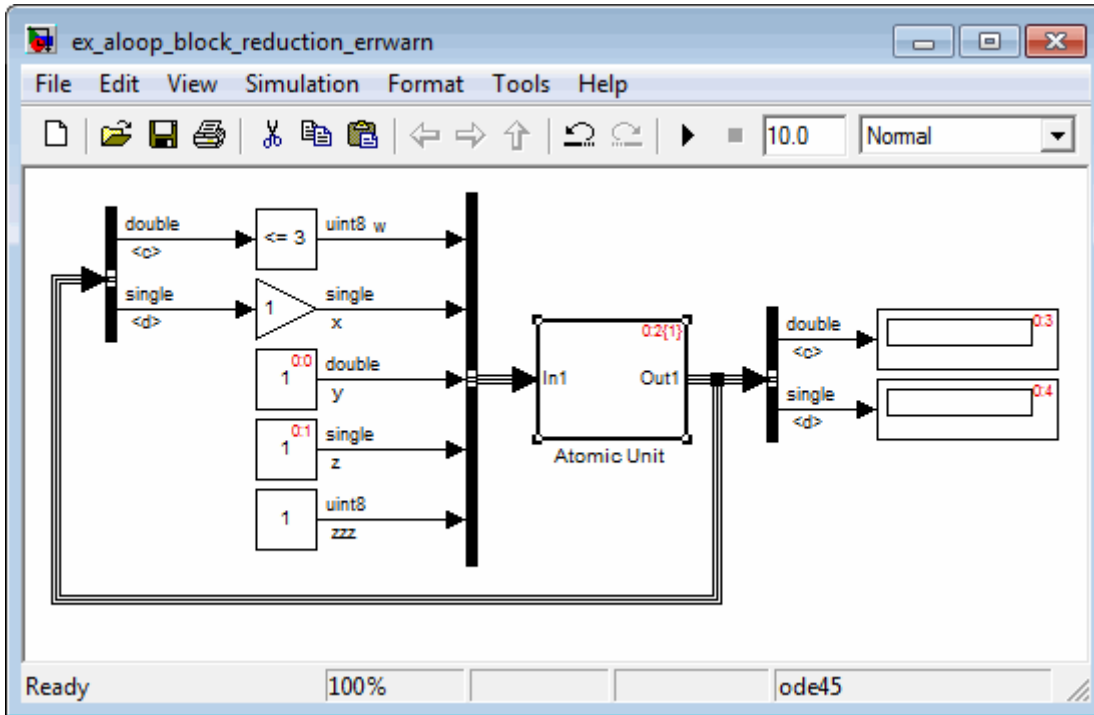




Initially, block reduction is turned off. When you simulate this model, the Atomic Unit subsystem and Gain and Compare to Constant blocks are part of an algebraic loop that Simulink cannot solve.



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:

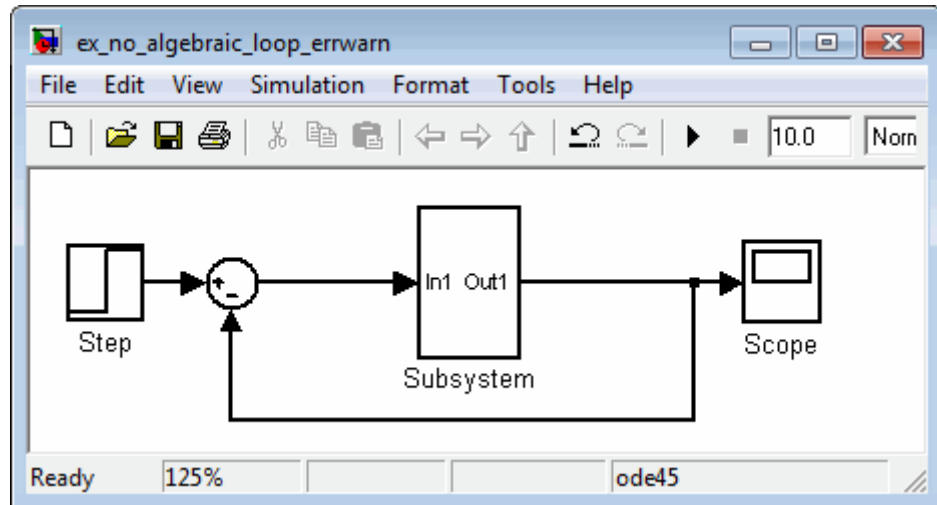
```
Warning: If the inport 'ex_aloop_block_reduction_errwarn/  
Atomic Unit/In1' of subsystem 'ex_aloop_block_reduction_errwarn/  
Atomic Unit' involves direct feedback, then an algebraic loop  
exists, which Simulink cannot remove. Consider clearing the  
'Minimize algebraic loop occurrences' parameter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

---

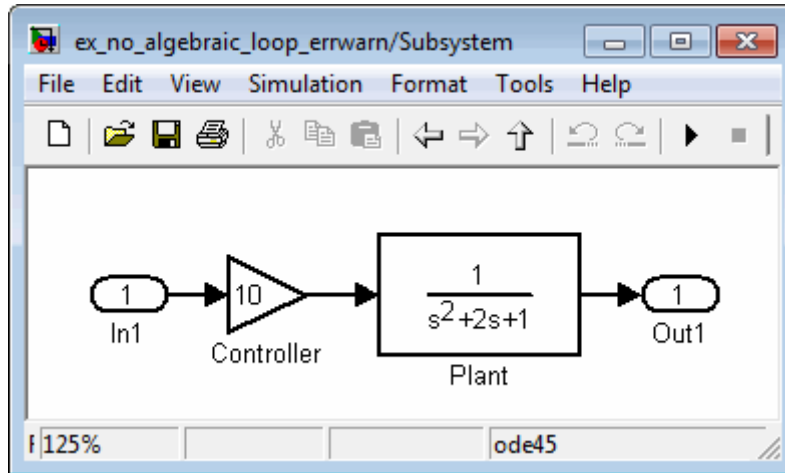
**Tip** Use Bus Selector blocks to pass only the required signals into atomic subsystems.

---

**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 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.

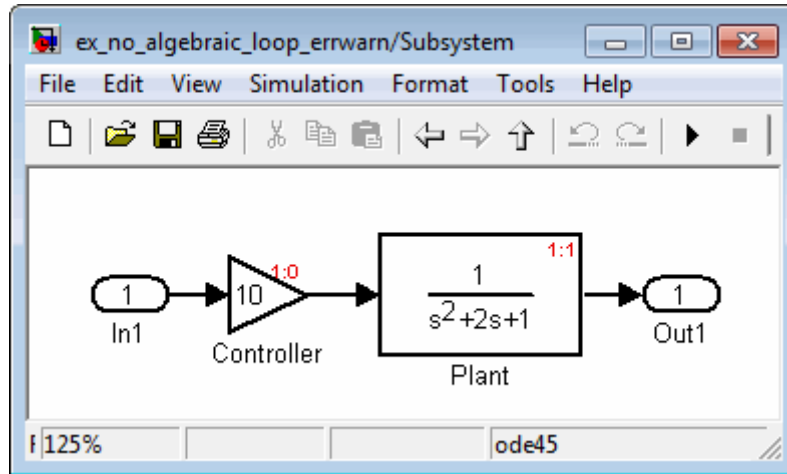
To see how Simulink tries to eliminate this algebraic loop, follow these steps:

- 1 Create the model from the preceding graphics, with the atomic subsystem that causes the artificial algebraic loop.
- 2 Select **Simulation > 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 “Controlling and Displaying the Sorted Order” on page 20-35.

---

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

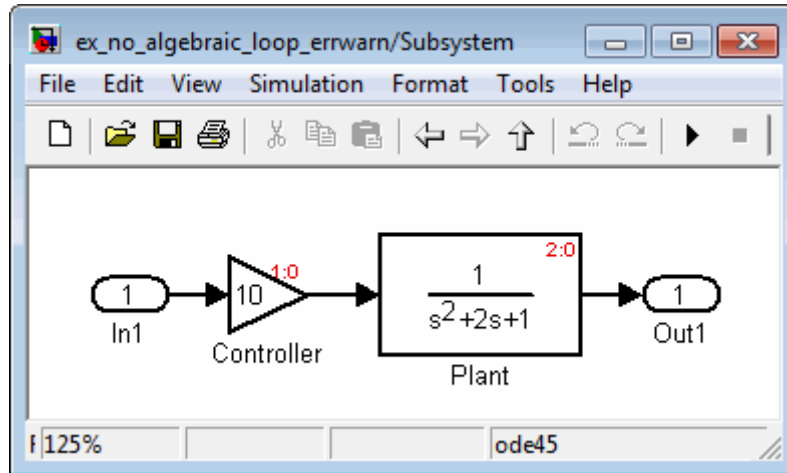
**8** Select **Minimize algebraic loop occurrences**.

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 **Edit > Update Diagram** to recalculate the sorted order.

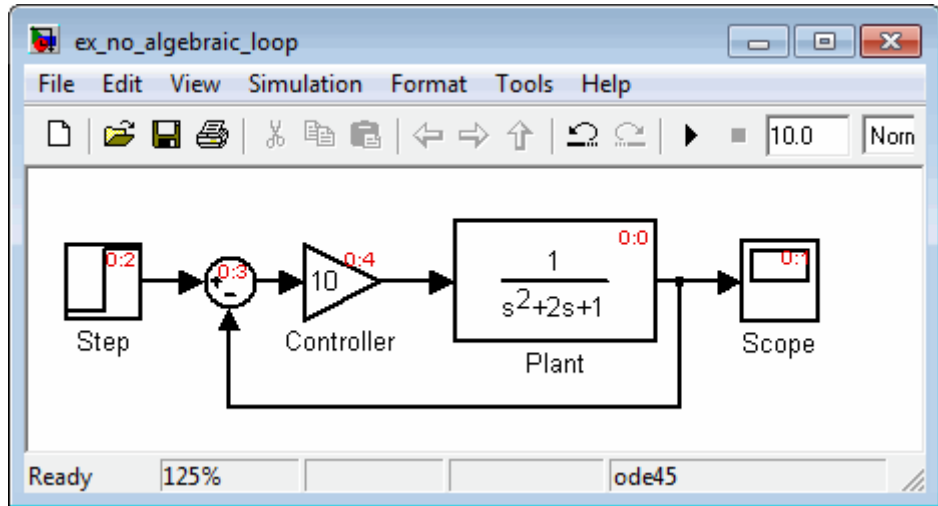
Now there are two levels of sorted order inside the subsystem: 1 and 2.



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

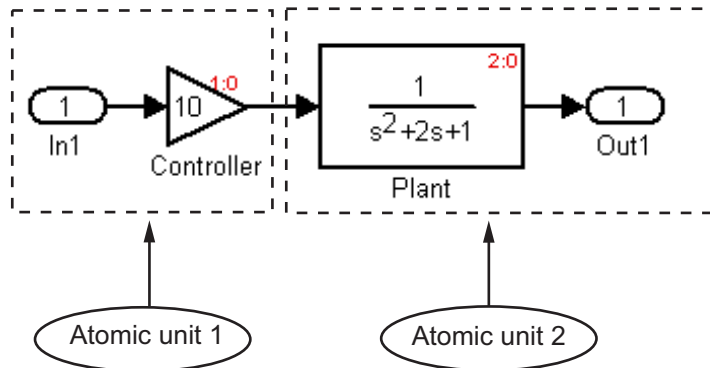
When you simulate a model, all the blocks first execute their `mdlOutputs` method, and then their `mdlDerivatives` and `mdlUpdate` methods.

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 2-16.

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.

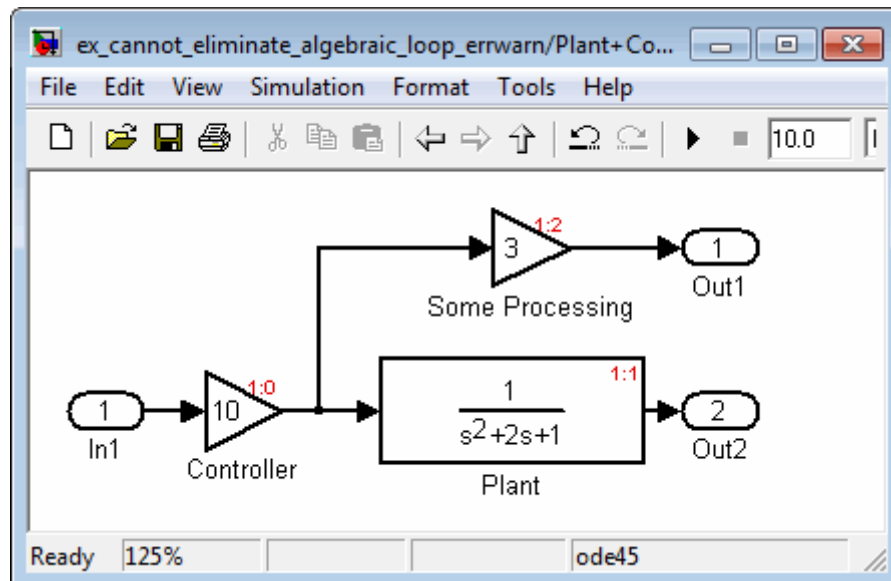
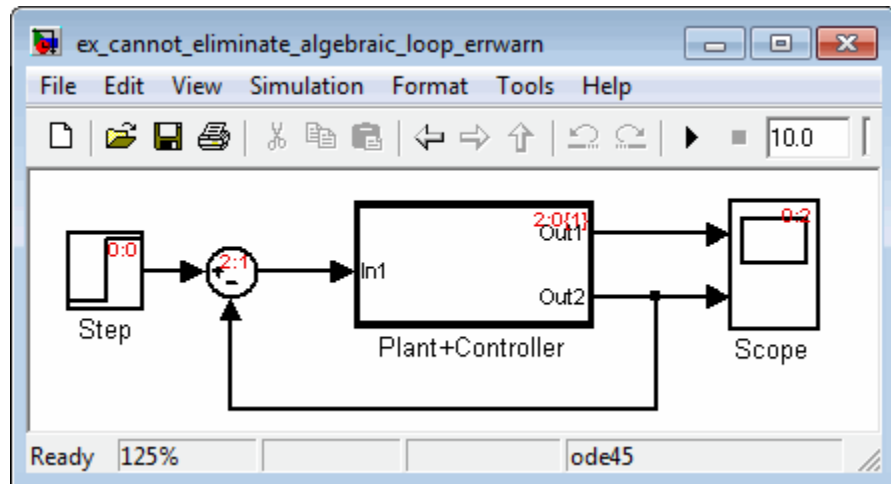
The new execution order for the model is:

- `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.

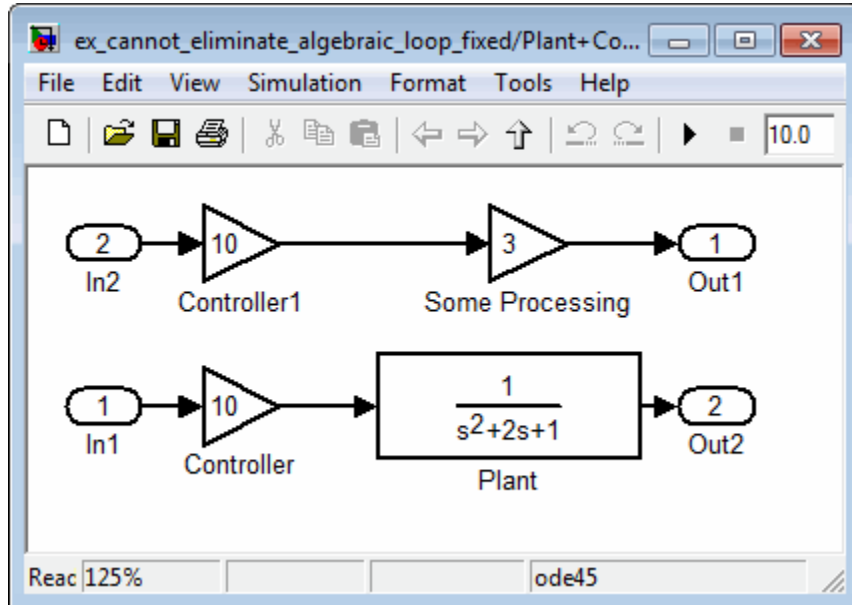
**When Simulink Cannot Eliminate Artificial Algebraic Loops.** Setting the **Minimize algebraic loop occurrences** parameter does not always work. Simulink cannot change the `DirectFeedthrough` property of an `Inport` for an atomic subsystem if the `Inport` is connected to an `Outport` only through direct-feedthrough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

---

- Chapter 3, “Creating a Model”
- Chapter 4, “Working with Sample Times”
- Chapter 5, “Referencing a Model”
- Chapter 6, “Creating Conditional Subsystems”
- Chapter 7, “Modeling Variant Systems”
- Chapter 8, “Exploring, Searching, and Browsing Models”
- Chapter 9, “Managing Model Configurations”
- Chapter 10, “Configuring Models for Targets with Multicore Processors”
- Chapter 11, “Modeling Best Practices”
- Chapter 12, “Managing Projects”



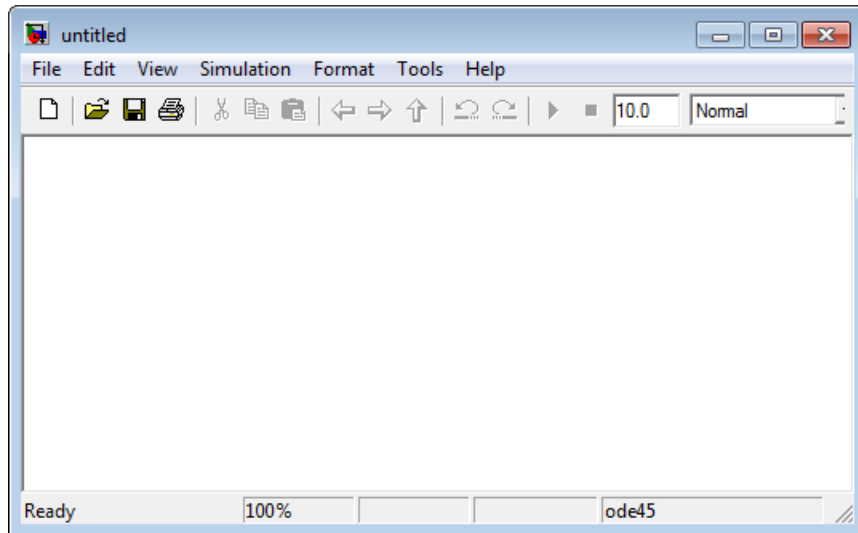
# Creating a Model

---

- “Creating an Empty Model” on page 3-2
- “Populating a Model” on page 3-4
- “Selecting Objects” on page 3-7
- “Specifying Block Diagram Colors” on page 3-9
- “Connecting Blocks” on page 3-15
- “Aligning, Distributing, and Resizing Groups of Blocks Automatically” on page 3-24
- “Annotating Diagrams” on page 3-26
- “Creating Subsystems” on page 3-37
- “Modeling Control Flow Logic” on page 3-44
- “Using Callback Functions” on page 3-54
- “Using Model Workspaces” on page 3-67
- “Resolving Symbols” on page 3-76
- “Consulting the Model Advisor” on page 3-81
- “Managing Model Versions” on page 3-102
- “Model Discretizer” on page 3-116

## Creating an Empty Model

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



## Creating a Model Template

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

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

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

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

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

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

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

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

## Populating a Model

### In this section...

“About the Library Browser” on page 3-4

“Opening the Library Browser” on page 3-4

“Browsing Block Libraries” on page 3-5

“Searching Block Libraries” on page 3-5


“Cloning Blocks to Models” on page 3-6

### About the Library Browser

Simulink provides the Simulink Library Browser, which you can use to browse, search, and clone blocks from built-in and user libraries to your model. This section summarizes the techniques for using the Library Browser. For additional details, see “Library Browser”. For information about creating your own libraries and adding them to the Library Browser, see Chapter 25, “Working with Block Libraries”.

### Opening the Library Browser

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

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

```
simulink
```

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

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

## Browsing Block Libraries

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

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

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

## Searching Block Libraries

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

- 1** Enter the character string in the text field of the Library Browser's **Search** field.
- 2** Press Return or click the tool's **Search** button.

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

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

### **Cloning Blocks to Models**

To copy a block from the Library Browser into a model, drag and drop the library block into the model window at the location where you want to create the copy. Simulink copies the block to the model at the point you selected. The resulting block retains a link to its library, so that updates to the source library automatically propagate to all copies. See Chapter 25, “Working with Block Libraries” for information about library links.



## Selecting Objects

### In this section...

“Selecting an Object” on page 3-7

“Selecting Multiple Objects” on page 3-7

### Selecting an Object

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



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

### Selecting Multiple Objects

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

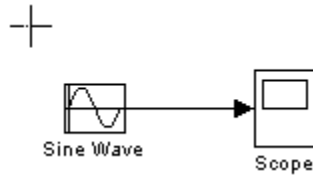
#### Selecting Multiple Objects One at a Time

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

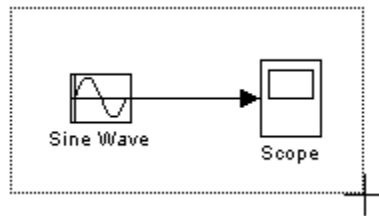
#### Selecting Multiple Objects Using a Bounding Box

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

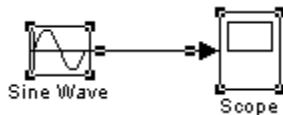
- 1 Define the starting corner of a bounding box by positioning the pointer at one corner of the box, then pressing and holding down the mouse button. Notice the shape of the cursor.



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



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



### Selecting All Objects

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

## Specifying Block Diagram Colors

### In this section...

“How to Specify Block Diagram Colors” on page 3-9

“Choosing a Custom Color” on page 3-10

“Defining a Custom Color” on page 3-10

“Specifying Colors Programmatically” on page 3-11

“Displaying Sample Time Colors” on page 3-12

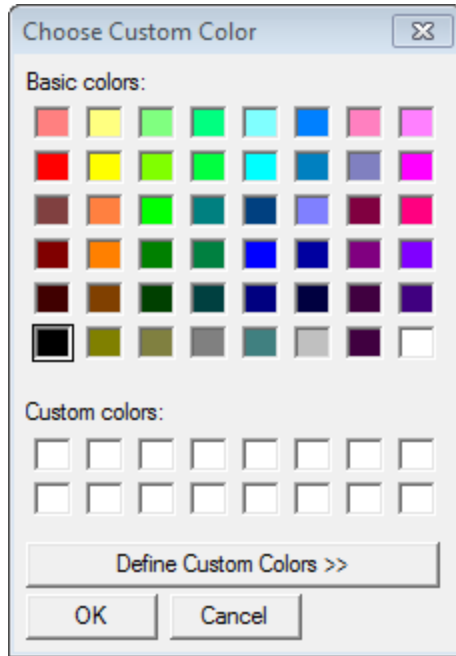
### How to Specify Block Diagram Colors

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

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

## Choosing a Custom Color

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

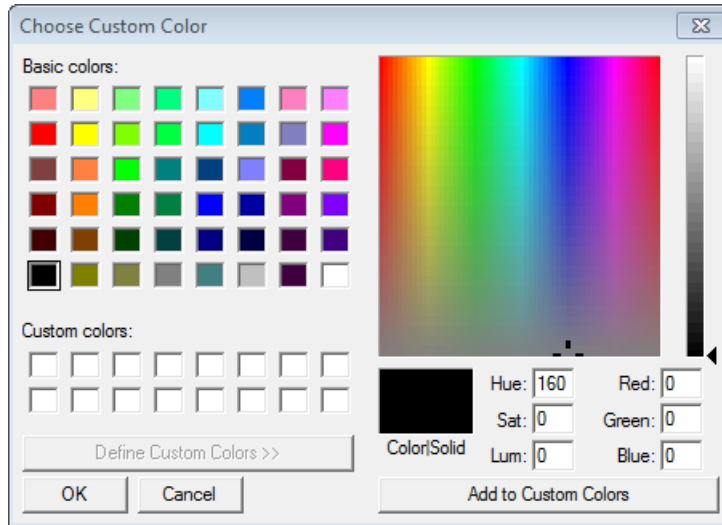


The dialog box displays a palette of basic colors and a palette of custom colors that you previously defined. If you have not previously created any custom colors, the custom color palette is all white. To choose a color from either palette, click the color, and then click the **OK** button.

## Defining a Custom Color

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

The dialog box expands to display a custom color definer.



The color definer allows you to specify a custom color by

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

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

## Specifying Colors Programmatically

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

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

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

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

- 'black', 'white', 'red', 'green', 'blue', 'cyan', 'magenta', 'yellow', 'gray', 'lightBlue', 'orange', 'darkGreen'
- '[r,g,b]'  
 where **r**, **g**, and **b** are the red, green, and blue components of the color normalized to the range 0.0 to 1.0.

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

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

## Displaying Sample Time Colors

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

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

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

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

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

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

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

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

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

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



## Connecting Blocks

### In this section...

“Automatically Connecting Blocks” on page 3-15

“Manually Connecting Blocks” on page 3-18

“Disconnecting Blocks” on page 3-23

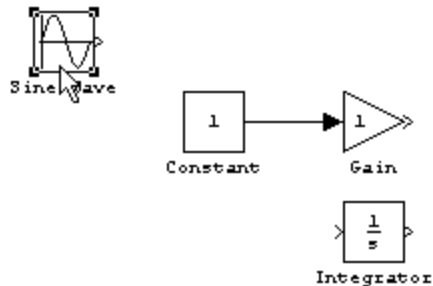
### Automatically Connecting Blocks

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

#### Connecting Two Blocks

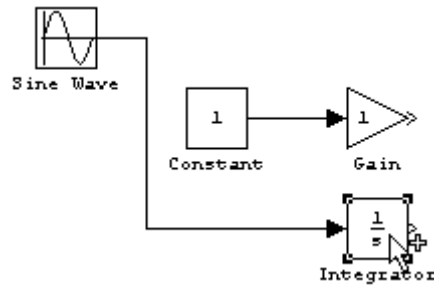
To autoconnect two blocks:

- 1 Select the source block.

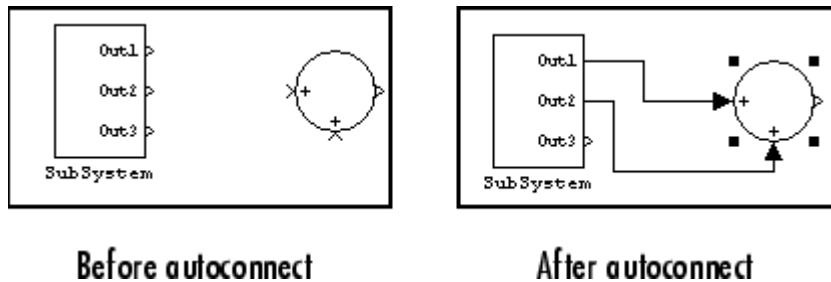


- 2 Hold down **Ctrl** and left-click the destination block.

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



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

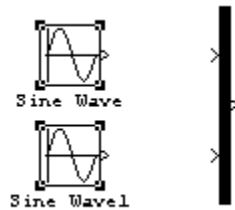


### Connecting Groups of Blocks

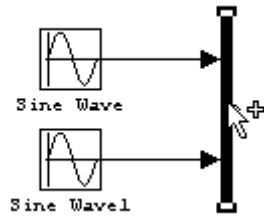
The Simulink software can connect a group of source blocks to a destination block or a source block to a group of destination blocks.

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

- 1 Select the source blocks.

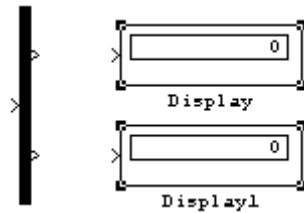


**2** Hold down **Ctrl** and left-click the destination block.

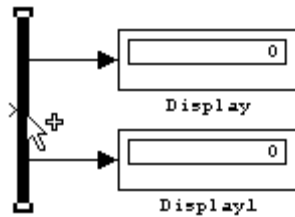


To connect a source block to a group of destination blocks:

**1** Select the *destination* blocks.



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



## Manually Connecting Blocks

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

## Drawing a Line Between Blocks

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

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

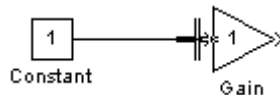
The cursor shape changes to crosshairs.



- 2 Press and hold down the mouse button.

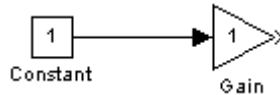
- 3 Drag the pointer to the second block's input port. You can position the cursor on or near the port or in the block. If you position the cursor in the block, the line is connected to the closest input port.

The cursor shape changes to double crosshairs.



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

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

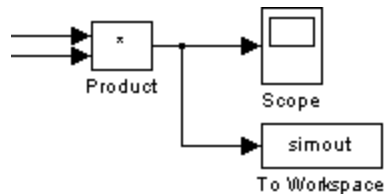


The Simulink software draws connecting lines using horizontal and vertical line segments. To draw a diagonal line, hold down the **Shift** key while drawing the line.

### Drawing a Branch Line

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

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



To add a branch line:

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

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

### Drawing a Line Segment

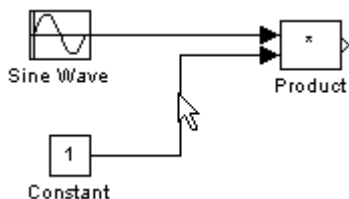
You might want to draw a line with segments exactly where you want them instead of where the Simulink software draws them. Or you might want to draw a line before you copy the block to which the line is connected. You can do either by drawing line segments.

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

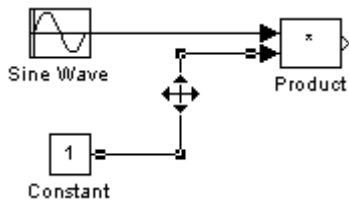
### Moving a Line Segment

To move a line segment:

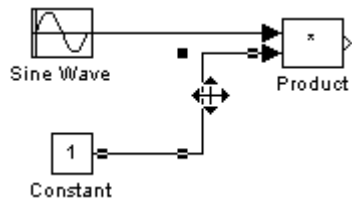
- 1 Position the pointer on the segment you want to move.



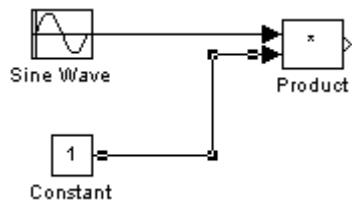
- 2 Press and hold down the left mouse button.



- 3 Drag the pointer to the desired location.



- 4 Release the mouse button.



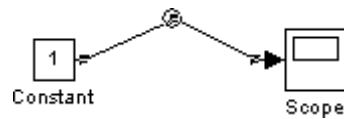
To move the segment connected to an input port, position the pointer over the port and drag the end of the segment to the new location. You cannot move the segment connected to an output port.

### Moving a Line Vertex

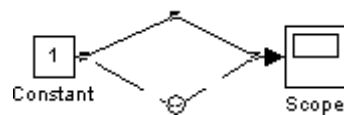
To move a vertex of a line:

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

The cursor changes to a circle that encloses the vertex.



- 2 Drag the pointer to the desired location.



- 3 Release the mouse button.

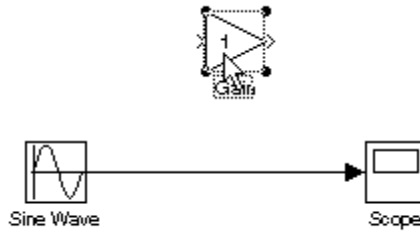


### Inserting Blocks in a Line

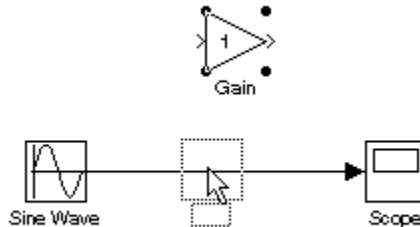
You can insert a block in a line by dropping the block on the line. The Simulink software inserts the block for you at the point where you drop the block. The block that you insert can have only one input and one output.

To insert a block in a line:

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



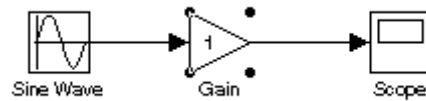
- 2 Drag the block over the line in which you want to insert the block.



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



The block is inserted where you dropped it.



## Disconnecting Blocks

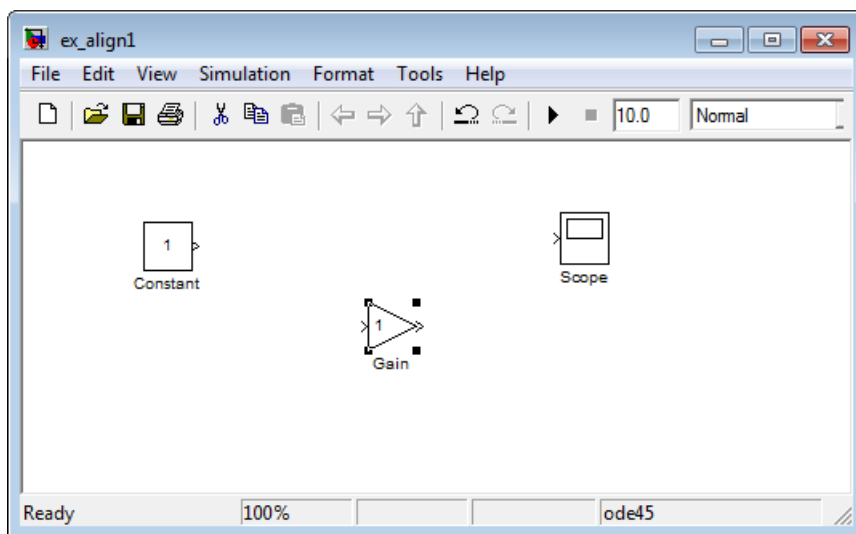
To disconnect a block from its connecting lines, hold down the **Shift** key, then drag the block to a new location.

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

## Aligning, Distributing, and Resizing Groups of Blocks Automatically

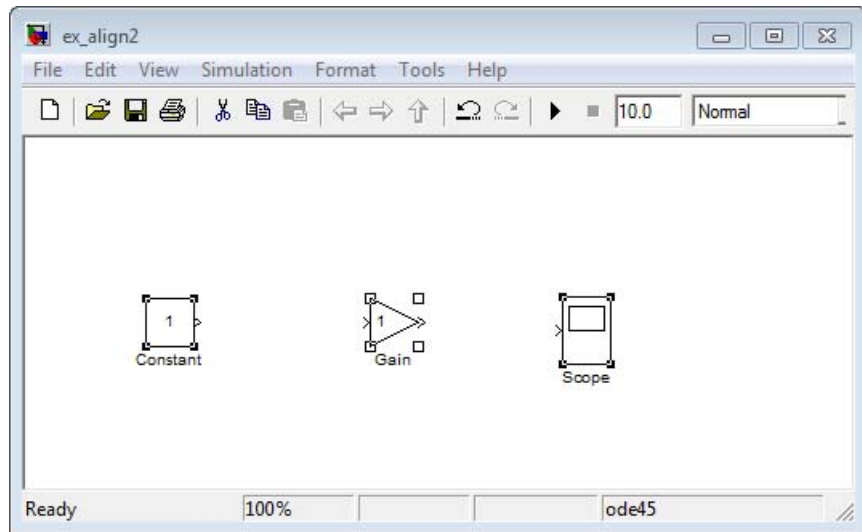
The model editor's **Format** menu includes commands that let you quickly align, distribute, and resize groups of blocks. To align (or distribute or resize) a group of blocks:

- 1 Select the blocks that you want to align.



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

- 2 Select one of the alignment options from the editor's **Format > Align Blocks** menu (or distribution options from the **Format > Distribute Blocks** or resize options from the **Format > Resize Blocks** menu). For example, selecting **Align Top Edges** aligns the top edges of the selected blocks with the top edge of the reference block.



## Annotating Diagrams

### In this section...

“How to Annotate Diagrams” on page 3-26

“Annotations Properties Dialog Box” on page 3-27

“Annotation Callback Functions” on page 3-30

“Associating Click Functions with Annotations” on page 3-31

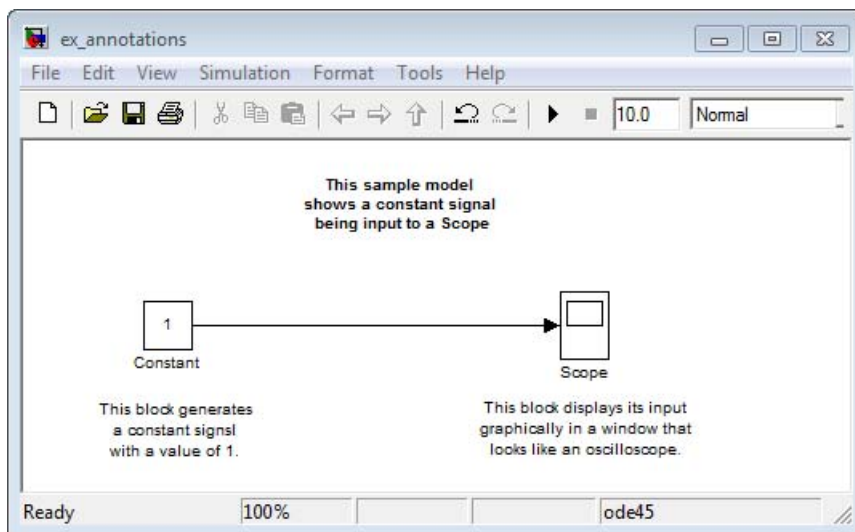
“Annotations API” on page 3-33

“Using TeX Formatting Commands in Annotations” on page 3-33

“Creating Annotations Programmatically” on page 3-35

### How to Annotate Diagrams

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



To create a model annotation, double-click an unoccupied area of the block diagram. A small rectangle appears and the cursor changes to an insertion

point. Start typing the annotation contents. Each line is centered in the rectangle that surrounds the annotation.

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

To edit an annotation, select it:

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

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

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

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

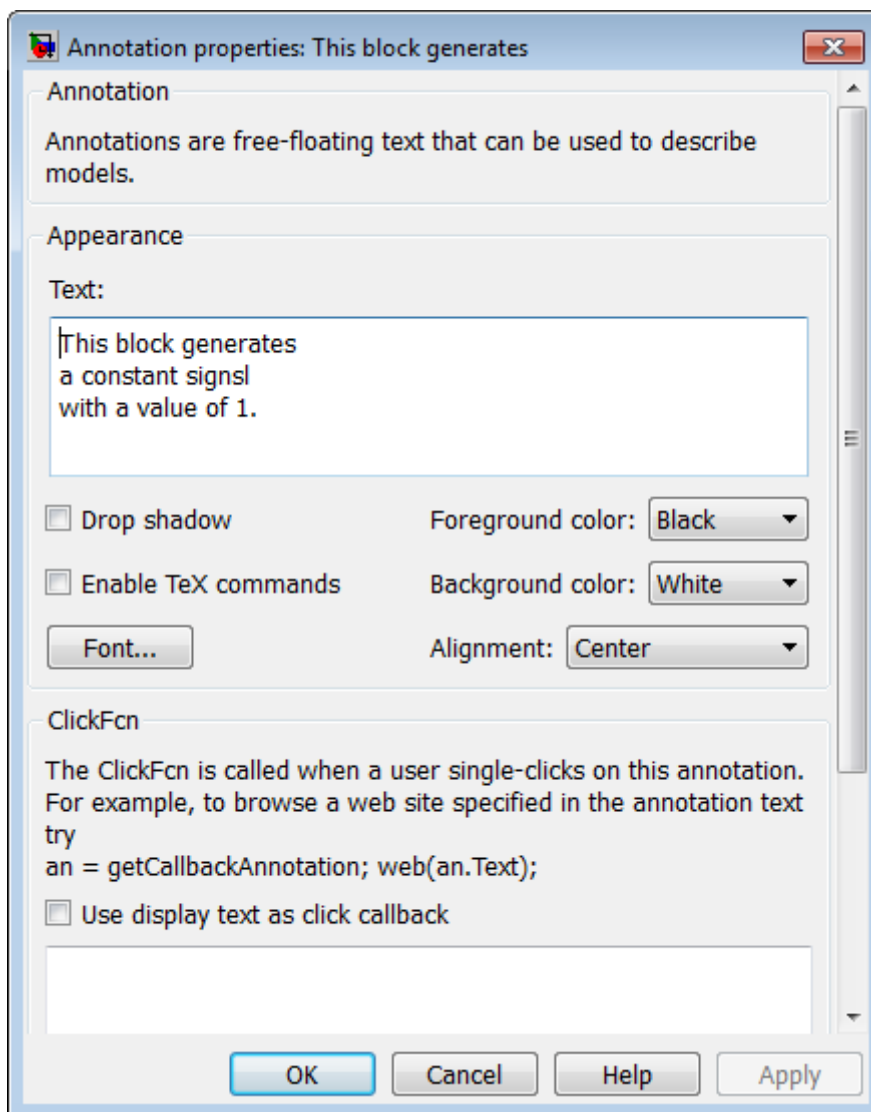
## Annotations Properties Dialog Box

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

To display the Annotation Properties dialog box for an annotation,

- 1 Select an annotation
- 2 From the Edit menu, select Annotation Properties.

The dialog box appears.



The dialog box includes the following controls.

**Text**

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

**Drop shadow**

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

**Enable TeX commands**

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

**Font**

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

**Foreground color**

Specifies the color of the annotation text.

**Background color**

Specifies the color of the background of the annotation’s bounding box.

**Alignment**

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

**ClickFcn**

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

### **Use display text as click callback**

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

## **Annotation Callback Functions**

You can associate the following callback functions with annotations.

### **Click Function**

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

### **Load Function**

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

### **Delete function**

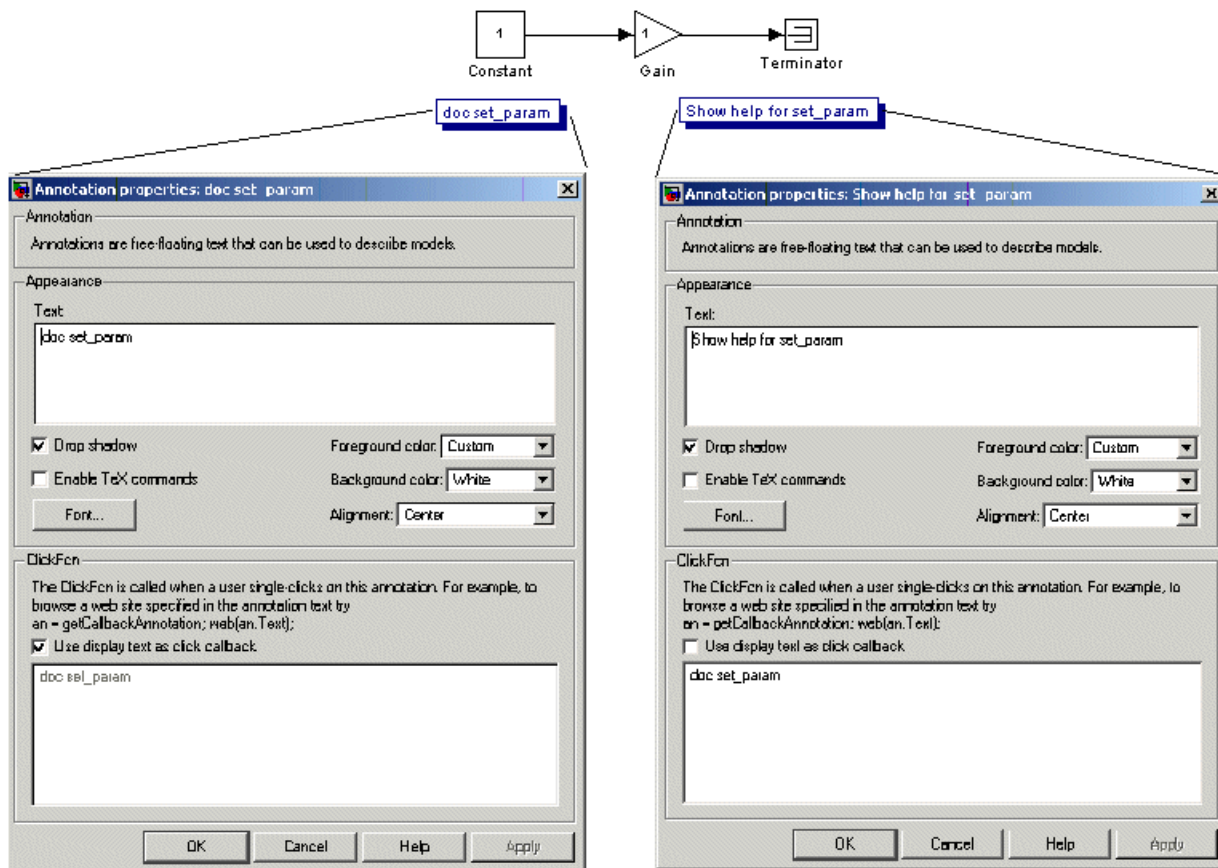
This function is invoked before deleting the associated annotation. To associate a delete function with an annotation, set the **DeleteFcn** property of the annotation to the desired function (see “Annotations API” on page 3-33).



## Associating Click Functions with Annotations

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

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



Annotation text as the click function

Separately defined click function

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

---

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

---

## Selecting and Editing Annotations Associated with Click Functions

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

## Annotations API

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

- `Simulink.Annotation` class  
Allows MATLAB code (for example, annotation load functions) to set the properties of annotations (see “Load Function” on page 3-30)
- `getCallbackAnnotation` function  
Gets the `Simulink.Annotation` object for the annotation associated with the currently executing annotation callback function

## Using TeX Formatting Commands in Annotations

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

Linearization of Double Pendulum

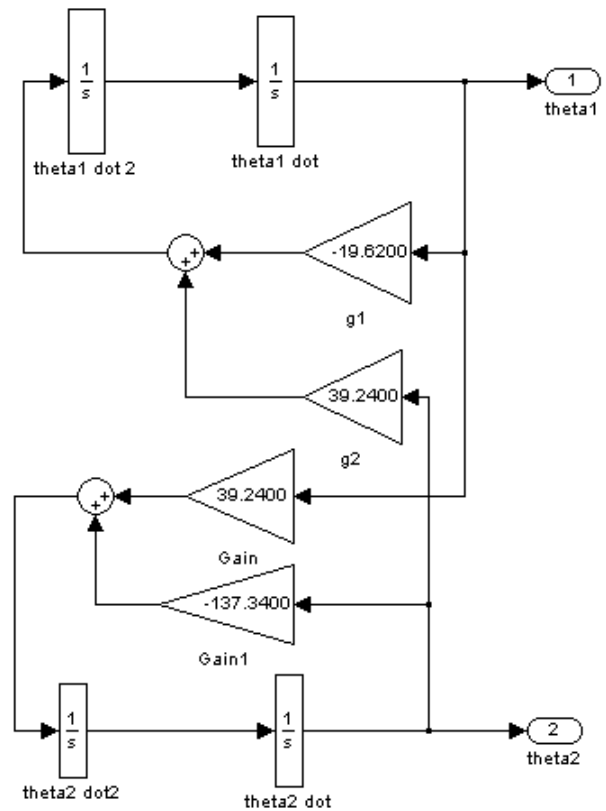
$$\theta_1'' = -19.6200\theta_1 + 39.2400\theta_2$$

$$\theta_2'' = 39.2400\theta_1 - 132.6603\theta_2$$

where

$\theta_1$  = position of top joint

$\theta_2$  = position of bottom joint



To use TeX commands in an annotation:

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

```

Linearization of Double Pendulum

\theta1" = -19.6200*\theta1 + 39.2400*\theta2
\theta2" = 39.2400*\theta1 -132.6603*\theta2

where

\theta1 = position of top joint
\theta2 = position of bottom joint

```

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

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

The formatted text is displayed.

```

Linearization of Double Pendulum

θ1" = -19.6200*θ1 + 39.2400*θ2
θ2" = 39.2400*θ1 -132.6603*θ2

where

θ1 = position of top joint
θ2 = position of bottom joint

```

## Creating Annotations Programmatically

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

```

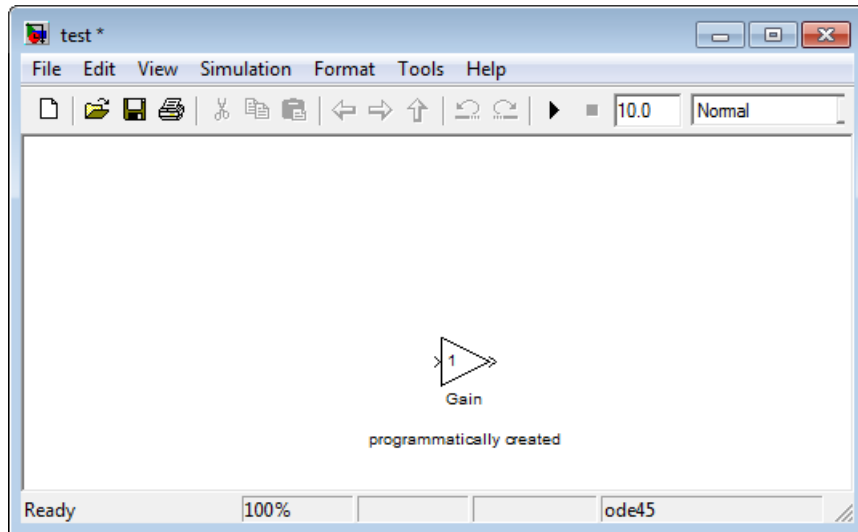
add_block('built-in/Note', 'path/text', 'Position', ...
[center_x, 0, 0, center_y]);

```

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

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

creates the following model:



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

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

## Creating Subsystems

### In this section...

“Why Subsystems are Advantageous” on page 3-37

“Creating Subsystems” on page 3-38

“Creating a Subsystem by Adding the Subsystem Block” on page 3-38

“Creating a Subsystem by Grouping Existing Blocks” on page 3-38

“Executing Subsystems” on page 3-40

“Model Navigation Commands” on page 3-40

“Window Reuse” on page 3-41

“Labeling Subsystem Ports” on page 3-41

“Controlling Access to Subsystems” on page 3-42

“Interconverting Subsystems and Block Diagrams” on page 3-43

“Emptying Subsystems and Block Diagrams” on page 3-43

### Why Subsystems are Advantageous

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

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

For additional information about how subsystems compare to other Simulink componentization techniques, see “Componentization Guidelines” on page 11-17.

## Creating Subsystems

You can create a subsystem in two ways:

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

## Creating a Subsystem by Adding the Subsystem Block

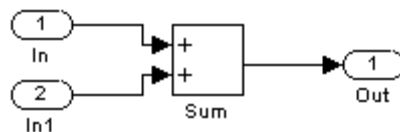
To create a subsystem before adding the blocks it contains, add a Subsystem block to the model, then add the blocks that make up the subsystem:

- 1 Copy the Subsystem block from the Ports & Subsystems library into your model.
- 2 Open the Subsystem block by double-clicking it.

The subsystem is opened in the current or a new model window, depending on the model window reuse mode that you selected (see “Window Reuse” on page 3-41).

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

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



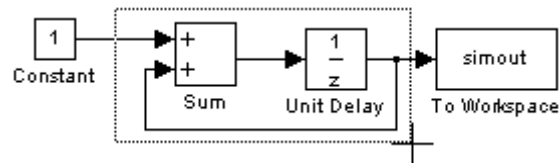
## Creating a Subsystem by Grouping Existing Blocks

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



- 1 Enclose the blocks and connecting lines that you want to include in the subsystem within a bounding box. You cannot specify the blocks to be grouped by selecting them individually or by using the **Select All** command. For more information, see “Selecting Multiple Objects Using a Bounding Box” on page 3-7.

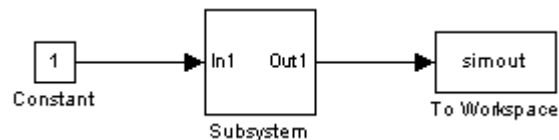
For example, this figure shows a model that represents a counter. The Sum and Unit Delay blocks are selected within a bounding box.



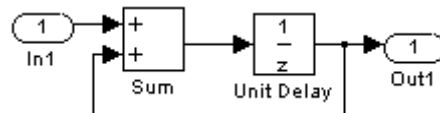
When you release the mouse button, the two blocks and all the connecting lines are selected.

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

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



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



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

As with all blocks, you can change the name of the Subsystem block. You can also use the masking feature to customize the block's appearance and dialog box. See Chapter 23, "Working with Block Masks".

### Undoing Subsystem Creation

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

### Executing Subsystems

You can configure a subsystem to execute 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 Chapter 6, "Creating Conditional Subsystems".

### Model Navigation Commands

Subsystems allow you to create a hierarchical model comprising many layers. You can navigate this hierarchy using the Model Browser (see "The Model Browser" on page 8-77) and/or the following model navigation commands:

- **Open Block**  
The **Open Block** command opens the currently selected subsystem. To execute the command, select **Open Block** from either the **Edit** menu or the subsystem's context (right-click) menu, press **Enter**, or double-click the subsystem.
- **Open Block In New Window**  
Opens the currently selected subsystem regardless of the window reuse settings (see "Window Reuse" on page 3-41). To execute the command, select **Open Block In New Window** from the subsystem's context (right-click) menu.

- **Go To Parent**

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

## Window Reuse

You can specify whether the Simulink software model navigation commands use the current window or a new window to display a subsystem or its parent. Reusing windows avoids cluttering your screen with windows. Creating a window for each subsystem allows you to view subsystems side by side with their parents or siblings. To specify your preference regarding window reuse, select **Preferences** from the **File** menu and then select one of the following **Window reuse type** options listed in the **Preferences** dialog box.

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

## Labeling Subsystem Ports

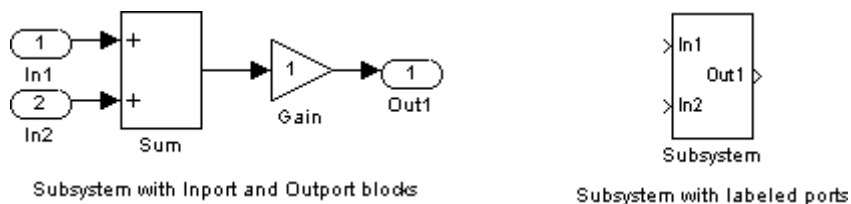
Simulink labels ports on a Subsystem block. The labels are the names of Inport and Outport blocks that connect the subsystem to blocks outside the subsystem through these ports.

You can hide (or show) the port labels by

- Selecting the Subsystem block, then choosing **Hide Port Labels** (or **Show Port Labels**) from the **Format** menu

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

This figure shows two models.



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

## Controlling Access to Subsystems

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

---

**Note** This method does not necessarily prevent a user from changing the access restrictions. To completely hide proprietary information in a subsystem, use Simulink Coder to create a reusable S-function from your subsystem. See “Create an S-Function Block from a Subsystem”.

---

To restrict access to a library subsystem, open the subsystem's 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 Chapter 25, “Working with Block Libraries”). See the Subsystem block in the *Simulink Reference* guide for more information on subsystem access options.

---

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

---

## Interconverting Subsystems and Block Diagrams

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

`Simulink.SubSystem.copyContentsToBlockDiagram`

Copies the contents of a subsystem to an empty block diagram.

`Simulink.BlockDiagram.copyContentsToSubSystem`

Copies the contents of a block diagram to an empty subsystem.

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

## Emptying Subsystems and Block Diagrams

These functions are provided to empty subsystems and block diagrams:

`Simulink.SubSystem.deleteContents`

Deletes the contents of a subsystem.

`Simulink.BlockDiagram.deleteContents`

Deletes the contents of a block diagram.

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

## Modeling Control Flow Logic

**In this section...**

“Equivalent C Language Statements” on page 3-44

“Modeling Conditional Control Flow Logic” on page 3-44

“Modeling While and For Loops” on page 3-47

### Equivalent C Language Statements

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

- for
- if-else
- switch
- while

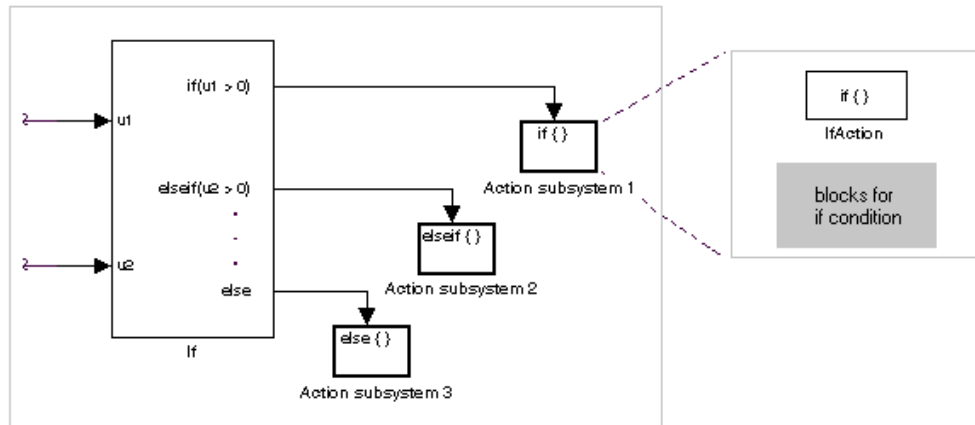
### Modeling Conditional Control Flow Logic

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

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

### Modeling If-Else Control Flow

The following diagram models if-else control flow.



Construct an if-else control flow diagram as follows:

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

Inputs to the If block are set in the If block properties dialog box. Internally, they are designated as  $u_1$ ,  $u_2$ ,  $\dots$ ,  $u_n$  and are used to construct output conditions.

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

Output ports for the If block are also set in its properties dialog box. You use the input values  $u_1$ ,  $u_2$ ,  $\dots$ ,  $u_n$  to express conditions for the if, elseif, and else condition fields in the dialog box. Of these, only the if field is required. You can enter multiple elseif conditions and select a check box to enable the else condition.

- Connect each condition output port to an Action subsystem.

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

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

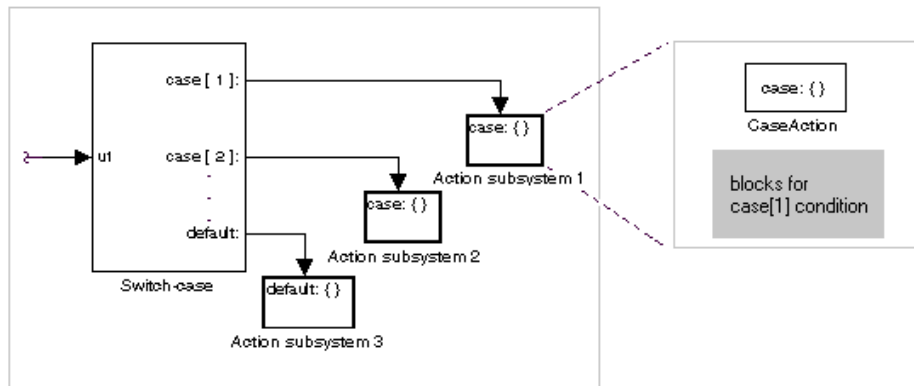
---

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

---

## Modeling Switch Control Flow

The following diagram models switch control flow.



Construct a switch control flow statement as follows:

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

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

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

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

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

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



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

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

---

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

---

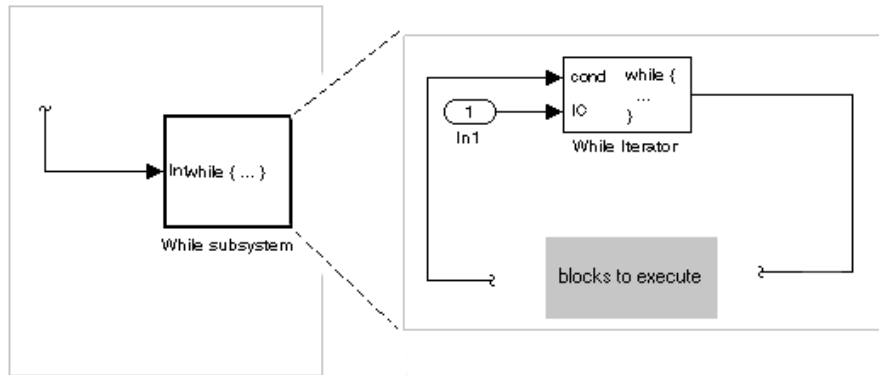
## Modeling While and For Loops

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

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

## Modeling While Loops

The following diagram illustrates a *while* loop.



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

---

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

---

Construct a *while* loop as follows:

- Place a While Iterator block in a subsystem.

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

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

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

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

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

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

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

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

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

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

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

---

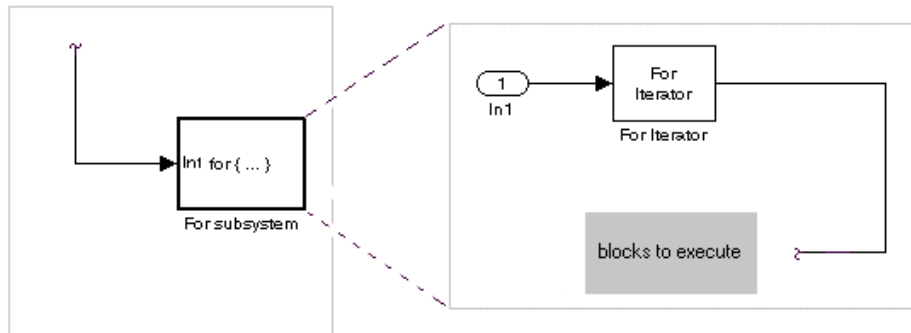
**Note** The diagram must not contain blocks with continuous states, e.g., blocks from the Continuous block library, and the sample times of all the blocks must be inherited (-1) or constant (inf).

---

For more information, see the While Iterator block.

## Modeling For Loops

The following diagram models a for loop:



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

---

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

---

Construct a for loop as follows:

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

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

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

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

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

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

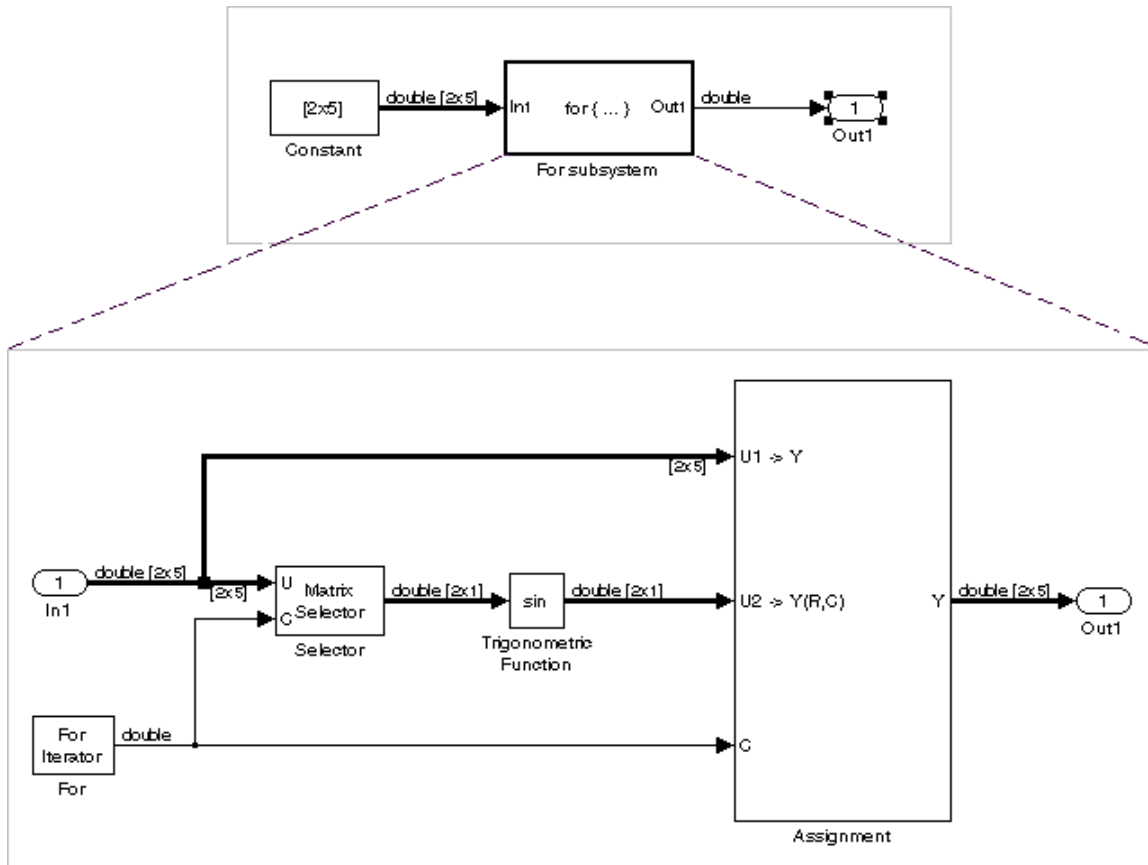
- Create a block diagram in the subsystem that defines the subsystem's outputs.

---

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

---

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



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

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

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

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

---

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

---

## Using Callback Functions

In this section...
“About Callback Functions” on page 3-54
“Tracing Callbacks” on page 3-55
“Creating Model Callback Functions” on page 3-55
“Creating Block Callback Functions” on page 3-58
“Port Callback Parameters” on page 3-63
“Example Callback Function Tasks” on page 3-64

### About Callback Functions

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

Common tasks you can achieve by using callback functions include:

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

For examples of these tasks, see “Example Callback Function Tasks” on page 3-64.



For related tasks, see

- “Using Model Workspaces” on page 3-67 for loading and modifying variables required by your model
- “Model Dependencies” on page 12-60 for analyzing model and block callbacks, and identifying and packaging files required by your model

## Tracing Callbacks

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

## Creating Model Callback Functions

You can create model callback functions interactively or programmatically. Use the **Callbacks** pane of the model’s Model Properties dialog box (see “Specifying Callbacks” on page 3-106) to create model callbacks interactively. To create a callback programmatically, use the `set_param` command to assign a MATLAB expression that implements the function to the model parameter corresponding to the callback (see “Model Callback Functions” on page 3-56).

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

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

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

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

- CloseFcn

### Model Callback Functions

The following table describes callback functions associated with models.

Parameter	When Executed
CloseFcn	Before the block diagram is closed. Any ModelCloseFcn and DeleteFcn callbacks set on blocks in the model are called prior to the model's CloseFcn. The DestroyFcn callback of any blocks in the model is called after the model's CloseFcn.
ContinueFcn	Before the simulation continues.
InitFcn	Called at start of model simulation.
PauseFcn	After the simulation pauses.
PostLoadFcn	<p>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.</p> <hr/> <p><b>Note</b> 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.</p> <hr/>
PostSaveFcn	<p>After the model is saved.</p> <hr/> <p><b>Note</b> 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.</p> <hr/>

Parameter	When Executed
PreLoadFcn	<p data-bbox="676 302 1270 392">Before the model is loaded. Defining a callback routine for this parameter might be useful for loading variables used by the model.</p> <hr data-bbox="676 447 1326 451"/> <p data-bbox="676 461 1285 583"><b>Note</b> In a PreLoadFcn callback routine, the <code>get_param</code> command does not return the model's parameter values because the model is not yet loaded.</p> <p data-bbox="676 621 1234 649">In a PreLoadFcn routine, <code>get_param</code> returns:</p> <ul data-bbox="676 687 1326 826" style="list-style-type: none"> <li data-bbox="676 687 1326 749">• The default value for a standard model parameter such as <code>solver</code></li> <li data-bbox="676 767 1326 826">• An error message for a model parameter added with <code>add_param</code></li> </ul> <p data-bbox="676 864 1285 951">In a PostLoadFcn callback routine, however, <code>get_param</code> returns the model's parameter values because the model is loaded.</p> <hr data-bbox="676 961 1326 965"/>
PreSaveFcn	Before the model is saved.
StartFcn	Before the simulation starts.
StopFcn	After the simulation stops. Output is written to workspace variables and files before the StopFcn is executed.

---

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

---

## Creating Block Callback Functions

You can create block callback functions interactively or programmatically. Use the **Callbacks** pane of the block’s Block Properties dialog box (see “Callbacks Pane” on page 20-19) to create block callbacks interactively. To create a callback programmatically, use the `set_param` command to assign a MATLAB expression that implements the function to the block parameter corresponding to the callback (see “Block Callback Parameters” on page 3-58).

---

**Note** A callback for a masked subsystem cannot directly reference the parameters of the masked subsystem (see Chapter 23, “Working with Block Masks”). The Simulink software evaluates block callbacks in the MATLAB base workspace whereas the mask parameters reside in the masked subsystem’s private workspace. A block callback, however, can use `get_param` to obtain the value of a mask parameter, e.g., `get_param(gcf, 'gain')`, where `gain` is the name of a mask parameter of the current block.

---

## Block Callback Parameters

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

<b>Parameter</b>	<b>When Executed</b>
ClipboardFcn	When the block is copied or cut to the system clipboard.
CloseFcn	When the block is closed using the <code>close_system</code> command. The <code>CloseFcn</code> 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 <code>close_system</code> .
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 <code>CopyFcn</code> parameter is defined, the routine is also executed). The routine is also executed if an <code>add_block</code> command is used to copy the block.
DeleteChildFcn	After a block or line is deleted in a subsystem. If the block has a <code>DeleteFcn</code> or <code>DestroyFcn</code> , those functions are executed prior to the <code>DeleteChildFcn</code> . Only Subsystem blocks have a <code>DeleteChildFcn</code> callback.
DeleteFcn	After a block is graphically deleted, e.g., when you graphically delete the block, invoke <code>delete_block</code> on the block, or close the model containing the block. When the <code>DeleteFcn</code> is called, the block handle is still valid and can be accessed using <code>get_param</code> . The <code>DeleteFcn</code> callback is recursive for Subsystem blocks. If the block is graphically deleted by invoking <code>delete_block</code> or by closing the model, after deletion the block is destroyed from memory and the block's <code>DestroyFcn</code> is called.

<b>Parameter</b>	<b>When Executed</b>
DestroyFcn	When the block has been destroyed from memory, e.g., when you invoke <code>delete_block</code> 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 <code>DeleteFcn</code> is called prior to the <code>DestroyFcn</code> . When the <code>DestroyFcn</code> is called, the block handle is no longer valid.
ErrorFcn	When an error has occurred in a subsystem. Only Subsystem blocks have an <code>ErrorFcn</code> callback. For more information, see “Subsystem Error Function Callback” on page 3-62.
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 <code>ModelCloseFcn</code> is called prior to its <code>DeleteFcn</code> . This callback is recursive for Subsystem blocks.
MoveFcn	When the block is moved or resized.
NameChangeFcn	After a block's name and/or path changes. When a Subsystem block's path is changed, it recursively calls this function for all blocks it contains after calling its own <code>NameChangeFcn</code> routine.
OpenFcn	When the block is opened. This parameter is generally used with Subsystem blocks. The routine is executed when you double-click the block or when an <code>open_system</code> command is called with the block as an argument. The <code>OpenFcn</code> parameter overrides the normal behavior associated with opening a block, which is to display the block's dialog box or to open the subsystem.

<b>Parameter</b>	<b>When Executed</b>
ParentCloseFcn	Before closing a subsystem containing the block or when the block is made part of a new subsystem using the <code>new_system</code> command (see <code>new_system</code> in the online Simulink software reference) or the <b>Create Subsystem</b> item in model editor's <b>Edit</b> menu. The <code>ParentCloseFcn</code> 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 <code>PreCopyFcn</code> parameter is defined, that routine is also executed). The block's <code>CopyFcn</code> is called after all <code>PreCopyFcn</code> callbacks are executed, unless the <code>PreCopyFcn</code> invokes the <code>error</code> command either explicitly or via a command used in any <code>PreCopyFcn</code> . The <code>PreCopyFcn</code> is also executed if an <code>add_block</code> command is used to copy the block.
PreDeleteFcn	Before a block is graphically deleted, e.g., when the user graphically deletes the block or invokes <code>delete_block</code> on the block. The <code>PreDeleteFcn</code> is not called when the model containing the block is closed. The block's <code>DeleteFcn</code> is called after the <code>PreDeleteFcn</code> unless the <code>PreDeleteFcn</code> invokes the <code>error</code> command either explicitly or via a command used in the <code>PreDeleteFcn</code> .
PreSaveFcn	Before the block diagram is saved. This callback is recursive for Subsystem blocks.

Parameter	When Executed
StartFcn	After the block diagram is compiled and before the simulation starts. In the case of an S-Function block, StartFcn executes immediately before the first execution of the block's mdlProcessParameters function. See "S-Function Callback Methods" in the online Simulink software documentation for more information.
StopFcn	At any termination of the simulation. In the case of an S-Function block, StopFcn executes after the block's mdlTerminate function executes. See "S-Function Callback Methods" in the online Simulink software documentation for more information.
UndoDeleteFcn	When a block deletion is undone.

---

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

---

### Subsystem Error Function Callback

The callback 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 14-15)



- `newException` is an `MSLException` specifying the error message to be displayed to the user

If you provide the original exception, then specifying the subsystem and the error type is unnecessary.

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. The Simulink software displays the error message `errorMsg` returned by the callback function.

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(gcf, 'PortHandles');  
set_param(phs.Inport, 'ConnectionCallback', 'foo');
```

where, `foo` is defined as:

```
function foo(portHandle)
```

### Example Callback Function Tasks

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

- “Loading Variables Automatically When Opening a Model” on page 3-64
- “Executing a MATLAB Script by Double-Clicking a Block” on page 3-65
- “Executing Commands Before Starting Simulation” on page 3-65

### Loading Variables Automatically When Opening a Model

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

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

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

To create model callbacks interactively, open the model’s Model Properties dialog box and use the **Callbacks** pane to edit callbacks (see “Specifying Callbacks” on page 3-106).

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

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

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

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

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

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

### Executing a MATLAB Script by Double-Clicking a Block

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

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

To create block callbacks interactively, open the block's Block Properties dialog box and use the **Callbacks** pane to edit callbacks (see "Callbacks Pane" on page 20-19). To create the `OpenFcn` callback programmatically, click the block that you want to add this property to, then enter the following at the MATLAB command prompt:

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

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

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

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

### Executing Commands Before Starting Simulation

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

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

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

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

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

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

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

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

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

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

## Using Model Workspaces

### In this section...

“About Model Workspaces” on page 3-67

“Simulink.ModelWorkspace Data Object Class” on page 3-68

“Changing Model Workspace Data” on page 3-69

“Model Workspace Dialog Box” on page 3-71

### About Model Workspaces

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

- Variables in a model workspace are visible only in the scope of the model.  
If both the MATLAB workspace and a model workspace define a variable of the same name, and the variable does not appear in any intervening masked subsystem or model workspaces, the Simulink software uses the value of the variable in the model workspace. A model’s workspace effectively provides it with its own name space, allowing you to create variables for the model without risk of conflict with other models.
- When the model is loaded, the workspace is initialized from a data source.  
The data source can be the MDL-file for the model, a MAT-file, a MATLAB file, or MATLAB code stored in the model file (see “Data source” on page 3-72 for more information).
- You can interactively reload and save MAT-file, MATLAB file, and MATLAB code data sources.
- Only `Simulink.Parameter` and `Simulink.Signal` objects for which the storage class is set to `Auto` can reside in a model workspace. You must create all other Simulink data objects in the base MATLAB workspace to ensure the objects are unique within the global Simulink context and accessible to all models.

---

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

---

- In general, parameter variables in a model workspace are not tunable. However, you can tune model workspace variables declared as model arguments for referenced models (for more information, see “Using Model Arguments” on page 5-53).

---

**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. (See Chapter 5, “Referencing a Model”.)

---

---

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

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

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

---

### **Simulink.ModelWorkspace Data Object Class**

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

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

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

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

## Changing Model Workspace Data

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

### Changing Workspace Data Whose Source Is the Model File

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

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

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

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

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

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

### Changing Workspace Data Whose Source Is MATLAB Code

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

To save and reload alternative versions of the workspace that result from editing the MATLAB code source or the workspace variables themselves, see “Exporting Workspace Variables” on page 8-58 and “Importing Workspace Variables” on page 8-60.

### Using MATLAB Commands to Change Workspace Data

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

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

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

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



- Save and reload the workspace

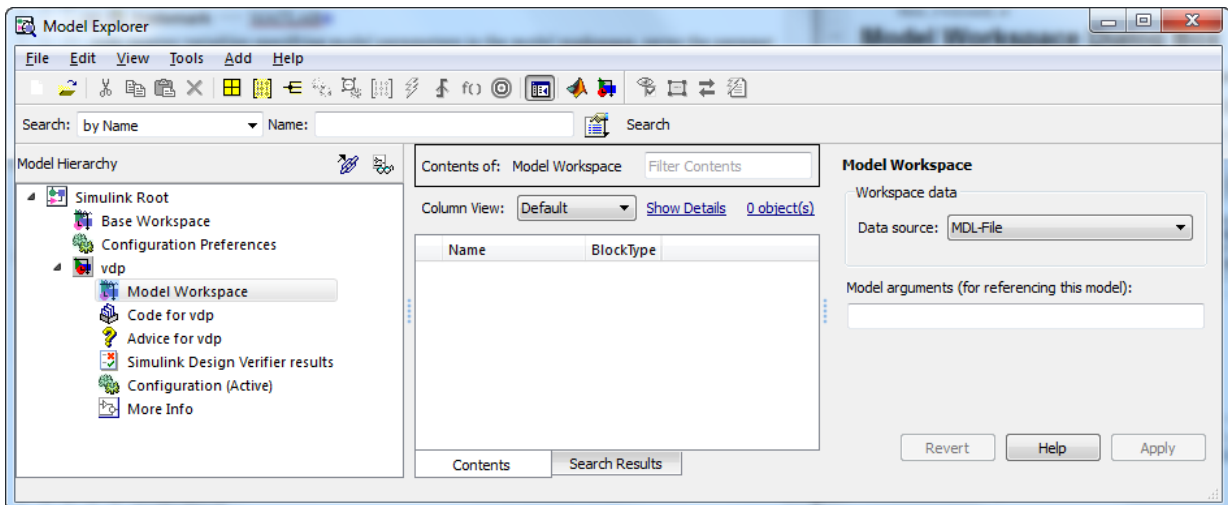
For example, the following MATLAB code creates variables specifying model parameters in the model workspace, saves the parameters, modifies one of them, and then reloads the workspace to restore it to its previous state.

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

## Model Workspace Dialog Box

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

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



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

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

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

### **Data source**

Specifies the data source of this workspace. The options are

- **Mdl-File**

Specifies that the data source is the model itself.

- **MAT-File**

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

- **MATLAB File**

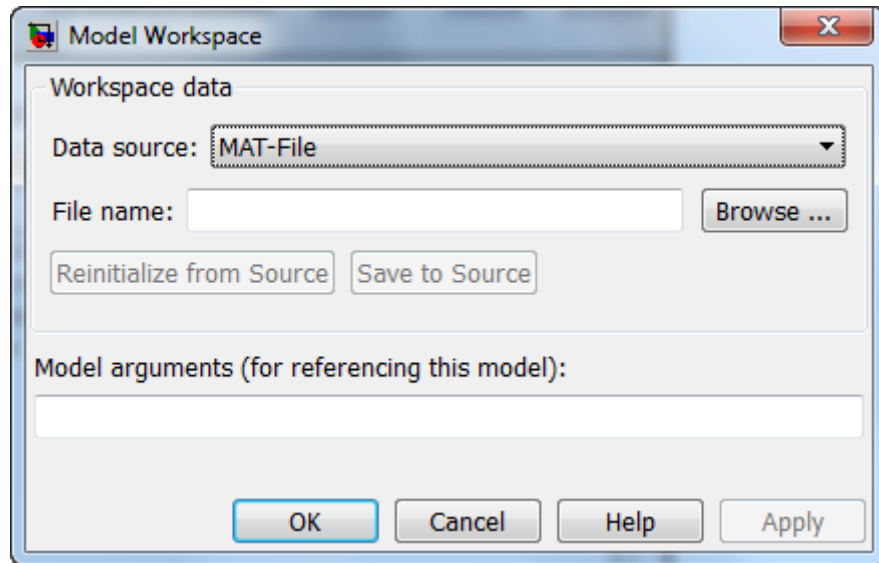
Specifies that the data source is a MATLAB file. Selecting this option causes additional controls to appear (see “MAT-File and MATLAB File Source Controls” on page 3-72).

- **MATLAB Code**

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

### **MAT-File and MATLAB File Source Controls**

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



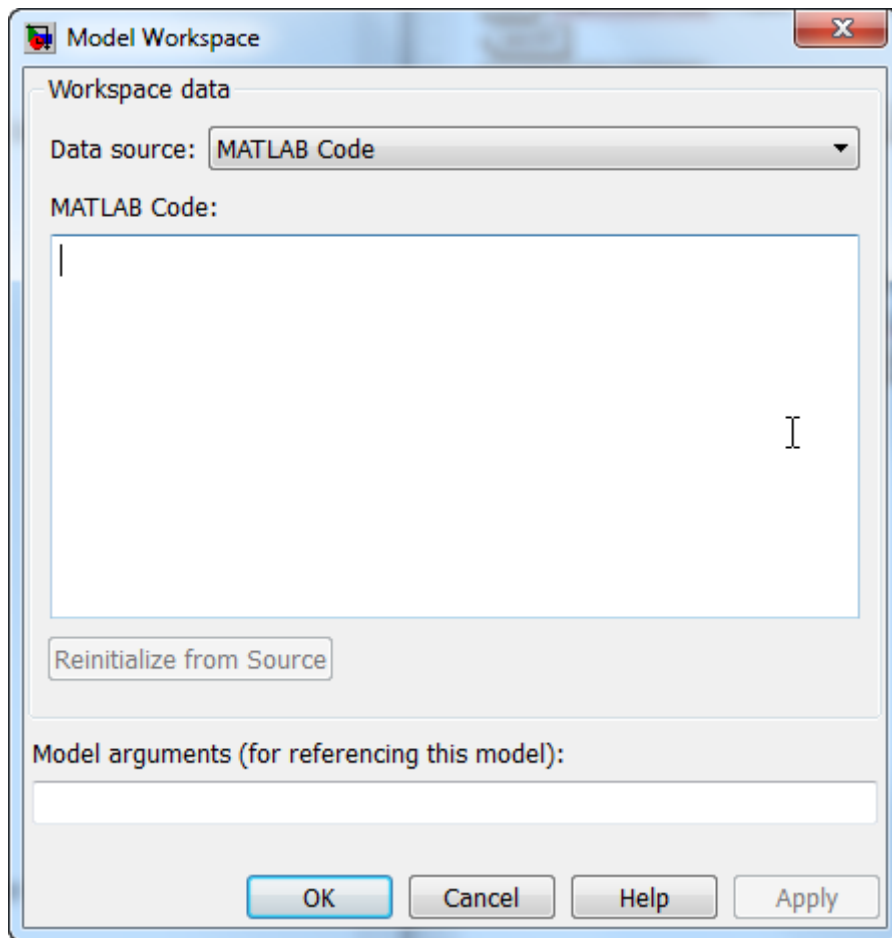
**File name.** File name or path name of the MAT-file or MATLAB file that is the data source for the selected workspace. If you specify a file name, the name must reside on the MATLAB path.

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

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

### **MATLAB Code Source Controls**

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



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

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

**Model Arguments (For Referencing This Model)**

This field allows you to specify arguments that can be passed to instances of this model referenced by another model. For more information, see “Using Model Arguments” on page 5-53.

## Resolving Symbols

### In this section...

“About Symbol Resolution” on page 3-76

“Hierarchical Symbol Resolution” on page 3-77

“Specifying Numeric Values with Symbols” on page 3-78

“Specifying Other Values with Symbols” on page 3-78

“Limiting Signal Resolution” on page 3-79

“Explicit and Implicit Symbol Resolution” on page 3-79

### About Symbol Resolution

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

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

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

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

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

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

## Hierarchical Symbol Resolution

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

- 1 Any mask workspaces, in order from the block upwards (see “Understanding Mask Parameters” on page 23-19)
- 2 The model workspace of the model that contains the block (see “Using Model Workspaces” on page 3-67)
- 3 The MATLAB base workspace (See “MATLAB Workspace Browser”)

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

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

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

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

## Specifying Numeric Values with Symbols

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

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

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

## Specifying Other Values with Symbols

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

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



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

## Limiting Signal Resolution

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

- **All**  
Continue searching up the workspace hierarchy trying to resolve the symbol. This is the default value.
- **None**  
Do not continue searching up the hierarchy.
- **ExplicitOnly**  
Continue searching up the hierarchy only if the symbol specifies a block parameter value, data store memory (where no block exists), or a signal or state that explicitly requires resolution. Do not continue searching for an implicit resolution. See “Explicit and Implicit Symbol Resolution” on page 3-79 for more information.

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

## Explicit and Implicit Symbol Resolution

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

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

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

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

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

## Consulting the Model Advisor

### In this section...

- “About the Model Advisor” on page 3-81
- “Starting the Model Advisor” on page 3-82
- “Overview of the Model Advisor Window” on page 3-83
- “Running Model Advisor Checks” on page 3-85
- “Model Advisor Highlighting” on page 3-89
- “Fixing a Warning or Failure” on page 3-91
- “Reverting Changes Using Restore Points” on page 3-95
- “Viewing and Saving Model Advisor Reports” on page 3-97
- “Running the Model Advisor Programmatically” on page 3-101
- “Model Advisor Limitations” on page 3-101

### 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 “Get 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 “Model Advisor Checks” in the Simulink, Simulink Coder, and Simulink Verification and Validation Reference documentation.

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.

### Starting the Model Advisor

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

---

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

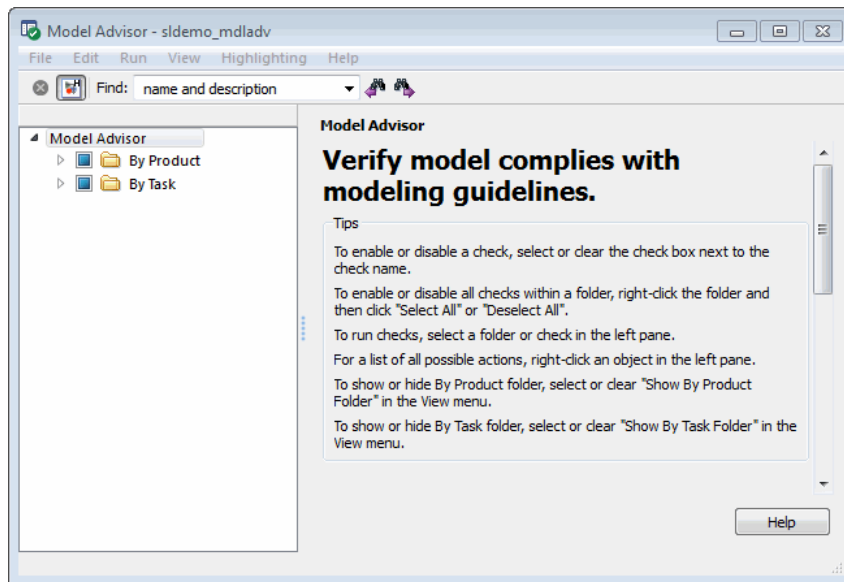
The Model Advisor uses the Simulink project (`s1prj`) folder in the current folder to store reports and other information. If this folder does not exist in the current folder, the Model Advisor creates it.

---

To start the Model Advisor...	For a...	Do this:
From the Model Editor	Model or subsystem	<ol style="list-style-type: none"> <li><b>1</b> From the <b>Tools</b> menu, select <b>Model Advisor</b>.</li> <p>The System Selector window opens.</p> <li><b>2</b> Select the model or subsystem of interest.</li> <li><b>3</b> Click <b>OK</b>.</li> </ol>
From the Model Explorer	Model	In the <b>Contents</b> pane, select <b>Advice for <i>model</i></b> . <i>model</i> is the name of the model that you want to check. (For more information, see “The Model Explorer: Overview” on page 8-2.)
From the context menu	Subsystem	Right-click the subsystem that you want to check and select <b>Model Advisor</b> .
Programmatically	Model or subsystem	At the MATLAB prompt, enter <code>modeladvisor(model)</code> . <i>model</i> is a handle or name of the model or subsystem that you want to check. (For more information, see the <code>modeladvisor</code> 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.



From the left pane, you can:

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


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**

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 optionally view this report in a separate browser window by clicking the **Report** link at the folder level.

You can specify that the Model Advisor use color highlighting on the model diagram to view the analysis results for individual Model Advisor checks. To enable Model Advisor highlighting, do 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 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**. You can create or modify exclusions to the Model Advisor checks with a Simulink Verification and Validation license.

---

**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 you checked the model. If you recheck the model, the new results replace the previous results in the Model Advisor window.

---

## Running Model Advisor Checks

To perform checks on your model and view the check results:

- 1 Open your model. For example, open the Model Advisor demo: `sdemo_mdladv`.

**2** Start the Model Advisor.

**a** From the Model Editor **Tools** menu, select **Model Advisor**.

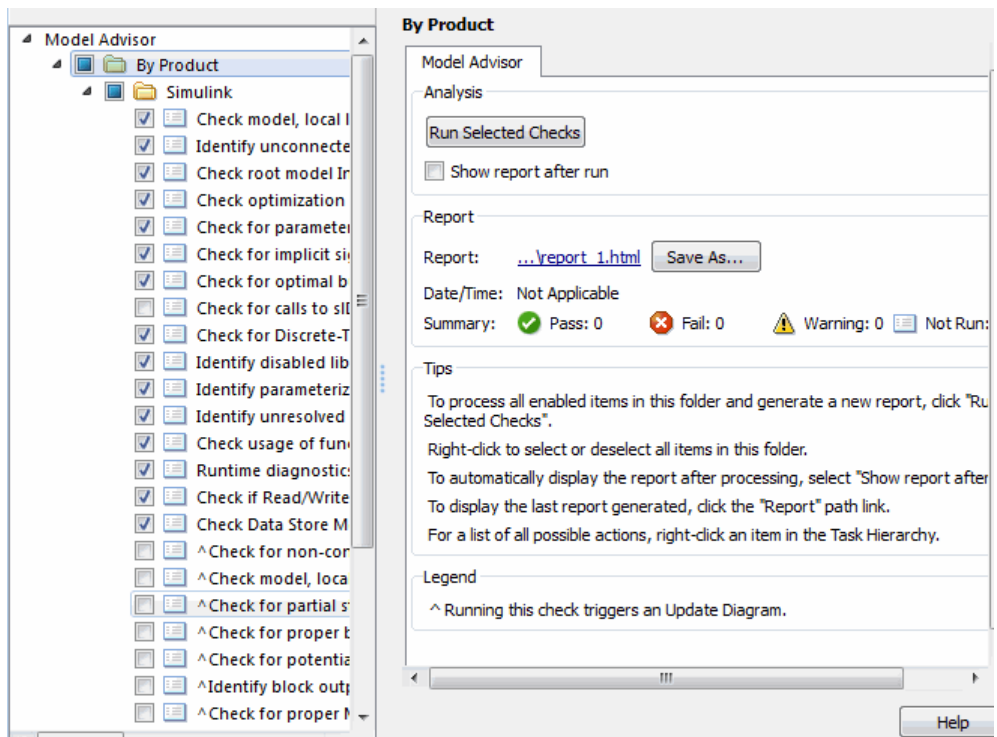
The System Selector window opens.

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

The Model Advisor window opens and displays checks for the `sldemo_mdldadv` 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** Select the **By Product** folder in the left pane. The right pane changes to a **By Product** view.





- 5 Select the **Show report after run** check box to see an HTML report of check results after you run the checks.

---

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





---

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

**Report name: Model Advisor - By Product**

**Simulink version: 8.0** **Model version: 1.77**  
**System: sldemo\_mdldv** **Current run: 04-Apr-2011 08:16:53**

**Run Summary**

<input checked="" type="checkbox"/> Pass	<input checked="" type="checkbox"/> Fail	<input checked="" type="checkbox"/> Warning	<input checked="" type="checkbox"/> Not Run	Total
 68	 0	 45	 51	164

**By Product**

- Simulink**

---

- Check model, local libraries, and referenced models for known upgrade issues**

Passed

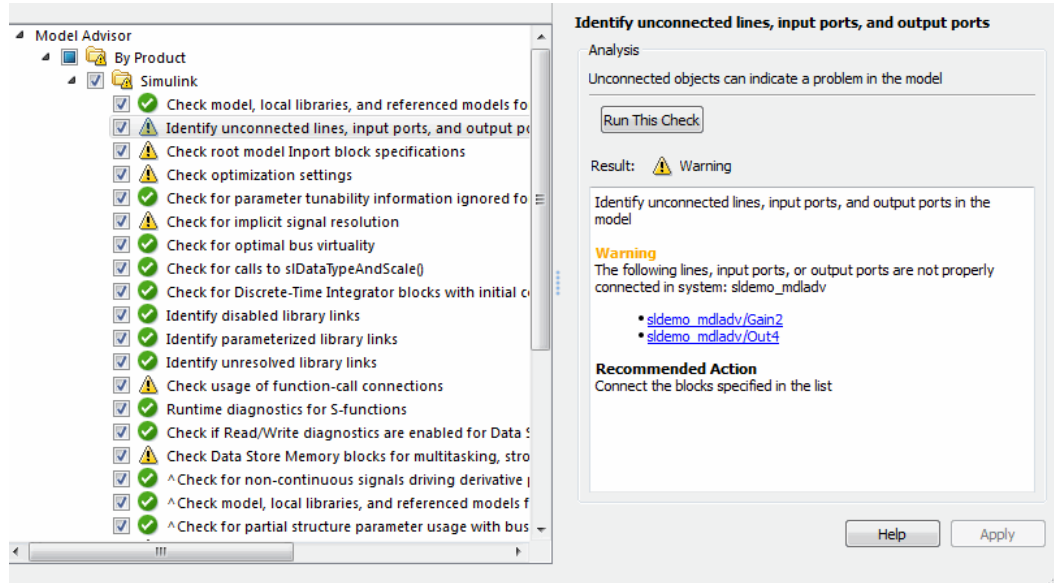
---

- Identify unconnected lines, input ports, and output ports**

Identify unconnected lines, input ports, and output ports in the model

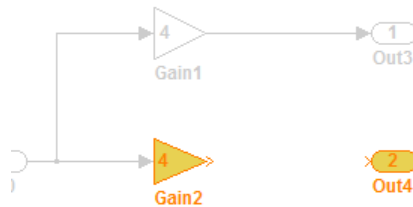
- 7 Return to the Model Advisor window, which shows the check results.
- 8 Select an individual check to open a detailed view of the results in the right pane. For example, selecting **Identify unconnected lines, input ports,**

and output ports changes the right pane to the following view. Use this view to examine and exercise a check individually.



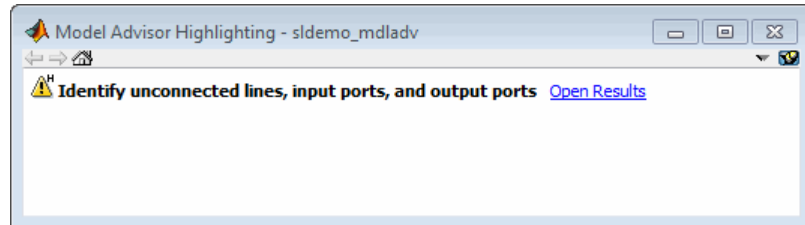
9 In the Model Advisor window, click the **Enable Model Advisor highlighting** toggle button (🔍). Checks with highlighted results are indicated with the ⚠️ icon.

- 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 the check results in the Model Advisor window, you can choose to fix warnings or failures as described in “Fixing a Warning or Failure” on page 3-91.


## Model Advisor Highlighting


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 blocks:

- 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 (.

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

The model window highlights in...		
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.
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 the model window and the Model Advisor window, you can choose to fix warnings or failures as described in “Fixing a Warning or Failure” on page 3-91.
- 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.

---

## Fixing a Warning or Failure

Checks fail when a model or submodel has a suboptimal condition. A warning result is informational. You can choose to fix the reported issue, or move on to the next task. For more information on why a specific check does not pass, see the “Simulink Checks” documentation. 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.

---

The Model Advisor provides the following ways to fix warnings and failures:

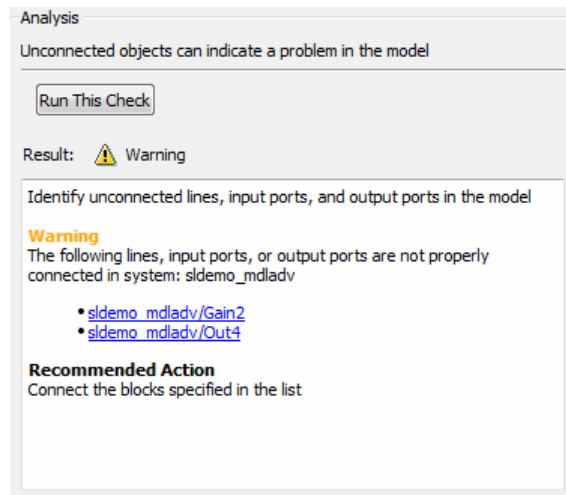
- Follow the instructions in the Analysis Result box to manually fix any warning or failure. See “Manually Fixing Warnings or Failures” on page 3-92.
- Use the Action box, when available, to automatically fix all failures. See “Automatically Fixing Warnings or Failures” on page 3-93.
- Use the Model Advisor Results Explorer, when available, to batch-fix failures. See “Batch-Fixing Warnings or Failures” on page 3-93.

### Manually Fixing Warnings or Failures

All checks have an Analysis Result box that describes the recommended actions to manually fix warnings or failures.

To manually fix warnings or failures within a task:

- 1 Optionally, save a model and data restore point so you can undo the changes that you make. For more information, see “Reverting Changes Using Restore Points” on page 3-95.
- 2 In the Analysis Result box, review the recommended actions. Use the information to make changes to your model.



- 3 Rerun the check to verify that it passes.

---

**Caution** When you fix a warning or failure, rerun all checks to update the results of all checks. If you do not rerun all checks, the Model Advisor might report an invalid check result.

---

## Automatically Fixing Warnings or Failures

Some checks have an Action box where you can automatically fix failures. The action box applies all of the recommended actions listed in the Analysis Result box.

---

**Caution** Review the Analysis Result box before automatically fixing failures to ensure that you want to apply all of the recommended actions. If you do not want to apply all of the recommended actions, do not use this method to fix warnings or failures.

---

To automatically fix all warnings or failures within a check:

- 1 Optionally, save a model and data restore point so you can undo the changes that you made by clicking the **Modify All** button. For more information, see “Reverting Changes Using Restore Points” on page 3-95.
- 2 In the Action box, click **Modify All**.

The Action Result box displays a table of changes.

- 3 Rerun the check to verify that it passes.

---

**Caution** When you fix a warning or failure, rerun all checks to update the results of all checks. If you do not rerun all checks, the Model Advisor might report an invalid check result.

---

## Batch-Fixing Warnings or Failures

Some checks in the Model Advisor have an **Explore Result** button that starts the Model Advisor Result Explorer. The Model Advisor Result Explorer allows you to quickly locate, view, and change elements of a model.

The Model Advisor Result Explorer, a version of the Model Explorer, helps you to modify only the items that the Model Advisor is checking. For more information about using this window, see “The Model Explorer: Overview” on page 8-2.

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

- 1 Optionally, save a model and data restore point so you can undo any changes that you make. For more information, see “Reverting Changes Using Restore Points” on page 3-95.
- 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.

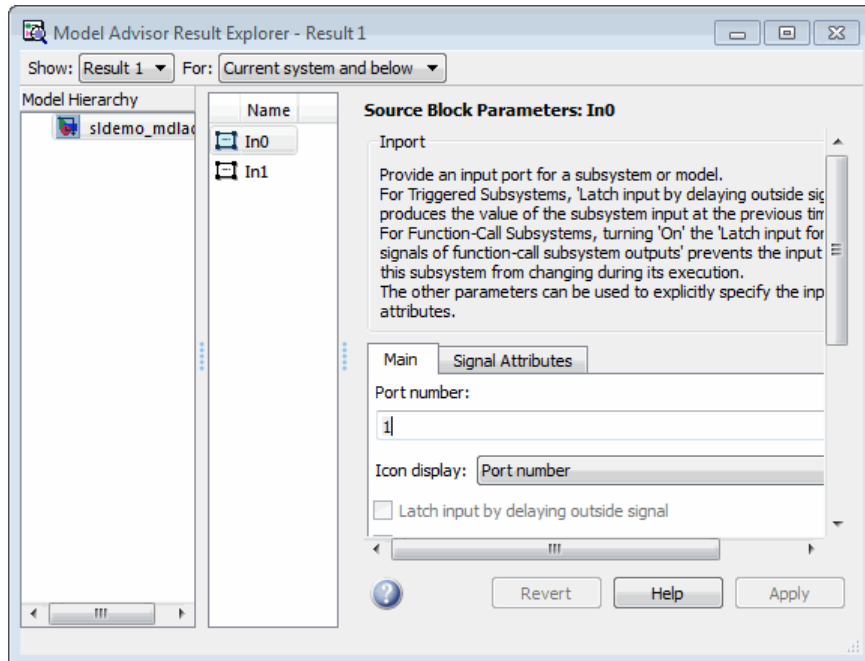
---

**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_mdldadv` model. The result is a warning. Clicking the **Explore Result** button opens the Model Advisor Result Explorer window.



## Reverting Changes Using Restore Points

The Model Advisor provides a model and data restore point capability for reverting changes that you made in response to advice from the Model Advisor. A *restore point* is a snapshot in time of the model, base workspace, and Model Advisor. The Model Advisor maintains restore points for the model or subsystem of interest through multiple sessions of MATLAB.

---

**Caution** A restore point saves only the current working model, base workspace variables, and Model Advisor tree. It does not save other items, such as libraries and referenced submodels.

---

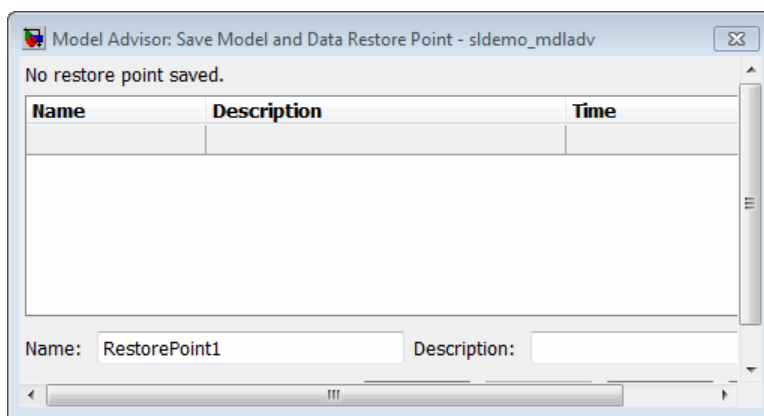
## Saving a Restore Point

You can save a restore point and give it a name and optional description, or allow the Model Advisor to automatically name the restore point for you.

To save a restore point with a name and optional description:

- 1** Go to **File > Save Restore Point As**.

The Save Model and Data Restore Point dialog box opens.



- 2** In the **Name** field, enter a name for the restore point.
- 3** In the **Description** field, you can optionally add a description to help you identify the restore point.
- 4** Click **Save**.

The Model Advisor saves a restore point of the current model, base workspace, and Model Advisor status.

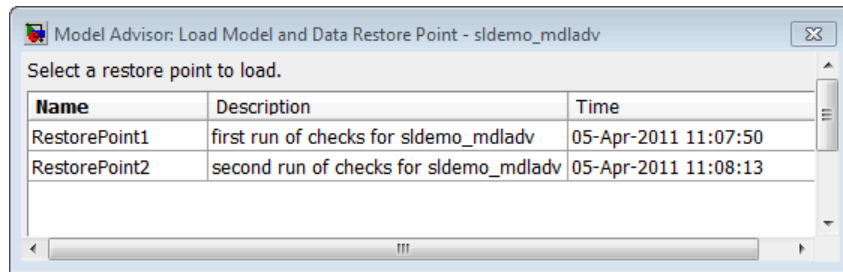
To quickly save a restore point, go to **File > Save Restore Point**. The Model Advisor saves a restore point with the name `autosaven`, where `n` is the sequential number of the restore point. If you use this method, you cannot change the name of, or add a description to, the restore point.

## Loading a Restore Point

To load a restore point:

- 1 Optionally, save a model and data restore point so you can undo any changes that you make.
- 2 Go to **File > Load Restore Point**.

The Load Model and Data Restore Point dialog box opens.



- 3 Select the restore point that you want.
- 4 Click **Load**.

The Model Advisor issues a warning that the restoration will remove all changes that you made after saving the restore point.

- 5 Click **Load** to load the restore point you selected.

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

## Viewing and Saving Model Advisor Reports

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

### Viewing Model Advisor Reports

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

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

As you run checks, the Model Advisor updates the reports with the latest information for each check in the folder. A message appears in the report when you run the checks at different times. Time stamps indicate when checks have been run. The time of the current run appears at the top right of the report. Checks that occurred during previous runs have a time stamp following the check name.

**Report name: Model Advisor - By Product**

**Simulink version: 8.0** **Model version: 1.77**  
**System: sldemo\_mdadv** **Current run: 04-Apr-2011 08:16:53**

**Run Summary**

<input checked="" type="checkbox"/> Pass	<input checked="" type="checkbox"/> Fail	<input checked="" type="checkbox"/> Warning	<input checked="" type="checkbox"/> Not Run	Total
68	0	45	51	164

▢ **By Product**

▢ **Simulink**

---

**Check model, local libraries, and referenced models for known upgrade issues**

Passed

---

**Identify unconnected lines, input ports, and output ports**

Identify unconnected lines, input ports, and output ports in the model





You can manipulate the report to show only what you are interested in viewing as follows:

- The check boxes next to the Run Summary status allow you to view only the checks with the status that you are interested in viewing. For example, you can remove the checks that have not run by clearing the check box next to the Not Run status.
- Minimize folder results in the report by clicking the minus sign next to the folder name. When you minimize a folder, the report updates to display a run summary for that folder:

















**Report name: Model Advisor - By Task**

Simulink version: **8.0** Model version: **1.77**  
 System: **sldemo\_mdldv** Current run: **04-Apr-2011 10:13:43**  
Model Advisor configuration: **sldemo\_mdldv.mat**

**Run Summary**

<input checked="" type="checkbox"/> Pass	<input checked="" type="checkbox"/> Fail	<input checked="" type="checkbox"/> Warning	<input checked="" type="checkbox"/> Not Run	Total
 16	 0	 8	 0	24

**By Task**

- Simulation Performance and Accuracy**  1  0  0  0
- Simulation Runtime Accuracy Diagnostics**  2  0  0  0
- Code Generation Efficiency**  4  0  2  0
- Model Referencing**  2  0  3  0

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:

#### ✔ Check for proper Merge block usage

Passed

---

#### Input Parameters Selection

Name	Value
Maximum analysis time (seconds)	inf

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

### Saving Model Advisor Reports

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

- 1 In the Model Advisor window, navigate to the folder that contains the report you want to save.
- 2 Select the folder that you want. The right pane of the Model Advisor window displays information about that folder, including a **Report** box.
- 3 In the Report box, click **Save As**. A save as dialog box opens.
- 4 In the save as dialog box, navigate to the location where you want to save the report, and click **Save**. The Model Advisor saves the report to the new location.

---

**Note** If you rerun the Model Advisor, the report is updated in the working folder, not in the save location.

---

You can find the full path to the report in the title bar of the report window. Typically, the report is in the working folder: `s1prj/modeladvisor/model_name`.

## Running the Model Advisor Programmatically

If you have a Simulink Verification and Validation license, you can create MATLAB scripts and functions that run the Model Advisor programmatically. For example, you can create a function to check whether your model passes a specified set of the Model Advisor checks every time you open the model or start a simulation or generate code from the model. For more information, see the `ModelAdvisor.run` function in the Simulink Verification and Validation documentation.

## Model Advisor Limitations

When you use the Model Advisor to check systems, the following limitations apply:

- If you rename a system, you must restart the Model Advisor to check that system.
- In systems that contain a variant subsystem, the Model Advisor checks only the active subsystem.
- Checks do not search in model blocks or subsystem blocks with 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.

## Managing Model Versions

### In this section...

“How Simulink Helps You Manage Model Versions” on page 3-102

“Model File Change Notification” on page 3-103

“Specifying the Current User” on page 3-104

“Managing Model Properties” on page 3-105

“Creating a Model Change History” on page 3-112

“Version Control Properties” on page 3-114

### 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 Chapter 12, “Managing Projects”.
- Model File Change Notification helps you manage work with source control operations and multiple users. See “Model File Change Notification” on page 3-103.
- As you edit a model, the Simulink software generates version control information about the model, including a version number, who created and last updated the model, and an optional change history. The Simulink software automatically saves these **Version Control Properties** with the model.
- Use the Model Properties dialog box to view and edit some of the version control information stored in the model and control change history logging.
- The Model Info block lets you display version control information, including information maintained by an external version control system, as an annotation block in a model diagram.
- You can access Simulink version control parameters from the MATLAB command line or a MATLAB script.



## Model File Change Notification

You can use the Simulink Preferences window to specify whether to notify if the model has changed on disk when updating, simulating, editing, or saving the model. This can occur, for example, with source control operations and multiple users.

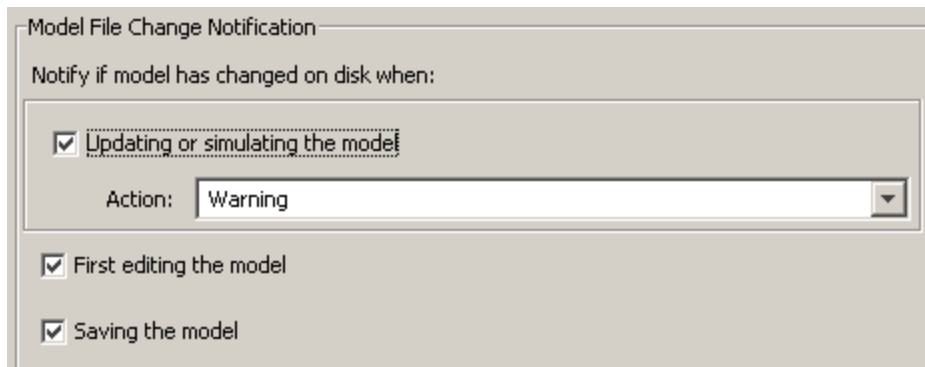
---

**Note** To programmatically check whether the model has changed on disk since it was loaded, use the function `slIsFileChangedOnDisk`.

---

To access the Simulink Preferences window,

- Select **File > Preferences** in the Simulink product.
- Select **File > Preferences** in MATLAB to open the MATLAB Preferences, then select **Simulink** in the left pane, and click the button **Launch Simulink Preferences**.



The Model File Change Notification options are in the right pane. You can use the three independent options as follows:

- If you select the **Updating or simulating the model** check box, you can choose what form of notification you want from the **Action** list:
  - Warning — in the MATLAB command window.

- **Error** — in the MATLAB command window if simulating from the command line, or if simulating from a menu item, in the Simulation Diagnostics window.
- **Reload model (if unmodified)** — if the model is modified, you see the prompt dialog. If unmodified, the model is reloaded.
- **Show prompt dialog** — in the dialog, you can choose to close and reload, or ignore the changes.
- If you select the **First editing the model** check box, and the file has changed on disk, and the block diagram is unmodified in Simulink:
  - Any command-line operation that causes the block diagram to be modified (e.g., a call to `set_param`) will result in a warning:

Warning: Block diagram 'mymodel' is being edited but file has changed on disk since it was loaded. You should close and reload the block diagram.

- Any graphical operation that modifies the block diagram (e.g., adding a block) causes a warning dialog to appear.
- If you select the **Saving the model** check box, and the file has changed on disk:
  - The `save_system` function displays an error, unless the `OverwriteIfChangedOnDisk` option is used.
  - Saving the model by using the menu (**File > Save**) or a keyboard shortcut causes a dialog to be shown. In the dialog, you can choose to overwrite, save with a new name, or cancel the operation.

### Specifying the Current User

When you create or update a model, your name is logged in the model for version control purposes. The Simulink software assumes that your name is specified by at least one of the following environment variables: `USER`, `USERNAME`, `LOGIN`, or `LOGNAME`. If your system does not define any of these variables, the Simulink software does not update the user name in the model.

UNIX systems define the `USER` environment variable and set its value to the name you use to log on to your system. Thus, if you are using a UNIX system, you do not have to do anything to enable the Simulink software to identify you as the current user.

Windows systems, on the other hand, might define some or none of the “user name” environment variables that the Simulink software expects, depending on the version of Windows installed on your system and whether it is connected to a network. Use the MATLAB command `getenv` to determine which of the environment variables is defined. For example, enter

```
getenv('user')
```

at the MATLAB command line to determine whether the `USER` environment variable exists on your Windows system. If not, you must set it yourself.

On Windows, set the `USER` environment variable (if it is not already defined).

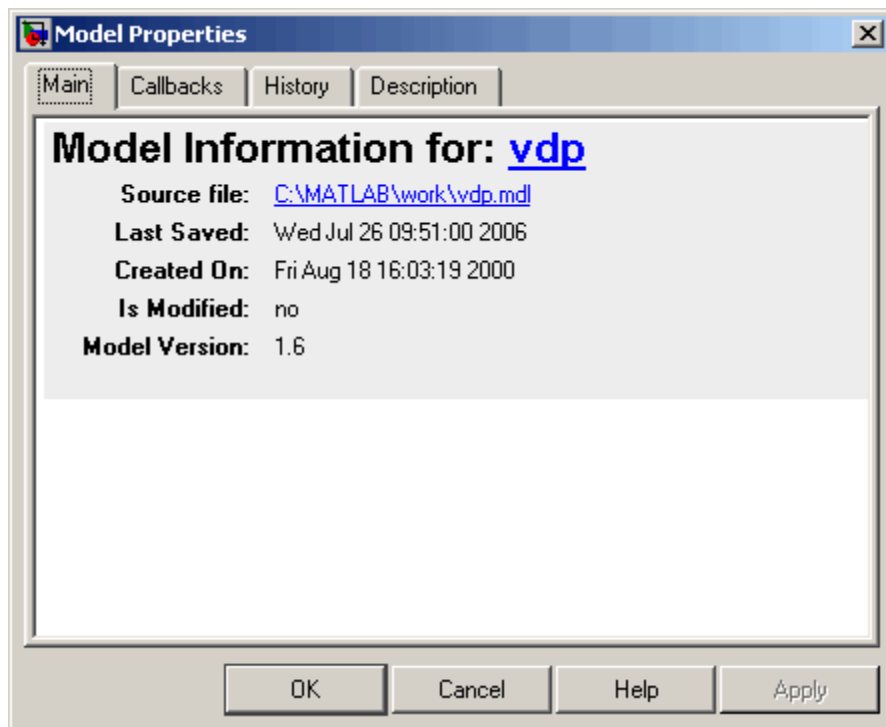
## Managing Model Properties

You can use the Model Properties dialog box to view and edit model information (including some version control 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 Forwarding Table, see “Making Backward-Compatible Changes to Libraries” on page 25-23.

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.



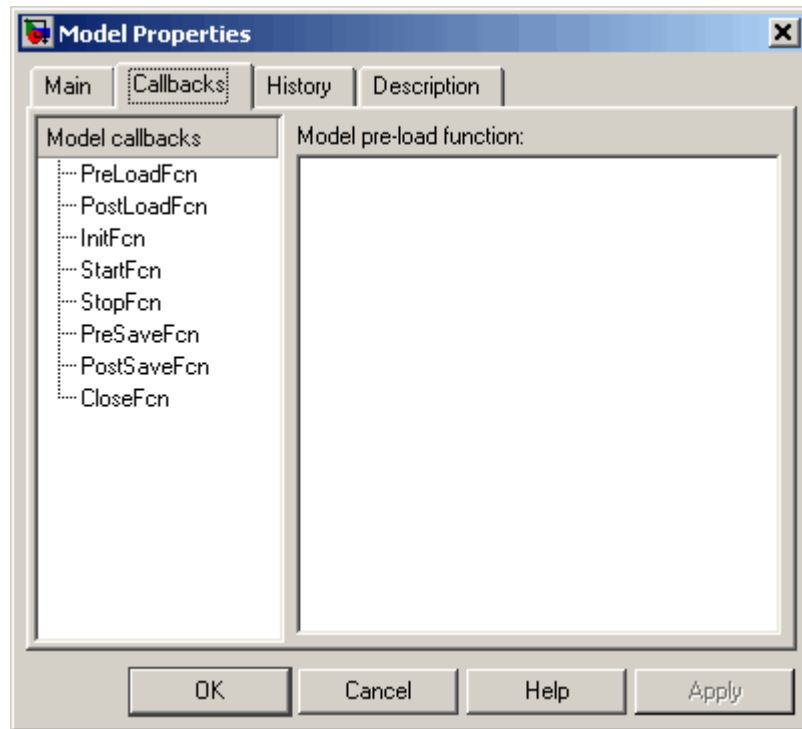
The dialog box includes the following panes.

#### 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 3-107.

#### Specifying Callbacks

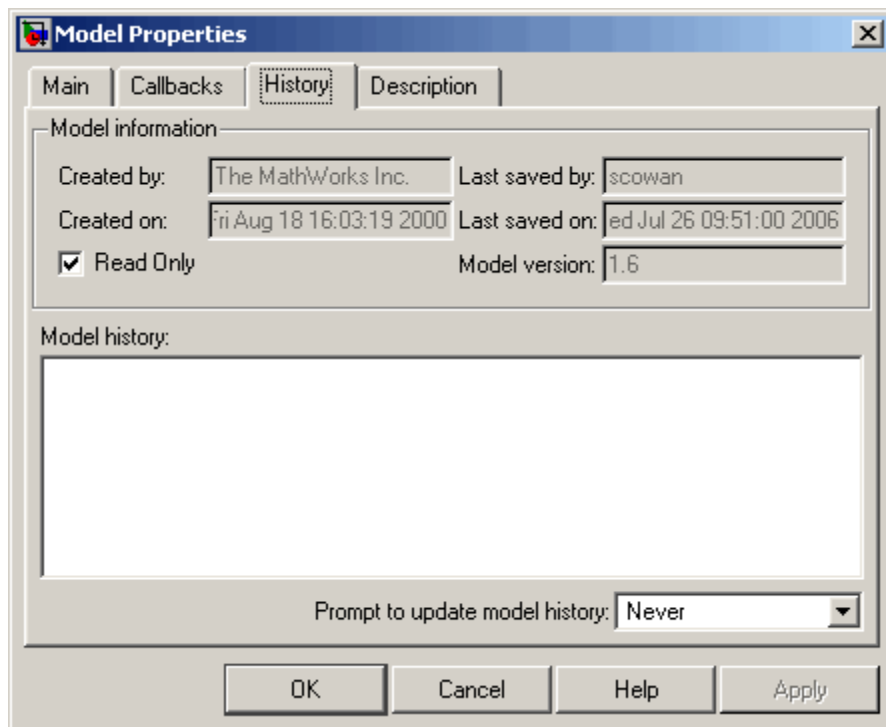
Use the **Callbacks** pane to specify functions to be invoked at specific points in the simulation of the model.



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 “Creating Model Callback Functions” on page 3-55 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 pane. To use the history controls see “Creating a Model Change History” on page 3-112.



**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.

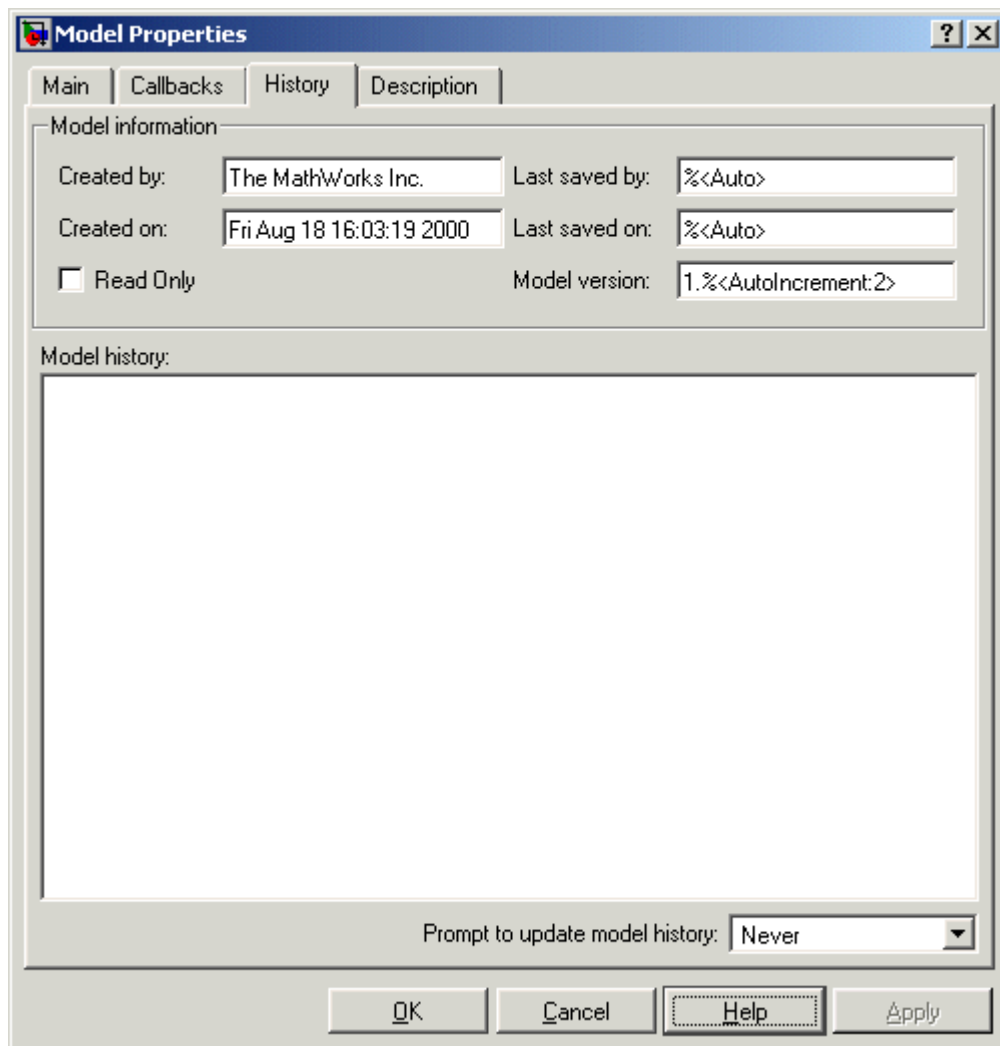
- **Last saved on**

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>. The Simulink software replaces occurrences of this tag with the current value of the USER environment variable.

- **Last saved on**

Enter a format string describing the format used to display the **Last saved on** date in the **History** pane and the **ModifiedOn** entry in the history log and the in Model Info blocks. The value of this field can be any string. The string can contain the tag %<Auto>. The Simulink software replaces occurrences of this tag with the current date and time.

- **Model version**

Enter a format string describing the format used to display the model version number in the **Model Properties** pane and in Model Info blocks. The value of this parameter can be any text string. The text string can include occurrences of the tag %<AutoIncrement:#> where # is an integer. The Simulink software replaces the tag with an integer when displaying the model's version number. For example, it displays the tag

```
1.%<AutoIncrement:2>
```

as

```
1.2
```

The Simulink software increments # by 1 when saving the model. For example, when you save the model,

```
1.%<AutoIncrement:2>
```

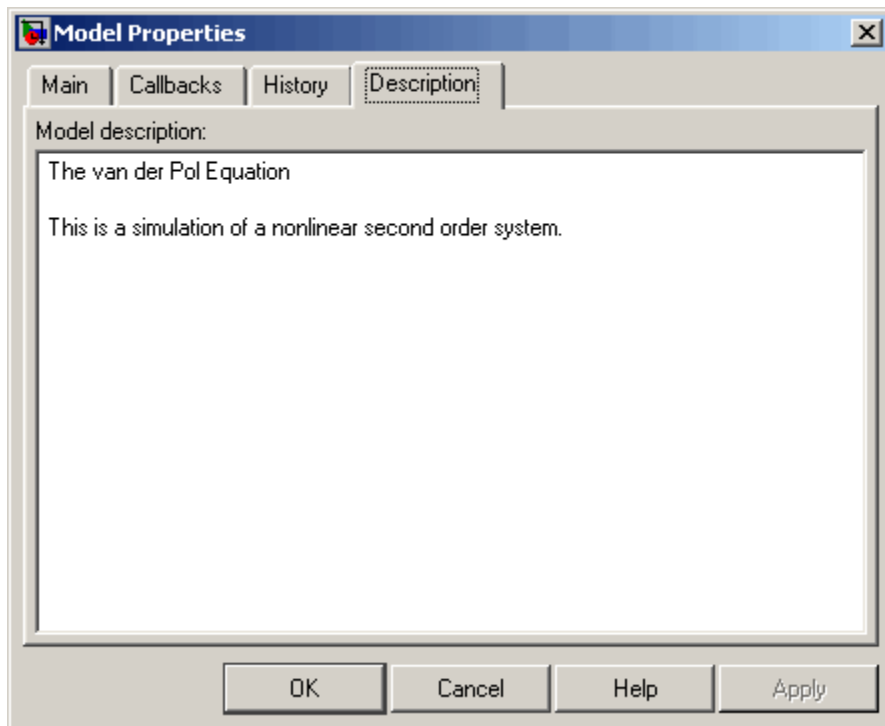
becomes

```
1.%<AutoIncrement:3>
```

and the model version number is reported as 1.3.

## 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.



## Creating a Model Change History

You can create and store a record of changes to a model in the model itself. The Simulink software compiles the history automatically from comments that you or other users enter when they save changes to a model.

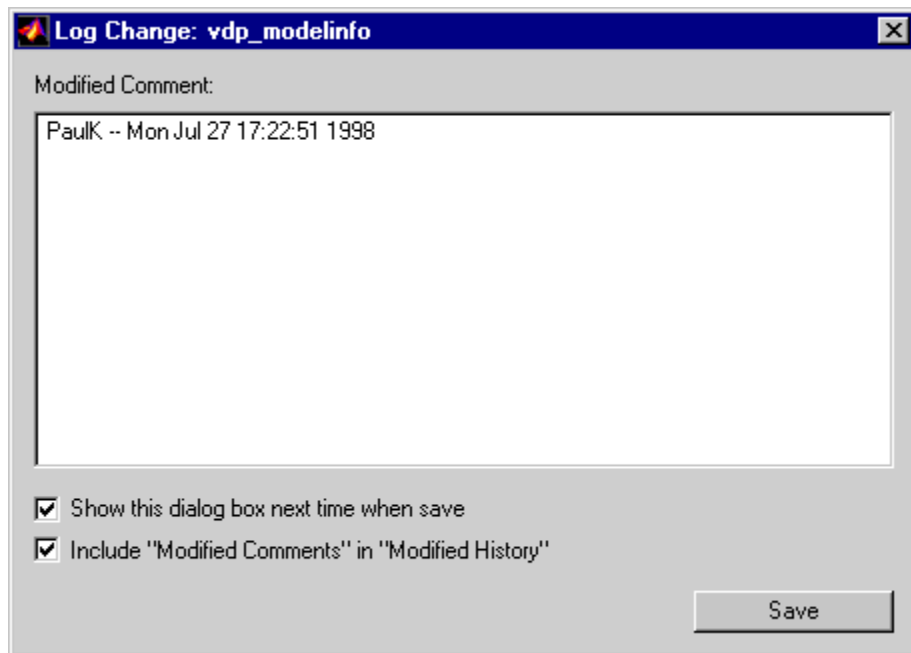
### Logging Changes

To start a change history,

- 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 the Simulink software 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 Contents" 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 Control Properties

Version control information is stored as model parameters in a model. You can access this information from the MATLAB command line or from a MATLAB script, using the Simulink `get_param` command. The following table describes the model parameters used by Simulink to store version control information.

Property	Description
Created	Date created.
Creator	Name of the person who created this model.
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  <code>help 'mymodelname'</code>  at the MATLAB command line.

<b>Property</b>	<b>Description</b>
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.
ModifiedDate	Current value of the date-stamp. When you save, this information is saved with the file as LastModifiedDate.
ModifiedDateFormat	Format of the ModifiedDate parameter. Value can be any string. The string can include the tag %<Auto>. The Simulink software replaces the tag with the current date and time when saving the model.
ModifiedComment	Comment entered by user who last updated this model.
ModifiedHistory	History of changes to this model.
ModelVersion	Version number.
ModelVersionFormat	Format of model version number. Can be any string. The string can contain the tag %<AutoIncrement:#> where # is an integer. The Simulink software replaces the tag with # when displaying the version number. It increments # when saving the model.

LibraryVersion is a block parameter for a linked block. LibraryVersion is the ModelVersion of the library at the time the link was created.

## Model Discretizer

### In this section...

“What Is the Model Discretizer?” on page 3-116

“Requirements” on page 3-116

“How to Discretize a Model from the Model Discretizer GUI” on page 3-117

“Viewing the Discretized Model” on page 3-126

“How to Discretize Blocks from the Simulink Model” on page 3-129

“How to Discretize a Model from the MATLAB Command Window” on page 3-140

### What Is the Model Discretizer?

Model Discretizer selectively replaces continuous Simulink blocks with discrete equivalents. Discretization is a critical step in digital controller design and for hardware in-the-loop simulations.

You can use the Model Discretizer to:

- Identify a model’s continuous blocks
- Change a block’s parameters from continuous to discrete
- Apply discretization settings to all continuous blocks in the model or selected blocks
- Create configurable subsystems that contain multiple discretization candidates along with the original continuous block(s)
- Switch among the different discretization candidates and evaluate the resulting model simulations

### Requirements

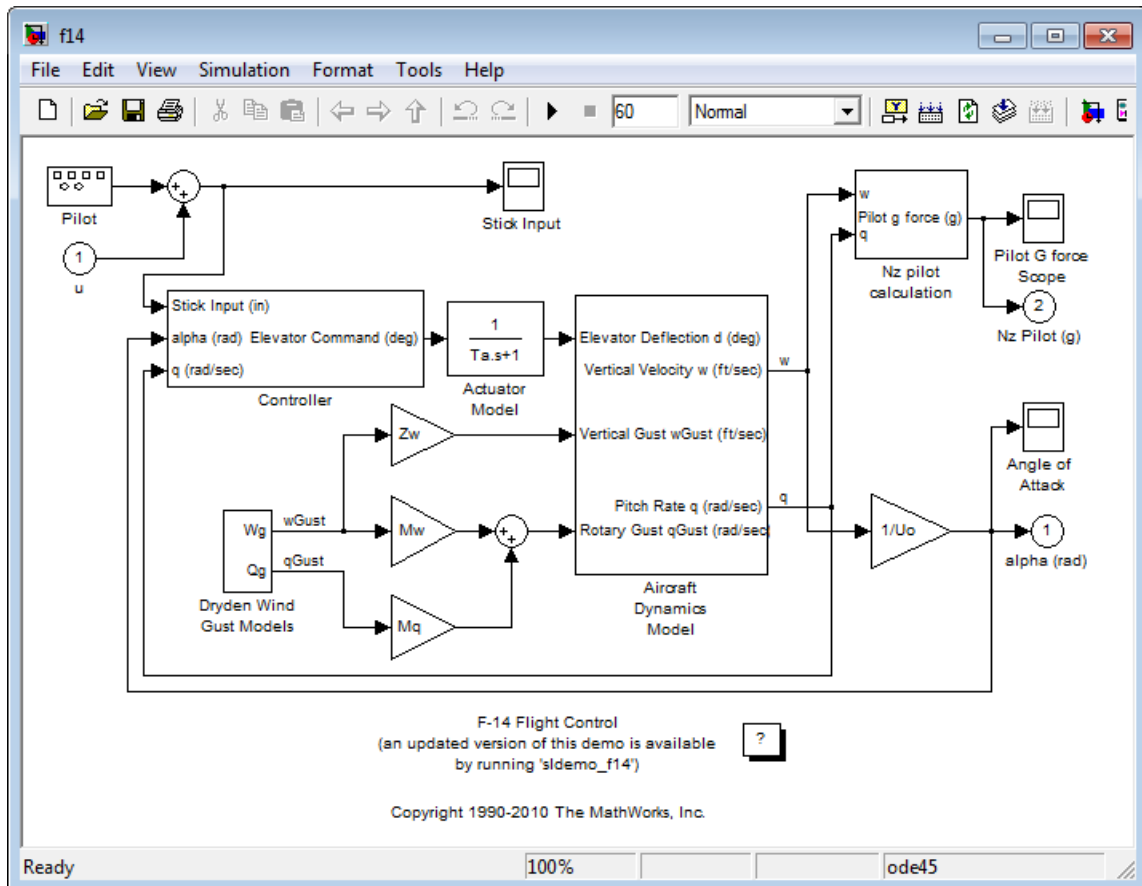
To use Model Discretizer, you must have a Control System Toolbox™ license, Version 5.2 or later.

## **How to Discretize a Model from the Model Discretizer GUI**

To discretize a model:

- Start the Model Discretizer
- Specify the Transform Method
- Specify the Sample Time
- Specify the Discretization Method
- Discretize the Blocks

The f14 model, shown below, demonstrates the steps in discretizing a model.

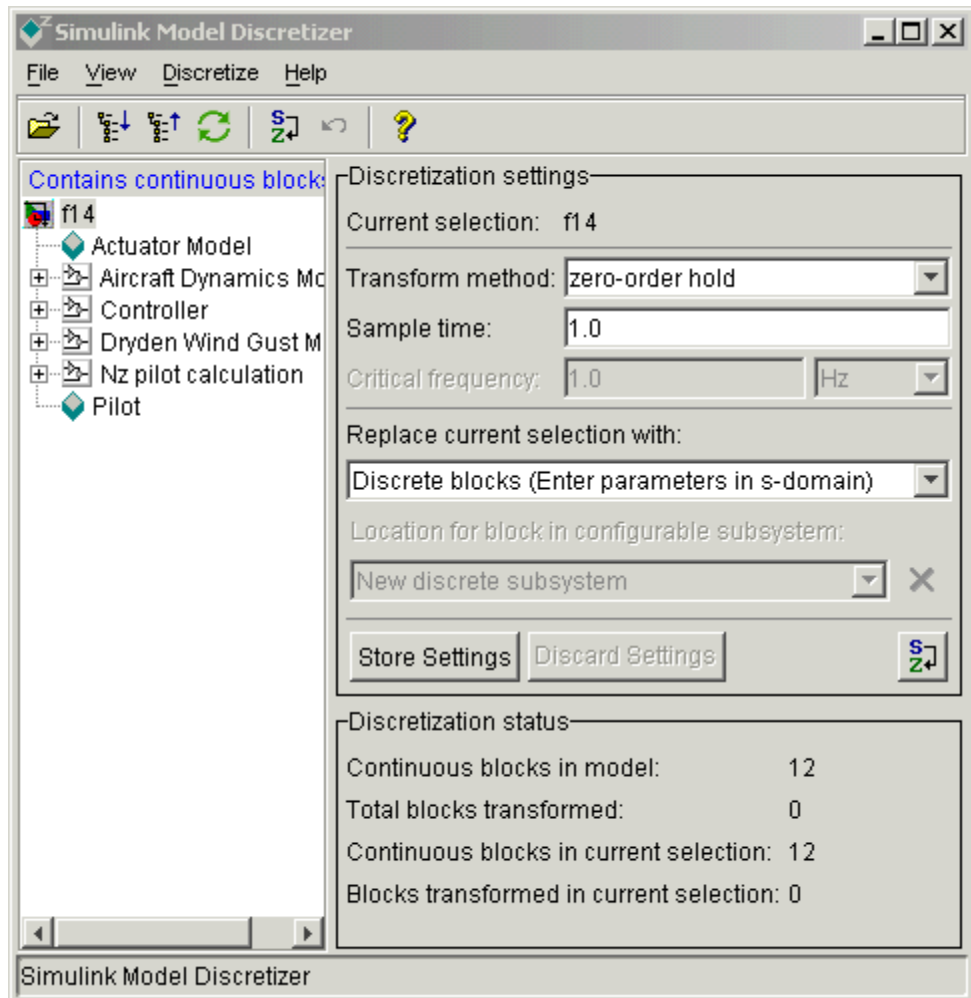


### Start Model Discretizer

To open the tool, select **Tools > Control Design > Model Discretizer** from the model editor's menu bar.



The **Simulink Model Discretizer** appears.



Alternatively, you can open Model Discretizer from the MATLAB Command Window using the `slmdliscui` function.

The following command opens the **Simulink Model Discretizer** window with the f14 model:

```
slmdliscui('f14')
```

To open a new model or library from Model Discretizer, select **Load model** from the **File** menu.

### Specify the Transform Method

The transform method specifies the type of algorithms used in the discretization. For more information on the different transform methods, see the Control System Toolbox documentation.

The Transform method drop-down list contains the following options:

- **zero-order hold**  
Zero-order hold on the inputs.
- **first-order hold**  
Linear interpolation of inputs.
- **tustin**  
Bilinear (Tustin) approximation.
- **tustin with prewarping**  
Tustin approximation with frequency prewarping.
- **matched pole-zero**  
Matched pole-zero method (for SISO systems only).

### Specify the Sample Time

Enter the sample time in the **Sample time** field.

You can specify an offset time by entering a two-element vector for discrete blocks or configurable subsystems. The first element is the sample time and the second element is the offset time. For example, an entry of [1.0 0.1] would specify a 1.0 second sample time with a 0.1 second offset. If no offset is specified, the default is zero.

You can enter workspace variables when discretizing blocks in the s-domain. See “Discrete blocks (Enter parameters in s-domain)” on page 3-121.

## Specify the Discretization Method

Specify the discretization method in the **Replace current selection with** field. The options are

- “Discrete blocks (Enter parameters in s-domain)” on page 3-121  
Creates a discrete block whose parameters are retained from the corresponding continuous block.
- “Discrete blocks (Enter parameters in z-domain)” on page 3-122  
Creates a discrete block whose parameters are “hard-coded” values placed directly into the block’s dialog.
- “Configurable subsystem (Enter parameters in s-domain)” on page 3-123  
Create multiple discretization candidates using s-domain values for the current selection. A configurable subsystem can consist of one or more blocks.
- “Configurable subsystem (Enter parameters in z-domain)” on page 3-124  
Create multiple discretization candidates in z-domain for the current selection. A configurable subsystem can consist of one or more blocks.

**Discrete blocks (Enter parameters in s-domain).** Creates a discrete block whose parameters are retained from the corresponding continuous block. The sample time and the discretization parameters are also on the block’s parameter dialog box.

The block is implemented as a masked discrete block that uses `c2d` to transform the continuous parameters to discrete parameters in the mask initialization code.

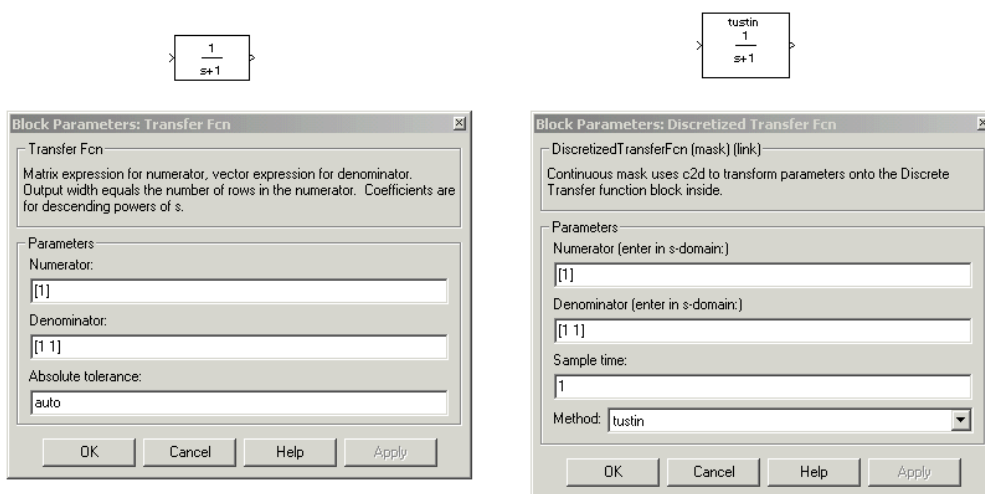
These blocks have the unique capability of reverting to continuous behavior if the sample time is changed to zero. Entering the sample time as a workspace variable (‘`Ts`’, for example) allows for easy changeover from continuous to discrete and back again. See “Specify the Sample Time” on page 3-120.

---

**Note** Parameters are not tunable when **Inline parameters** is selected in the model's Configuration Parameters dialog box.

---

The following figure shows a continuous Transfer Function block next to a Transfer Function block that has been discretized in the s-domain. The **Block Parameters** dialog box for each block appears below the block.

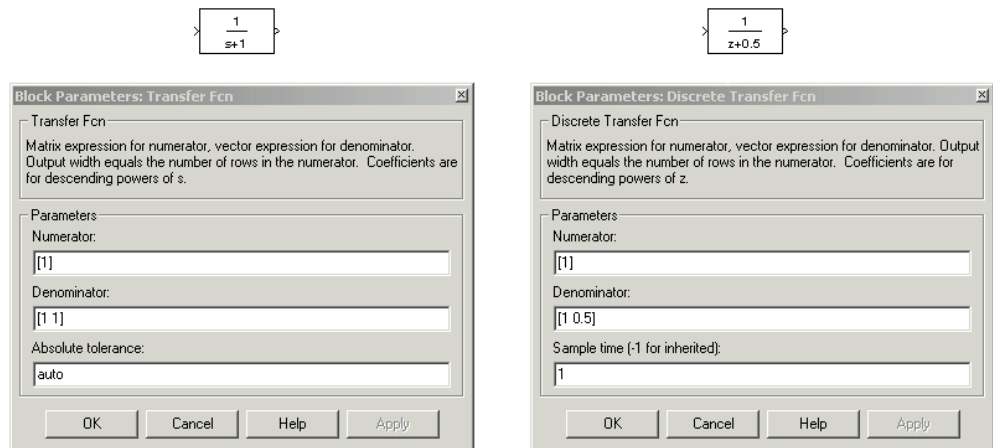


**Discrete blocks (Enter parameters in z-domain).** Creates a discrete block whose parameters are “hard-coded” values placed directly into the block’s dialog box. Model Discretizer uses the c2d function to obtain the discretized parameters, if needed.

For more help on the c2d function, type the following in the Command Window:

```
help c2d
```

The following figure shows a continuous Transfer Function block next to a Transfer Function block that has been discretized in the z-domain. The Block Parameters dialog box for each block appears below the block.




---

**Note** If you want to recover exactly the original continuous parameter values after the Model Discretization session, you should enter parameters in the s-domain.

---

**Configurable subsystem (Enter parameters in s-domain).** Create multiple discretization candidates using s-domain values for the current selection. A configurable subsystem can consist of one or more blocks.

The **Location for block in configurable subsystem** field becomes active when this option is selected. This option allows you to either create a new configurable subsystem or overwrite an existing one.

---

**Note** The current folder must be writable in order to save the library or libraries for the configurable subsystem option.

---

**Configurable subsystem (Enter parameters in z-domain).** Create multiple discretization candidates in z-domain for the current selection. A configurable subsystem can consist of one or more blocks.

The **Location for block in configurable subsystem** field becomes active when this option is selected. This option allows you to either create a new configurable subsystem or overwrite an existing one.

---

**Note** The current folder must be writable in order to save the library or libraries for the configurable subsystem option.

---

Configurable subsystems are stored in a library containing the discretization candidates and the original continuous block. The library will be named `<model name>_disc_lib` and it will be stored in the current . For example a library containing a configurable subsystem created from the `f14` model will be named `f14_disc_lib`.

If multiple libraries are created from the same model, then the filenames will increment accordingly. For example, the second configurable subsystem library created from the `f14` model will be named `f14_disc_lib2`.

You can open a configurable subsystem library by right-clicking on the subsystem in the model and selecting **Link options > Go to library block** from the pop-up menu.

### Discretize the Blocks

To discretize blocks that are linked to a library, you must either discretize the blocks in the library itself or disable the library links in the model window.

You can open the library from Model Discretizer by selecting **Load model** from the **File** menu.

You can disable the library links by right-clicking on the block and selecting **Link options -> Disable link** from the pop-up menu.

There are two methods for discretizing blocks.

## Select Blocks and Discretize.

- 1 Select a block or blocks in the Model Discretizer tree view pane.

To choose multiple blocks, press and hold the **Ctrl** button on the keyboard while selecting the blocks.

---

**Note** You must select blocks from the Model Discretizer tree view. Clicking blocks in the editor does not select them for discretization.

---

- 2 Select **Discretize current block** from the **Discretize** menu if a single block is selected or select **Discretize selected blocks** from the **Discretize** menu if multiple blocks are selected.

You can also discretize the current block by clicking the **Discretize** button, shown below.



## Store the Discretization Settings and Apply Them to Selected Blocks in the Model.

- 1 Enter the discretization settings for the current block.
- 2 Click **Store Settings**.

This adds the current block with its discretization settings to the group of preset blocks.

- 3 Repeat steps 1 and 2, as necessary.
- 4 Select **Discretize preset blocks** from the **Discretize** menu.

## Deleting a Discretization Candidate from a Configurable Subsystem

You can delete a discretization candidate from a configurable subsystem by selecting it in the **Location for block in configurable subsystem** field and clicking the **Delete** button, shown below.



## Undoing a Discretization

To undo a discretization, click the **Undo** discretization button, shown below.



Alternatively, you can select **Undo discretization** from the **Discretize** menu.

This operation undoes discretizations in the current selection and its children. For example, performing the undo operation on a subsystem will remove discretization from all blocks in all levels of the subsystem's hierarchy.

## Viewing the Discretized Model

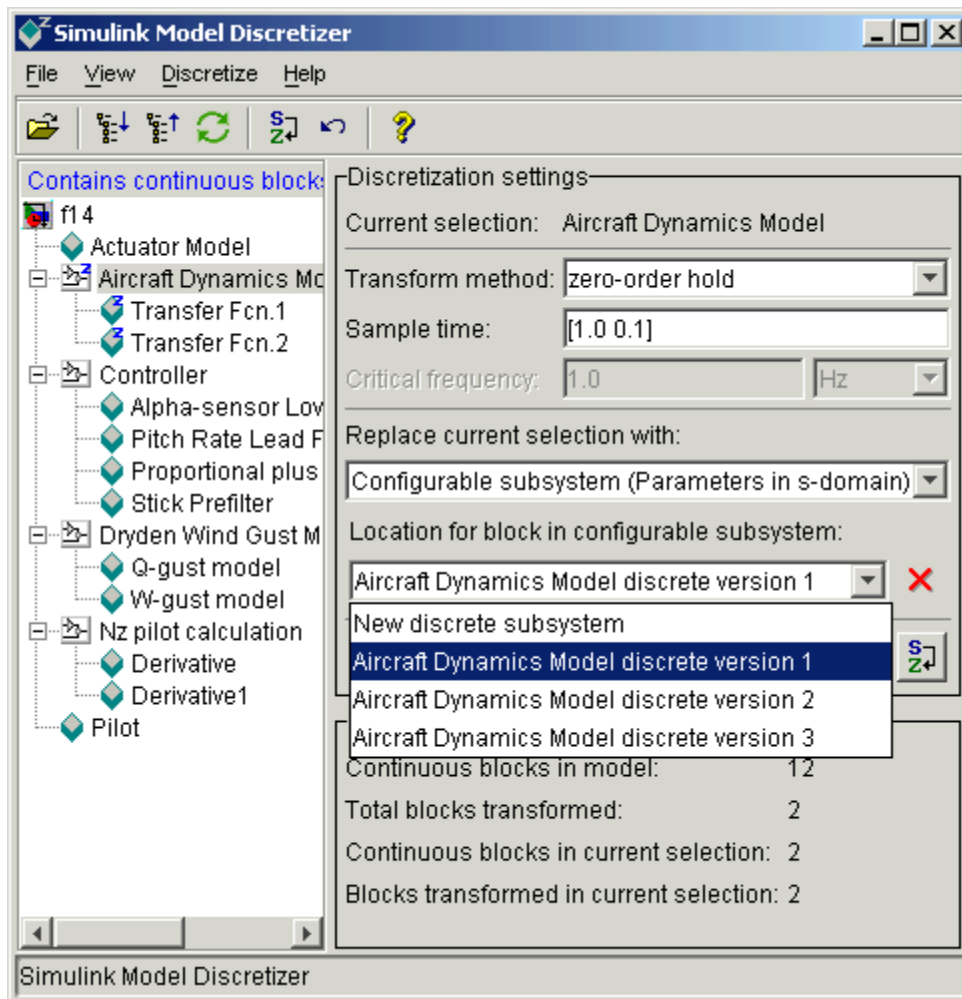
Model Discretizer displays the model in a hierarchical tree view.

## Viewing Discretized Blocks

The block's icon in the tree view becomes highlighted with a "z" when the block has been discretized.



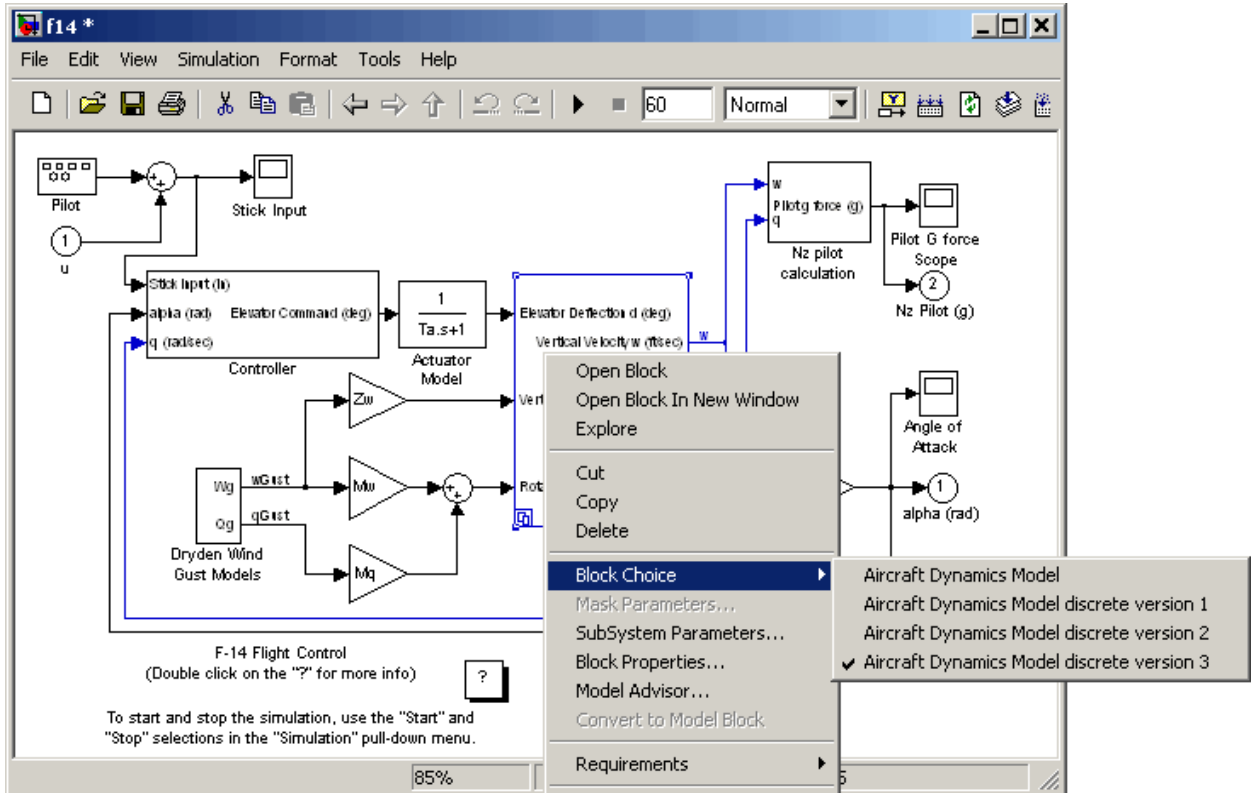
The following figure shows that the Aircraft Dynamics Model subsystem has been discretized into a configurable subsystem with three discretization candidates.



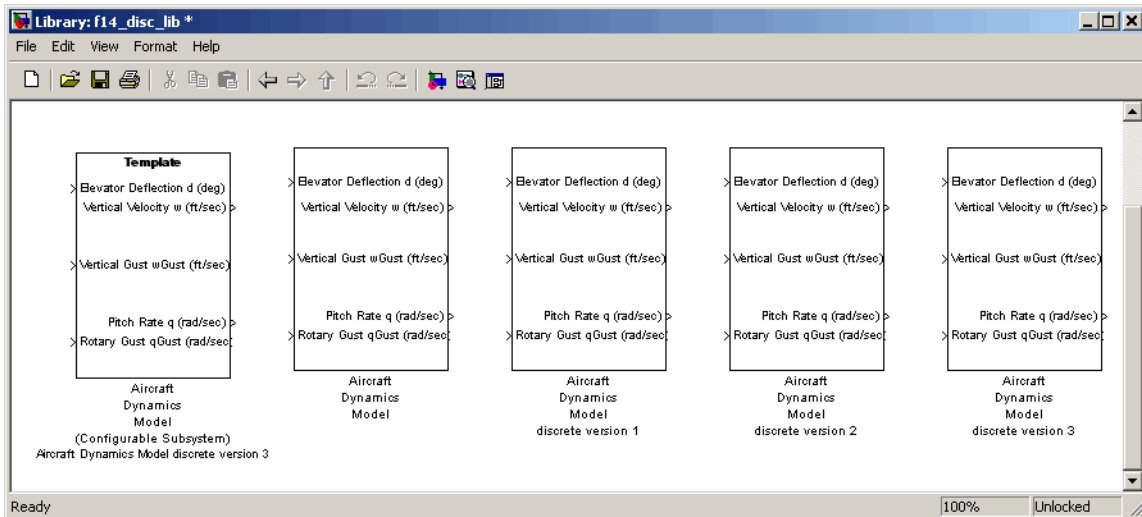
The other blocks in this f14 model have not been discretized.

### 3 Creating a Model

The following figure shows the Aircraft Dynamics Model subsystem of the f14 demo model after discretization into a configurable subsystem containing the original continuous model and three discretization candidates.



The following figure shows the library containing the Aircraft Dynamics Model configurable subsystem with the original continuous model and three discretization candidates.



## Refreshing Model Discretizer View of the Model

To refresh Model Discretizer's tree view of the model when the model has been changed, click the **Refresh** button, shown below.



Alternatively, you can select **Refresh** from the **View** menu.

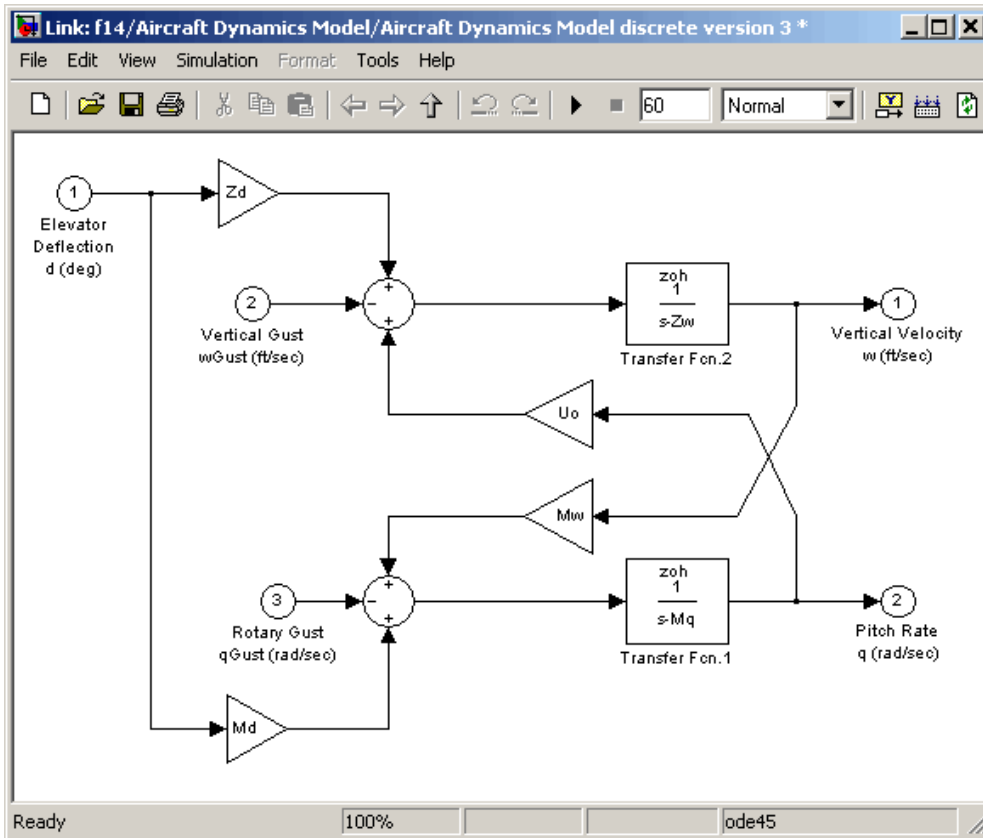
## How to Discretize Blocks from the Simulink Model

You can replace continuous blocks in a Simulink software model with the equivalent blocks discretized in the s-domain using the Discretizing library.

The procedure below shows how to replace a continuous Transfer Fcn block in the Aircraft Dynamics Model subsystem of the f14 model with a discretized Transfer Fcn block from the Discretizing Library. The block is discretized

in the s-domain with a zero-order hold transform method and a two second sample time.

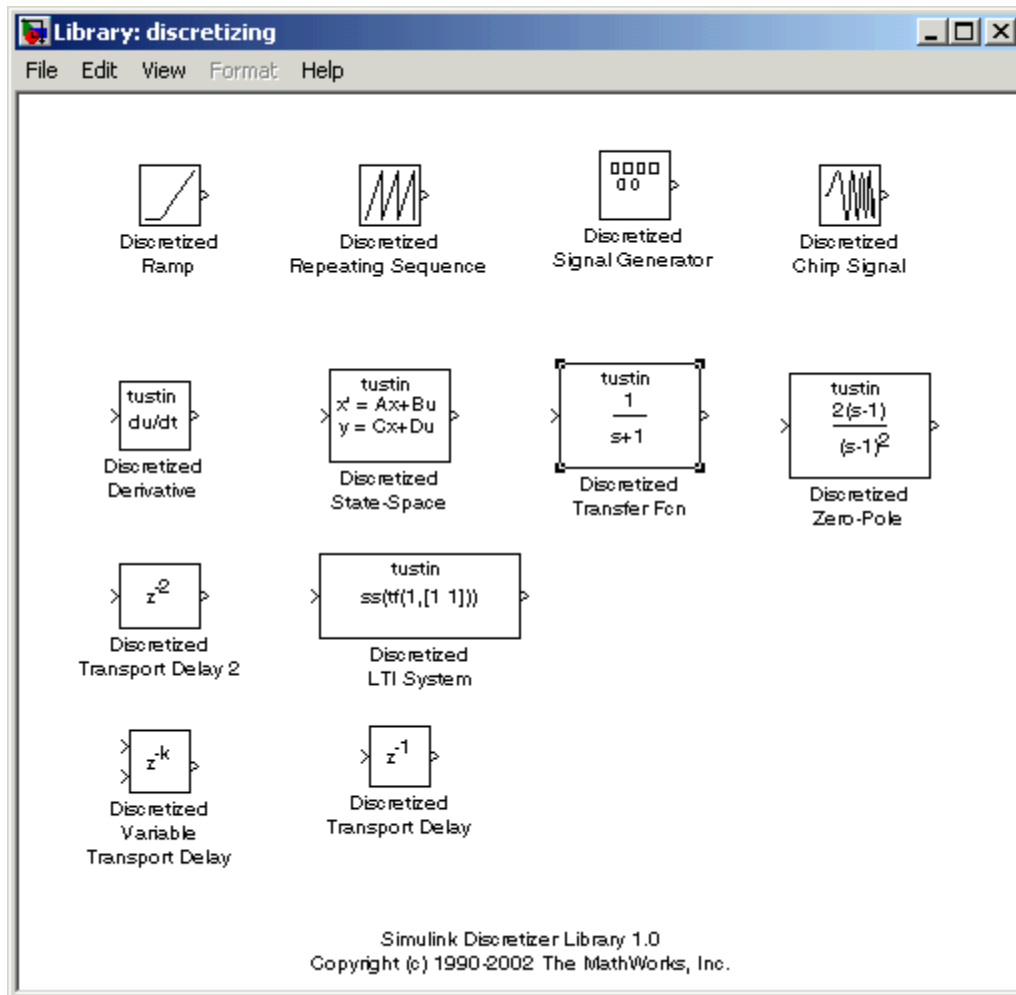
- 1 Open the f14 model.
- 2 Open the Aircraft Dynamics Model subsystem in the f14 model.



- 3 Open the Discretizing library window.

Enter discretizing at the MATLAB command prompt.

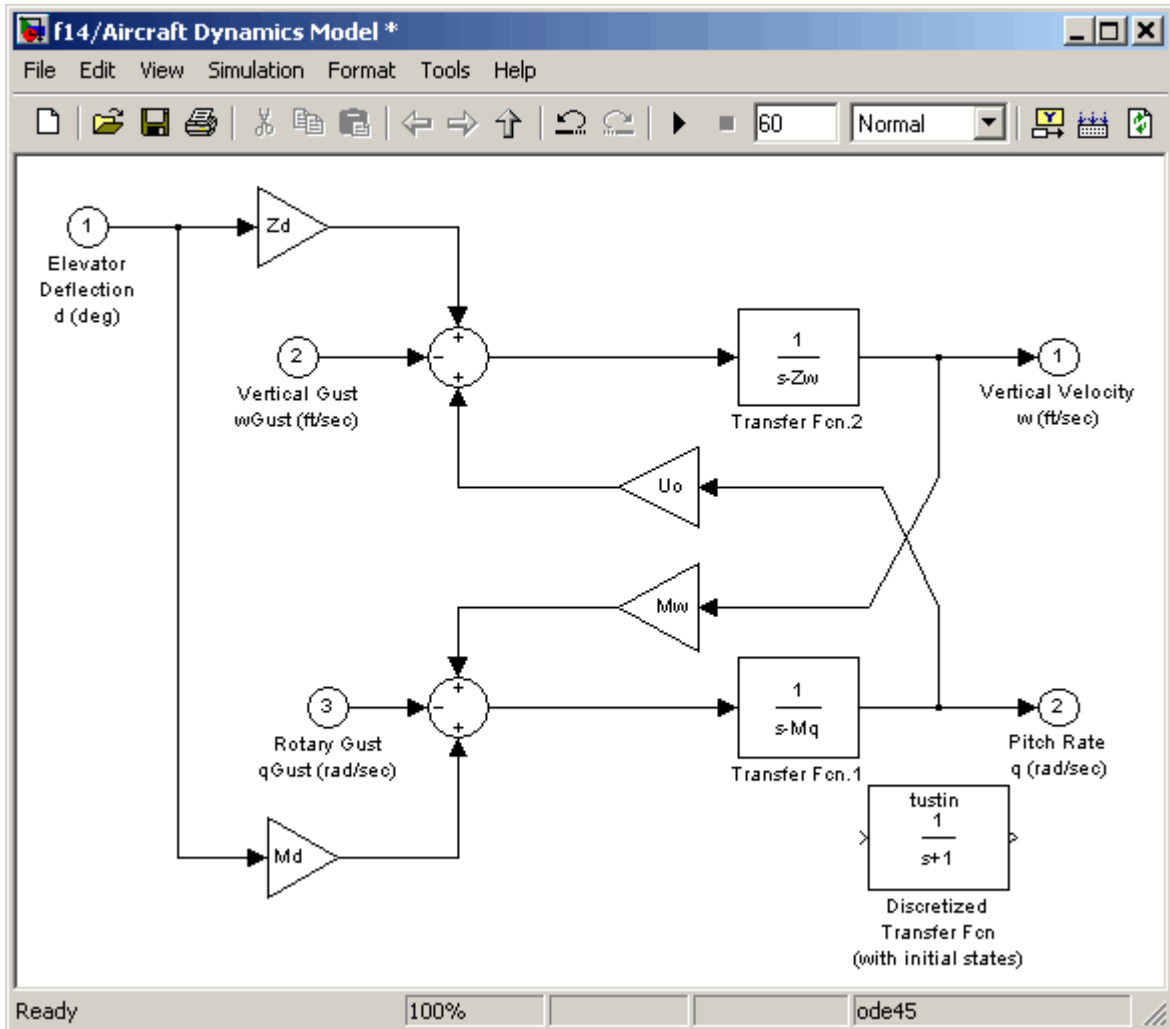
The **Library: discretizing** window opens.



This library contains s-domain discretized blocks.

- 4** Add the Discretized Transfer Fcn block to the **f14/Aircraft Dynamics Model** window.

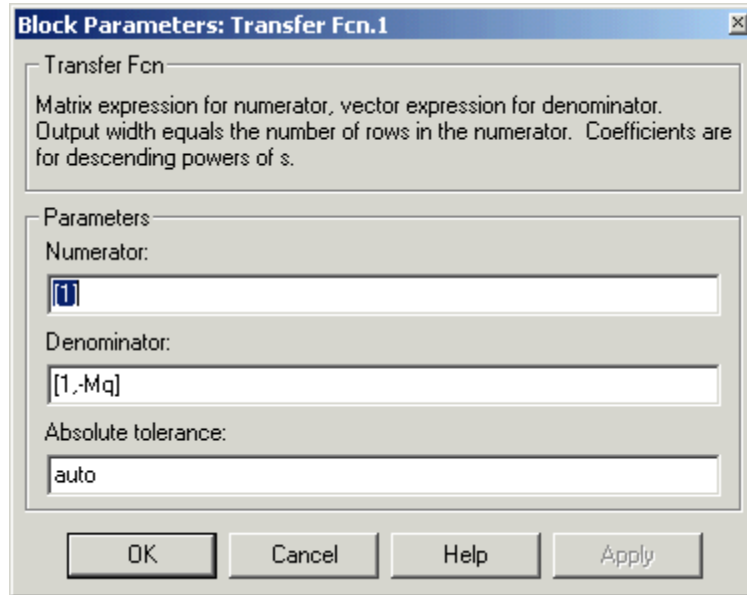
- a Click the Discretized Transfer Fcn block in the **Library: discretizing** window.
- b Drag it into the **f14/Aircraft Dynamics Model** window.



- 5 Open the parameter dialog box for the Transfer Fcn.1 block.

Double-click the Transfer Fcn.1 block in the **f14/Aircraft Dynamics Model** window.

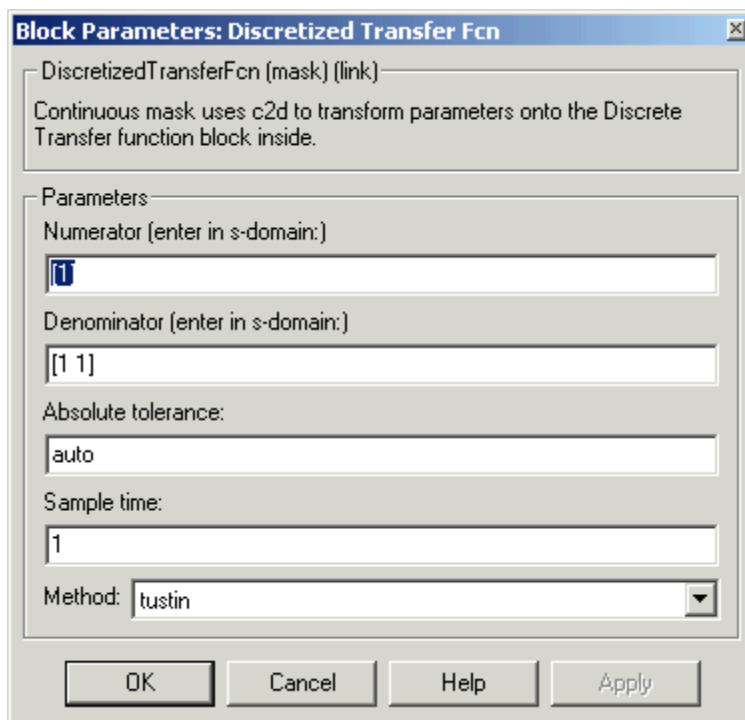
The Block Parameters: Transfer Fcn.1 dialog box opens.



- 6 Open the parameter dialog box for the Discretized Transfer Fcn block.

Double-click the Discretized Transfer Fcn block in the **f14/Aircraft Dynamics Model** window.

The Block Parameters: Discretized Transfer Fcn dialog box opens.





Copy the parameter information from the Transfer Fcn.1 block's dialog box to the Discretized Transfer Fcn block's dialog box.

**Block Parameters: Discretized Transfer Fcn**

- DiscretizedTransferFcn (mask) (link)  
Continuous mask uses c2d to transform parameters onto the Discrete Transfer function block inside.

Parameters

Numerator (enter in s-domain):  
[1]

Denominator (enter in s-domain):  
[1,-Mq]

Absolute tolerance:  
auto

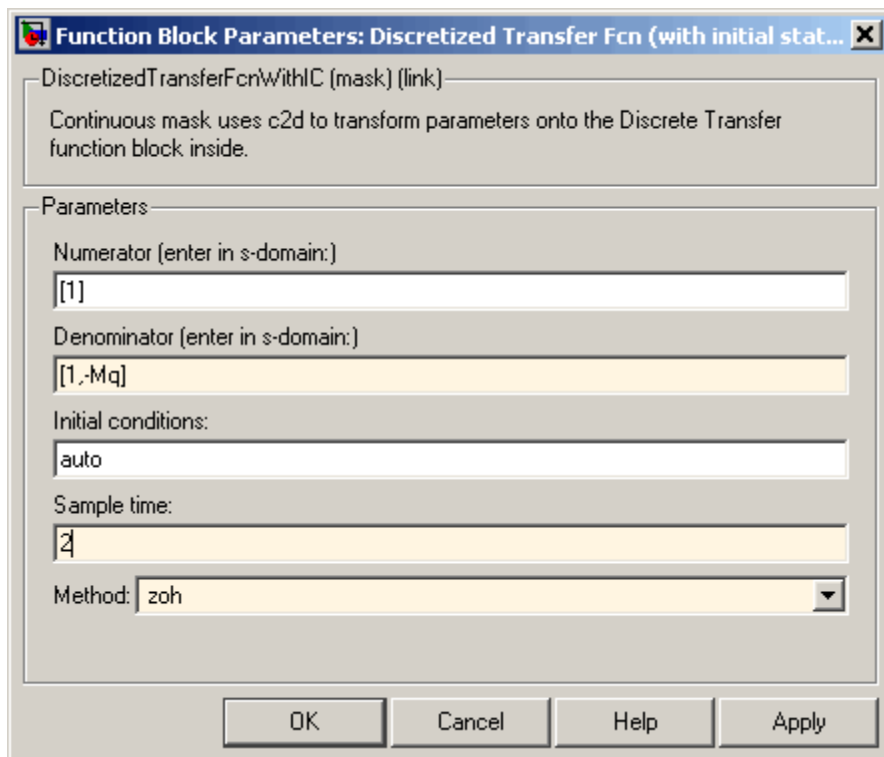
Sample time:  
1

Method: tustin

OK Cancel Help Apply

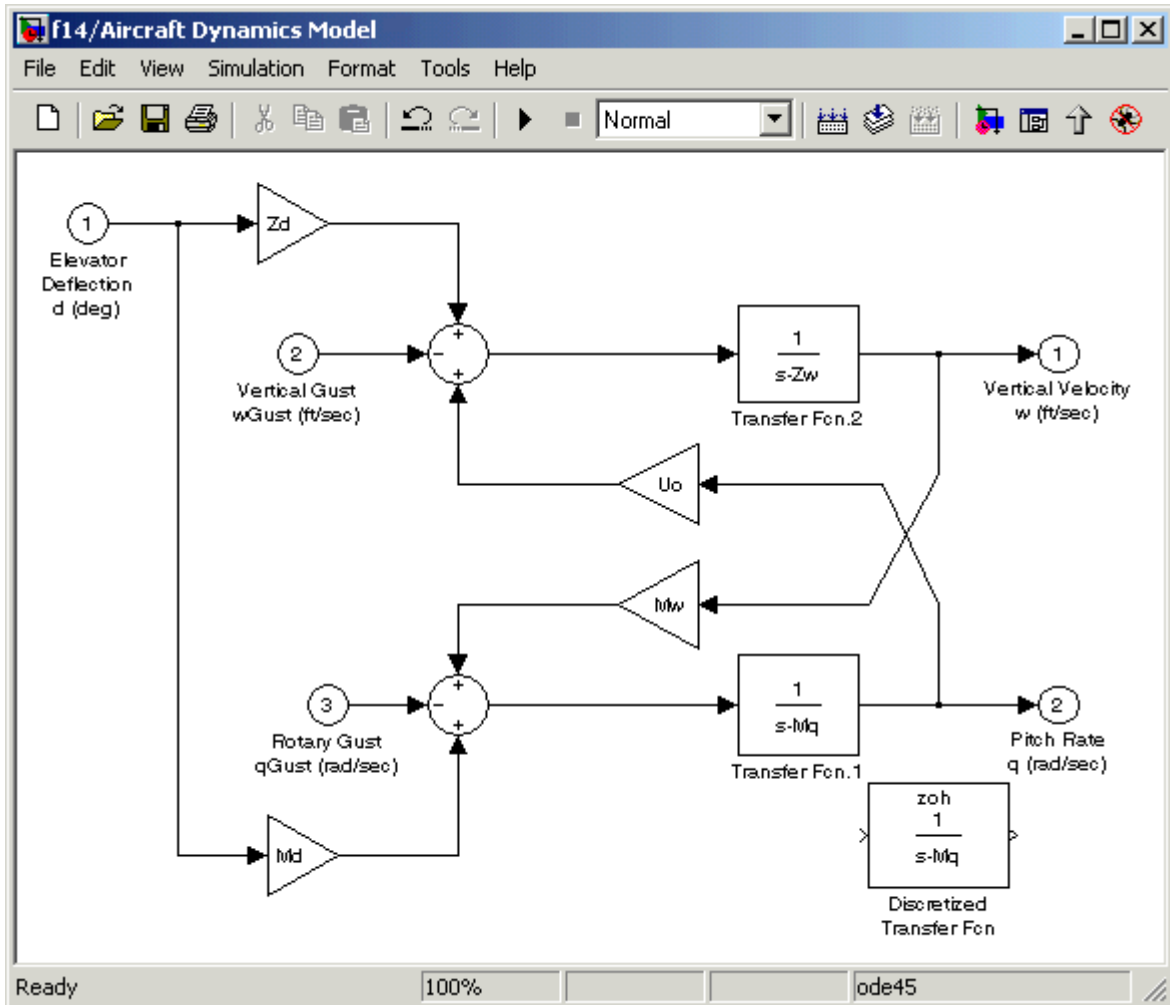
- 7** Enter 2 in the **Sample time** field.
- 8** Select zoh from the **Method** drop-down list.

The parameter dialog box for the Discretized Transfer Fcn now looks like this.



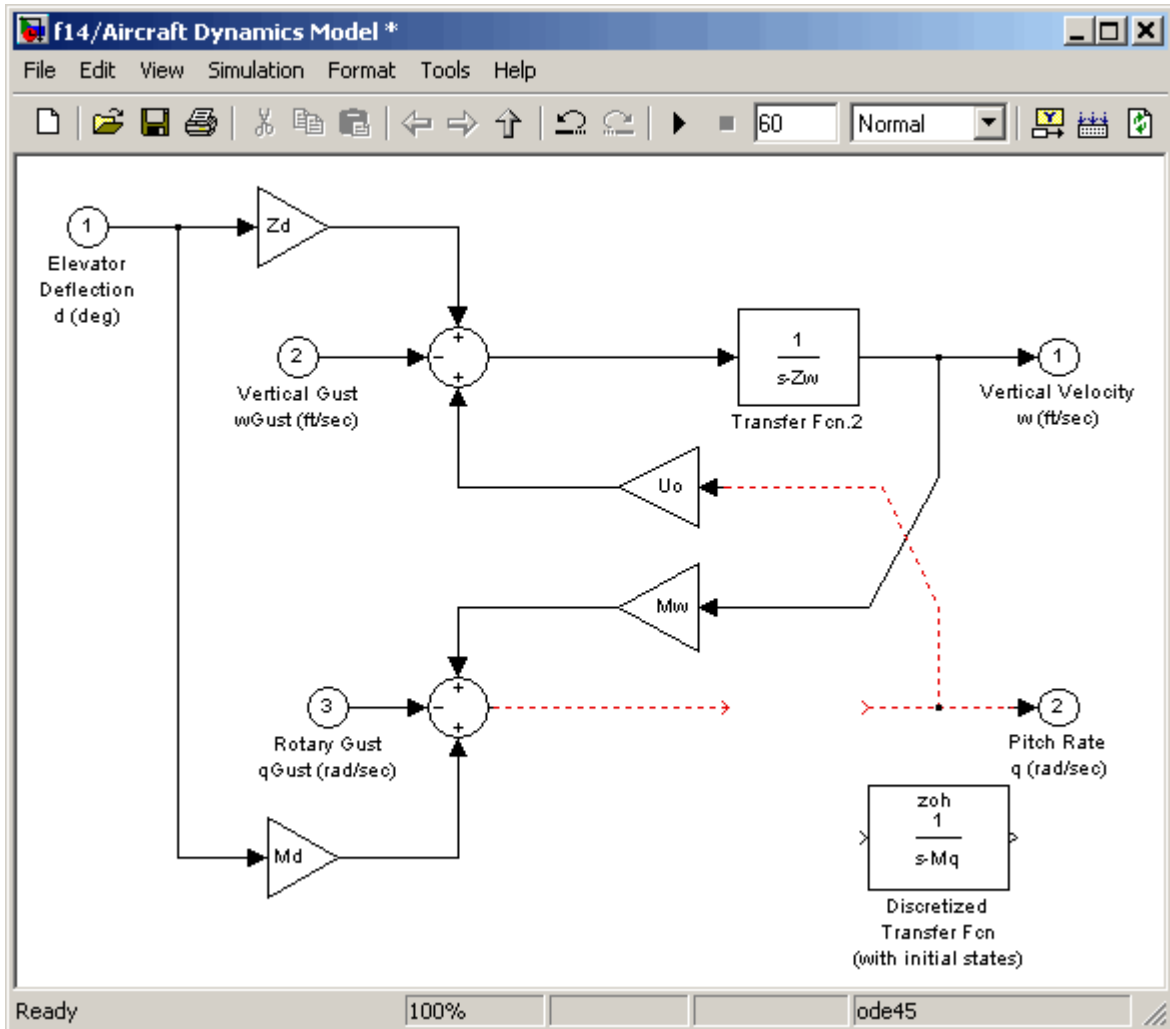
9 Click **OK**.

The f14/Aircraft Dynamics Model window now looks like this.



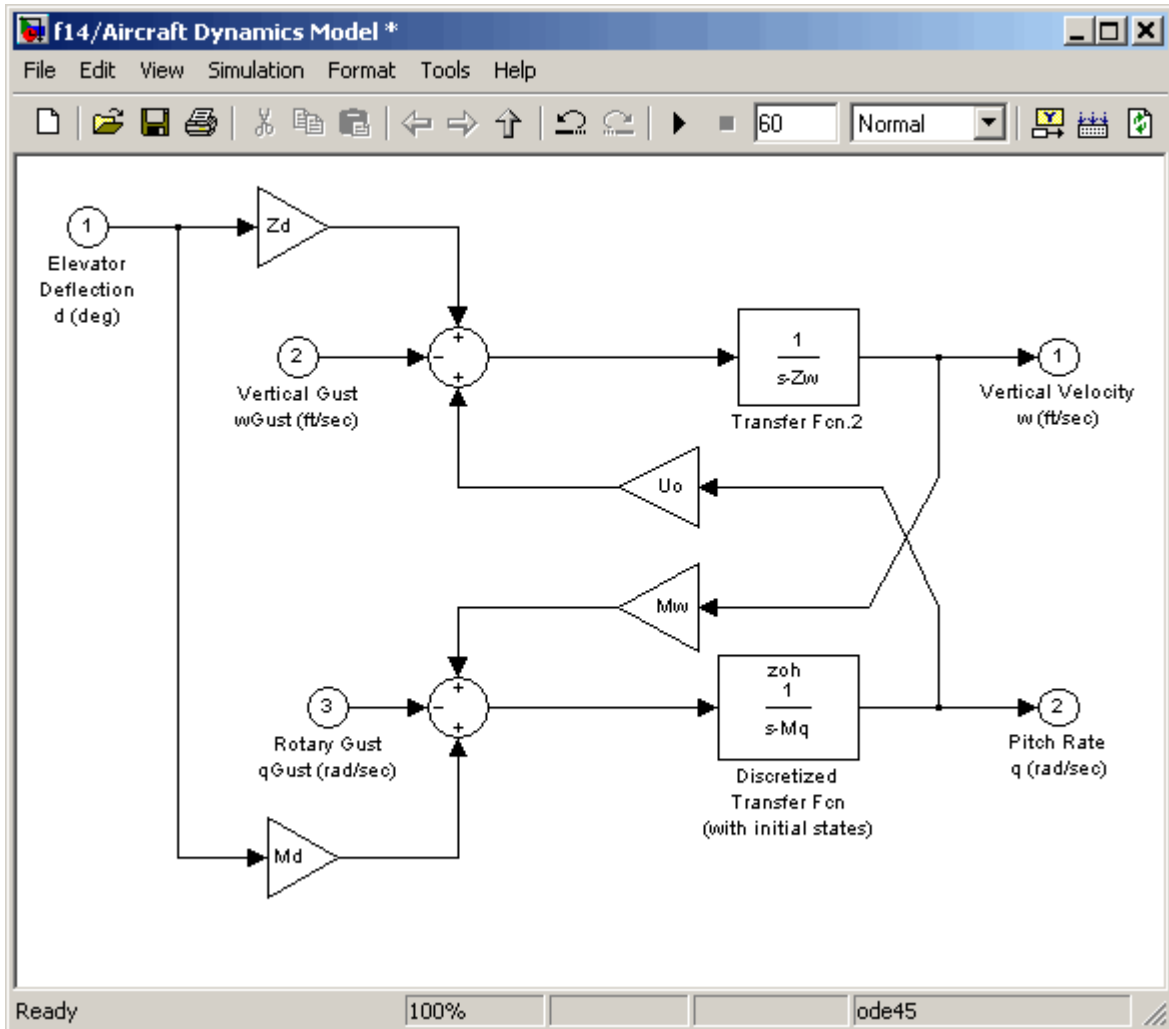
- 10** Delete the original Transfer Fcn.1 block.
  - a** Click the Transfer Fcn.1 block.
  - b** Press the **Delete** key.

The f14/Aircraft Dynamics Model window now looks like this.



- 11 Add the Discretized Transfer Fcn block to the model.
  - a Click the Discretized Transfer Fcn block.
  - b Drag the Discretized Transfer Fcn block into position to complete the model.

The f14/Aircraft Dynamics Model window now looks like this.



## How to Discretize a Model from the MATLAB Command Window

Use the `sldiscmdl` function to discretize Simulink software models from the MATLAB Command Window. You can specify the transform method, the sample time, and the discretization method with the `sldiscmdl` function.

For example, the following command discretizes the `f14` model in the s-domain with a 1-second sample time using a zero-order hold transform method:

```
sldiscmdl('f14',1.0,'zoh')
```

For more information on the `sldiscmdl` function, see “Model Construction” in the *Simulink Reference*.

# Working with Sample Times

---

- “What Is Sample Time?” on page 4-2
- “How to Specify the Sample Time” on page 4-3
- “How to View Sample Time Information” on page 4-9
- “How to Print Sample Time Information” on page 4-13
- “Types of Sample Time” on page 4-14
- “Determining the Compiled Sample Time of a Block” on page 4-20
- “Managing Sample Times in Subsystems” on page 4-21
- “Managing Sample Times in Systems” on page 4-22
- “Resolving Rate Transitions” on page 4-28
- “How Propagation Affects Inherited Sample Times” on page 4-29
- “Monitoring Backpropagation in Sample Times” on page 4-31

# What Is Sample Time?

The *sample time* of a block is a parameter that indicates when, during simulation, the block produces outputs and if appropriate, updates its internal state. The internal state includes but is not limited to continuous and discrete states that are logged.

---

**Note** Do not confuse the Simulink usage of the term sample time with the engineering sense of the term. In engineering, sample time refers to the rate at which a discrete system samples its inputs. Simulink allows you to model single-rate and multirate discrete systems and hybrid continuous-discrete systems through the appropriate setting of block sample times that control the rate of block execution (calculations).

---

For many engineering applications, you need to control the rate of block execution. In general, Simulink provides this capability by allowing you to specify an explicit `SampleTime` parameter in the block dialog or at the command line. Blocks that do not have a `SampleTime` parameter have an implicit sample time. You cannot specify implicit sample times. Simulink determines them based upon the context of the block in the system. The Integrator block is an example of a block that has an implicit sample time. Simulink automatically sets its sample time to 0.

Sample times can be port-based or block-based. For block-based sample times, all of the inputs and outputs of the block run at the same rate. For port-based sample times, the input and output ports can run at different rates.

Sample times can also be discrete, continuous, fixed in minor step, inherited, constant, variable, triggered, or asynchronous. The following sections discuss these sample time types, as well as sample time propagation and rate transitions between block-based or port-based sample times. You can use this information to control your block execution rates, debug your model, and verify your model.



## How to Specify the Sample Time

In this section...
“Designating Sample Times” on page 4-3
“Specifying Block-Based Sample Times Interactively” on page 4-5
“Specifying Port-Based Sample Times Interactively” on page 4-6
“Specifying Block-Based Sample Times Programmatically” on page 4-7
“Specifying Port-Based Sample Times Programmatically” on page 4-7
“Accessing Sample Time Information Programmatically” on page 4-8
“Specifying Sample Times for a Custom Block” on page 4-8
“Determining Sample Time Units” on page 4-8
“Changing the Sample Time After Simulation Start Time” on page 4-8

### Designating Sample Times

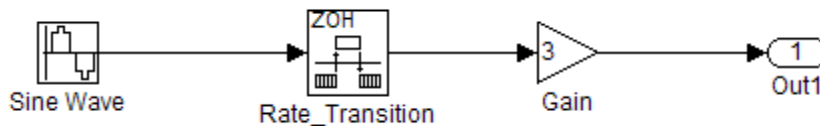
Simulink allows you to specify a block sample time directly as a numerical value or symbolically by defining a sample time vector. In the case of a discrete sample time, the vector is  $[T_s, T_o]$  where  $T_s$  is the sampling period and  $T_o$  is the initial time offset. For example, consider a discrete model that produces its outputs every two seconds. If your base time unit is seconds, you can directly set the discrete sample time by specifying the numerical value of 2 as the `SampleTime` parameter. Because the offset value is zero, you do not need to specify it; however, you can enter  $[2, 0]$  in the **Sample time** field.

For nondiscrete blocks, the components of the vector are symbolic values that represent one of the types in “Types of Sample Time” on page 4-14. 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 “How to View Sample Time Information” on page 4-9.)

### Designations of Sample Time Information

Sample Time Type	Sample Time	Color	Annotation	Explicit
Discrete	$[T_s, T_o]$	red, green, blue, light blue, dark green, orange	D1, D2, D3, D4, D5, D6, D7,... $D_i$	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	$[-\infty, 0]$	magenta	Inf	Yes
Variable	$[-2, T_{vo}]$	brown	$V_1, V_2, \dots V_i$	No
Hybrid	N/A	yellow	N/A	No
Triggered	$[-1, -1]$	cyan	T	No
Asynchronous	$[-1, -n]$	purple	$A_1, A_2, \dots A_i$	No

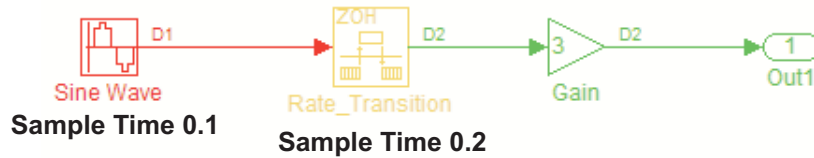
You can use the explicit sample time values in this table to specify sample times interactively or programmatically for either block-based or port-based sample times. The following model, `ex_specify_sample_time.mdl`, serves as a reference for this section.



#### `ex_specify_sample_time.mdl`

In this example, our goal is to set the sample time of the input sine wave signal to 0.1 and to achieve an output sample time of 0.2. The Rate Transition block serves as a zero-order hold. The resulting block diagram after setting

the sample times and simulating the model is shown in the following figure. (The colors and annotations indicate that this is a discrete model.)



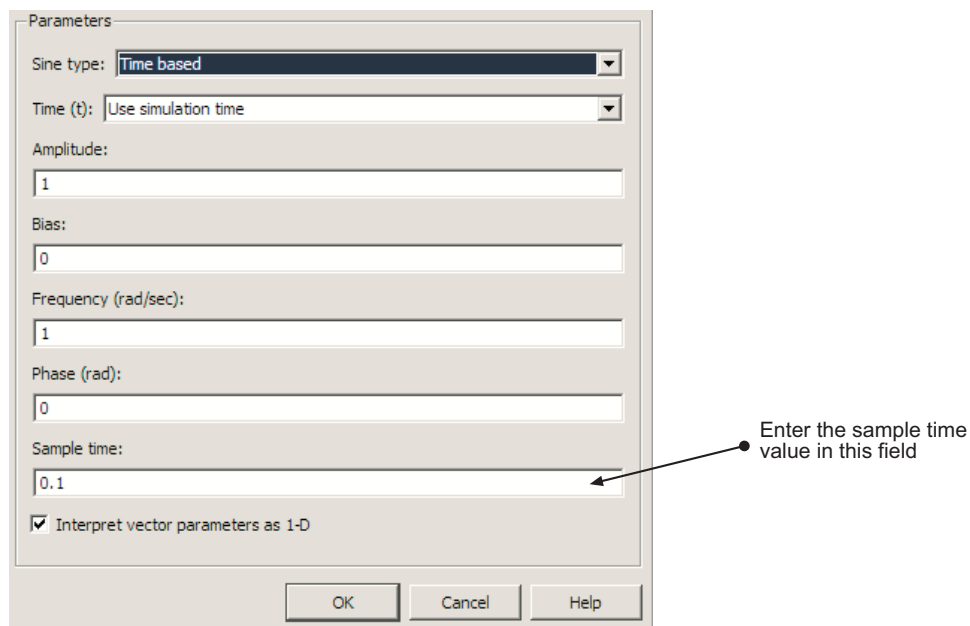
**ex\_specify\_sample\_time.mdl after Setting Sample Times**

## Specifying Block-Based Sample Times Interactively

To set the sample time of a block interactively:

- 1** In the Simulink model window, double-click the block. The block parameter dialog box opens.
- 2** Enter the sample time in the **Sample time** field.
- 3** Click **OK**.

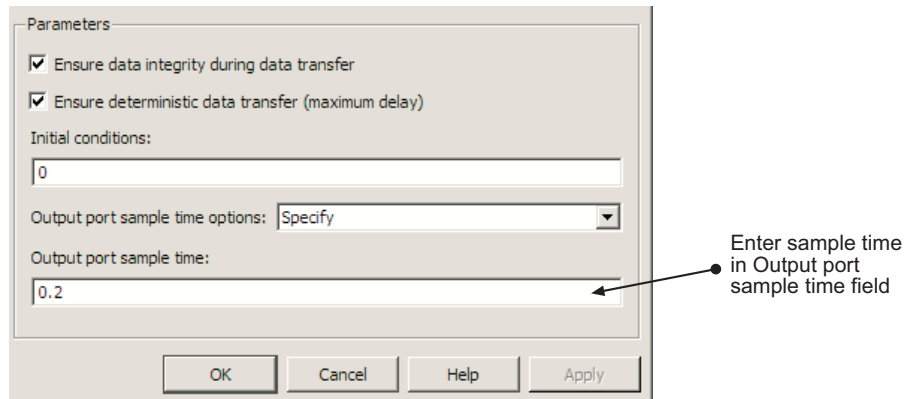
Following is a figure of a parameters dialog box for the Sine Wave block after entering 0.1 in the **Sample time** field.



### Specifying Port-Based Sample Times Interactively

The Rate Transition block has port-based sample times. You can set the output port sample time interactively by completing the following steps:

- 1 Double-click the Rate Transition block. The parameters dialog box opens.
- 2 Leave the drop-down menu choice of the **Output port sample time options** as Specify.
- 3 Replace the -1 in the **Output port sample time** field with 0.2.



#### 4 Click **OK**.

For more information about the sample time options in the Rate Transition parameters dialog box, see the Rate Transition reference page.

## Specifying Block-Based Sample Times Programmatically

To set a block sample time programmatically, set its `SampleTime` parameter to the desired sample time using the `set_param` command. For example, to set the sample time of the Gain block in the “Specify\_Sample\_Time” model to inherited (-1), enter the following command:

```
set_param('Specify_Sample_Time/Gain','SampleTime','[-1, 0]')
```

As with interactive specification, you can enter just the first vector component if the second component is zero.

```
set_param('Specify_Sample_Time/Gain','SampleTime','-1')
```

## Specifying Port-Based Sample Times Programmatically

To set the output port sample time of the Rate Transition block to 0.2, use the `set_param` command with the parameter `OutPortSampleTime`:

```
set_param('Specify_Sample_Time/Rate Transition',...
```

```
'OutPortSampleTime', '0.2')
```

### **Accessing Sample Time Information Programmatically**

To access all sample times associated with a model, use the API `Simulink.BlockDiagram.getSampleTimes`.

To access the sample time of a single block, use the API `Simulink.Block.getSampleTimes`.

### **Specifying Sample Times for a Custom Block**

You can design custom blocks so that the input and output ports operate at different sample time rates. For information on specifying block-based and port-based sample times for S-functions, see “Sample Times”.

### **Determining Sample Time Units**

Since the execution of a Simulink model is not dependent on a specific set of units, you must determine the appropriate base time unit for your application and set the sample time values accordingly. For example, if your base time unit is second, then you would represent a sample time of 0.5 second by setting the sample time to 0.5.

### **Changing the Sample Time After Simulation Start Time**

To change a sample time after simulation begins, you must stop the simulation, reset the `SampleTime` parameter, and then restart execution.

## How to View Sample Time Information

In this section...
“Viewing Sample Time Display” on page 4-9
“Managing the Sample Time Legend” on page 4-10

### Viewing Sample Time Display

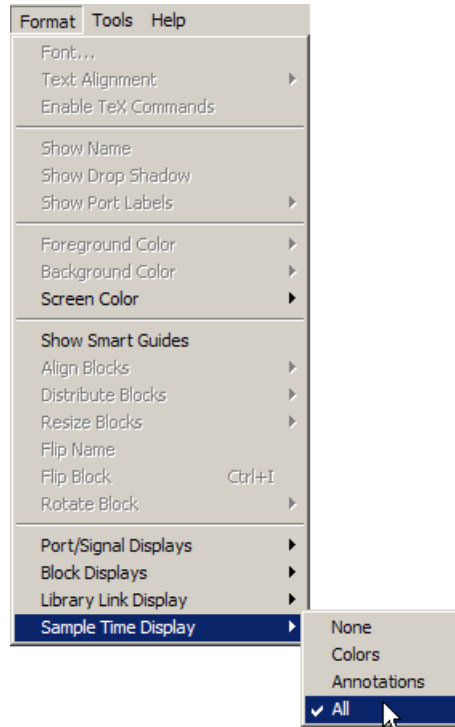
Simulink models can display color coding and annotations that represent specific sample times. As shown in the table Designations of Sample Time Information on page 4-4, each sample time type has one or more colors associated with it. You can display the blocks and signal lines in color, the annotations in black, or both the colors and the annotations. To choose one of these options:

- 1 In the Simulink model window, select **Format > Sample Time Display**.
- 2 Select **Colors**, **Annotations**, or **All**.

Selecting **All** results in the display of both the colors and the annotations. Regardless of your choice, Simulink performs an **Update Diagram** automatically. To turn off the colors and annotations:

- 1 Select **Format > Sample Time Display**.
- 2 Select **None**.

Simulink performs another **Update Diagram** automatically.



Your Sample Time Display choices directly control the information that the Sample Time Legend displays.

---

**Note** The discrete sample times in the table Designations of Sample Time Information on page 4-4 represent a special case. Five colors indicate the fastest through the fifth fastest discrete rate. A sixth color, orange, represents all rates that are slower than the fifth discrete rate. You can distinguish between these slower rates by looking at the annotations on their respective signal lines.

---

### Managing the Sample Time Legend

You can view the Sample Time Legend for an individual model or for multiple models. Additionally, you can prevent the legend from automatically opening when you select options on the **Sample Time Display** menu.



## Viewing the Legend

To assist you with interpreting your block diagram, a **Sample Time Legend** is available that contains the sample time color, annotation, description, and value for each sample time in the model. You can use one of three methods to view the legend, but upon first opening the model, you must first perform an **Update Diagram**.

- 1** In the Simulink model window, select **Edit > Update Diagram**.
- 2** Select **View > Sample Time Legend** or press **Ctrl +J**.

In addition, whenever you select **Colors**, **Annotations**, or **All** from the **Sample Time Display** menu, Simulink updates the model diagram and opens the legend by default. The legend contents reflect your **Sample Time Display** choices. By default or if you have selected **None**, the legend contains a description of the sample time and the sample time value. If you turn colors on, the legend displays the appropriate color beside each description. Similarly, if you turn annotations on, the annotations appear in the legend.

The legend does not provide a discrete rate for all types of sample times. For asynchronous and variable sample times, the legend displays a link to the block that controls the sample time in place of the sample time value. Clicking one of these links highlights the corresponding block in the block diagram. The rate listed under hybrid and asynchronous hybrid models is “Not Applicable” because these blocks do not have a single representative sample time.

---

**Note** The Sample Time Legend displays all of the sample times in the model, including those that are not associated with any block. For example, if the fixed step size is 0.1 and all of the blocks have a sample time of 0.2, then both rates (i.e., 0.1 and 0.2) appear in the legend.

---

For subsequent viewings of the legend, you must repeat the **Update Diagram** to access the latest known information.

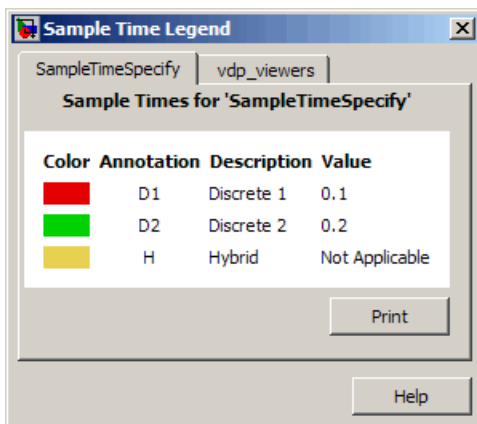
### Turning the Legend Off

If you prefer not to view the legend upon selecting **Sample Time Display**:

- 1 In the Simulink model window, select **File > Preferences**.
- 2 Scroll to the bottom of the main **Preferences** pane.
- 3 Clear **Open the Sample Time Legend whenever the Sample Time Display is changed**.

### Viewing Multiple Legends

If you have more than one model open and you view the **Sample Time Legend** for each one, a single legend window appears with multiple tabs. Each tab contains the name of the model and the respective legend information. The following figure shows the tabbed legends for `SampleTimeSpecify.mdl` and `vdp_viewers.mdl`.



## How to Print Sample Time Information

You can print the sample time information in the Sample Time Legend by using either of these methods:

- In the Sample Time Legend window, click **Print**.
- Print the legend from the **Print Model** dialog box:
  - 1** In the model window, select **File > Print**.
  - 2** Under **Options**, select the check box beside **Print Sample Time Legend**.
  - 3** Click **OK**.

## Types of Sample Time

### In this section...

“Discrete Sample Time” on page 4-14  
 “Continuous Sample Time” on page 4-15  
 “Fixed in Minor Step” on page 4-15  
 “Inherited Sample Time” on page 4-15  
 “Constant Sample Time” on page 4-16  
 “Variable Sample Time” on page 4-17  
 “Triggered Sample Time” on page 4-18  
 “Asynchronous Sample Time” on page 4-18

### 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:

$$0 \leq n \leq \frac{T_{sim}}{T_s}$$

As simulation progresses, Simulink computes block outputs only once at each of these fixed time intervals of  $t_n$ . These simulation times, at which Simulink executes the output method of a block for a given sample time, are referred to as *sample time hits*. Discrete sample times are the only type for which sample time hits are known *a priori*.

If you need to delay the initial sample hit time, you can define an offset,  $T_o$ .

The Unit Delay block is an example of a block with a discrete sample time.

## Continuous Sample Time

Unlike the discrete sample time, continuous sample hit times are divided into major time steps and minor time steps, where the minor steps represent subdivisions of the major steps (see “Minor Time Steps” on page 2-24). The ODE solver you choose integrates all continuous states from the simulation start time to a given major or minor time step. The solver determines the times of the minor steps and uses the results at the minor time steps to improve the accuracy of the results at the major time steps. However, you see the block output only at the major time steps.

To specify that a block, such as the Derivative block, is continuous, enter  $[0, 0]$  or 0 in the **Sample time** field of the block dialog.

## Fixed in Minor Step

If the sample time of a block is set to  $[0, 1]$ , the block becomes *fixed in minor step*. For this setting, Simulink does not execute the block at the minor time steps; updates occur only at the major time steps. This process eliminates unnecessary computations of blocks whose output cannot change between major steps.

While you can explicitly set a block to be fixed in minor step, more typically Simulink sets this condition as either an inherited sample time or as an alteration to a user specification of 0 (continuous). This setting is equivalent to, and therefore converted to, the fastest discrete rate when you use a fixed-step solver.

## Inherited Sample Time

If a block sample time is set to  $[-1, 0]$  or  $-1$ , the sample time is *inherited* and Simulink determines the best sample time for the block based on the block context within the model. Simulink performs this task during the compilation stage; the original inherited setting never appears in a compiled model. Therefore, you never see inherited ( $[-1, 0]$ ) in the Sample Time Legend. (See “How to View Sample Time Information” on page 4-9.)

Examples of inherited blocks include the Gain and Add blocks.

All inherited blocks are subject to the process of sample time propagation, as discussed in “How Propagation Affects Inherited Sample Times” on page 4-29

## 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** option is enabled 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 6-4).
- The block has no tunable parameters.

One exception is an empty subsystem. A subsystem that has no blocks—not even an input or output block—always has a constant sample time regardless of the status of the conditions listed above.

This optimization process speeds up the simulation by eliminating the need to recompute the block output at each step. Instead, during each model update, Simulink first establishes the constant sample time of the block and then computes the initial values of its output ports. Simulink then uses these values, without performing any additional computations, whenever it needs the outputs of the block.

---

**Note** The Simulink block library includes several blocks, such as the MATLAB S-Function block, the Level-2 MATLAB S-Function block, and the Model block, whose ports can produce outputs at different sample rates. It is possible for some of the ports of such blocks to have a constant sample time. These ports produce outputs only once—at the beginning of a simulation. Any other ports produce output at their respective sample times.

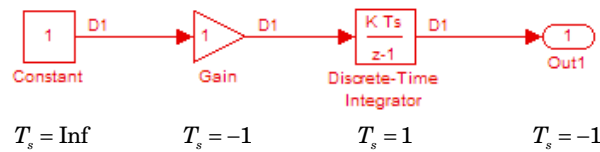
---

If Simulink cannot honor the request to use the optimization, then Simulink treats the block as if it had specified an inherited sample time (-1).

One specific case for which Simulink rejects the request is when parameters are tunable. By definition, you can change the parameter values of a block having tunable parameters; therefore, the block outputs are variable rather than constant. For such cases, Simulink performs sample time propagation (see “How Propagation Affects Inherited Sample Times” on page 4-29) to determine the block sample time.

An example of a Constant block with tunable parameters is shown below (ex\_inline\_parameters\_off.mdl). 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 6-26.)
- 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”.

### Determining the Compiled Sample Time of a Block

During the compilation phase of a simulation, Simulink determines the sample time of a block from its `SampleTime` parameter (if it has an explicit sample time), its block type (if it has an implicit sample time), or by its context within the model. This compiled sample time determines the sample rate of a block during simulation. You can determine the compiled sample time of any block in a model by first updating the model and then getting the block `CompiledSampleTime` parameter, using the `get_param` command.

## Managing Sample Times in Subsystems

Subsystems fall into two categories: triggered and nontriggered. For triggered subsystems, in general, the subsystem gets its sample time from the triggering signal. One exception occurs when you use a Trigger block to create a triggered subsystem. If you set the block **Trigger type** to **function-call** and the **Sample time type** to **periodic**, the `SampleTime` parameter becomes active. In this case, *you* specify the sample time of the Trigger block, which in turn, establishes the sample time of the subsystem.

The four nontriggered subsystems are virtual, enabled, atomic, and action. Simulink calculates the sample times of virtual and enabled subsystems based on the respective sample times of their contents. The atomic subsystem is a special case in that the subsystem block has a `SampleTime` parameter. Moreover, for a sample time other than the default value of `-1`, the blocks inside the atomic subsystem can have only a value of `Inf`, `-1`, or the identical (discrete) value of the subsystem `SampleTime` parameter. If the atomic subsystem is left as inherited, Simulink calculates the block sample time in the same manner as the virtual and enabled subsystems. However, the main purpose of the subsystem `SampleTime` parameter is to allow for the simultaneous specification of a large number of blocks, within an atomic subsystem, that are all set to inherited. Finally, the sample time of the action subsystem is set by the If block or the Switch Case block.

## Managing Sample Times in Systems

In this section...
“Purely Discrete Systems” on page 4-22
“Hybrid Systems” on page 4-25

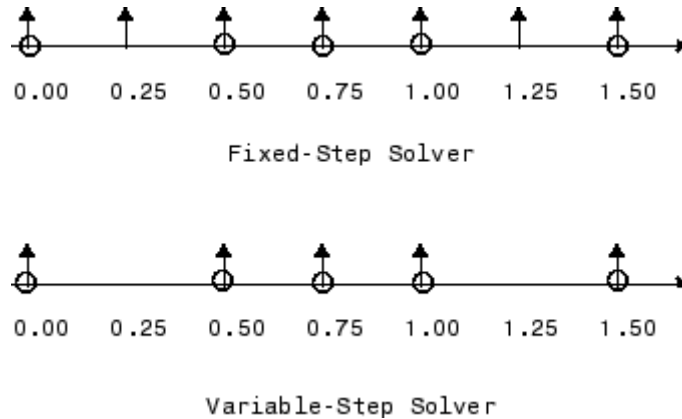
### Purely Discrete Systems

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.

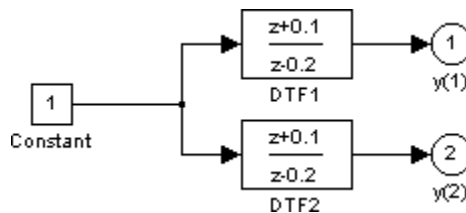
The importance of the fundamental sample time directly relates to whether you direct the Simulink software to use a fixed-step or a variable-step discrete solver to solve your multirate discrete system. A fixed-step solver sets the simulation step size equal to the fundamental sample time of the discrete 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.

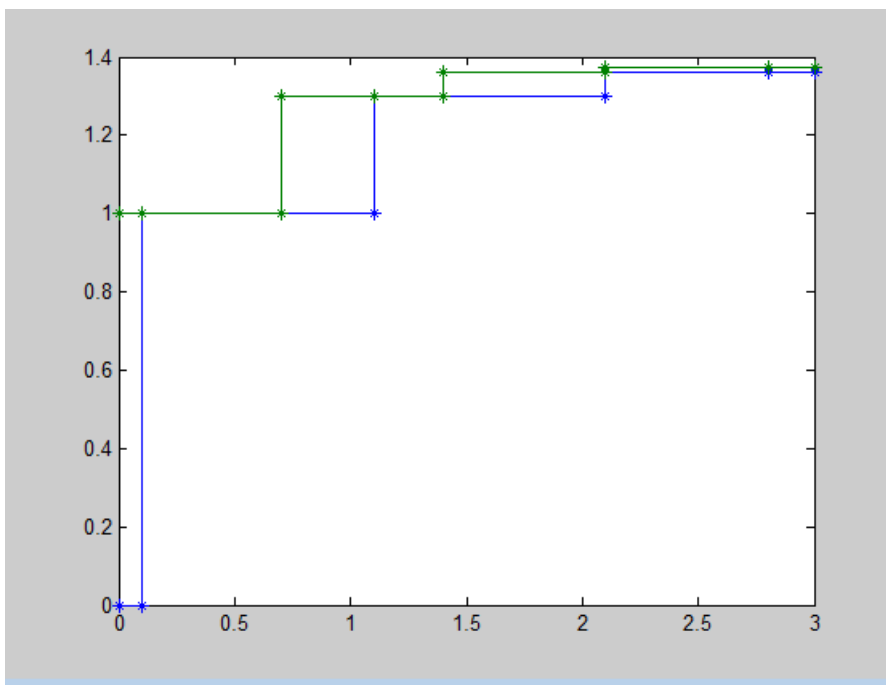
Consider the following example of a simple multirate system. For this example, the DTF1 Discrete Transfer Fcn block's **Sample time** is set to [1 0.1], which gives it an offset of 0.1. The **Sample time** of the DTF2 Discrete Transfer Fcn block is set to 0.7, with no offset. The solver is set to a variable-step 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.



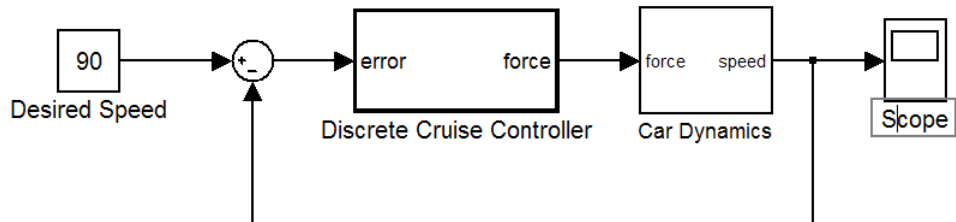
(See Chapter 14, “Running a Simulation Programmatically” for information on the `sim` command.)

As the figure demonstrates, because the DTF1 block has a 0.1 offset, the DTF1 block has no output until  $t = 0.1$ . Similarly, the initial conditions of the transfer functions are zero; therefore, the output of DTF1,  $y(1)$ , is zero before this time.

## Hybrid Systems

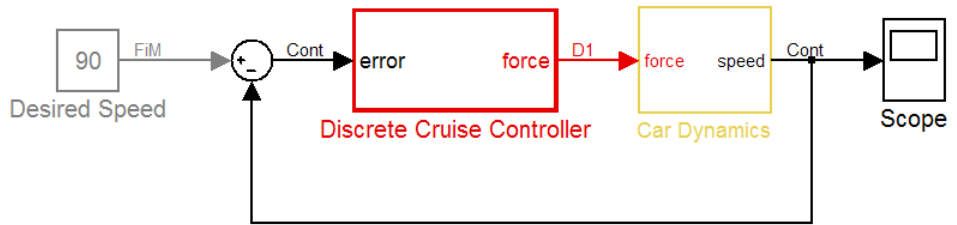
*Hybrid systems* contain both discrete and continuous blocks and thus have both discrete and continuous states. However, Simulink solvers treat any system that has both continuous and discrete sample times as a hybrid system. For information on modeling hybrid systems, see “Modeling Hybrid Systems” on page 2-8.

In block diagrams, the term hybrid applies to both hybrid systems (mixed continuous-discrete systems) and systems with multiple sample times (multirate systems). Such systems turn yellow in color when you perform an **Update Diagram** with Sample Time Display **Colors** turned 'on'. As an example, consider the following model that contains an atomic subsystem, “Discrete Cruise Controller”, and a virtual subsystem, “Car Dynamics”. (See `ex_execution_order.mdl`.)

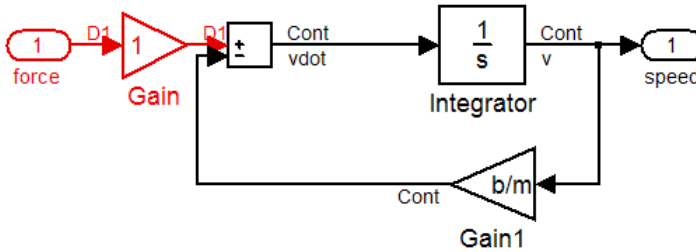


### Car Model

With the Sample Time Display option set to **All**, an **Update Diagram** turns the virtual subsystem yellow, indicating that it is a hybrid subsystem. In this case, the subsystem is a true hybrid system since it has both continuous and discrete sample times. As shown below, the discrete input signal,  $D1$ , combines with the continuous velocity signal,  $v$ , to produce a continuous input to the integrator.



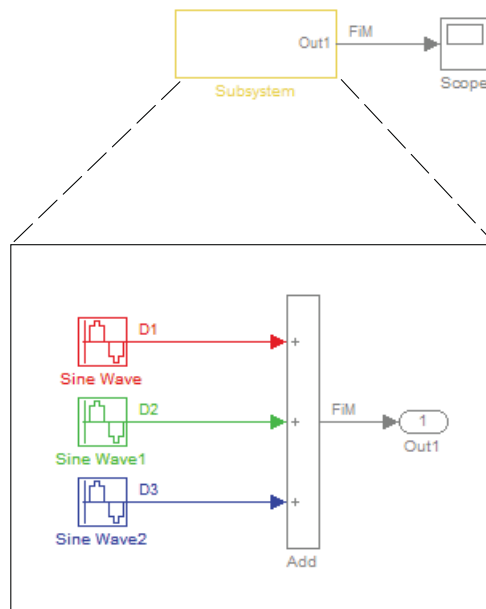
**Car Model after an Update Diagram**



**Car Dynamics Subsystem after an Update Diagram**

Now consider a multirate subsystem that contains three Sine Wave source blocks, each of which has a unique sample time — 0.2, 0.3, and 0.4, respectively.





### Multirate Subsystem 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  $[\text{inf}, 0]$  or asynchronous  $[-1, -n]$  sample times. Thus a subsystem consisting of one block with a constant sample time and one block with a discrete sample time will not be designated as hybrid.

The hybrid annotation and coloring are very useful for evaluating whether or not the subsystems in your model have inherited the correct or expected sample times.

# Resolving Rate Transitions

In general, a rate transition exists between two blocks if their sample times differ, that is, if either of their sample-time vector components are different. The exceptions are:

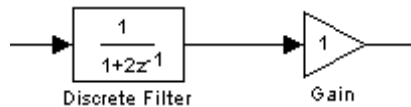
- A constant sample time ( $[Inf, 0]$ ) never has a rate transition with any other rate.
- A continuous sample time (black) and the fastest discrete rate (red) never has a rate transition if you use a fixed-step solver.
- A variable sample time and fixed in minor step do not have a rate transition.

You can resolve rate transitions by inserting rate transition blocks and by using two diagnostic tools. For the single-tasking execution mode, the **Single task rate transition** diagnostic allows you to set the level of Simulink rate transition messages. The **Multitask rate transition** diagnostic serves the same function for multitasking execution mode. These execution modes directly relate to the type of solver in use: Variable-step solvers are always single-tasking; fixed-step solvers may be explicitly set as single-tasking or multitasking.

For a detailed discussion on rate transitions, see “Single-Tasking and Multitasking Execution Modes” and “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.

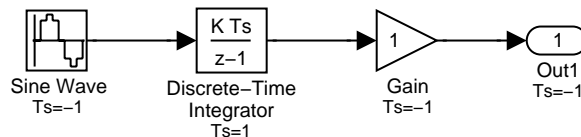
### Simulink Rules for Assigning Sample Times

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:

<b>If...</b>	<b>then</b>
all of the inputs have the same sample time and the block can accept that sample time	Simulink assigns the sample time to the block
the inputs have different discrete sample times and all of the input sample times are integer multiples of the fastest input sample time	Simulink assigns the sample time of the fastest input to the block . (This assignment assumes that the block can accept the fastest sample time.)
the inputs have different discrete sample times, some of the input sample times are not integer multiples of the fastest sample time, and the model uses a variable-step solver	Simulink assigns a fixed-in-minor-step sample time to the block.
the inputs have different discrete sample times, some of the input sample times are not integer multiples of the fastest sample time, the model uses a fixed-step solver, and Simulink can compute the greatest common integer divisor (GCD) of the sample times coming into the block,	Simulink assigns the GCD sample time to the block. Otherwise, Simulink assigns the fixed step size of the model to the block.
the sample times of some of the inputs are unknown, or if the block cannot accept the sample time	Simulink determines a sample time for the block based on a set of heuristics.

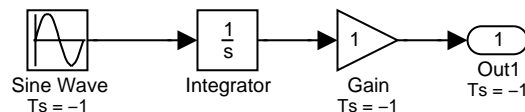
## Monitoring Backpropagation in Sample Times

When you update or simulate a model that specifies the sample time of a source block as inherited ( $-1$ ), the sample time of the source block may be backpropagated; Simulink may set the sample time of the source block to be identical to the sample time specified by or inherited by the block connected to the source block. For example, in the model below, the Simulink software recognizes that the Sine Wave block is driving a Discrete-Time Integrator block whose sample time is 1; so it assigns the Sine Wave block a sample time of 1.



You can verify this sample time setting by selecting **Sample Time Display > Colors** from the Simulink **Format** menu and noting that both blocks are red. Because the Discrete-Time Integrator block looks at its input only during its sample hit times, this change does not affect the results of the simulation, but does improve the simulation performance.

Now replacing the Discrete-Time Integrator block with a continuous Integrator block, as shown in the model below, causes the Sine Wave and Gain blocks to change to continuous blocks. You can test this change by selecting **Update Diagram** from the **Edit** menu to update the colors; both blocks now appear black.



---

**Note** Backpropagation makes the sample times of model sources dependent on block connectivity. If you change the connectivity of a model whose sources inherit sample times, you can inadvertently change the source sample times. For this reason, when you update or simulate a model, by default, Simulink displays warnings at the command line if the model contains sources that inherit their sample times.

---

# Referencing a Model

---

- “Overview of Model Referencing” on page 5-2
- “Creating a Model Reference” on page 5-8
- “Converting a Subsystem to a Referenced Model” on page 5-12
- “Referenced Model Simulation Modes” on page 5-21
- “Viewing a Model Reference Hierarchy” on page 5-35
- “Model Reference Simulation Targets” on page 5-37
- “Simulink Model Referencing Requirements” on page 5-45
- “Parameterizing Model References” on page 5-52
- “Conditional Referenced Models” on page 5-59
- “Protecting Referenced Models” on page 5-67
- “Inheriting Sample Times” on page 5-78
- “Refreshing Model Blocks” on page 5-82
- “Using S-Functions with Model Referencing” on page 5-83
- “Logging Signals in Referenced Models” on page 5-86
- “Model Referencing Limitations” on page 5-87

## Overview of Model Referencing

In this section...
“About Model Referencing” on page 5-2
“Referenced Model Advantages” on page 5-5
“Masking Model Blocks” on page 5-6
“Model Referencing Demos” on page 5-6
“Model Referencing Resources” on page 5-7

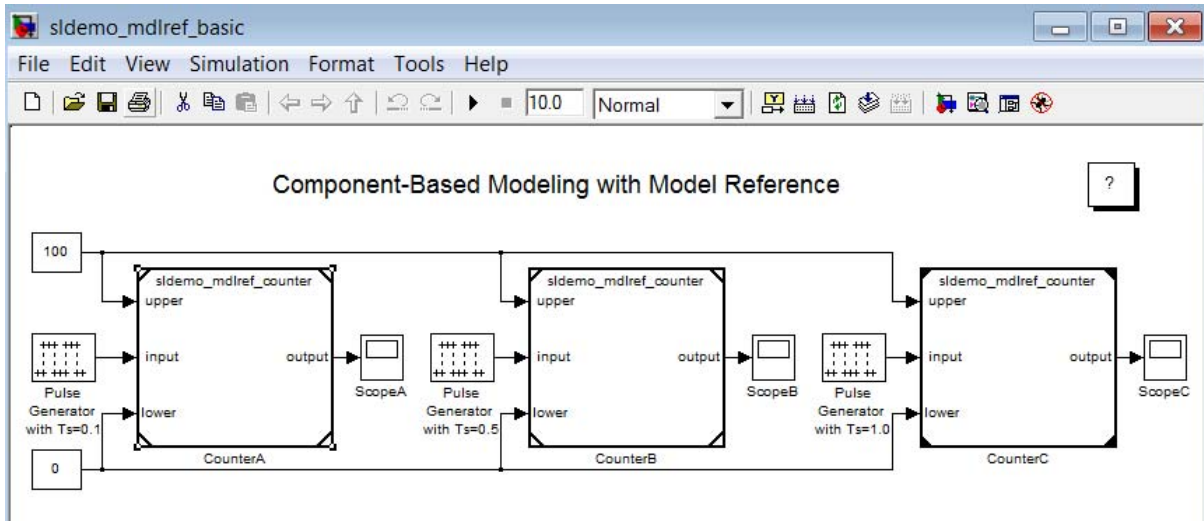
### About Model Referencing

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.

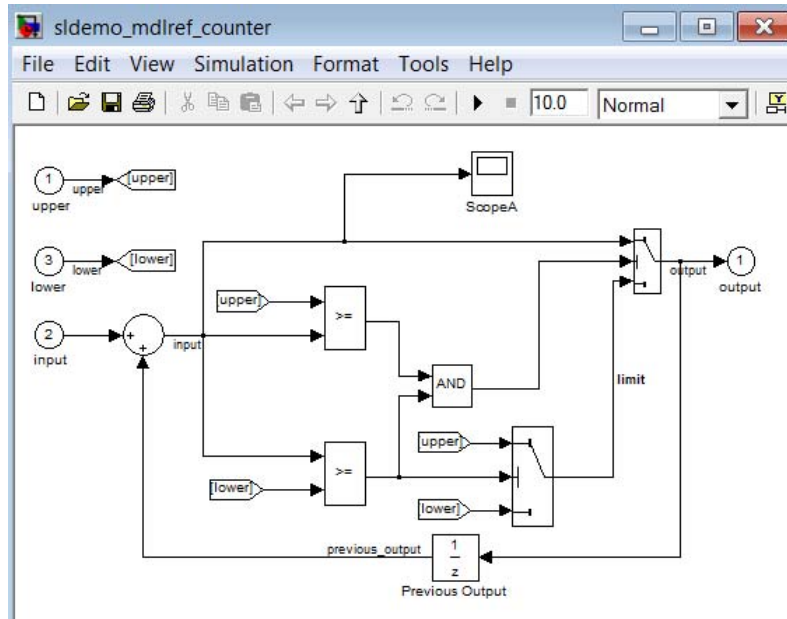
For example, in the demo `sldemo_mdref_basic` has a parent model, `sldemo_mdref_basic`, that includes three instances of the same referenced model, `sldemo_mdref_counter`.



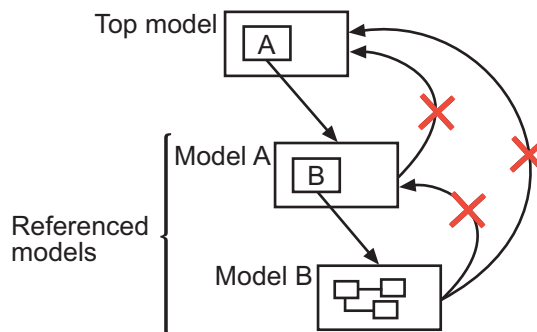


Use the ports on a Model block to connect the submodel to other elements of the parent model. Connecting a signal to a Model block port has the same effect as connecting the signal to the corresponding port in the submodel. For example, in the demo, the Model block CounterA has three inputs: two Constant 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. In the demo, 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. In the demo, sldemo\_mdref\_counter 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 “Parameterizing Model References” on page 5-52 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 5-21 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 11-17.

### Masking Model Blocks

You can use the masking facility to create custom dialog boxes and icons for Model blocks. Masked dialog boxes can make it easier to specify additional parameters for Model blocks. For details about masking, see Chapter 23, “Working with Block Masks”.

### Model Referencing Demos

Simulink includes several demos that illustrate model referencing. To access these demos:

- 1 In the MATLAB Help browser **Contents** pane, select **Simulink > Demos > Modeling Features > Model Reference**.

A list of Simulink demos appears on the left side of the Help browser.

- 2 Select a model reference demo.

The Introduction to Managing Data with Model Reference demo introduces the basic concepts and workflow related to managing data with

model referencing. To explore these topics in more detail, select the Detailed Workflow for Managing Data with Model Reference demo.

In addition, the demo `sldemo_absbrake` (**Simulink > Demos > Automotive Applications > Modeling an Anti-Lock Brake System**) represents a wheel speed calculation as a Model block within the context of an anti-lock braking system (ABS).

## Model Referencing Resources

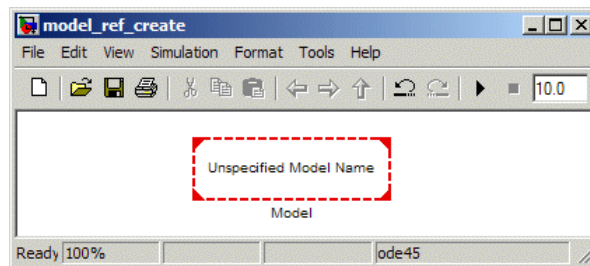
The following are the most commonly needed resources for working with model referencing:

- The Model block, which represents a model that another model references. See the Model block parameters in “Ports & Subsystems Library Block Parameters” for information about accessing a Model block programmatically.
- The **Configuration Parameters > Diagnostics > Model Referencing** pane, which controls the diagnosis of problems encountered in model referencing. See “Diagnostics Pane: Model Referencing” for details.
- The **Configuration Parameters > Model Referencing** pane, which provides options that control model referencing and list files on which referenced models depend. See “Model Referencing Pane” for details.

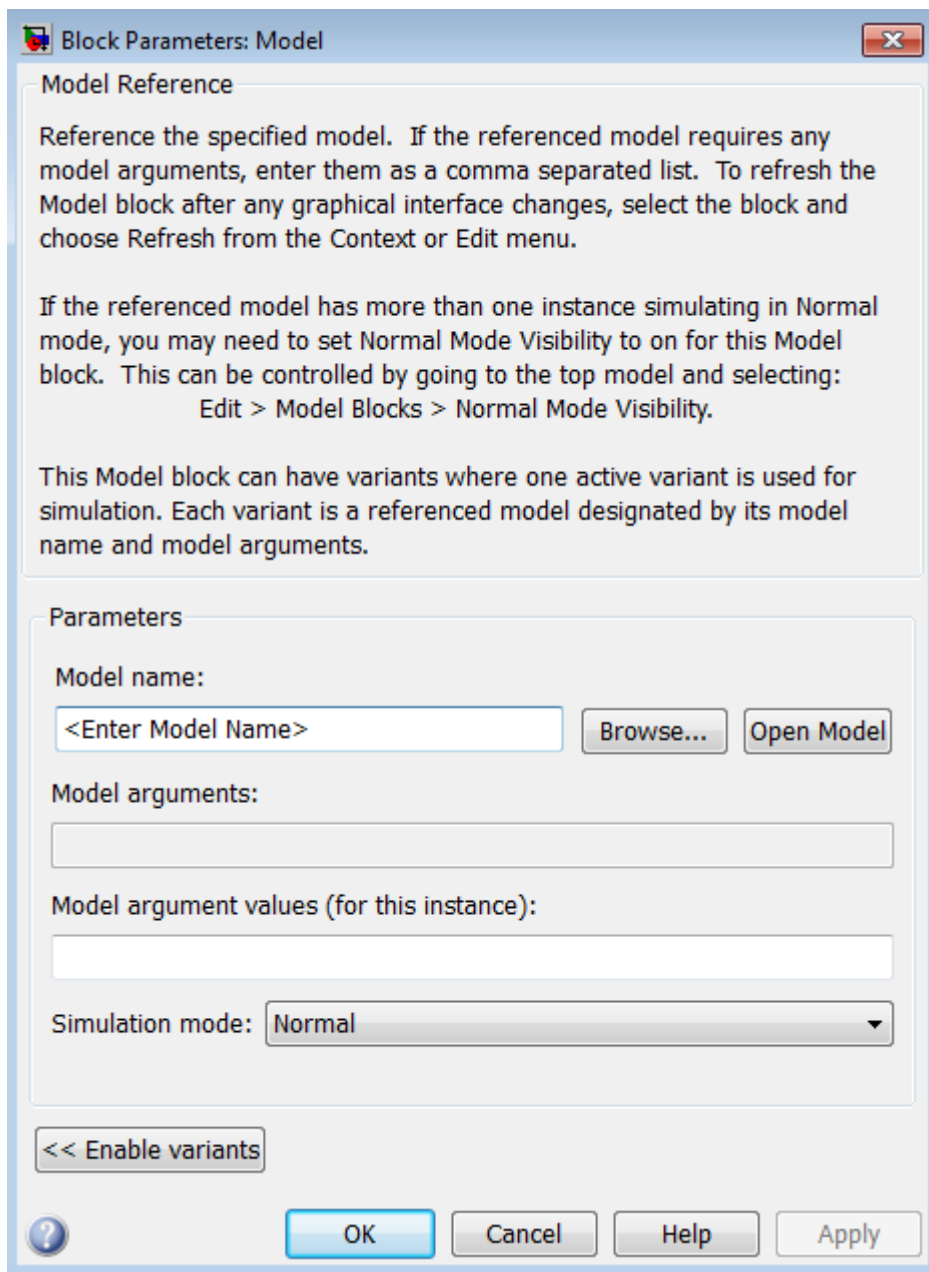
## Creating a Model Reference

A model becomes a submodel when a Model block in some other model references it. Any model can function as a submodel, and such use does not preclude using it as a separate model also. To create a reference to a model (submodel) in another model (parent model):

- 1 If the folder containing the submodel you want to reference is not on the MATLAB path, add the folder to the MATLAB path.
- 2 In the submodel:
  - Enable **Configuration Parameters > Optimization > Inline parameters**. You must enable **Inline parameters** for all models in a model reference hierarchy except the top model in the hierarchy. See “Inline Parameter Requirements” on page 5-49 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.





- 5** Enter the name of the submodel in the **Model name** field. This name must contain fewer than 60 characters. (See “Name Length Requirement” on page 5-45.)
  - For information about **Model Arguments** and **Model argument values**, see “Using Model Arguments” on page 5-53.
  - For information about the **Simulation mode**, see “Referenced Model Simulation Modes” on page 5-21.
- 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 5-50.

## Converting 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 5-12.
- 2 “Prepare the Model for Conversion” on page 5-13.
- 3 “Run a Conversion Tool” on page 5-16.
- 4 “Connect the Model Block and Perform Other Post-Conversion Tasks” on page 5-18.

### 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 5-5.

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 11-17.

The types of subsystems that you can convert to a referenced model are:

- Atomic Subsystem
- “Triggered Subsystems” on page 6-17
- “Enabled Subsystems” on page 6-4
- “Triggered and Enabled Subsystems” on page 6-21
- “Function-Call Subsystems” on page 6-26

---

**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 5-19.

## 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.

- 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 “Avoiding Mux/Bus Mixtures” on page 32-93.

As an alternative for steps b and c, consider using the associated Model Advisor checks.

**3** Configure subsystem interfaces to the model.

<b>Subsystem Interface</b>	<b>What to Look For</b>	<b>Model Modification</b>
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 <code>Simulink.Signal</code> object. For details, see “Defining Data Stores with Signal Objects” on page 30-12.
Tunable parameters	Global tunable parameters listed in the dialog box that opens when you select the <b>Configuration Parameters &gt; Optimization &gt; Signals and Parameters &gt; Configure</b> button.	Use <code>tunablevars2parameterobjects</code> to create a <code>Simulink.Parameter</code> object for each tunable parameter.  The <code>Simulink.Parameter</code> objects must have a non-Auto storage class.  For more information, see “Parameterizing Model References” on page 5-52 and “Tunable Parameters” on page 2-9.

**4** Configure the subsystem and its contents.

<b>Subsystem Configuration</b>	<b>What to Look For</b>	<b>Model Modification</b>
Inactive subsystem variants	Variant Subsystem blocks.	<p>Make active the subsystem variant that you want to convert. The conversion tool does not convert inactive subsystem variants.</p> <p>To have the new Model block behave similar to the subsystem variant, convert each variant subsystem separately.</p> <p>For details, see “Setting Up Variant Subsystems” on page 7-15.</p>
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 <code>namelengthmax</code> 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 **Convert to Model Block**.
- Use the `Simulink.SubSystem.convertToModelReference` command.

This function provides more capabilities than the **Convert to Model Block** 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 “Setting Up Model Variants” on page 7-5.



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 5-19.

## Convert a Masked Subsystem

Perform the tasks described in:

- “Select Subsystems to Convert” on page 5-12.
- “Prepare the Model for Conversion” on page 5-13.
- “Run a Conversion Tool” on page 5-16.
- “Connect the Model Block and Perform Other Post-Conversion Tasks” on page 5-18.

If the subsystem that you converted contains a mask, then you might want to mask the Model block in your new referenced model (see Chapter 23, “Working with Block Masks”). 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.

---

<b>Masked Subsystem Functionality</b>	<b>Referenced Model Configuration</b>
Masked parameters	<ol style="list-style-type: none"> <li><b>1</b> In the model workspace of the referenced model, create a variable for each masked parameter.</li> <li><b>2</b> In the Model Explorer, select the Model Workspace node. In the Dialog pane, in the <b>Model arguments</b> parameter, enter the variables that you want to be model arguments.</li> </ol>

<b>Masked Subsystem Functionality</b>	<b>Referenced Model Configuration</b>
	<b>3</b> In the new Model block, for the <b>Model arguments</b> 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...

“About Referenced Model Simulation Modes” on page 5-21

“Specifying the Simulation Mode” on page 5-23

“Mixing Simulation Modes” on page 5-23

“Using Normal Mode for Multiple Instances of Referenced Models” on page 5-25

“Accelerating a Freestanding or Top Model” on page 5-33

### About Referenced Model Simulation Modes

Simulink executes the top model in a model reference hierarchy just as it would if no referenced models existed. All Simulink simulation modes are available to the top model. Simulink can execute a referenced model in any of four modes: Normal, Accelerator, Software-in-the-loop (SIL), or Processor-in-the-loop (PIL).

#### Normal Mode

Simulink executes a Normal mode submodel interpretively. Normal mode, compared to other simulation modes:

- Requires no delay for code generation or compilation
- Works with more Simulink and Stateflow tools, supporting tools such as:
  - Scopes, port value display, and other output viewing tools
    - Scopes work with Accelerator mode referenced models, but require using the Signal & Scope Manager and adding test points to signals. Adding or removing a test point necessitates rebuilding the SIM target for a model, which can be time-consuming.
  - Model coverage analysis
  - Stateflow debugging and animation
- Provides more accurate linearization analysis
- Supports more S-functions than Accelerator mode does

Normal mode executes slower than Accelerator mode does.

Simulation results for a given model are nearly the same in either Normal or Accelerator mode. Trivial differences can occur due to differences in the optimizations and libraries that you use.

You can use Normal mode with multiple instances of a referenced model. For details, see “Using Normal Mode for Multiple Instances of Referenced Models” on page 5-25.

### **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 5-37 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 Checking” 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 Checking” in the Embedded Coder documentation.

### **Specifying the Simulation Mode**

The Model block for each instance of a referenced model controls its simulation mode. To set or change the simulation mode for a submodel:

- 1** Access the block parameter dialog box for the Model block. (See “Navigating a Model Block”.)
- 2** Set the **Simulation mode** parameter.
- 3** Click **OK** or **Apply**.

### **Mixing Simulation Modes**

The following table summarizes the relationship between the simulation mode of the parent model and its submodels.

<b>Parent Model Simulation Mode</b>	<b>Submodel Simulation Modes</b>
Normal	<ul style="list-style-type: none"> <li>• Submodels can use Normal, Accelerator, SIL, or PIL mode.</li> <li>• A submodel can execute in Normal mode <i>only</i> 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.</li> </ul>
Accelerator	<ul style="list-style-type: none"> <li>• All subordinate models must also execute in Accelerator mode.</li> <li>• When a Normal mode model is subordinate to an Accelerator mode model, Simulink posts a warning and temporarily overrides the Normal mode specification.</li> <li>• When a SIL-mode or PIL-mode model is subordinate to an Accelerator mode model, an error occurs.</li> </ul>
SIL	<ul style="list-style-type: none"> <li>• All subordinate models also execute in SIL mode regardless of the simulation mode specified by their Model blocks.</li> <li>• The SIL mode Model block uses the model reference targets of the blocks beneath.</li> <li>• 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”.</li> </ul>
PIL	<ul style="list-style-type: none"> <li>• All subordinate models also execute in PIL mode regardless of the simulation mode specified by their Model blocks.</li> <li>• The PIL mode Model block uses the model reference targets of the blocks beneath.</li> </ul>

Parent Model Simulation Mode	Submodel Simulation Modes
	<ul style="list-style-type: none"> <li>• 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”.</li> </ul>

For more information about SIL and PIL modes, see in the Embedded Coder documentation:

- “SIL and PIL Code Interfaces”
- “SIL and PIL Simulation Support and Limitations”

## Using Normal Mode for Multiple Instances of Referenced Models

You can simulate a model that has multiple references in Normal mode.

### Normal Mode Visibility

All instances of 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 “Specifying the Instance That Has Normal Mode Visibility” on page 5-28.

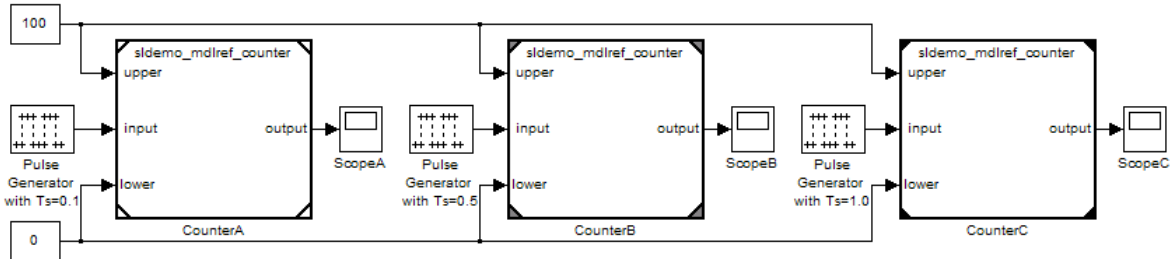
**Note** If you change the Normal Mode Visibility setting for a referenced model, you must simulate the top model in the model reference hierarchy to make use of the new setting.

### Examples of a Model with Multiple Referenced Instances in Normal Mode

**sldemo\_md1ref\_basic.** The sldemo\_md1ref\_basic demo model has three Model blocks (CounterA, CounterB, and CounterC) that each reference the sldemo\_md1ref\_counter model.

If you update the diagram, the sldemo\_md1ref\_basic displays different icons for each of the three Model blocks that reference sldemo\_md1ref\_counter.

Component-Based Modeling with Model Reference

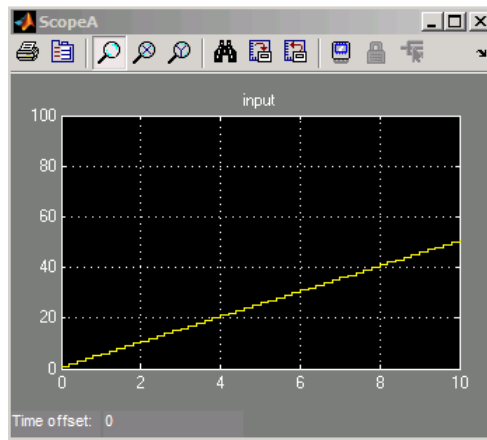


Model Block	Icon Corners	Simulation Mode and Normal Mode Visibility Setting
CounterA	White	Normal mode, with Normal Mode Visibility enabled
CounterB	Gray corners	Normal mode, with Normal Mode Visibility disabled
CounterC	Black corner	Accelerator mode (Normal Mode Visibility is not applicable)



If you do the following steps, then the ScopeA block appears as shown below:

- 1 Simulate `sldemo_md1ref_basic`.
- 2 Open the `sldemo_md1ref_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 `md1ref_counter` model from the CounterB Model block (for example, by double-clicking the Model block), ScopeA in `md1ref_counter` still shows the results of the CounterA Model block, because that is the Model block with Normal Mode Visibility set to on.

**`sldemo_md1ref_depgraph`.** The `sldemo_md1ref_depgraph` demo model shows the use of the Model Dependency Viewer for a model that has multiple Normal mode instances of a referenced model. The demo shows what you need to do to set up a model with multiple referenced instances in Normal mode.

### Setting Up a Model with Multiple Instances of a Referenced Model in Normal Mode

This section describes how to set up a model to support the use of multiple instances of Normal mode referenced models.

- 1 Set the **Configuration Parameters > Model Referencing > Total number of instances allowed per top model** parameter to **Multiple**.

If you cannot use the **Multiple** setting for your model, because of the requirements described in the “Total number of instances allowed per top model” parameter documentation, then you can have only one instance of that referenced model be in Normal mode.

- 2 For each instance of the referenced model that you want to be in Normal mode, in the block parameters dialog box for the Model block, set the **Simulation Mode** parameter to **Normal**. Ensure that all the ancestors in the hierarchy for that Model block are in Normal mode.

The corners of icons for Model blocks that are in Normal mode can be white (empty), or gray after you update the diagram or simulate the model.

- 3 (If necessary) Modify S-functions used by the model so that they work with multiple instances of referenced models in Normal mode. For details, see “Supporting the Use of Multiple Instances of Referenced Models That Are in Normal Mode”.

By default, Simulink assigns Normal mode visibility to one of the instances. After you have performed the steps in this section, you can specify a non-default instance to have Normal mode visibility. For details, see “Specifying the Instance That Has Normal Mode Visibility” on page 5-28.

### Specifying the Instance That Has Normal Mode Visibility

This section describes how to specify Normal Mode Visibility for an instance other than the one that an instance that Simulink selects automatically.

You need to:

- 1 (Optionally) “Determine Which Instance Has Normal Mode Visibility” on page 5-29.

**2** “Set Normal Mode Visibility” on page 5-30.

**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_mdref_basic',...
  'ModelReferenceNormalModeVisibilityBlockPath')
```

```
ans =
```

```
Simulink.BlockPath
Package: Simulink
```

```
Block Path:
  'sldemo_mdref_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_mdref_depgraph',...
  'CompiledModelBlockInstancesBlockPath')
```

```
a =
```

```
sldemo_mdhref_F2C: [1x1 Simulink.BlockPath]
sldemo_mdhref_heater: [1x1 Simulink.BlockPath]
sldemo_mdhref_outdoor_temp: [1x1 Simulink.BlockPath]
```

**Set Normal Mode Visibility.** To enable Normal Mode Visibility for a different instance of the referenced model than the instance that currently has Normal Mode Visibility, use *one* of these approaches:

- Navigate to the top model and select the **Edit > Links and Model Blocks > Normal Mode Visibility** menu item.

The Model Block Normal Mode Visibility dialog box appears. That dialog box includes instructions in the right pane. For additional details about the dialog box, see “Working with the Model Block Normal Mode Visibility Dialog Box” on page 5-31.

- 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.

---

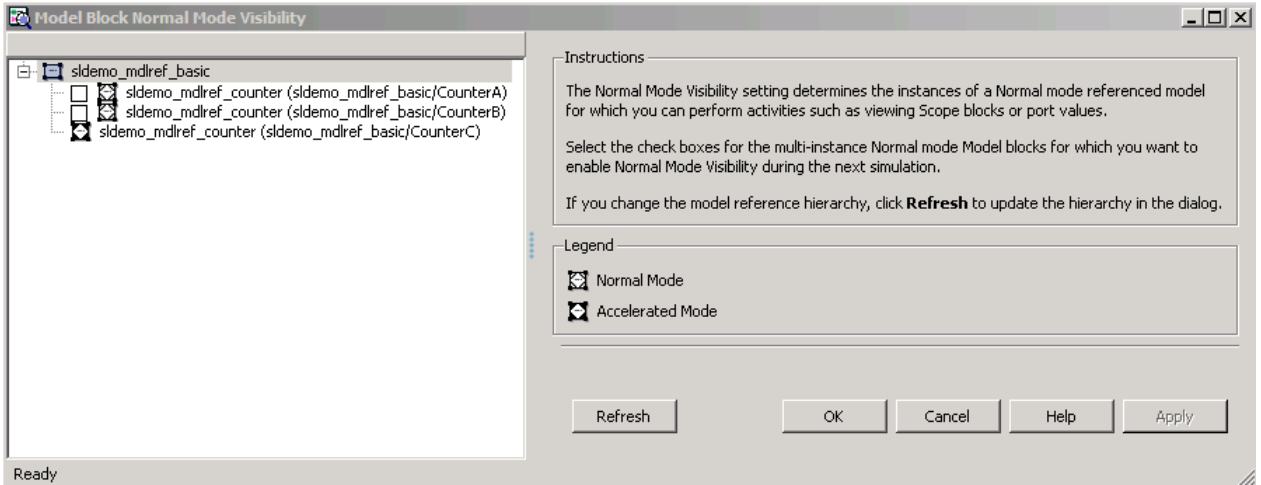
## Working with the Model Block Normal Mode Visibility Dialog Box

If you have a model that has multiple instances of a referenced model in Normal mode, you can use the Block Model Normal Mode Visibility dialog box to set Normal Mode Visibility for a specific instance. For a description of Normal mode visibility, see “Normal Mode Visibility” on page 5-25.

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 “Specifying the Instance That Has Normal Mode Visibility” on page 5-28.

**Opening the Model Block Normal Mode Visibility Dialog Box.** To open the Model Block Normal Mode Visibility dialog box, navigate to the top model and select the **Edit > Links and Model Blocks > Normal Mode Visibility** menu item.

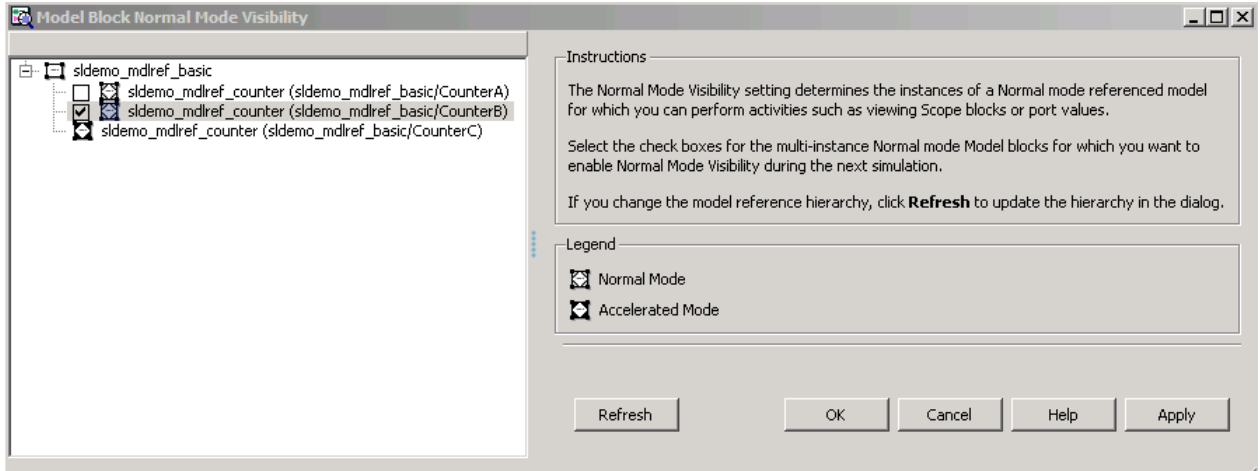
The dialog box for the `sldemo_md1ref_basic` demo model, with the hierarchy pane expanded, looks like this:



The model hierarchy pane shows a partial model hierarchy for the model from which you opened the dialog box. The hierarchy stops at the first Model block that is not in Normal mode. The model hierarchy pane does not display Model blocks that reference protected models.

### Selecting a Model for Normal Mode Visibility.

The dialog box shows the complete model block hierarchy for the top model. The Normal mode instances of referenced models have check boxes. Select the check box for the instance of each model that you want to have Normal mode visibility.



When you select a model, Simulink:

- Selects all ancestors of that model
- Deselects all other instances of that model

When a model is deselected, Simulink deselects all children of that model.

**Opening a Model from the Model Block Normal Mode Visibility Dialog Box.** You can open a model from the Model Block Normal Mode Visibility dialog box by right-clicking the model in the model hierarchy pane and clicking **Open**.

**Refreshing the Model Reference 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 Chapter 19, “Accelerating Models” 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 a warning message.

Be careful not to confuse Accelerator mode execution of a referenced model with:

- Accelerator mode execution of a freestanding or top model, as described in Chapter 19, “Accelerating Models”
- 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.



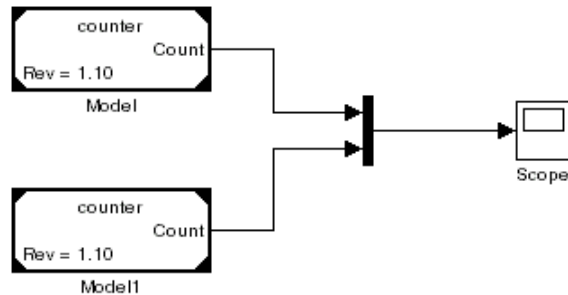
## Viewing a Model Reference Hierarchy

Simulink provides tools and functions that you can use to examine a model reference hierarchy:

- **Model Dependency Viewer** — Shows the structure the hierarchy lets you open constituent models. The Referenced Model Instances view displays Model blocks differently to indicate Normal, Accelerator, and PIL modes. See “Model Dependency Viewer” on page 8-80 for more information.
- **view\_mdrefs function** — Invokes the Model Dependency Viewer to display a graph of model reference dependencies.
- **find\_mdrefs function** — Finds all models directly or indirectly referenced by a given model.

## Displaying Version Numbers

To display the version numbers of the models referenced by a model, for the parent model, choose **Format > Block displays > Model block version**. Simulink displays the version numbers in the icons of the corresponding Model block instances.



The version number displayed on a Model block icon refers to the version of the model used to either:

- Create the block
- Refresh the block most recently

See “Managing Model Versions” on page 3-102 and “Refreshing Model Blocks” on page 5-82 for more information.

## Model Reference Simulation Targets

### In this section...

“About Simulation Targets” on page 5-37

“Building Simulation Targets” on page 5-38

“Simulation Target Output File Control” on page 5-39

“Parallel Building for Large Model Reference Hierarchies” on page 5-42

### About Simulation Targets

A *simulation target*, or *SIM target*, is a MEX-file that implements a referenced model that executes in Accelerator mode. Simulink invokes the simulation target as needed during simulation to compute the behavior and outputs of the referenced model. Simulink uses the same simulation target for all Accelerator mode instances of a given referenced model anywhere in a reference hierarchy.

Be careful not to confuse the simulation target of a submodel with any of these other types of target:

- Hardware target — A platform for which 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 5-91 for details.

### Building Simulation Targets

Simulink by default generates the needed target from the referenced model:

- If a simulation target does not exist at the beginning of a simulation
- When you 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.

## Reducing Change Checking Time

You can reduce the time that Simulink spends checking whether any or all simulation targets require rebuilding by setting configuration parameter values as follows:

- In all referenced models throughout the hierarchy, set **Configuration Parameters > Diagnostics > Data Validity > Signal resolution** to **Explicit only**. (See “Signal resolution”.)
- 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 `s1prj` subfolder of the working folder. If `s1prj` does not exist, Simulink creates it.

---

**Note** Simulink Coder code generation also uses the `s1prj` folder. Subdirectories in `s1prj` 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.

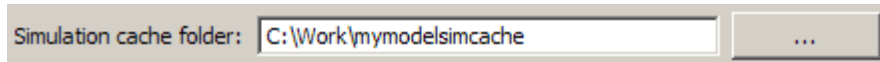
To allow you to control the output locations for the files generated by diagram updates and model builds, the software allows you to separately specify the *simulation cache folder* build folder. The simulation cache folder is the root folder in which to place artifacts used for simulation.

To specify the simulation cache folder, use *one* of these approaches:

- Use the CacheFolder MATLAB session parameter.
- Open the Simulink Preferences dialog box (**File > 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.

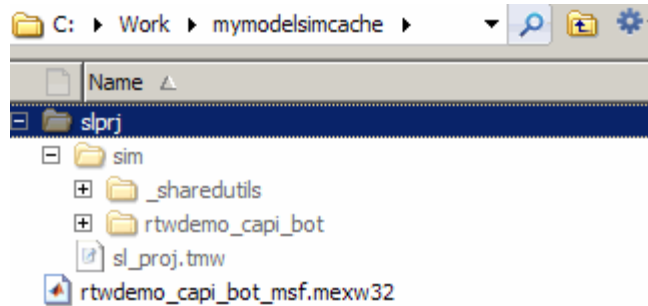
### Controlling the Output Location for Model Build Artifacts Used for Simulation

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 demo 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.

## Overriding 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.

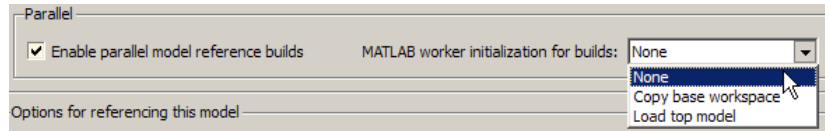
### Parallel Building for Large Model Reference Hierarchies

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” on page 5-45
“Name Length Requirement” on page 5-45
“Configuration Parameter Requirements” on page 5-45
“Model Structure Requirements” on page 5-50

## 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 5-87.

## Name Length Requirement

The name of a referenced model must contain fewer than 60 characters, exclusive of the .mdl suffix. An error occurs if the name of a referenced model is too long.

## Configuration Parameter Requirements

A referenced model uses a configuration set in the same way that any other model does, as described in “Manage a Configuration Set” on page 9-8. 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 9-14 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 <b>Stop time</b> of the top model for simulation, overriding any differing <b>Stop time</b> in a submodel.
	Type Solver	The <b>Type</b> and <b>Solver</b> of the top model apply throughout the hierarchy. See “Solver Requirements” on page 5-48.
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 5-49.
	Application lifespan (days)	Must be the same for top and referenced models.

<b>Dialog Box Pane</b>	<b>Option</b>	<b>Requirement</b>
<b>Model Referencing</b>	<b>Total number of instances allowed per top model</b>	Must not be Zero in a referenced model. Specifying One rather than Multiple is preferable or required in some cases. See “Model Instance Requirements” on page 5-49.
<b>Hardware Implementation</b>	<b>Embedded hardware options</b>	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.

<b>Top Model Solver Type</b>	<b>Submodel Solver Type</b>	<b>Compatibility</b>
Fixed Step	Fixed Step	Allowed
Variable Step	Variable Step	Allowed
Variable Step	Fixed-step	Allowed unless the submodel is multi-rate and specifies both a discrete sample time and a continuous sample time
Fixed Step	Variable Step	Error

If an incompatibility exists between the top model solver and any submodel solver, one or both models must change to use compatible solvers. For information about solvers, see “Solvers” on page 2-22 and “Choosing a Solver” on page 13-9.

**Inline Parameter Requirements.** Simulink requires enabling **Configuration Parameters > Optimization > Inline parameters** (see “Inline parameters”) for all referenced models in a reference hierarchy. The top model can enable or disable inline parameters. If a referenced model disables inlined parameters, and you try to simulate the parent model:

- For a Normal mode submodel, Simulink generates an error and cancels the build. All models and compiled files remain unchanged after the failed build.
- For an Accelerator mode submodel, Simulink temporarily enables inline parameters, posts no warning, and builds the model. Inline parameters remain disabled after the build completes.

Simulink ignores tunable parameter specifications in the Model Parameter Configuration dialog box for both the top model and referenced models. Do not use this dialog box to override the inline parameters optimization for selected parameters to permit them to be tuned. Instead, see “Parameterizing Model References” on page 5-52 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 5-88 and “Accelerator Mode Reusability Limitations” on page 5-92.

### **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 Output block of a referenced model. A signal connected to an unlabeled line of an Output block of a referenced model cannot propagate out of the Model block to the parent model.

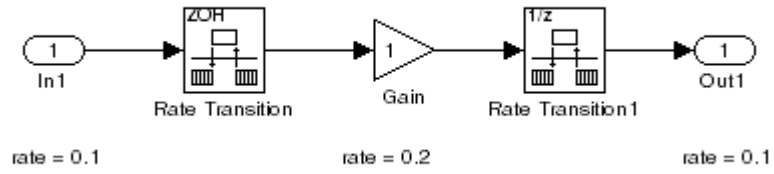
### **Bus Usage Requirements**

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 32-2 for more information.

### **Sample Time Requirements**

The first nonvirtual block connected to a root-level Inport or Output 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.





## Parameterizing Model References

In this section...
“Introduction” on page 5-52
“Global Nontunable Parameters” on page 5-53
“Global Tunable Parameters” on page 5-53
“Using Model Arguments” on page 5-53

### Introduction

A parameterized referenced model obtains values that affect the behavior of the referenced model from some source outside the model. Changing the values changes the behavior of the model, without recompiling the model.

Due to the constraints described in “Inline Parameter Requirements” on page 5-49, 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 “Using Structure Parameters” on page 21-16.

## Global Nontunable Parameters

A *global nontunable parameter* is a MATLAB variable or a Simulink.Parameter object whose storage class is auto. The parameter can exist in the MATLAB workspace or any model workspace visible to all referenced models that use the parameter.

Using a global nontunable parameter in a referenced model sets the parameter value before the simulation begins. This allows you to control the behavior of the referenced model. All instances of the model use the same value. You cannot change the value during simulation, but you can change it between one simulation and the next. The change requires rebuilding the model in which the change occurs, but not any models that it references. See “Specifying Parameter Values” on page 21-6 for details.

## Global Tunable Parameters

A *global tunable parameter* is a Simulink.Parameter object whose storage class is other than auto. The parameter exists in the MATLAB workspace.

Using a global tunable parameter in a referenced model allows you to control the behavior of the referenced model by setting the parameter value. All instances of the model use the same value. You can change the value during simulation or between one simulation and the next. The change does not require rebuilding the model in which the change occurs, or any models that it references. See “Using Tunable Parameters” on page 21-13 for details.

To reference a model that uses tunable parameters defined with the “Model Parameter Configuration Dialog Box”, change the model to implement tunability another way. To facilitate this task, Simulink provides a command that converts tunable parameters specified in the Model Parameter Configuration dialog box to global tunable parameters. See `tunablevars2parameterobjects` for details.

## Using Model Arguments

Model arguments let you parameterize references to the same model so that each instance of the model behaves differently. Without model arguments, a variable in a referenced model has the same value in every instance of the model. Declaring a variable to be a model argument allows each instance of the model to use a different value for that variable.

To create model arguments for a referenced model:

- 1 Create MATLAB variables in the model workspace.
- 2 Add the variables to a list of model arguments associated with the model.
- 3 Specify values for those variables separately in each Model block that references the model

The values specified in the Model block replace the values of the MATLAB variables for that instance of the model.

A referenced model that uses model arguments can also appear as a top model or a standalone model. No Model block then exists to provide model argument values. The model uses the values of the MATLAB variables themselves, as defined in the model workspace. Thus, you can use the same model without change as a top model, a standalone model, and a parameterized referenced model.

The demo model `sldemo_md1ref_datamngt` demonstrates techniques for using model arguments. The demo passes model argument values to referenced models through masked Model blocks. Such masking can be convenient, but is independent of the definition and use of model arguments themselves. See Chapter 23, “Working with Block Masks” for information about masking.

The rest of this section describes techniques for declaring and using model arguments to parameterize a referenced model independently of any Model block masking. The steps are:

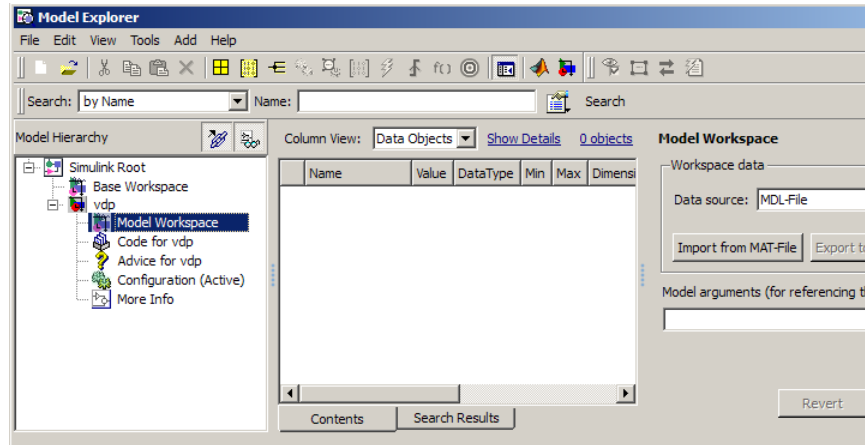
- Create MATLAB variables in the model workspace.
- Register the variables to be model arguments.
- Assign values to those arguments in Model blocks.

### **Creating the MATLAB Variables**

To create MATLAB variables for use as model arguments:

- 1 Open the model for which you want to define model arguments.
- 2 Open the Model Explorer.

- 3** In the Model Explorer **Model Hierarchy** pane, select the workspace of the model:



- 4** From Model Explorer's **Add** menu, select **MATLAB Variable**.

A new MATLAB variable appears in the **Contents** pane with a default name and value.

- 5** In the **Contents** pane:
- a** Change the default name of the new MATLAB variable to a name that you want to declare as a model argument.
  - b** If you also use the model as a top or standalone model, specify the value for that variable for use in that context. This value must be numeric.
  - c** If the variable type does not match the dimensions and complexity of the model argument, specify a value that has the correct type. This type must be numeric.
- 6** Repeat adding and naming MATLAB variables until you have defined all the variables that you need.

## Registering the Model Arguments

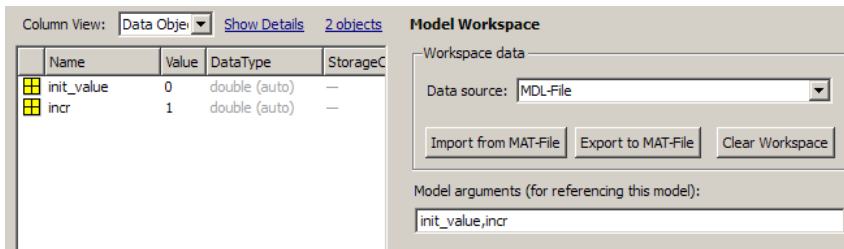
To register MATLAB variables as model arguments:

- 1 Again, in the Model Explorer **Model Hierarchy** pane, select the workspace of the model.

The Dialog pane displays the Model Workspace dialog.

- 2 In the Model Workspace dialog, enter the names of the MATLAB variables that you want to declare as model arguments. Use a comma-separated list in the **Model arguments** field.

For example, suppose you added two MATLAB variables named `init_value` and `incr`, and you declared them to be model arguments. The **Contents** and **Dialog** panes of the Model Explorer could look like this:

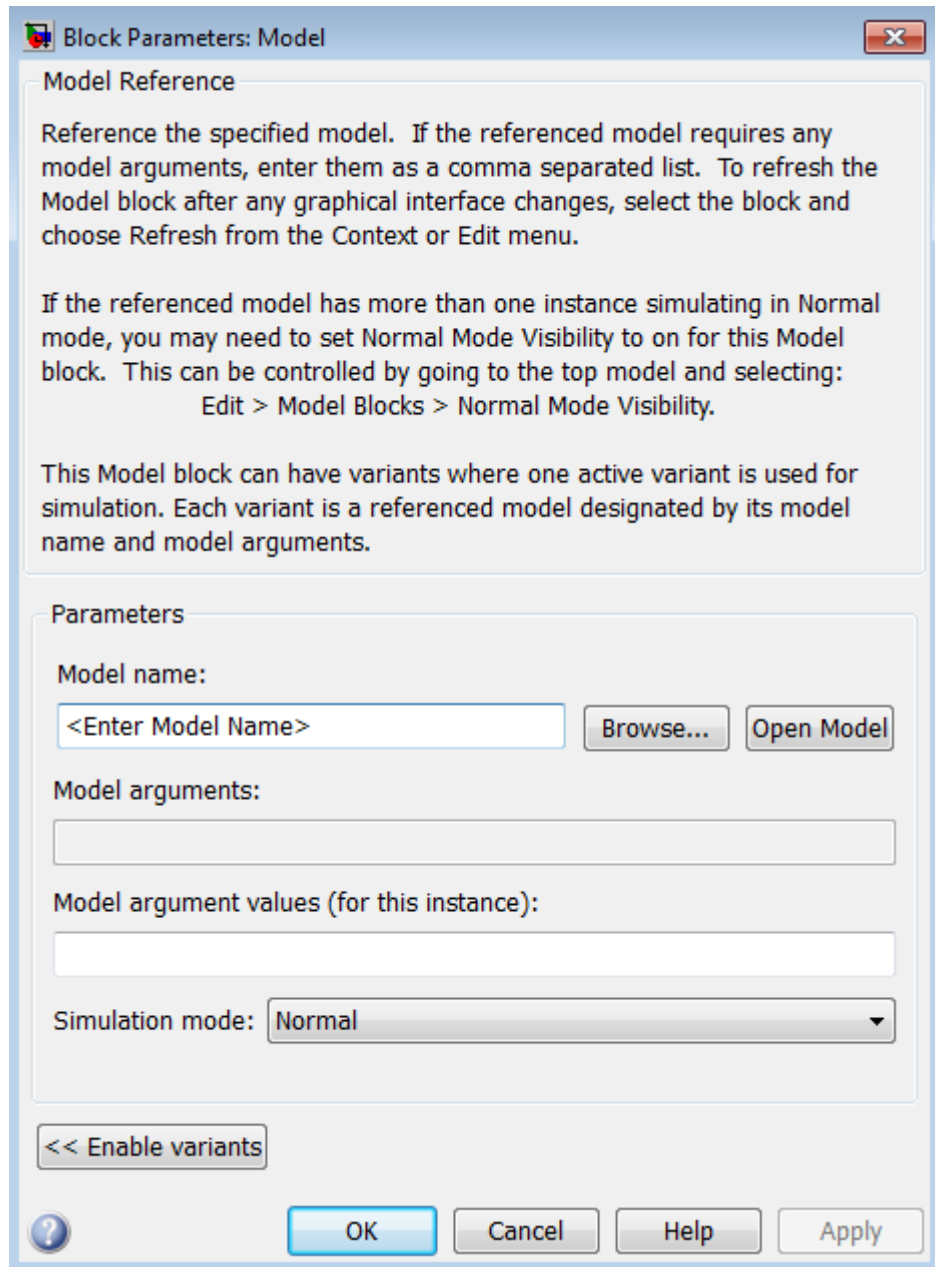


- 3 Click **Apply** to confirm the entered names.

### Assigning Model Argument Values

If a model declares model arguments, assign values to those arguments in each Model block that references the model. Failing to assign a value to a model argument causes an error: the value of the model argument does *not* default to the value of the corresponding MATLAB variable. That value is available only to a standalone or top model. To assign values to the arguments of a referenced model:

- 1 Open the parameter dialog box of the Model block by right-clicking the block and choosing **Model Reference Parameters** from the context menu.



The second field, **Model arguments**, specifies the same MATLAB variables, in the same order, that you previously typed into the **Model arguments** field of the Model Workspace dialog. This field is not editable. It provides a reminder of which model arguments need values assigned, and in what order.

- 2** In the **Model argument values** field, enter a comma-delimited list of values for the model arguments that appear in the **Model arguments** field. Simulink assigns the values to arguments in positional order, so they must appear in the same order as the corresponding arguments.

You can enter the values as literal values, variable names, MATLAB expressions, and Simulink parameter objects. Any symbols used resolve to values as described in “Hierarchical Symbol Resolution” on page 3-77. 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” on page 5-59

“Working with Conditional Referenced Models” on page 5-60

“Create Conditional Models” on page 5-61

“Reference Conditional Models” on page 5-63

“Simulate Conditional Models” on page 5-63

“Generate Code for Conditional Models” on page 5-64

“Requirements for Conditional Models” on page 5-64

### 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 6-2.

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 demo that illustrates how you can use trigger ports in referenced models, see the Introduction to Managing Data with Model Reference demo. In that demo, 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 6-26 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_mdref_fcncall` demo.

### 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 5-61
- “Reference Conditional Models” on page 5-63
- “Simulate Conditional Models” on page 5-63
- “Generate Code for Conditional Models” on page 5-64

Each kind of conditionally executed model has some model creating requirements. For details, see “Requirements for Conditional Models” on page 5-64.

## 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

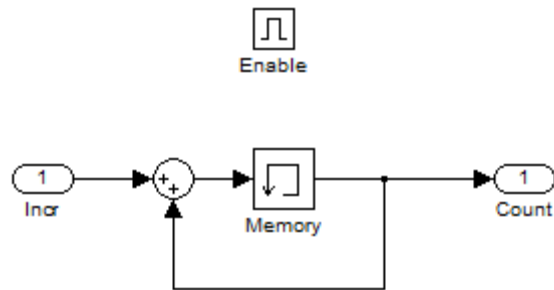
For an enabled model, go to Step 3.

- 2 For the Trigger block, set the **Trigger type** parameter, based on the kind of model:

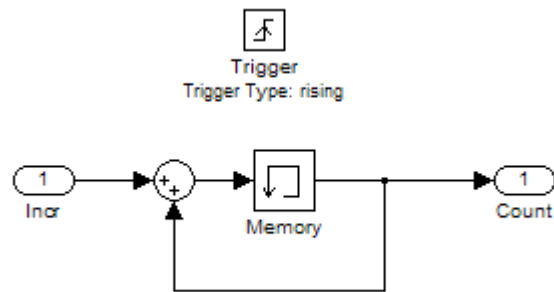
Kind of Model	Trigger Type Parameter Setting
Triggered Triggered and enabled	One of the following: <ul style="list-style-type: none"> <li>• rising</li> <li>• falling</li> <li>• either</li> </ul>
Function-Call	function-call

- 3 Create and connect other blocks to implement the model.

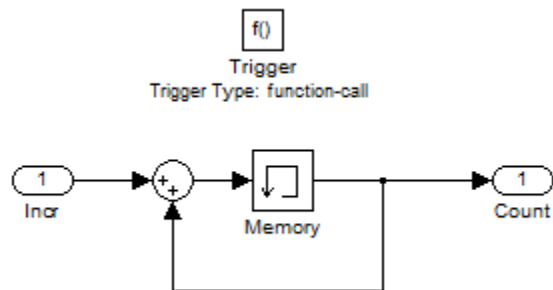
**Enabled** model example:



**Triggered** model example:



**Function-call** model example:



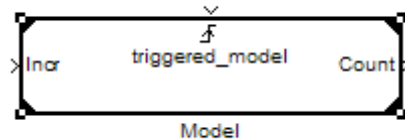
- 4 Ensure that the model satisfies the requirements for a conditional model. See the appropriate section:
  - “Enabled Model Requirements” on page 5-65
  - “Triggered Model Requirements” on page 5-65
  - “Function-Call Model Requirements” on page 5-65

## 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 “Creating a Model Reference” on page 5-8 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 5-45 and “Model Referencing Limitations” on page 5-87 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 “Importing Signal Data in Simulink” on page 29-61.

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 Chapter 6, “Creating Conditional Subsystems”)
- Referenced models (see “Simulink Model Referencing Requirements” on page 5-45)

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 output 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 output.
  - 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 timeOtherwise, the referencing model can trigger the function-call model at any rate.
- A function-call model must not have direct internal connections between its root-level input and output ports. Simulink does not honor the None and

Warning settings for the **Invalid root Inport/Outport block connection** diagnostic for a referenced function-call model. It reports all invalid root port connections as errors.

- If the **Sample time type** is periodic, the sample-time period must not contain an offset.
- The signal connected to a function-call port of a Model block must be scalar.



## Protecting Referenced Models

### In this section...

“About Protected Models” on page 5-67

“The Model Protection Facility” on page 5-68

“Model Protection Requirements” on page 5-68

“Creating a Protected Model” on page 5-69

“Obtaining Object and Variable Names for a Protected Model” on page 5-72

“Packaging a Protected Model” on page 5-74

“Testing a Protected Model” on page 5-74

“Using a Protected Model” on page 5-76

“Model Protection Limitations” on page 5-77

### About Protected Models

A *protected model* is a referenced model that eliminates all block and line information. Protecting a model does not use encryption technology. You can distribute a protected model without revealing the intellectual property that it embodies. When simulated, a protected model gives the same results that its source model does when referenced in Accelerator mode.

You can use a protected model much as you could any other referenced model. Simulink tools work with protected models to the extent possible given that contents of the model are hidden. For example, the Model Explorer and the Model Dependency Viewer show the hierarchy under an ordinary referenced model, but not under a protected model. You cannot log signals in a protected model, because the log could reveal information about the protected model contents.

Some referenced model require object definitions or tunable parameters that are defined in the MATLAB base workspace. For those models, the protected version may need some of those same definitions when it executes as part of a third-party model. Simulink provides techniques for identifying and obtaining the needed data, and then packaging it with the protected model for delivery.

Protecting a model requires a Simulink Coder license, which makes code generation capabilities available for use internally when creating the protected version of the model.

A third party that receives the model does not need a Simulink Coder license to use the model. Also, a third party cannot use Simulink Coder to generate code for the model or any model that references it.

### The Model Protection Facility

The *Model Protection facility* is a set of Simulink commands, tools, and techniques that you can use to:

- Protect a referenced mode
- Identify definitions that it needs
- Package the model and any definitions for delivery to a third party

The receiver can then unpackage and use the protected model and any definitions.

To see a demo of the Model Protection facility, access MATLAB Help browser and choose **Simulink > Demos > Modeling Features > Model Reference > Model Reference Protected Models**

### Model Protection Requirements

Protecting a model requires meeting all requirements listed in “Simulink Model Referencing Requirements” on page 5-45, as well as the following:

- You must have a Simulink Coder license, which you can obtain via <http://www.mathworks.com>.
- Your platform and your version of Simulink must match the platform and version of Simulink that the protected model uses.
- The model that you protect must be available on the MATLAB path and have no unsaved changes.
- The model that you protect cannot reference any subordinate protected model directly or indirectly.

Model protection is also subject to certain limitations, as described in “Model Protection Limitations” on page 5-77.

## Creating a Protected Model

You can create a protected model using either:

- The `Simulink.ModelReference.protect` command
- The Model block context menu (see “Creating a Protected Model Using the Model Block Context Menu” on page 5-70)

The command-line interface allows you to:

- Specify the path for the protected model (The Model block interface creates the protected model in the current folder.)
- Choose whether to generate a test harness (The Model block interface automatically generates a test harness.) For details about the generated test harness, see “The Harness Model” on page 5-71.

When you create a protected model:

- By default Simulink creates a protected version of the referenced model and stores the protected version in the current working folder. The protected model has the same name as the source model, with the suffix `.mdlp`.

---

**Caution** *Never change the name of a protected model.* If you rename a protected model, or change its suffix, the model is unusable until you restore its original name and suffix. You also cannot change a protected model internally in any way: any internal change destroys the usability of the file.

---

- In the Library Browser, a small image of a lock appears in the upper-left corner of the icon for a protected model.
- If the Model block uses variants, only the active variant is protected. For more information, see Chapter 7, “Modeling Variant Systems”.

### Creating a Protected Model Using the Simulink.ModelReference.protect Command

You can use the `Simulink.ModelReference.protect` command create a protected model.

To create only a protected model, with no harness model or list of names, specify the source model to the `protect` command:

```
Simulink.ModelReference.protect(model)
```

To specify a folder other than the current working folder to contain the protected model, use the optional `Path` argument:

```
Simulink.ModelReference.protect(model, 'Path', pathname)
```

where *pathname* is a fully qualified pathname of an accessible writeable folder.

To create a harness model when you protect a model, specify the optional `Harness` argument as `true`. The `protect` command returns the handle of the harness model in the first output argument:

```
[harnessHandle] = Simulink.ModelReference.protect(model, 'Harness', true)
```

For details about the generated test harness, see “The Harness Model” on page 5-71.

### Creating a Protected Model Using the Model Block Context Menu

- 1 In the Simulink Editor, right-click the Model block that references the model for which you want to generate protected model code.
- 2 On the context menu, select **Code Generation > Generate Protected Model**.

When you choose the **Generate Protected Model** menu item, Simulink:

- Leaves the original model unchanged
- Creates a protected model version of the referenced model in the current working folder

- Creates a harness model in the current working folder (for details, see “The Harness Model” on page 5-71)

## The Harness Model

If you use the `Simulink.ModelReference.protect` command to create a protected model, you can choose whether to create a harness model. If you use the Model block interface to create a protected model, Simulink automatically creates a harness model.

The harness model contains a Model block that works with the protected model. This Model block:

- Names the protected model as its referenced model
- Has the same number of input and output ports as the protected model
- Defines any model reference arguments that the protected model uses, but provides no values

The harness model opens as a new untitled model that contains only the Model block. This block, and any other Model block that references a protected model, shows a small image of a lock in its upper left corner.

Some ways to use the harness model include:

- Save the harness model and use it as needed
- Use the handle in `harnessHandle` to manipulate the model programmatically
- Copy the Model block into another model, where it functions as the interface to the protected model

See “Packaging a Protected Model” on page 5-74 for more about how to use a harness model and the Model block that it contains.

## Obtaining Object and Variable Names for a Protected Model

Some referenced models require objects or tunable parameters that are defined in the MATLAB base workspace. Executing the protected version of such a referenced model requires that same entity if it is:

- A global tunable parameter
- A global data store
- Any of the following objects used by a signal that connects to a root-level model Inport or Outport:
  - Simulink.Signal
  - Simulink.Bus
  - Simulink.Alias
  - Simulink.NumericType that is an alias

When you protect a model, you must obtain the definitions of all necessary base workspace entities and ship them along with the model. The necessary steps for obtaining the definitions are:

- Obtain candidate names
- Prune unneeded names
- Save workspace definitions

See “Packaging a Protected Model” on page 5-74 for information about how to ship the base workspace definitions.

### Obtaining Candidate Names

When the `protect` command executes, it always generates a cell array that includes the names of all base workspace entities that the protected model needs. You can obtain this array by accepting the second return value when you execute the command:

```
[-, neededVars] = Simulink.ModelReference.protect(model)
```

The tilde (~) operator discards the first argument, or you could accept it if you create a harness model at the same time. The returned cell array *neededVars* includes the name of every needed base workspace entity.

### Pruning Unnecessary Names

The cell array *neededVars* might also include the names of base workspace entities that the protected model does not need. For example, *neededVars* could contain names of workspace objects that define signals that do not connect to any root I/O port within the protected model. The protected version of the model does not need the corresponding definitions, because the definitions do not specify anything about its interface to other model entities.

Leaving unnecessary names in *neededVars*:

- Risks disclosing intellectual property
- Adds unnecessary definitions to the model of the receiver
- Increases the likelihood of a name conflict with that model

Because you cannot change a protected model, resolving such a conflict requires changing the model of the receiver.

To remove unnecessary names, edit the cell array *neededVars*. Delete any names that do not correspond to definitions that serve the protected model in one of the capacities listed under “Obtaining Object and Variable Names for a Protected Model” on page 5-72. If you are not sure which names are extra, you can remove any doubtful cases and later test to see whether any missing definitions result.

### Saving Workspace Definitions

The cell array derived in the previous steps contains only the names of base workspace entities. The protected model needs the definitions themselves, in a separate file that you can ship along with the model. To create this file, execute:

```
save(myFile.mat, neededVars{:})
```

where *myFile* is any file (or path) name, and *neededVars* is the (possibly pruned) second return value of the `protect` command. The `{:}` operator

converts the cell array *neededVars* into a list of comma-separated names, which become arguments to `save`. When the command executes, it evaluates each name, thus obtaining the corresponding definition from the base workspace, and stores all the definitions in *myFile.mat*. The receiver of the protected model can then restore the base workspace definitions by loading *myFile.mat*.

### Packaging a Protected Model

A protected model consists of the model itself, optionally a harness model, and any needed definitions saved in a MAT-file, as described in “Saving Workspace Definitions” on page 5-73. The Model Protection facility does not require packaging these files in any specific way. For example, you could use one of the following approaches to package the files:

- Providing them as three separate files
- Combining them into a ZIP or other container file
- Packaging them using a manifest (see “Export Files in a Manifest” on page 12-73)
- Providing them in some other standard or proprietary format specified by the receiver

Whichever approach you use to package a protected model, be sure the receiver of the package has the information necessary retrieve the original files. One approach to consider is to use the Simulink Manifest Tools, as described in “Model Dependencies” on page 12-60.

### Testing a Protected Model

To test a protected model, use the same sequence that the protected model receiver will use, as described in “Using a Protected Model” on page 5-76. Because you are also the supplier, both the original and the protected model might exist on the MATLAB path. If the **Model name** field of a Model block names the model without providing a suffix, the unprotected version takes precedence over the protected model. This occurs regardless of the relative positions of the versions on the MATLAB path. If you need to override this default when testing a protected model, then in the Model block **Model**



**name** parameter, explicitly specify the file name with the extension of the protected model.

To compare unprotected and protected versions of a model, use the Simulation Data Inspector.

**1** For the unprotected model, select the **Configuration Parameters > Data Import/Export > Record and inspect simulation output** parameter.

**2** Simulate the unprotected model.

When the simulation completes, the Simulation Data Inspector opens.

**3** In the Simulation Data Inspector, rename the run to indicate that it is for the unprotected model.

**4** Close the unprotected model.

**5** Make sure that the protected model is in a different folder than the folder that contains the unprotected model.

**6** For the protected model, select the **Configuration Parameters > Data Import/Export > Record and inspect simulation output** parameter.

**7** Simulate the protected model.

When the simulation completes, the Simulation Data Inspector opens.

**8** In the Simulation Data Inspector, rename the run to indicate that it is for the protected model.

**9** In the Simulation Data Inspector, select the **Compare Runs** tab to compare the runs for the unprotected and the protected model. For details, see “Comparison of All Logged Signal Data From Multiple Simulations” on page 15-59.

For more information about using the Simulation Data Inspector, see “Inspecting and Comparing Logged Signal Data” on page 15-33.

## Using a Protected Model

Using a protected model does not require a Simulink Coder license. Using a protected model requires that the model:

- Be available somewhere on the MATLAB path
- Be referenced by a Model block in a model that executes in Normal mode
- 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

A typical workflow for meeting these requirements is:

- 1** If necessary, unpack the files according to any accompanying directions.
- 2** If there is a MAT-file containing workspace definitions, load that MAT-file.
- 3** If there is a harness model, copy the Model block into a Normal-mode model.
- 4** Connect signals to the Model block that match its input and output port requirements.
- 5** Provide any needed model argument values. See “Assigning Model Argument Values” on page 5-56.

Now you can simulate the model that references the protected model. The simulation produces the same outputs that it did when used in Accelerator mode in the source model. Many variations on these instructions are possible, such as:

- Use your own Model block rather than the Model block in the harness model.
- Start with the harness model, add more constructs to it, and use it in your model.
- Use the protected model as a variant, as described in Chapter 7, “Modeling Variant Systems”.

- Apply a mask to the Model block that references the protected model. See Chapter 23, “Working with Block Masks”.
- Configure a callback function such as **LoadFcn** to load the MAT file automatically. See “Using Callback Functions” on page 3-54.

To facilitate locating protected models:

- The MATLAB Folder Browser shows a small image of a lock in the upper left corner of the icon of a protected model.
- A Model block that references a protected model shows a small image of a lock in the upper left corner of the block icon.
- When the Model block **Browse** button shows a protected model, a lock icon appears.

When you change a Model block to reference a protected model, the **Simulation mode** of the block becomes Accelerator and you cannot change it.

## Model Protection Limitations

Protected models are subject to all limitations listed in “Limitations on All Model Referencing” on page 5-87 and “Limitations on Accelerator Mode Referenced Models” on page 5-91. The following limitations also apply to protected models:

- A model that you protect cannot use a non-inlined S-function directly or indirectly.
- Simulating a protected model requires that all models superior to it execute in Normal mode.

Protected models must also meet certain requirements, as described in “Model Protection Requirements” on page 5-68.

## Inheriting Sample Times

In this section...
“How Sample-Time Inheritance Works for Model Blocks” on page 5-78
“Conditions for Inheriting Sample Times” on page 5-78
“Determining Sample Time of a Referenced Model” on page 5-79
“Blocks That Depend on Absolute Time” on page 5-79
“Blocks Whose Outputs Depend on Inherited Sample Time” on page 5-81

### How Sample-Time Inheritance Works for Model Blocks

The sample times of a Model block are the sample times of the model that it references. If the referenced model must run at specific rates, the model specifies the required rates. Otherwise, the referenced model inherits its sample time from the parent model.

Placing a Model block in a triggered, function call, or iterator subsystem relies on the ability to inherit sample times. Additionally, allowing a Model block to inherit sample time maximizes its reuse potential. For example, a model might fix the data types and dimensions of all its input and output signals. You could reuse the model with different sample times (for example, discrete at 0.1 or discrete at 0.2, triggered, and so on).

### Conditions for Inheriting Sample Times

A referenced model inherits its sample time if the model:

- Does not have any continuous states
- Specifies a fixed-step solver and the **Fixed-step size** is auto
- Contains no blocks that specify sample times (other than inherited or constant)
- Does not contain any S-functions that use their specific sample time internally

- Has only one sample time (not counting constant and triggered sample time) after sample time propagation
- Does not contain any blocks, including Stateflow charts, that use absolute time, as listed in “Blocks That Depend on Absolute Time” on page 5-79
- Does not contain any blocks whose outputs depend on inherited sample time, as listed in “Blocks Whose Outputs Depend on Inherited Sample Time” on page 5-81.

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(gcf, '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 *Developing S-Functions* for information on how to create S-functions that declare whether their output depends on their inherited sample time.

To avoid simulation errors with referenced models that inherit their sample time, do not include S-functions in the referenced models that fail to declare whether their output depends on their inherited sample time. By default, Simulink warns you if your model contains such blocks when you update or simulate the model. See “Unspecified inheritability of sample time” for details.

# Refreshing Model Blocks

Refreshing a Model block updates its internal representation to reflect changes in the interface of the model that it references.

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 refresh all Model blocks in a model (as well as linked blocks in a library or model), in the Model Editor select **Edit > Links and Model Blocks > Refresh**. You can also refresh a model by starting a simulation or generating code.

To update a specific Model block, select **Refresh** from the context menu of the Model block.

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**



## Using S-Functions with Model Referencing

In this section...
“S-Function Support for Model Referencing” on page 5-83
“Sample Times” on page 5-83
“S-Functions with Accelerator Mode Referenced Models” on page 5-84
“Using C S-Functions in Normal Mode Referenced Models” on page 5-85
“Protected Models” on page 5-85
“Simulink® Coder™ Considerations” on page 5-85

### 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	<ul style="list-style-type: none"> <li>• Supports Normal and Accelerator mode</li> <li>• Accelerator mode requires a TLC file</li> </ul>
Handwritten C MEX S-function	<ul style="list-style-type: none"> <li>• Supports Normal and Accelerator mode</li> <li>• May be inlined with TLC file</li> </ul>
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 “Using S-Functions in Normal Mode Referenced Models”.

Use the `ssSetModelReferenceNormalModeSupport SimStruct` function to specify whether an S-function can be used in a Normal mode referenced model.

You may need to modify S-functions that are used by a model so that the S-functions work with multiple instances of referenced models in Normal mode. The S-functions must indicate explicitly that they support multiple `exec` instances. For details, see “Supporting the Use of Multiple Instances of Referenced Models That Are in Normal Mode”.

## Protected Models

A protected model cannot use non-inlined S-functions directly or indirectly.

## 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 “Referenced Models”.

## Logging Signals in Referenced Models

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 29-42.

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 31-59. However, MathWorks recommends using the `Dataset` format for signal logging. For a description of the benefits of using the `Dataset` format, see “Benefits of Using the Dataset Format for Signal Logging” on page 29-35. Dataset format does not support using test points for logging in referenced models.

You can log signal data in a parent model and use that logged data to perform a standalone simulation of a referenced model. For details, see “Importing Signal Logging Data” on page 29-72.

# Model Referencing Limitations

In this section...
“Introduction” on page 5-87
“Limitations on All Model Referencing” on page 5-87
“Limitations on Normal Mode Referenced Models” on page 5-90
“Limitations on Accelerator Mode Referenced Models” on page 5-91
“Limitations on PIL Mode Referenced Models” on page 5-94

## 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 5-45.

## 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 Output 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 Chapter 23, “Working with Block Masks”.

### **Simulink Tool Limitations**

- Working with the Simulink Debugger in a parent model, you can set breakpoints at Model block boundaries. Setting those breakpoints allows you to look at the input and output values of the Model block. However, you cannot set a breakpoint inside the model that the Model block references. See Chapter 18, “Simulink Debugger” for more information.
- The Model Browser does not display Model blocks in its tree view. To browse a referenced model hierarchy, use the Model Explorer.

### **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 “Importing and Exporting State Information for Referenced Models” on page 29-101.
- 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



“Setting Up a Model with Multiple Instances of a Referenced Model in Normal Mode” on page 5-28.

### **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 “Capturing Performance Data” on page 19-30.

### **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 model is referenced more than once in the model reference hierarchy. To work around this limitation:
    - 1 Make copies of the referenced model.
    - 2 Assign different names to the copies.
    - 3 Reference a different copy at each location that needs the model.
- The S-function uses string parameters.

## 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 “Specifying the Simulation Mode” on page 5-23.
- 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 “Specifying the Simulation Mode” on page 5-23.

For more information about using PIL mode with model referencing, see “Referenced Models” in the Embedded Coder documentation.

# Creating Conditional Subsystems

---

- “About Conditional Subsystems” on page 6-2
- “Enabled Subsystems” on page 6-4
- “Triggered Subsystems” on page 6-17
- “Triggered and Enabled Subsystems” on page 6-21
- “Function-Call Subsystems” on page 6-26
- “Conditional Execution Behavior” on page 6-28

## 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 “Creating Subsystems” on page 3-37.

A *conditional subsystem*, also known as a *conditionally executed subsystem*, is a subsystem whose execution depends on the value of an input signal. The signal that controls whether a subsystem executes is called the *control signal*. The signal enters 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 6-4.
- A *triggered subsystem* executes once each time a trigger event occurs. A trigger event can occur on the rising or falling edge of a trigger signal, which can be continuous or discrete. For more information about triggered subsystems, see “Triggered Subsystems” on page 6-17.
- 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 6-21 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 “Modeling Control Flow Logic” on page 3-44 for more information.

---

**Note** The Simulink software imposes restrictions on connecting blocks with a constant sample time to the output port of a conditional subsystem. See “Using Blocks with Constant Sample Times in Enabled Subsystems” on page 6-13 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?” on page 6-4

“Creating an Enabled Subsystem” on page 6-5

“Blocks that an Enabled Subsystem Can Contain” on page 6-10

“Using Blocks with Constant Sample Times in Enabled Subsystems” on page 6-13

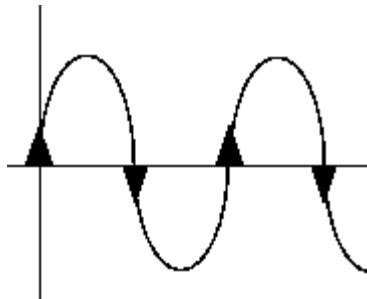
### What Are Enabled Subsystems?

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.

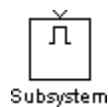




The Simulink software uses the zero-crossing slope method to determine whether an enable event is to occur. If the signal crosses zero and its slope is positive, then the subsystem becomes enabled. If the slope is negative at the zero crossing, then the subsystem becomes disabled. Note that a subsystem 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 Output 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 Output 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 6-7.

**Inheriting Initial Conditions.** The Output 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 Output 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 Output 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.

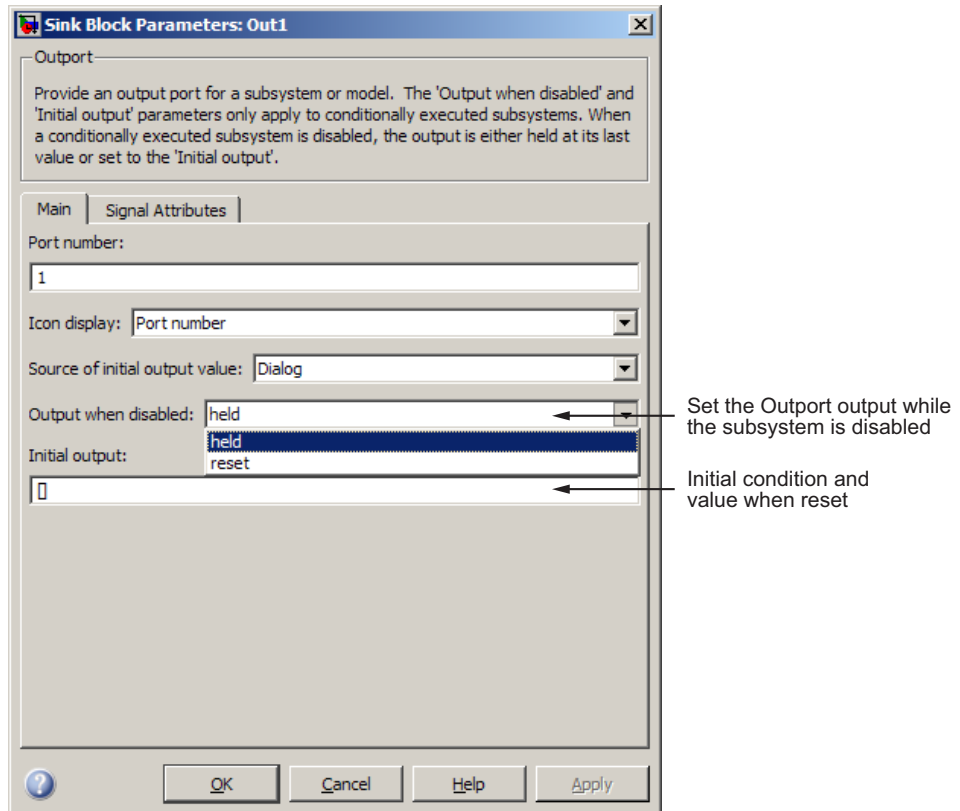
For more information on classic and simplified initialization mode, see “Underspecified initialization detection”.

### **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 Output 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”.

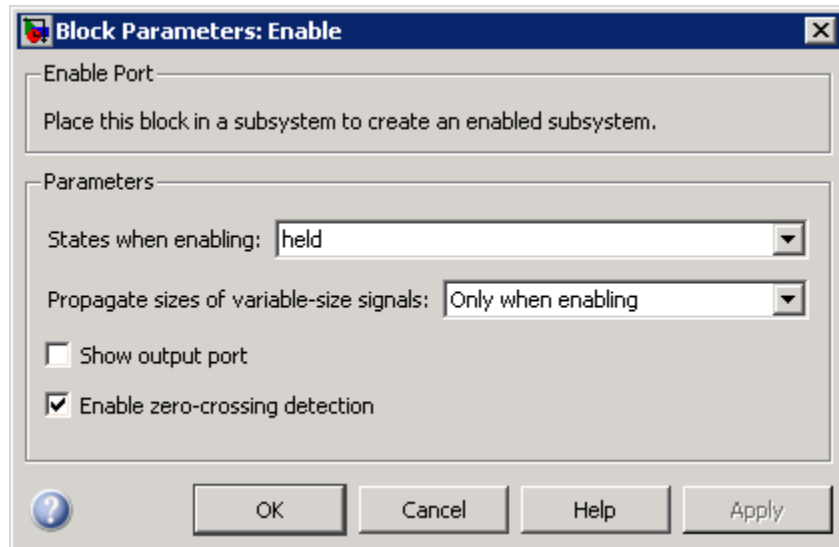
---

## 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.



---

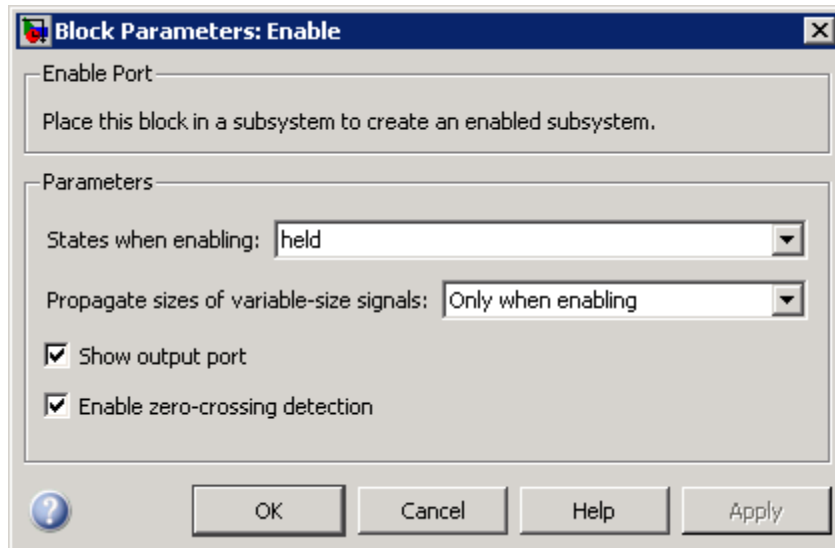
**Note** If you are using simplified initialization mode, the subsystem elapsed time is always reset during the first execution after becoming enabled, whether or not the subsystem is configured to reset on enable.

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.

---

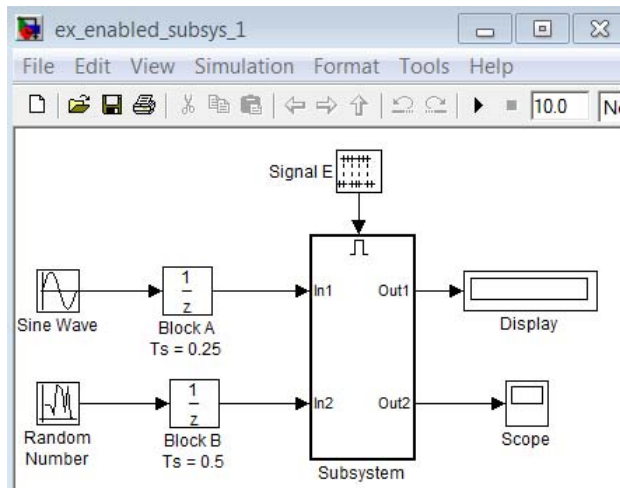
**Note** Enabled subsystems can contain Goto blocks. However, only state ports can connect to Goto blocks in an enabled subsystem. See the demo model, `clutch`, for an example of how to use Goto blocks in an enabled subsystem.

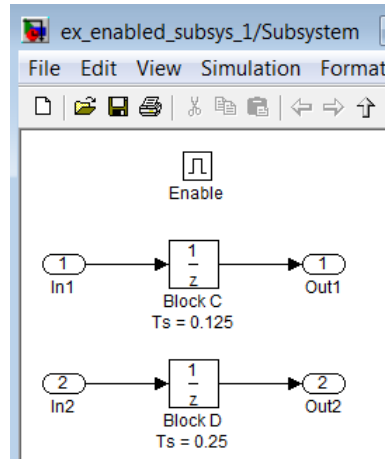
---

For example, this system contains four discrete blocks and a control signal. The discrete blocks are:

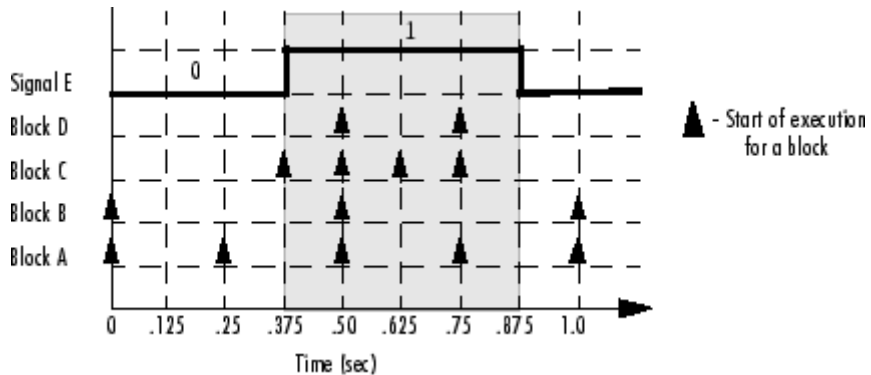
- Block A, which has a sample time of 0.25 second
- Block B, which has a sample time of 0.5 second
- Block C, within the enabled subsystem, which has a sample time of 0.125 second
- Block D, also within the enabled subsystem, which has a sample time of 0.25 second

The enable control signal is generated by a Pulse Generator block, labeled Signal E, which changes from 0 to 1 at 0.375 second and returns to 0 at 0.875 second.





The chart below indicates when the discrete blocks execute.



Blocks A and B execute independently of the enable control signal because they are not part of the enabled subsystem. When the enable control signal becomes positive, blocks C and D execute at their assigned sample rates until the enable control signal becomes zero again. Note that block C does not execute at 0.875 second when the enable control signal changes to zero.



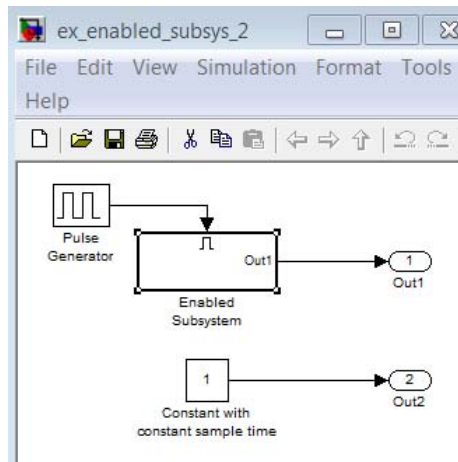
## Using Blocks with Constant Sample Times in Enabled Subsystems

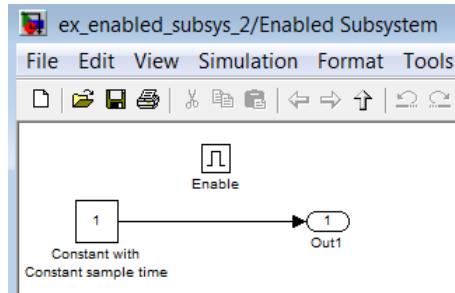
Certain restrictions apply when you connect blocks with constant sample times (see “Constant Sample Time” on page 4-16) to the output port of a conditional subsystem.

- 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.

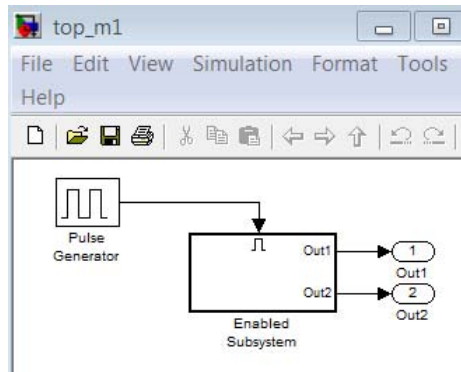
Consider the following model `ex_enabled_subsys_2.mdl`.

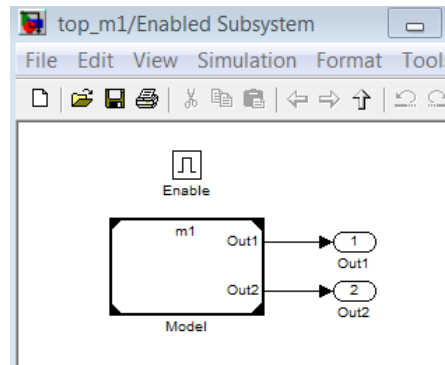




The two Constant blocks in this model have constant sample times. When you simulate the model, the Simulink software converts the sample time of the Constant block inside the enabled subsystem to the rate of the Pulse Generator. If you simulate the model with sample time colors displayed (see “Displaying Sample Time Colors” on page 3-12), the Pulse Generator and Enabled Subsystem blocks are colored red. However, the Constant and Outport blocks outside of the enabled subsystem are colored magenta, indicating that these blocks still have a constant sample time.

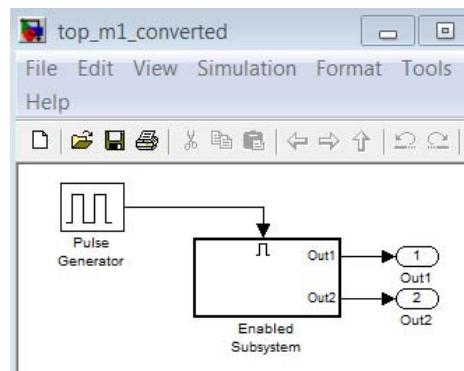
Suppose the model above is referenced from a Model block inside an enabled subsystem, as shown below. (See Chapter 5, “Referencing a Model”.)

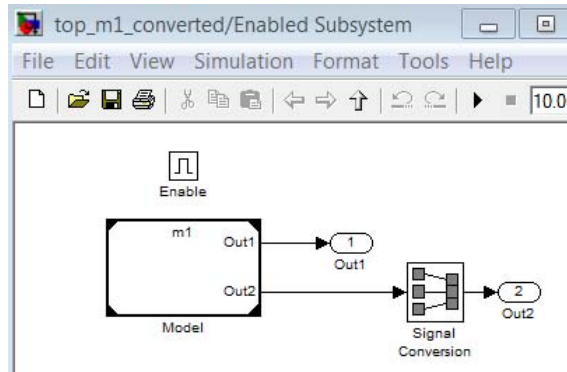




An error appears when you try to simulate the top model, indicating that the second output of the Model block may not be wired directly to the enabled subsystem output port because it has a constant sample time. (See Chapter 5, “Referencing a Model”.)

To avoid this error, insert a Signal Conversion block between the second output of the Model block and the 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?” on page 6-17

“Using Model Referencing Instead of a Triggered Subsystem” on page 6-18

“Creating a Triggered Subsystem” on page 6-19

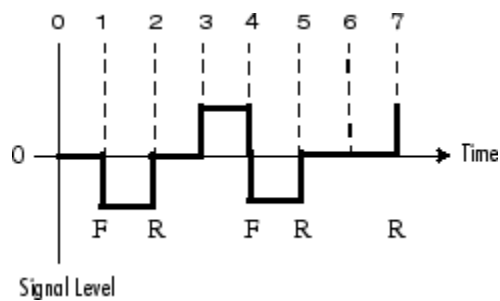
“Blocks That a Triggered Subsystem Can Contain” on page 6-20

### What Are Triggered Subsystems?

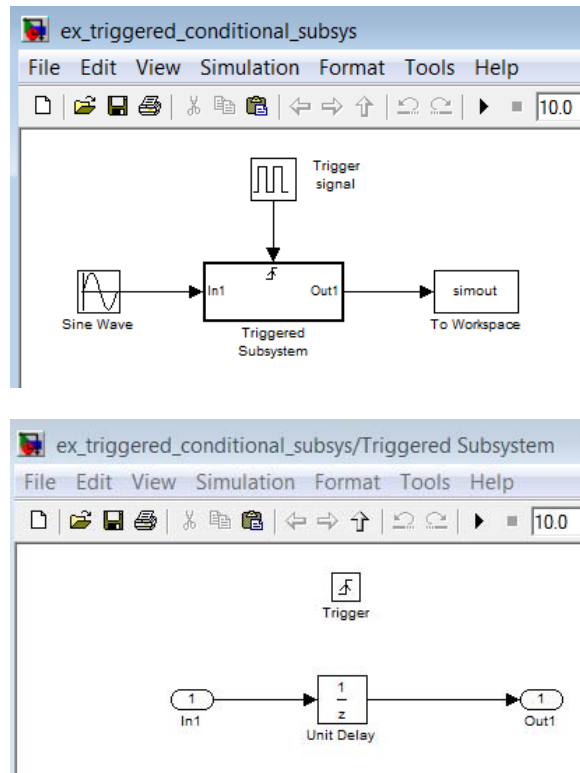
Triggered subsystems are subsystems that execute each time a trigger event occurs.

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 5-59.

To convert a subsystem to use model referencing, see “Converting a Subsystem to a Referenced Model” on page 5-12.

## 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?” on page 6-21

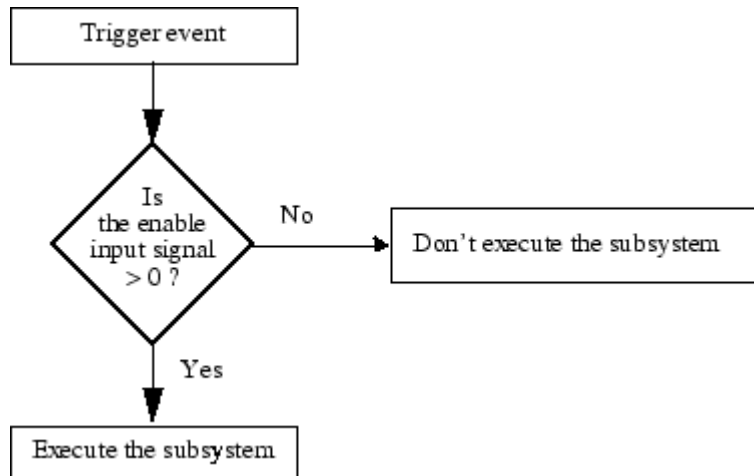
“Creating a Triggered and Enabled Subsystem” on page 6-22

“A Sample Triggered and Enabled Subsystem” on page 6-23

“Creating Alternately Executing Subsystems” on page 6-23

### 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.

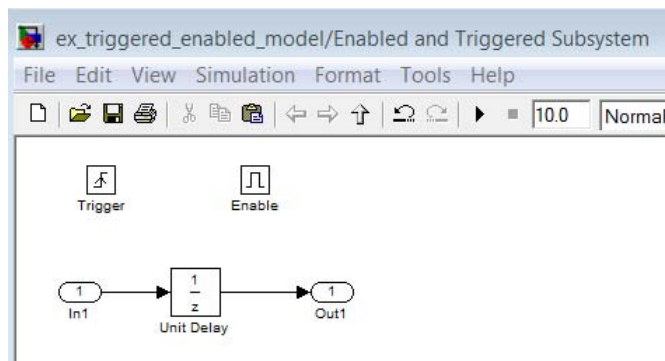
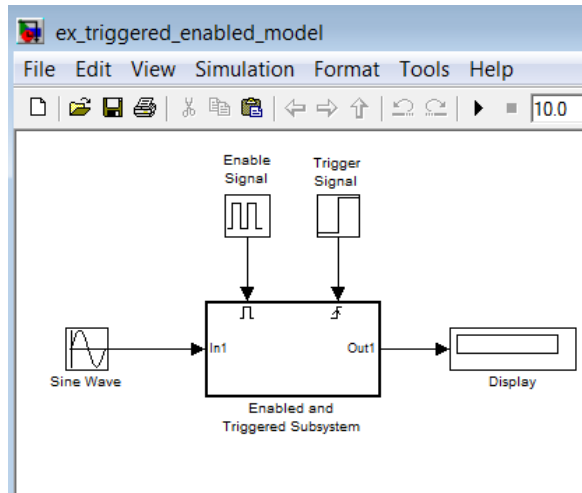


You can set output values when a triggered and enabled subsystem is disabled as you would for an enabled subsystem. For more information, see “Setting Output Values While the Subsystem Is Disabled” on page 6-7. Also, you can specify what the values of the states are when the subsystem is reenabled. See “Setting States When the Subsystem Becomes Enabled” on page 6-9.

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

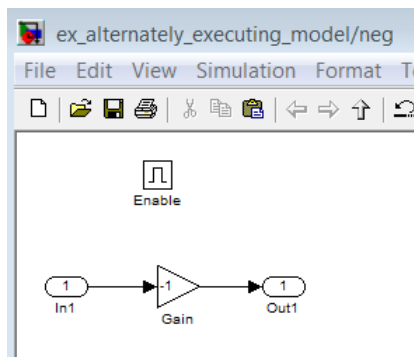
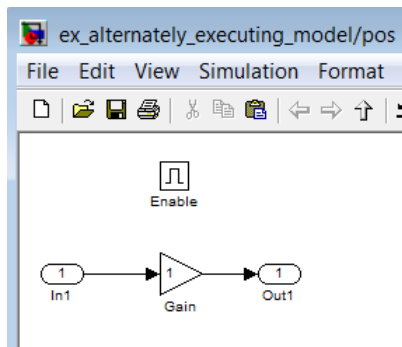
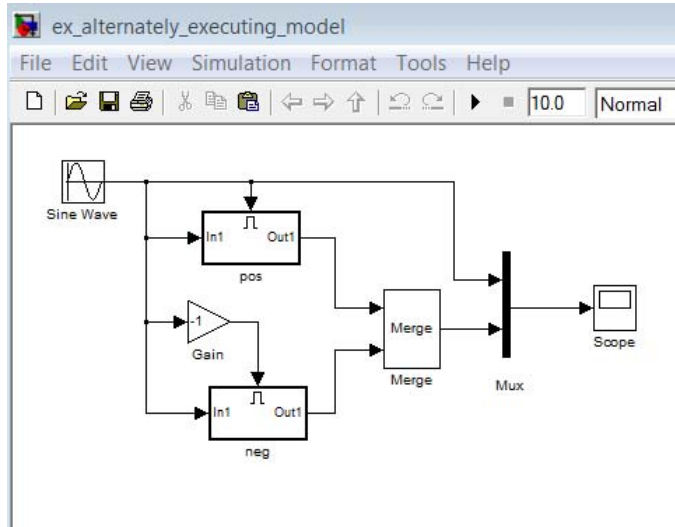
A simple example of a triggered and enabled subsystem is illustrated in the following model.



## Creating Alternately Executing Subsystems

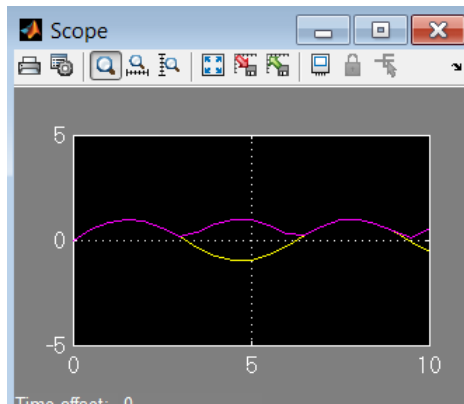
You can use conditional subsystems in combination with Merge blocks to create sets of subsystems that execute alternately, depending on the current state of the model.

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 2-16) of the blocks that the subsystem contains in sorted order (See “How Simulink Determines the Sorted Order” on page 20-46). 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

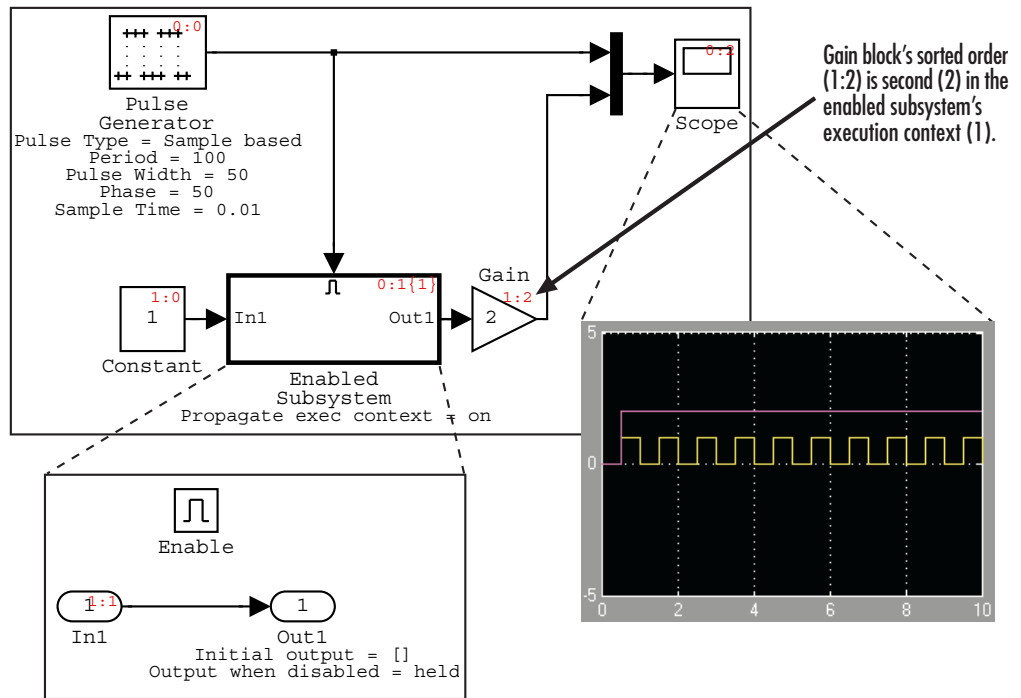
In this section...
“What Is Conditional Execution Behavior?” on page 6-28
“Propagating Execution Contexts” on page 6-30
“Behavior of Switch Blocks” on page 6-31
“Displaying Execution Contexts” on page 6-31
“Disabling Conditional Execution Behavior” on page 6-32
“Displaying Execution Context Bars” on page 6-32

### 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 6-32.

The following model illustrates conditional execution behavior.





The outputs of the Constant block and Gain blocks are computed only while the enabled subsystem is enabled. 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.

### 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 “Working with Test Points” on page 31-59).
- 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 6-32), 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

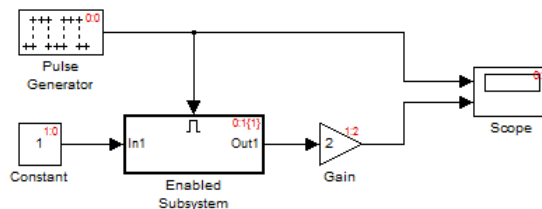
This behavior treats the input branches of a Switch or Multiport Switch block as invisible, conditional subsystems, each of which has its own execution context. This CE is enabled only when the control input of the switch selects the corresponding data input. As a result, switch branches execute only when selected by switch control inputs.

## Displaying Execution Contexts

To determine the execution context to which a block belongs, from the model window **Format** menu, select **Block Displays > Sorted 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 Multiplex 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.

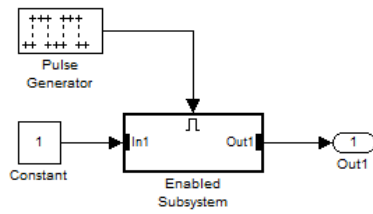
Even if this option is enabled, the execution context of the subsystem cannot propagate across its boundaries under either of the following circumstances:

- 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, from the **Format > Block Displays** menu, select **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.





# Modeling Variant Systems

---

- “Working with Variant Systems” on page 7-2
- “Setting Up Model Variants” on page 7-5
- “Setting Up Variant Subsystems” on page 7-15
- “Setting Up Variant Control” on page 7-25
- “Selecting the Active Variant” on page 7-29
- “About Variant Objects” on page 7-32
- “Code Generation of Variants” on page 7-36
- “Reference” on page 7-37

## Working with Variant Systems

In this section...
“Overview of Variant Systems” on page 7-2
“Workflow for Implementing Variant Systems” on page 7-3

### 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 7-5 and “Variant Subsystem Block Overview” on page 7-15.

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 7-3.



For *alternative* techniques to customize a model for different specifications, see:

Technique	Reference
Change data values in the base workspace.	“Tunable Parameters” on page 2-9
Select alternate subsystems from a library.	Configurable Subsystem block
Use a mask to change a subsystem.	“Creating Dynamic Masked Subsystems” on page 23-68
Change the arguments to a parameterized referenced model.	“Parameterizing Model References” on page 5-52

## 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 “Setting Up Model Variants” on page 7-5 and “Setting Up Variant Subsystems” on page 7-15.

- 3** Create the control variables for evaluating variant conditions and selecting the active variant. See “Setting Up Variant Control” on page 7-25 and “Selecting the Active Variant” on page 7-29.

- 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 7-36.
- 7** Save the control variables and objects for your variants from the base workspace as described in “Exporting Workspace Variables” on page 8-58.

## Setting Up Model Variants

### In this section...

“Model Variants Block Overview” on page 7-5

“Example of a Model Variants Block” on page 7-7

“Configuring the Model Variants Block” on page 7-9

“Disabling and Enabling Model Variants” on page 7-12

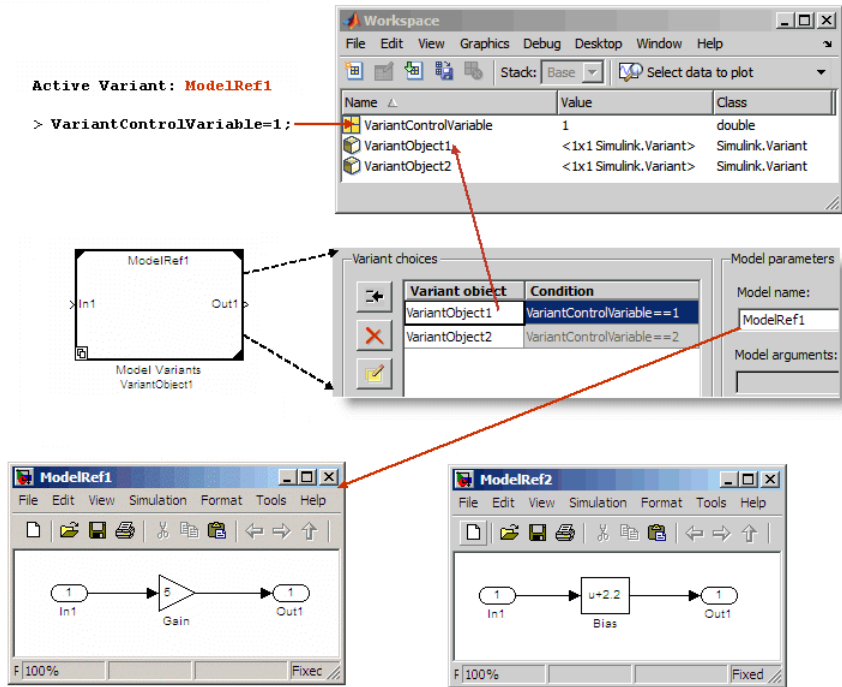
“Parameterizing Model Variants” on page 7-12

“Requirements, Limitations, and Tips for Model Variants” on page 7-13

“Model Variants Demo” on page 7-14

### Model Variants Block Overview

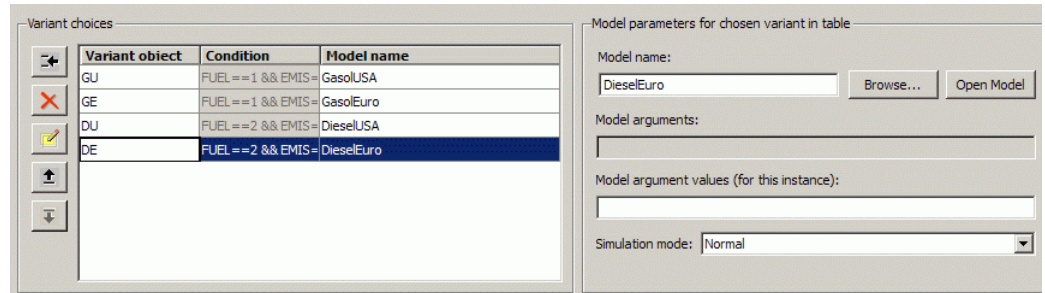
Model variants provide multiple implementations of a referenced model, with only one implementation active during simulation. You can programmatically swap the active implementation with another, without modifying the model. For example, you could use variants to switch between data types, such as `double` 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:

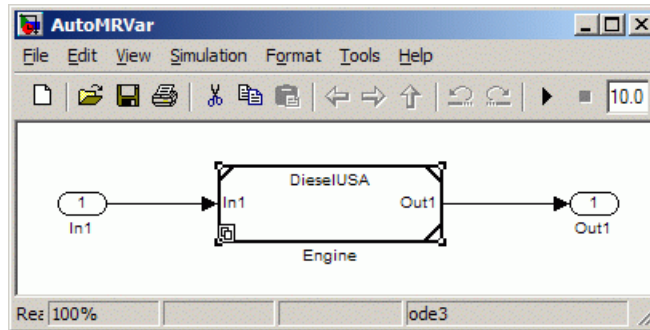
- The name of a variant object, in the **Variant object** column of the **Variant choices** table
- The name of a referenced model, in the **Model name** column of the **Variant choices** table
- A simulation mode, in the **Simulation mode** field of the **Model parameters** section
- Values in the **Model 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 7-9.

## Example of a Model Variants Block

To view the example model, either click `AutoMRVar.mdl`, or execute:

```
addpath([docroot '/toolbox/simulink/ug/examples/variants/mdlref/']);
open('AutoMRVar.mdl');
```



- 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 update the diagram, the variant block name changes.
- When you open the example model, a callback function loads a MAT-file that populates the base workspace with the variables and objects that the model uses. The base workspace contains the variant control variables and variant objects.

Name	Value
DE	<1x1 Simulink.Variant>
DU	<1x1 Simulink.Variant>
EMIS	1
FUJEL	2
GE	<1x1 Simulink.Variant>
GU	<1x1 Simulink.Variant>

The example implements the following application:

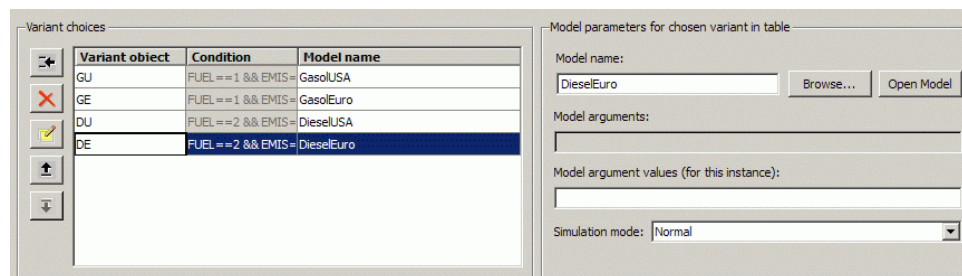
- An automobile that can use either a diesel or a gasoline engine

- 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.mdl
GE	FUEL==1 && EMIS==2	GasolEuro.mdl
DU	FUEL==2 && EMIS==1	DieselUSA.mdl
DE	FUEL==2 && EMIS==2	DieselEuro.mdl

To see how to specify these variants, from the model window, right-click the Engine block, and select **Model Reference Parameters** or select **Edit > Model Reference Parameters**. View the **Variant choices** table in the dialog box.



For instructions, see “Configuring the Model Variants Block” on page 7-9.

## Configuring the Model Variants Block

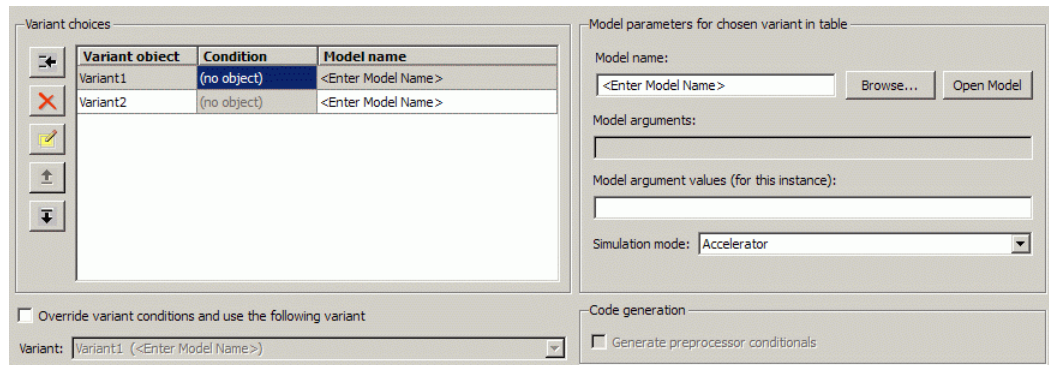
To add and configure a Model Variants block to specify your variants, do the following:


- 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. From the model diagram window, right-click the Model Variants block, and select **Model Reference Parameters** or select **Edit > Model Reference Parameters**.

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 a `.mdlp` extension. See “Protecting Referenced Models” on page 5-67.

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 7-12), or specify the **Simulation mode**. All simulation modes work with model variants. See “Referenced Model Simulation Modes” on page 5-21.
  - 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 7-25 and “Saving Variant Components” on page 7-26.

---

For next steps, see “Selecting the Active Variant” on page 7-29. The model diagram does not display the new active variant on the block until you update the diagram.

### 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 **Model Reference Parameters** to open the block parameters dialog box.
- 2 Select the **Disable Variants** button. Disabling variants:
  - Hides the Block parameter dialog box for variants
  - Leaves the active variant as the model name and the execution environment when the variants were disabled
  - 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 7-30.

### 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** section using the **Model argument values** field. You can use the same values as for

any referenced model. For more information, see “Parameterizing Model References” on page 5-52.

## 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 5-45 and “Model Referencing Limitations” on page 5-87. 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 29-42.

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 Demo**

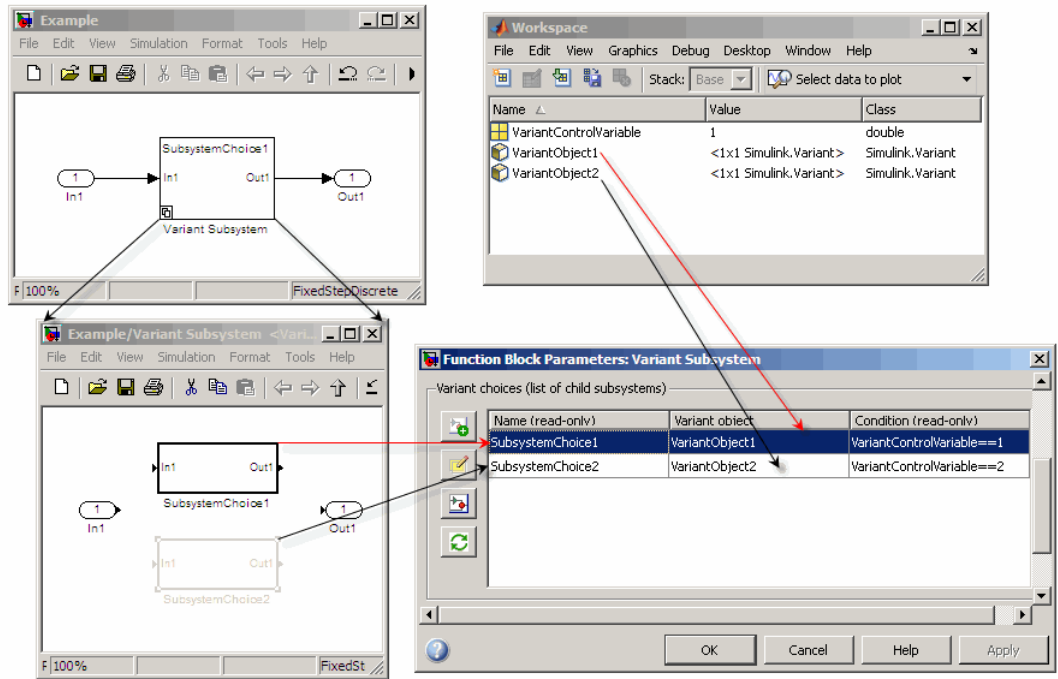
To see a demo that shows how to define a variant model in Simulink, click `sldemo_mdhref_variants`. In the Help Browser select: **Simulink > Demos > Modeling Features > Model Reference > Model Reference Variants**.

## Setting Up Variant Subsystems

In this section...
“Variant Subsystem Block Overview” on page 7-15
“Example of a Variant Subsystem Block” on page 7-17
“Configuring the Variant Subsystem Block” on page 7-20
“Disabling and Enabling Subsystem Variants” on page 7-23
“Variant Subsystem Block Requirements” on page 7-23
“Variant Subsystem Demo” on page 7-24

### 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:

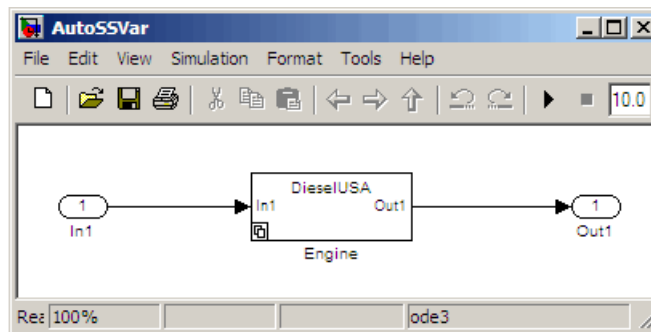
- The name of a variant object, in the **Variant object** column of the **Variant choices** table.
- The variant object must have a conditional expression that evaluates to true or false.


Instructions for specifying a variant subsystem are in “Configuring the Variant Subsystem Block” on page 7-20.

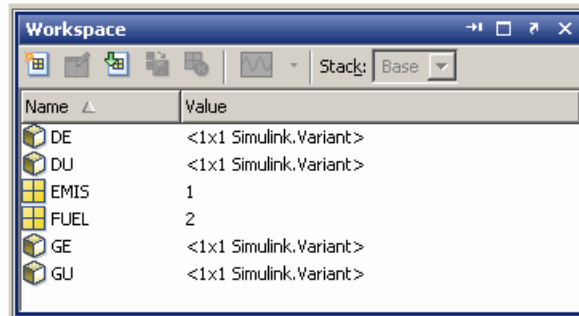
## Example of a Variant Subsystem Block

To view the example model, either click `AutoSSVar.mdl`, or execute:

```
addpath([docroot ' /toolbox/simulink/ug/examples/variants/mdlref/']);
open('AutoSSVar.mdl');
```



- 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 update the diagram, the variant block name changes.
- When you open the example model, a callback function loads a MAT-file that populates the base workspace with the variables and objects that the model uses. The base workspace contains the variant control variables and variant objects.



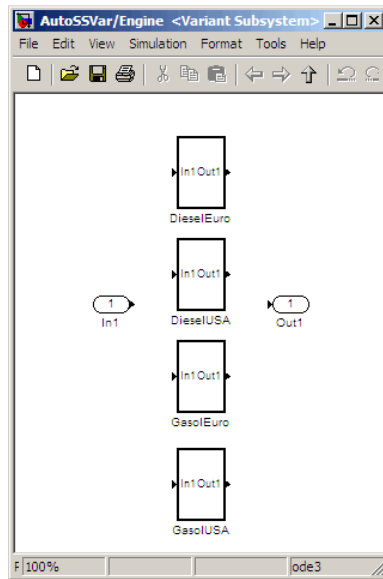
The example model illustrates the same application as the “Example of a Model Variants Block” on page 7-7, but using variant *subsystems* instead of variant *referenced models*. Both examples show the use of variants for the following cases:

- 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 Code Generation of a Variant Subsystem” in the Embedded Coder documentation.

To view how to specify these variants, from the model diagram window, right-click the Engine block, and select **Subsystem Parameters** or select **Edit > Subsystem Parameters**.

View the **Variant choices (list of child subsystems)** table in the dialog box, as shown in the following figure.

Variant choices (list of child subsystems)			
	Name (read-only)	Variant object	Condition (read-only)
	DieselEuro	DE	FUEL==2 && EMIS==2
	DieselUSA	DU	FUEL==2 && EMIS==1
	GasolEuro	GE	FUEL==1 && EMIS==2
	GasolUSA	GU	FUEL==1 && EMIS==1

For instructions, see “Configuring the Variant Subsystem Block” on page 7-20.

## Configuring the Variant Subsystem Block

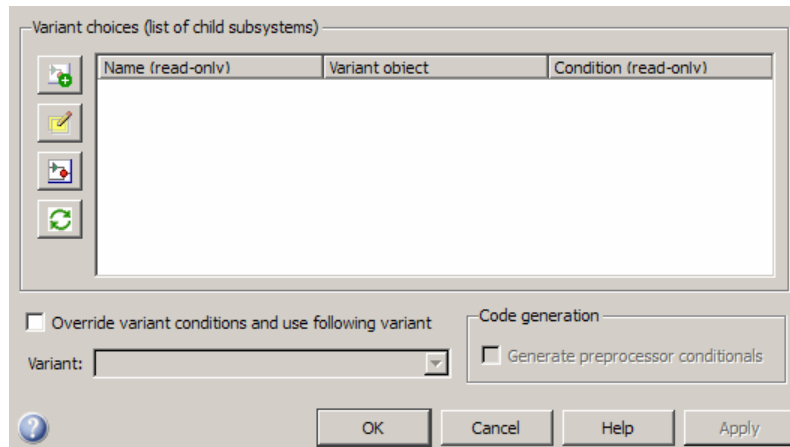
To add and configure a Variant Subsystem block to specify your variants, do the following:


- 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. From the model diagram window, right-click the Variant Subsystem block, Engine, and select **Subsystem Parameters** or select **Edit > Subsystem Parameters**.

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.

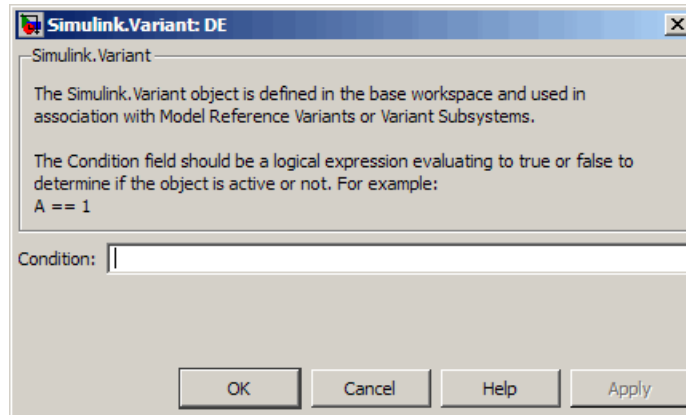
- 4 Rename the subsystem in the Variant Subsystem block diagram window, and open and configure the subsystem as desired. You can drag and drop existing subsystems into the new variant subsystem.

---

**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 7-25 and “Saving Variant Components” on page 7-26.

---

For next steps, see “Selecting the Active Variant” on page 7-29. The model diagram does not display the new active variant on the block until you update the diagram.

## 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 7-30.

## 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 “Variant Systems”.

---

### **Variant Subsystem Demo**

To see a demo that shows how to define a variant subsystem, click `sldemo_variant_subsystems.mdl`. In the Help Browser, select: **Simulink > Demos > Modeling Features > Subsystems > Variant Subsystems**.

## Setting Up Variant Control

### In this section...

“Creating Control Variables” on page 7-25

“Saving Variant Components” on page 7-26

“Example Variant Control Variables” on page 7-26

“Using Enumerated Types for Variant Control Variable Values” on page 7-27

### 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 7-27.

---

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 “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. For more information, see “Exporting to MAT-Files”.

## 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.mdl.



- 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.mdl, and the model AutoMRVar uses DieselEuro as its referenced model during simulation.
- 3 Select **Edit > Update Diagram** to see the active variant update.

---

**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 7-27.

---

For an example explaining control variables for variant subsystems, including the use of enumerated types, see the demo `sldemo_variant_subsystems.mdl`.

## Using Enumerated Types for Variant Control Variable Values

You can use enumerated types to give meaningful names to the integers that you use as values of variant control variables. For more information about defining and using enumerated types, see Chapter 28, “Enumerations and Modeling”. For example, suppose you defined the following enumerated class, whose elements represent vehicle properties:

```
classdef(Enumeration) VarParams < Simulink.IntEnumType
    enumeration
        gasoline(1)
        diesel(2)
        USA(1)
        European(2)
    end
end
```

With the class `VarParams` defined, you can use meaningful names to specify variant control variables and variant conditions. For example, you can substitute names for the integers for variant control variables `EMIS` and `FUEL`.

```
EMIS = VarParams.USA  
FUEL = VarParams.diesel
```

Using the techniques described in “About Variant Objects” on page 7-32, 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 demo `sldemo_variant_subsystems.mdl`.

## Selecting the Active Variant

### In this section...

“What Is an Active Variant?” on page 7-29

“Selecting the Active Variant for Simulation” on page 7-29

“Checking and Opening the Active Variant” on page 7-30

“Overriding Variant Conditions” on page 7-30

### 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 **Edit > 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 7-25.

You can also override the variant conditions and manually select one active variant. For instructions, see “Overriding Variant Conditions” on page 7-30.

### 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), the variant block name does not update until you select **Edit > Update Diagram**.

You can use the **Variant** menu to open the active variant. Right-click the block or select **Edit > Variant > Open > (active variant)**

To find the name of the active variant for the currently selected block, enter at the command line:

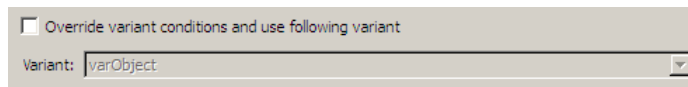
```
get_param(gcf, 'ActiveVariant')
```

### Overriding Variant Conditions

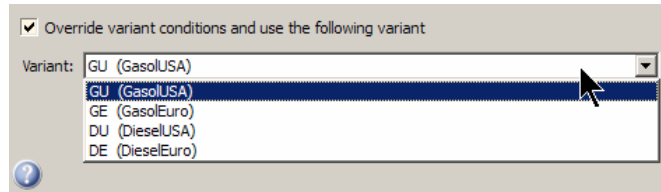
You can specify one variant as the active variant. You can either:

- Use the **Variant** menu to choose a variant. Right-click the block or select **Edit > 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?” on page 7-32
“Creating Variant Objects” on page 7-32
“Reusing Variant Objects” on page 7-33
“Variant Condition” on page 7-34

### 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 7-33.

---

### 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 7-9 and “Configuring the Variant Subsystem Block” on page 7-20.

- **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 7-9 and “Configuring the Variant Subsystem Block” on page 7-20.

For instructions on variant control variables, see “Setting Up Variant Control” on page 7-25.



---

**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 7-27.

---

## 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 “Variant Systems” in the Embedded Coder documentation.

## Reference

In this section...
“Custom Storage Classes” on page 7-37
“Blocks” on page 7-37

### 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



# Exploring, Searching, and Browsing Models

---

- “The Model Explorer: Overview” on page 8-2
- “The Model Explorer: Model Hierarchy Pane” on page 8-9
- “The Model Explorer: Contents Pane” on page 8-18
- “The Model Explorer: Controlling Contents Using Views” on page 8-25
- “The Model Explorer: Organizing How Data Displays” on page 8-35
- “The Model Explorer: Using the Row Filter Option and Filtering Contents” on page 8-46
- “The Model Explorer: Working with Workspace Variables” on page 8-52
- “The Model Explorer: Search Bar” on page 8-61
- “The Model Explorer: Dialog Pane” on page 8-67
- “The Finder” on page 8-70
- “The Model Browser” on page 8-77
- “Model Dependency Viewer” on page 8-80
- “Viewing Linked Requirements in Models and Blocks” on page 8-93

## The Model Explorer: Overview

### In this section...

“Introduction to the Model Explorer” on page 8-2

“Opening the Model Explorer” on page 8-2

“Model Explorer Components” on page 8-3

“The Main Toolbar” on page 8-4

“Adding Objects” on page 8-4

“Customizing the Model Explorer Interface” on page 8-5

“Basic Steps for Using the Model Explorer” on page 8-6


“Focusing on Specific Elements of a Model or Chart” on page 8-7

### Introduction to the Model Explorer

Use the Model Explorer to quickly view, modify, and add elements of Simulink models, Stateflow charts, and workspace variables. The Model Explorer provides several ways for you to focus on specific elements (for example, blocks, signals, and properties) without your having to navigate through the model diagram or chart.

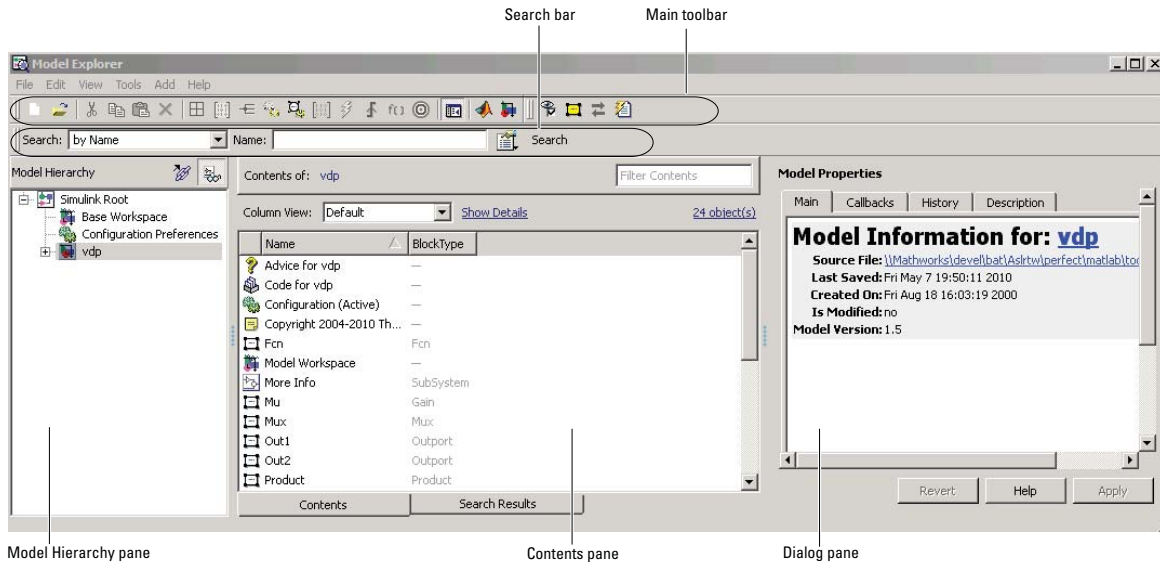
### Opening the Model Explorer

To open the Model Explorer, use one of these approaches:

- From the Simulink model editor **View** menu, select **Model Explorer** or select the Model Explorer icon  from the toolbar.
- In an open model in the Simulink model editor, right-click a block and from the context menu, select **Explore**.
- In an open Stateflow chart, right-click in the drawing area and from the context menu, select **Explore**.
- At the MATLAB command line, enter `daexplr`.

## Model Explorer Components

By default, the Model Explorer opens with three panes (**Model Hierarchy**, **Contents**, and **Dialog**), a main toolbar, and a search bar.





Component	Purpose	Documentation
Main toolbar	Execute Model Explorer commands	“The Main Toolbar” on page 8-4
Search bar	Perform a search within the context of the selected node in <b>Model Hierarchy</b> pane.	“The Model Explorer: Search Bar” on page 8-61
<b>Model Hierarchy</b> pane	Navigate and explore model, chart, and workspace nodes	“The Model Explorer: Model Hierarchy Pane” on page 8-9
<b>Contents</b> pane	Display and modify model or chart objects	“The Model Explorer: Contents Pane” on page 8-18
<b>Dialog</b> pane	View and change the details of object properties	“The Model Explorer: Dialog Pane” on page 8-67

## The Main Toolbar

The main toolbar at the top of the Model Explorer provides buttons you click to perform Model Explorer operations. Most of the toolbar buttons perform actions that you can also perform using Model Explorer menu items.

The toolbar buttons in the following table perform actions that you cannot perform using Model Explorer menus:

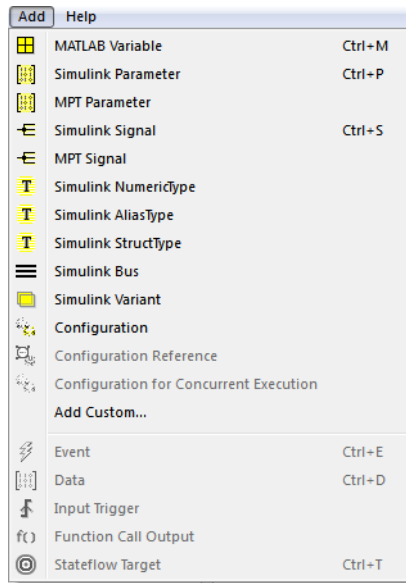
Button	Usage
	Bring the MATLAB desktop to the front.
	Display the Simulink Library Browser.

If you have Simulink Verification and Validation installed, you can use additional toolbar buttons relating to requirements links.

## Adding Objects

You can use the Model Explorer to add many kinds of objects to a model, chart, or workspace. The types of objects that you can add depend on what node you select in the **Model Hierarchy** pane. Use toolbar buttons or the **Add** menu to add objects. The **Add** menu lists the kinds of objects you can add.





## Customizing the Model Explorer Interface

You can customize the Model Explorer interface in several ways. This section describes how to show or hide the main toolbar and how to control the font size.

Other ways you can customize the Model Explorer interface include:

- “Marking Nonexistent Properties” on page 8-44
- “Showing and Hiding the Search Bar” on page 8-62
- “Showing and Hiding the Dialog Pane” on page 8-67

### Showing and Hiding the Main Toolbar

To show or hide the main toolbar, in the Model Explorer select **View > Toolbars > Main Toolbar**.

### Controlling the Font Size

You can change the font size in the Model Explorer panes:

- To increase the font size, press the **Ctrl + Plus Sign (+)**.  
Alternatively, from the Model Explorer **View** menu, select **Increase Font Size**.
- To decrease the font size, press the **Ctrl + Minus Sign (-)**.  
Alternatively, from the Model Explorer **View** menu, select **Decrease Font Size**.

---

**Note** The changes remain in effect for the Model Explorer and in the Simulink dialog boxes across Simulink sessions.

---

### Basic Steps for Using the Model Explorer

Use the Model Explorer to perform a wide range of activities relating to viewing and changing model and chart elements. You can perform activities in any order, using panes in the order you choose. Your actions in one pane often affect other panes.

For example, if you want to edit properties of objects in a model, you might use a general workflow such as:

- 1 Open a model.
- 2 Open the Model Explorer.
- 3 Select the model in the **Model Hierarchy** pane.
- 4 Control what model information the **Contents** pane displays, and how it displays that information, by using a combination of:
  - The **View > Column View** option to control which property columns to display
  - The **View > Row Filter** option to control which types of objects to display
  - Techniques to directly manipulate column headings
- 5 Identify model elements with specific values, using the search bar.

- 6 Edit the values for model elements, in either the **Contents** pane or the **Dialog** pane.

## Focusing on Specific Elements of a Model or Chart

As you explore a model or chart, you might want to narrow the contents that you see in the Model Explorer to particular elements of a model or chart. You can use several different techniques. The following table summarizes techniques for controlling what content the Model Explorer displays and how the contents appear.

Technique	When to Use	Documentation
Use the Row Filter option	To focus on, or hide, a specific kind of a model object, such as signals	“Using the Row Filter Option” on page 8-46
Search	To find objects that might not be currently displayed	“The Model Explorer: Search Bar” on page 8-61
Filter contents	To focus on specific objects in the <b>Contents</b> pane, based on a search string	“Filtering Contents” on page 8-49

Once you have the general set of data that you are interested in, you can use the following techniques to organize the display of contents.

Technique	When to Use	Documentation
Sort	To quickly organize data for a property in ascending or descending order	“Sorting Column Contents” on page 8-35
Group by property column	To logically group data based on values for a property	“How to Group by a Property Column” on page 8-38

<b>Technique</b>	<b>When to Use</b>	<b>Documentation</b>
Use column views	To display a named subset of property columns to apply to different kinds of nodes in the <b>Model Hierarchy</b> pane	“The Model Explorer: Controlling Contents Using Views” on page 8-25
Add, delete, or rearrange property table columns	To customize property columns	“The Model Explorer: Organizing How Data Displays” on page 8-35

## The Model Explorer: Model Hierarchy Pane

### In this section...

“What You Can Do with the Model Hierarchy Pane” on page 8-9

“Simulink Root” on page 8-10

“Base Workspace” on page 8-10

“Configuration Preferences” on page 8-11

“Model Nodes” on page 8-11

“Displaying Linked Library Subsystems” on page 8-12

“Displaying Masked Subsystems” on page 8-12

“Linked Library and Masked Subsystems” on page 8-13

“Displaying Node Contents” on page 8-13

“Navigating to the Block Diagram” on page 8-13

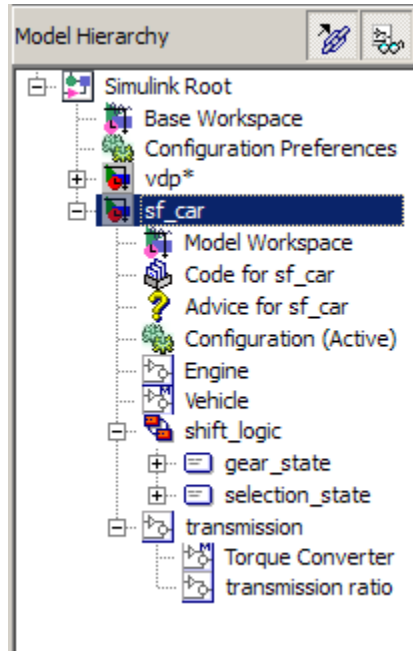
“Working with Configuration Sets” on page 8-13

“Expanding Model References” on page 8-14

“Cutting, Copying, and Pasting Objects” on page 8-16

### What You Can Do with the Model Hierarchy Pane

The **Model Hierarchy** pane displays a tree-structured view of the Simulink model and Stateflow chart hierarchy. Use the **Model Hierarchy** pane to navigate to the part of the model and chart hierarchy that you want to explore.



### Simulink Root

The first node in the hierarchy represents the Simulink root. Expand the root node to display nodes representing the MATLAB workspace, Simulink models, and Stateflow charts that are in the current session.

### Base Workspace

This node represents the MATLAB workspace. The MATLAB workspace is the base workspace for Simulink models and Stateflow charts. Variables defined in this workspace are visible to all open models and charts.

For information about exporting and importing workspace variables, see “Exporting Workspace Variables” on page 8-58 and “Importing Workspace Variables” on page 8-60.

## 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 9-8). 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 9-23).

## 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	<p>For information about how to use the Model Explorer to work with model workspace variables, see the following sections:</p> <ul style="list-style-type: none"> <li>• “Finding Variables That Are Used by a Model or Block” on page 8-52</li> <li>• “Finding Blocks That Use a Specific Variable” on page 8-55</li> <li>• “Exporting Workspace Variables” on page 8-58</li> <li>• “Importing Workspace Variables” on page 8-60</li> <li>• “Using Model Workspaces” on page 3-67</li> </ul>
Configuration sets	<p>For information about adding, deleting, saving, and moving configuration sets, see “Manage a Configuration Set” on page 9-8.</p>
Top-level subsystems	<p>Expand a node representing a subsystem to display underlying subsystems, if any.</p>

Node	Description
Model blocks	Expand to model blocks to show contents of referenced models (see “Expanding Model References” on page 8-14).
Stateflow charts	<ul style="list-style-type: none"><li>• Expand a node representing a Stateflow chart to display the top-level states of the chart.</li><li>• Expand a node representing a state to display its substates.</li></ul>

## 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

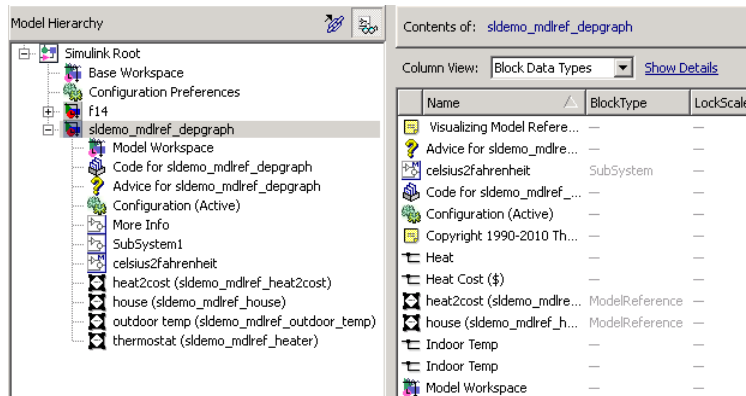
To open a graphical object (for example, a model, subsystem, or chart) in an editor window, right-click the object in the **Model Hierarchy** pane. From the context menu, select **Open**.

## Working with Configuration Sets

See “Manage a Configuration Set” on page 9-8 for information about using the **Model Hierarchy** pane to perform tasks such as adding, deleting, saving, and moving configuration sets.

## Expanding Model References

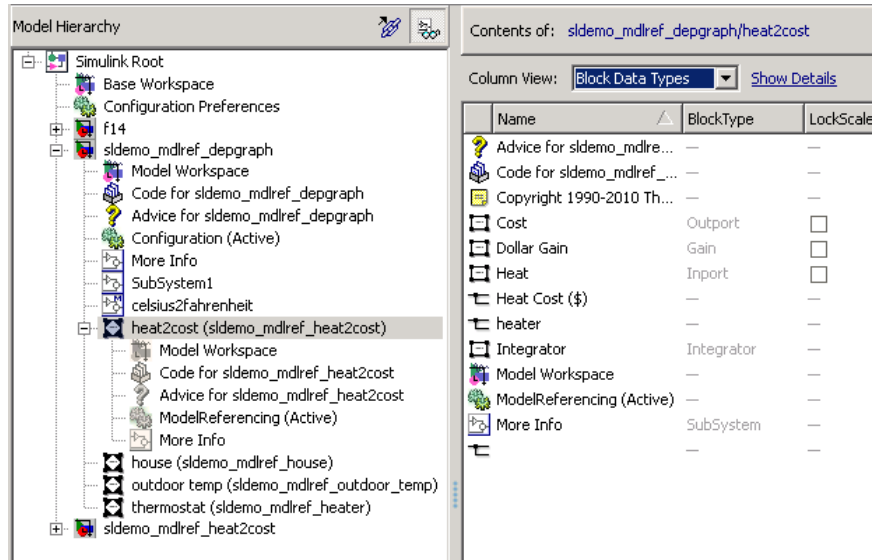
To browse a model that includes Model blocks, you can expand the **Model Hierarchy** pane nodes of the Model blocks. For example, the `sldemo_md1ref_depgraph` demo model includes Model blocks that reference other models. If you open the `sldemo_md1ref_depgraph` model and expand that model node in the **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).

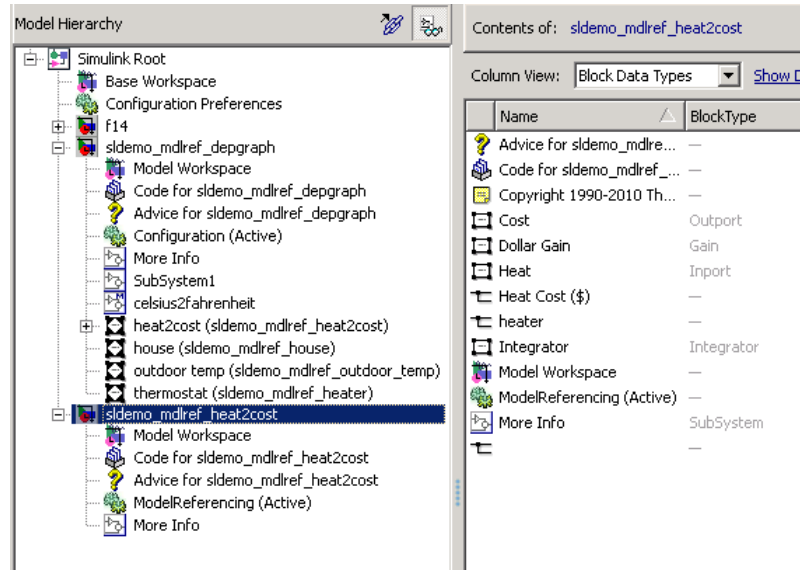
For example, if you right-click the `heat2cost` Model block node and select the **Open Model** option, the **Contents** pane displays the objects corresponding to the `heat2cost` Model block. You can expand the `heat2cost` node.



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_mdref_heat2cost` node:




You can now edit the properties of object in the referenced model.

For information about referenced models, see Chapter 5, “Referencing a Model”.

## Cutting, Copying, and Pasting Objects

To cut, copy, and paste workspace objects from one workspace into another workspace:

- 1 In the **Contents** pane, right-click on the workspace object you want to cut or copy.
- 2 From the context menu, select **Cut** or **Copy**.
  - You can also cut a workspace object by selecting in the **Contents** pane **Edit > Cut** or by clicking the **Cut** button (✂).
  - You can also copy a workspace object by selecting **Edit > Copy** or by clicking the **Copy** button (📄).

- 3** If you want to paste the workspace object that you cut or copied, in the **Model Hierarchy** pane, right-click the workspace into which you want to paste the object, and select **Paste**.
- You can also paste the object by selecting **Edit > Paste** or by clicking the **Paste** button ()

You can also perform cut, copy, and paste operations by selecting an object and performing drag and drop operations.

## The Model Explorer: Contents Pane

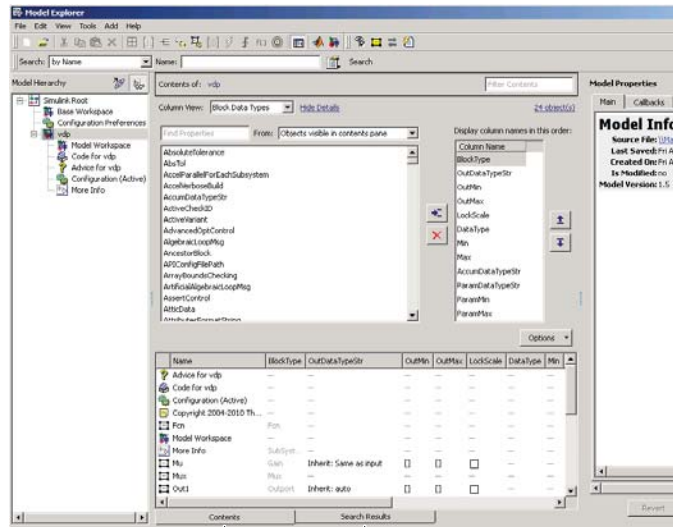
In this section...
“Contents Pane Tabs” on page 8-18
“Data Displayed in the Contents Pane” on page 8-21
“Link to the Currently Selected Node” on page 8-21
“Horizontal Scrolling in the Object Property Table” on page 8-22
“Working with the Contents Pane” on page 8-23
“Editing Object Properties” on page 8-24

### Contents Pane Tabs

The **Contents** pane displays one of two tables containing information about models and charts, depending on the tab that you select:

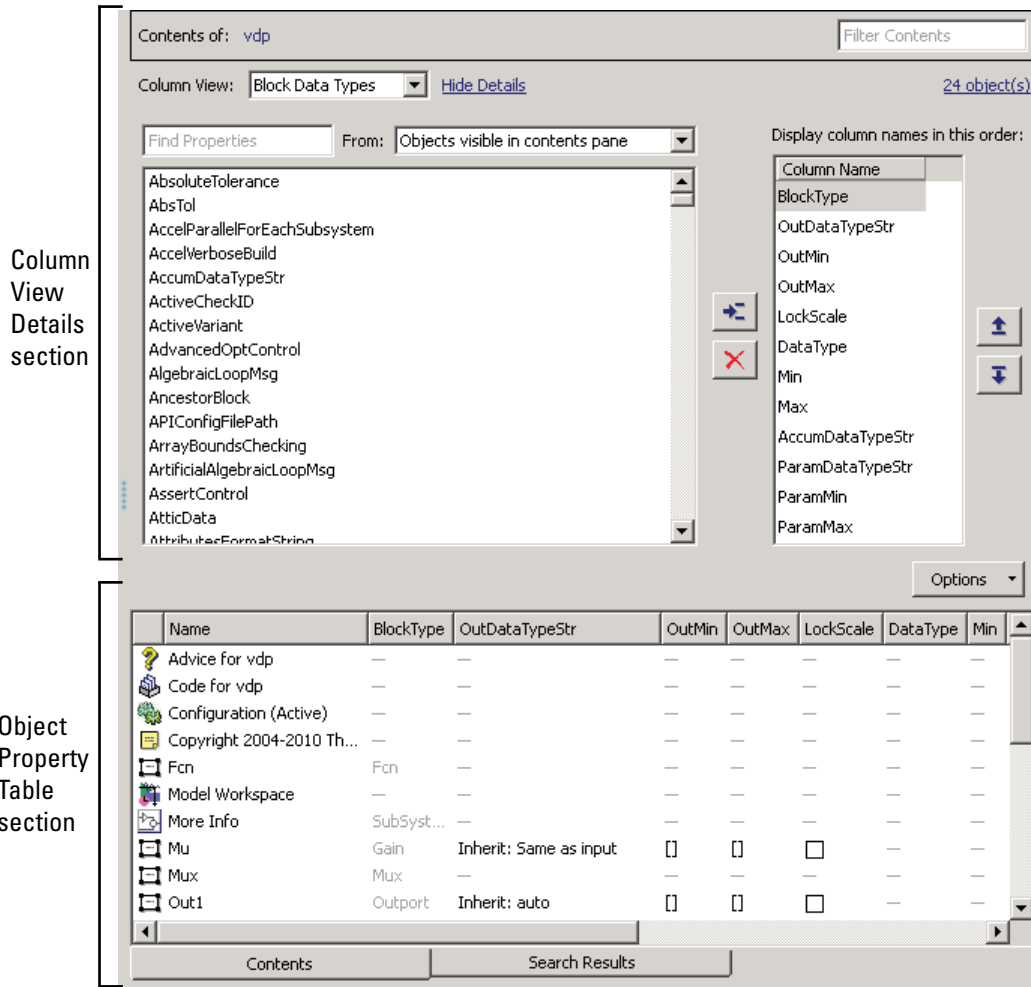
- The **Contents** tab displays an object property table for the node that you select in the **Model Hierarchy** pane.
- The **Search Results** tab displays the search results table (see “The Model Explorer: Search Bar” on page 8-61).

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.



Contents tab      Search Results tab

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:

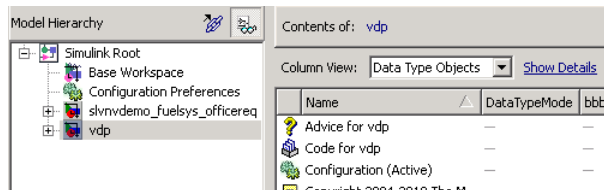
- The column view that you select in the **Contents** pane
- The node that you select in the **Model Hierarchy** pane
- The kind of object (for example, subsystem, chart, or configuration set) that you select in the **Model Hierarchy** pane
- The **View > Row Filter** options that you select

For more information about controlling which objects and properties to display in the **Contents** pane, see:

- “The Model Explorer: Controlling Contents Using Views” on page 8-25
- “The Model Explorer: Organizing How Data Displays” on page 8-35
- “The Model Explorer: Using the Row Filter Option and Filtering Contents” on page 8-46

## Link to the Currently Selected Node

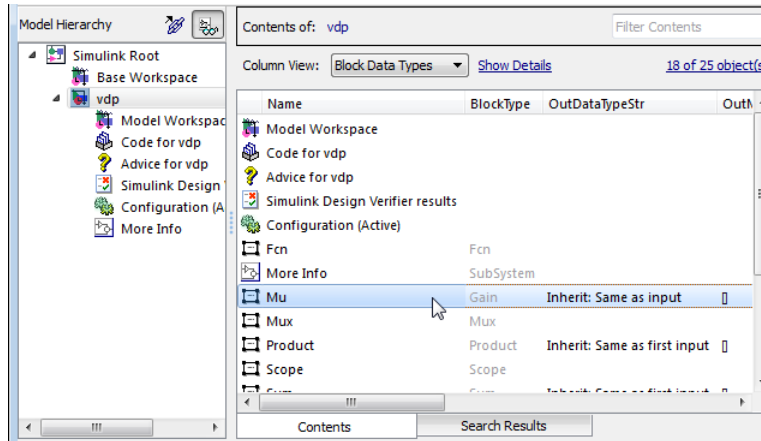
The **Contents of** link at the top left side of the **Contents** pane links to the currently selected node in the **Model Hierarchy** pane. In the following example, **Contents of** links to the vdp model, which is the currently selected node.



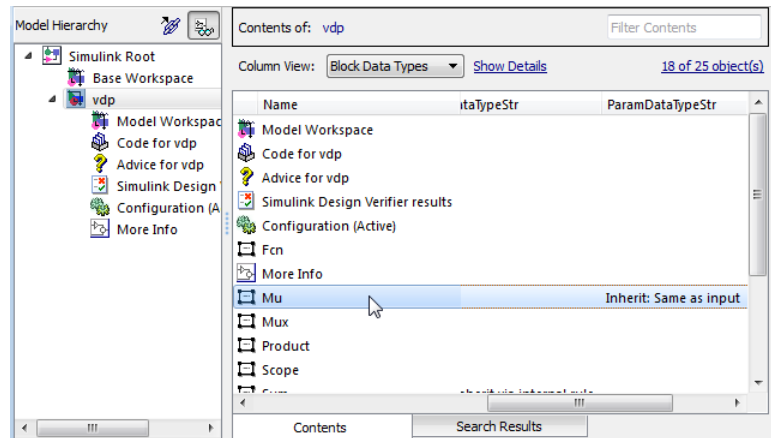
## Horizontal Scrolling in the Object Property Table

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 8-46
Search within the selected set of objects.	“The Model Explorer: Search Bar” on page 8-61
Specify a set of properties to display based on the kind of node.	“The Model Explorer: Controlling Contents Using Views” on page 8-25
Group data based on unique values in a property column.	“Grouping by a Property” on page 8-36
Manage views (for example, save and export a view).	“Managing Views” on page 8-29
Add, remove, or rearrange columns.	“The Model Explorer: Organizing How Data Displays” on page 8-35
Edit object property values.	“Editing Object Properties” on page 8-24

### Editing Object Properties

To open a properties dialog box for an object in the **Model Hierarchy** pane, right-click the object, and from the context menu, select **Properties**. Alternatively, click an object and from the **Edit** menu, select **Properties**.

You can change modifiable properties in the **Contents** pane (for example, a block name) by editing the displayed value. To edit a value, first select the row that contains the value, and then click the value. An edit control replaces the value (for example, an edit field for text values or a list for a range of values). Use the edit control to change the value of the selected property.

To assign the same property value to multiple objects in the **Contents** pane, select the objects and then change one of the selected objects to have the new property value. An edit control replaces the value with `<edit>`, indicating that you are doing batch editing. The Model Explorer assigns the new property value to the other selected objects, as well.

You can also change property values using the **Dialog** pane. See “The Model Explorer: Dialog Pane” on page 8-67.

# The Model Explorer: Controlling Contents Using Views

## In this section...

“Using Views” on page 8-25

“Customizing Views” on page 8-28

“Managing Views” on page 8-29

## Using Views

### What Is a Column View?

A view in the Model Explorer is a named set of properties.

The Model Explorer uses views to specify sets of property columns to display in the **Contents** pane.

For each kind of node in the **Model Hierarchy** pane, certain properties are most relevant for the objects displayed in the **Contents** pane. For example, for a Simulink model node, such as a model or subsystem, some properties that are useful to display include:

- BlockType (block type)
- OutDataTypeStr (output data type)
- OutMin (minimum value for the block output)

Generally, a column view does not contain the total set of properties for all the objects in a node. Specifying a subset of properties to display can streamline the task of exploring and editing model and chart object properties and increase the density of the data displayed in the **Contents** pane.

### What You Can Capture in a View

You can use a view to capture the following characteristics of the model information to show in the Model Explorer:

- Properties that you want to display in the **Contents** pane (see “Customizing Views” on page 8-28)

- Layout of the **Contents** pane (for example, grouping by property, the order of property columns, and sorting), as described in “The Model Explorer: Organizing How Data Displays” on page 8-35.

### Use Standard Views or Customized Views

You can use views in the following ways:

- Use the standard views shipped with the Model Explorer
- Customize the standard views
- Create your own views

### Automatically Applied Views

The first time you open the Model Explorer, the software automatically applies one of the standard views to the node you select in the **Model Hierarchy** pane. The Model Explorer applies a view based on the kind of node you select.

The Model Explorer assigns one of four categories of nodes in the **Model Hierarchy** pane. The Model Explorer initially associates a default view with each node category. The four node categories are:

Node Category	Kinds of Hierarchy Nodes Included	Initial Associated View
Simulink	Models, subsystems, and root level models	Block Data Types
Workspace	Base and model workspace objects	Data Objects
Stateflow	Stateflow charts and states	Stateflow
Other	Objects that do not fit into one of the first three categories; for example, configuration sets	Default

The **Column View** field at the top of the **Contents** pane displays the view that the Model Explorer is currently using.

**If you select a view.** In the **Contents** pane, from the **Column View** list, you can select a different view. If you select a different view, then the Model Explorer associates that view with the category of the current node. For example, suppose the selected node in the **Model Hierarchy** pane is a Simulink model, and the current view is **Data Objects**. If you change the view to **Signals**, then when you select another Simulink model node, the Model Explorer uses the **Signals** view. See “Selecting a View Manually” on page 8-27.

### Selecting a View Manually

By default, the Model Explorer automatically applies a view, based on the category of node that you select and the last view used for that node. You can manually select a view from the **Column View** list that better meets your current task.

You can shift from the default mode of having the Model Explorer automatically apply views to a mode in which you must manually select a view to change views.

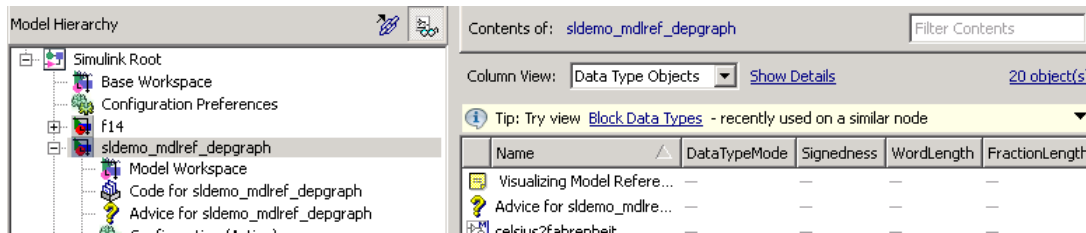
To enable the manual view selection mode:

- 1** Select **View > Column View > Manage Views**.

The View Manager dialog box opens.

- 2** In the View Manager dialog box, click the **Options** button and clear **Change View Automatically**.

In the manual view selection mode, if you switch to a different kind of node in the **Model Hierarchy** pane that has a different view associated with it, the **Contents** pane displays a yellow informational bar suggesting a view to use.



**Tip interface.** The tip interface appears immediately above the object property table.

The tip does not appear if you use automatic view selection.

To hide the currently displayed tip, from the menu button on the right-hand side of the tip bar, select **Hide This Tip**.

The tip interface displays a link for changing the current view to a suggested view. To choose the suggested view displayed in the tip bar, click the link.

Initially, the suggested view is the default view associated with a node. If you associate a different view with a node category, then the tip suggests the most recently selected view when you select similar nodes.

To change from manual specification of views to automatic specification, from the tip interface, select the down arrow and then the **Change View Automatically** menu item.

### Customizing Views

If a standard view does not meet your needs, you can either modify the view or create a new view.

You can customize the object property table represented by the current view in several ways, as described in these sections:

- “Adding Property Columns” on page 8-41
- “Hiding or Removing Property Columns” on page 8-42
- “Changing the Order of Property Columns” on page 8-40



## How the Model Explorer Saves Your Customizations

As you modify the object property table, you change the current view definition.

The Model Explorer saves the following changes to the object property table as part of the column view definition:

- Grouping by property
- Sorting in a column
- Changing the order of property columns
- Adding a property column
- Hiding and removing property columns

When you change from one view to another view, the Model Explorer saves any customizations that you have made to the previous view.

For example, suppose you use the **Block Data Types** view and you remove the **LockScale** property column. If you then switch to use the **Data Objects** view, and later use the **Block Data Types** view again, the **Block Data Types** view no longer includes the **LockScale** column that you deleted.

At the end of a Simulink session, the Model Explorer saves the view customizations that you made during that session. When you reopen the Model Explorer, Simulink uses the customized view, reflecting any changes that you made to the view in the previous session.

## Managing Views

If a standard view does not meet your needs, you can either modify the view or create a new view. See “Customizing Views” on page 8-28.

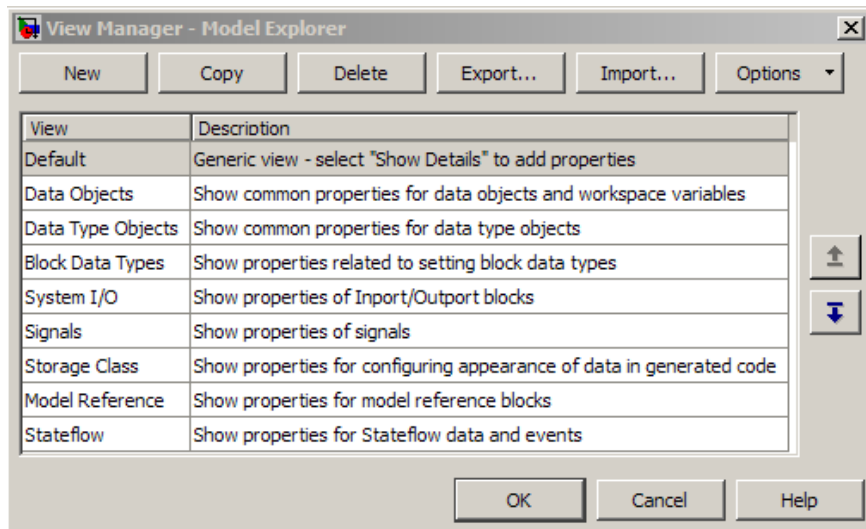
You can manage views (for example, create a new view or export a view) using the View Manager dialog box.

## Opening the View Manager Dialog Box

To open the View Manager dialog box, select the **Manage Views** option from either:

- The **View > Column View** menu
- The options listed when you click the **Options** button in the column view details section

The View Manager dialog box displays a list of defined views and provides tools for you to manage views.



You can manage views in several ways, including:

- “Creating a New View” on page 8-31
- “Deleting Views” on page 8-32
- “Reordering Views” on page 8-32
- “Exporting Views” on page 8-32
- “Importing Views” on page 8-33
- “Resetting Views to Factory Settings” on page 8-33

## Creating a New View

To create a new view that has a new name, you can use one of these approaches:

- Copy an existing view, rename it, and customize the view.
- Create a completely new view.

After you create a new view, you can customize the view as described in “Customizing Views” on page 8-28.

**Copying and renaming an existing view.** You can build a new view by copying an existing view, renaming it, and optionally customizing the renamed view. In the View Manager dialog box:

- 1 Select the view that you want to use as the starting point for your new view.
- 2 Click the **Copy** button.

A new row appears at the bottom of the View Manager table of views. The new row contains the name of the view you copied, followed by a number in parentheses. For example, if you copy the `Stateflow` view, the initial name of the copied view is `Stateflow (1)`.

**Creating a completely new view.** To create a completely view, in the View Manager dialog box, click the **New** button. A new view row appears at the bottom of the View Manager dialog box list of views.

**Naming and describing a new view.** Once you create a view, you can name the view and provide a description of the view:

- 1 Double-click `New View` in the left column of the table of views and replace the text with a name for the view.
- 2 Double-click `Description` in the table and replace the text with a description of the view.
- 3 Click **OK**.

### Deleting Views

To delete a view from the **Column View** list of views:

- 1 In the View Manager dialog box, select one or more views that you want to remove from the list.
- 2 Click the **Delete** button or the **Delete** key.
- 3 Click **OK**.

Deleting a view using the View Manager dialog box permanently deletes that view from the Model Explorer interface.

If you think you or someone else might want to use a view again, consider exporting the view before you delete it (see “Exporting Views” on page 8-32).

### Reordering Views

To change the position of a view in the **Column View** list, in the View Manager dialog box:

- 1 Select one or more views that you wish to move up or down one row in the table of views.
- 2 Click the up or down arrow buttons to the right of the table of views. Repeat this step until the view appears where you want it to be in the table.
- 3 Click **OK**.

### Exporting Views

To export views that you or others can then import, in the View Manager dialog box:

- 1 In the View Manager dialog box, select one or more views that you want to export.
- 2 Click the **Export** button.

An Export Views dialog box opens, with check marks next to the views that you selected.

**3** Click **OK**.

An Export to File Name dialog box opens.

**4** Navigate to the folder to which you want to export the view.

By default, the Model Explorer exports views to the MATLAB current folder.

**5** Specify the file name for the exported view.

The file format is `.mat`.

**6** Click **OK**.

## Importing Views

To import view files from another location for use by the Model Explorer:

**1** In the View Manager dialog box, click the **Import** button.

The Select `.mat` File to Import dialog box opens.

**2** Navigate to the folder from which you want to import the view.**3** Select the MAT-file containing the view that you want to import and then click **Open**.

A confirmation dialog box opens. Click **OK** to import the view.

The imported view appears at the bottom of the **Column View** list of views.

The Model Explorer automatically renames the view if a name conflict occurs.

## Resetting Views to Factory Settings

You can reset (restore) the original definition of a specific standard view (that is, a view shipped with the Model Explorer) if that view is the current view. To do so, click the **Options** button in the column view details section and select **Reset This View to Factory Settings**.

To reset the factory settings for *all* standard views in one step, in the View Manager dialog box, click the **Options** button and select **Reset All Views to Factory Settings**.

---

**Note** When you reset all views, the Model Explorer removes all the custom views you have created. Before you reset views to factory settings, export any views that you will want to use in the future.

---

## The Model Explorer: Organizing How Data Displays

### In this section...

“Layout Options” on page 8-35

“Sorting Column Contents” on page 8-35

“Grouping by a Property” on page 8-36

“Changing the Order of Property Columns” on page 8-40

“Adding Property Columns” on page 8-41

“Hiding or Removing Property Columns” on page 8-42

“Marking Nonexistent Properties” on page 8-44

### 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.

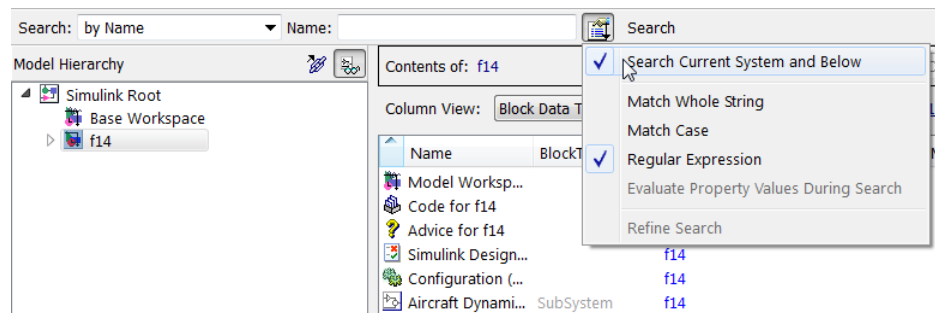
---

## Grouping by a Property

### Organizing Contents by Property Values

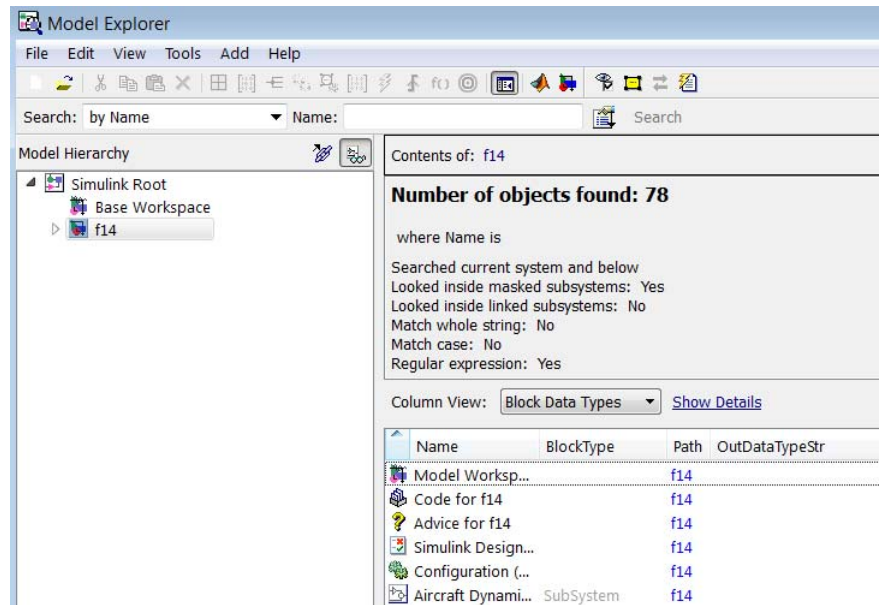
When you explore a model, you might want to focus on all objects with the same property value. One approach is to group data by a property column.

For example, suppose that you want to see all of the blocks in the f14 model. You could perform the following search.

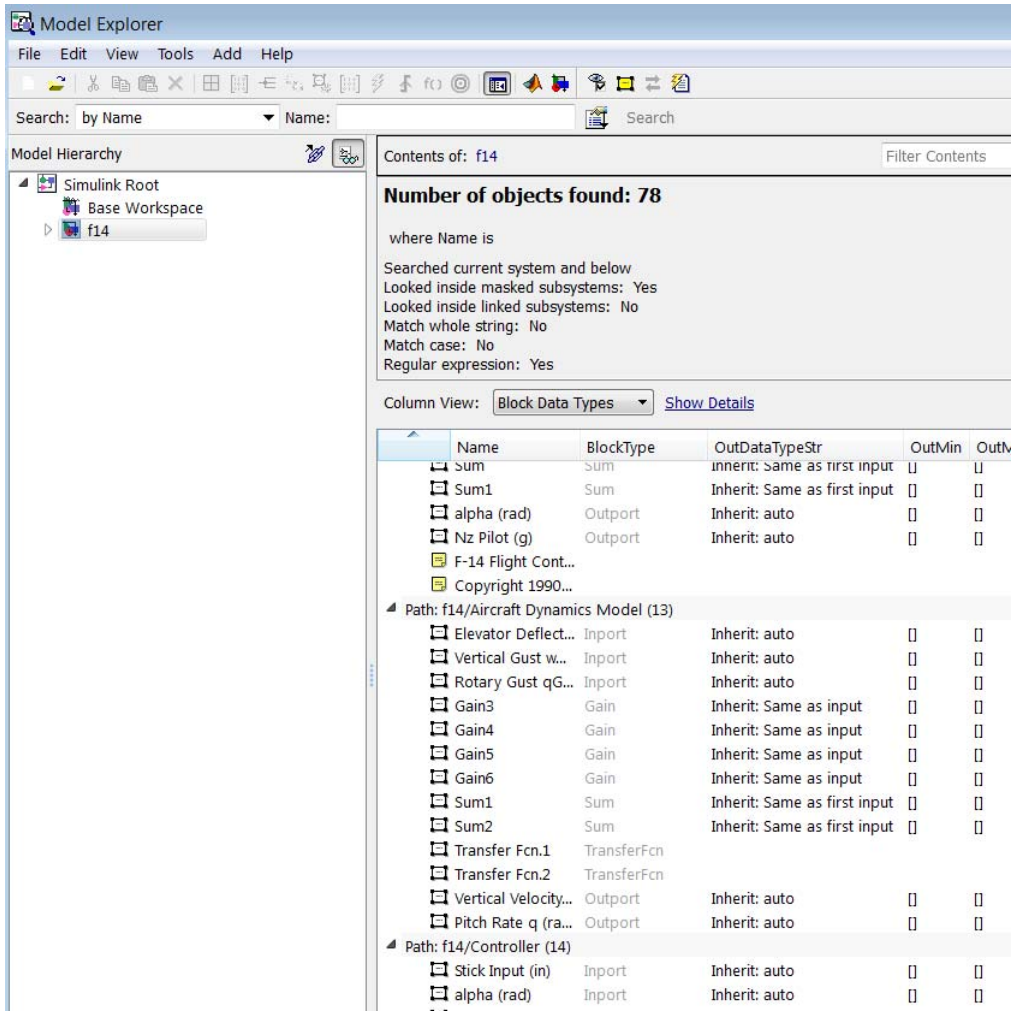


The search results obscure the whole path name for lower-level nodes:





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.

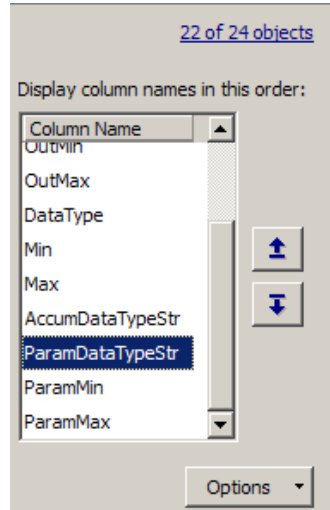
This approach avoids opening the column view details section and makes it easier to move a column a short distance to the right or left.



- 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.

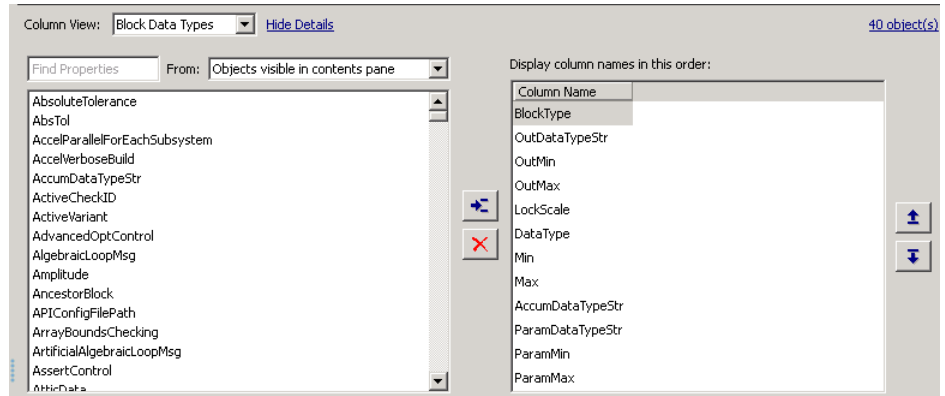



- 2 Click the **Move column left in view** button () or the **Move column right in view** button ()

## 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:

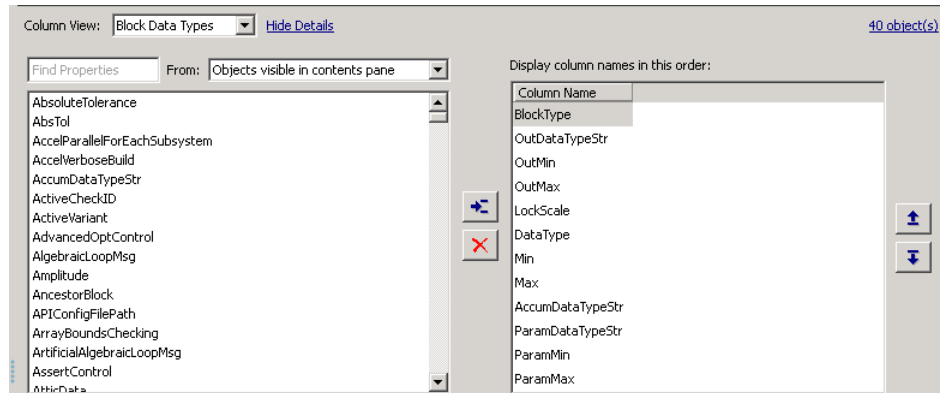
- Hide a column using the context menu for a column heading. This approach avoids needing to open the column view details section.
- Remove a column using the column view details interface. This approach allows you to delete several properties in one step.


## 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 8-42.

### Marking Nonexistent Properties

Usually, some of the properties that the **Contents** pane displays do not apply to all the displayed objects (in other words, some objects do not have values set). By default, the Model Explorer displays a dash (–) to mark properties that do not have a value.

If you want the Model Explorer to display a blank (instead of the default dash) in property cells that have no values, clear the **View > Show Nonexistent Properties as “–”** option. The **Contents** pane looks similar to the following graphic:



Column View: Block Data Types Show Details 24 obje

Name	BlockType	DataType	OutDataTypeStr	OutMin	LockScale	OutMax
<input type="checkbox"/> Elevator Deflec...	Inport	—	Inherit: auto	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> Vertical Gust w...	Inport	—	Inherit: auto	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> Rotary Gust q...	Inport	—	Inherit: auto	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> Gain3	Gain	—	Inherit: Same ...	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> Gain4	Gain	—	Inherit: Same ...	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> Gain5	Gain	—	Inherit: Same ...	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> Gain6	Gain	—	Inherit: Same ...	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> Sum1	Sum	—	Inherit: Same ...	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> Sum2	Sum	—	Inherit: Same ...	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> Transfer Fcn.1	Transfer...	—	—	—	—	—
<input type="checkbox"/> Transfer Fcn.2	Transfer...	—	—	—	—	—
<input type="checkbox"/> Vertical Velocity...	Output	—	Inherit: auto	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> Pitch Rate q(r...	Output	—	Inherit: auto	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> line	—	—	—	—	—	—
<input type="checkbox"/> line	—	—	—	—	—	—
<input type="checkbox"/> line	—	—	—	—	—	—

## The Model Explorer: Using the Row Filter Option and Filtering Contents

In this section...
“Controlling the Set of Objects to Display” on page 8-46
“Using the Row Filter Option” on page 8-46
“Filtering Contents” on page 8-49

### Controlling the Set of Objects to Display

Two techniques that you can use to control the set of objects that appear in the **Contents** pane are:

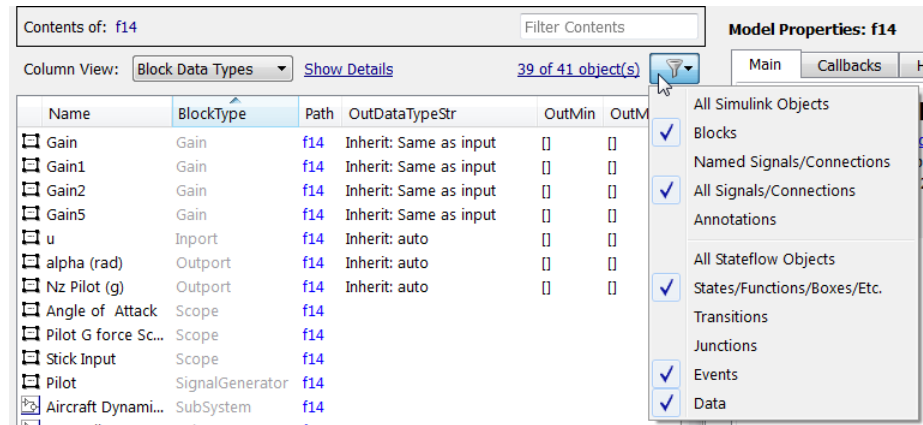
- Using the Row Filter option
- Filtering contents

For a summary of other techniques, see “Focusing on Specific Elements of a Model or Chart” on page 8-7.

### 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.

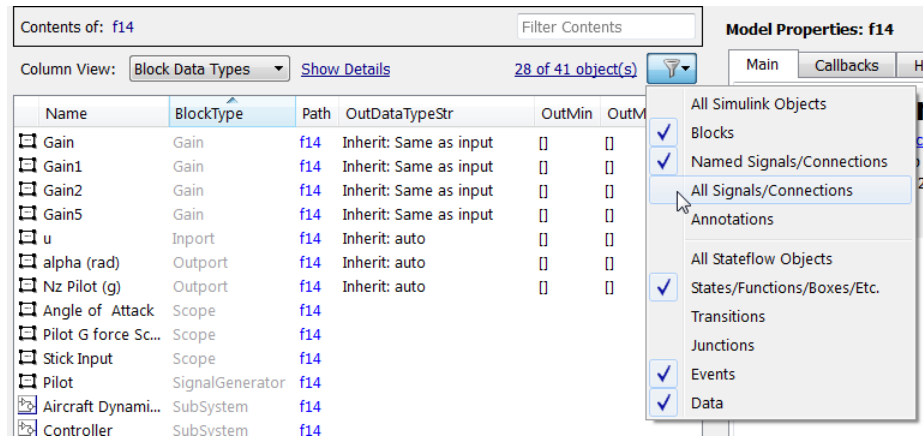


An alternative way to open the Row Filter menu is to select **View > Row Filter**.

By default, the **Contents** pane displays these kinds of objects for the selected node:

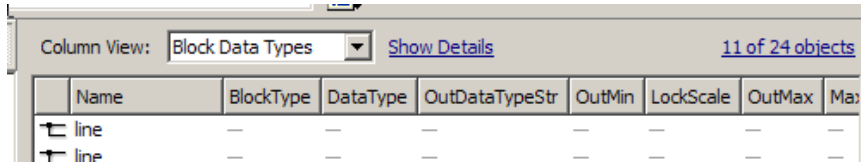
- Blocks
- Signals and connections
- Stateflow states, functions, and boxes
- Stateflow events
- Stateflow data

- 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.



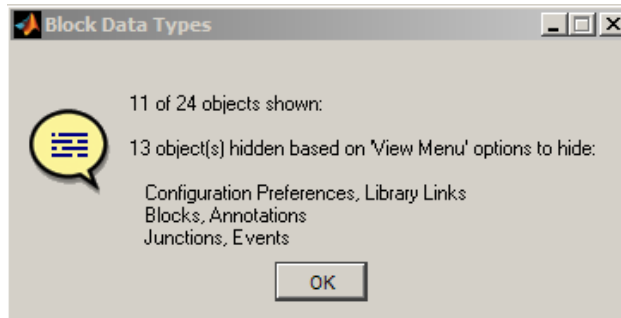
### Object Count

The top-right portion of the **Contents** pane includes an object counter, indicating how many objects the **Contents** pane is displaying.



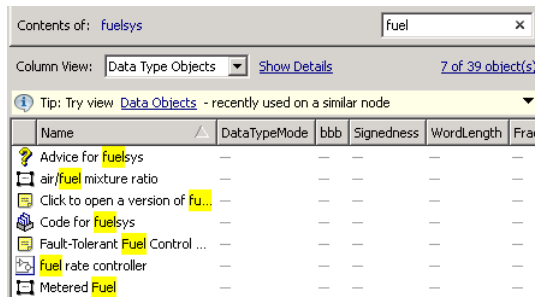
When you use the **Row Filter** option to filter objects, the object count indicator reflects that the **Contents** pane displays a subset of all the model and chart objects.

To view an explanation of the current object count, click the object count link (for example, 11 of 24 objects). That link displays a pop-up information box:



## Filtering Contents

To refine the display of objects that are currently displayed in the **Contents** pane, you can use the **Filter Contents** text box at the top of the **Contents** pane to specify search strings for filtering a subset of objects.



Using the **Filter Contents** text box can help you to find specific objects within the set of objects, based on a particular object name, property value, or property that is of interest to you. For example, if you enter the text string `fuel` in the **Filter Contents** edit box, the Model Explorer displays results similar to those shown above. The results highlight the text string that you specified.

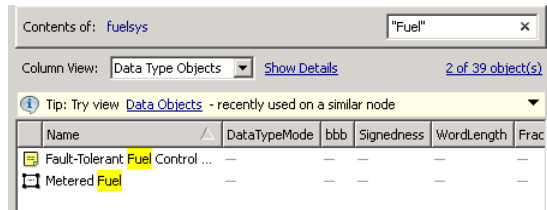
## Specifying Filter Text Strings

As you enter text in the **Filter Contents** text box, the Model Explorer performs a dynamic search, displaying results that reflect the text as you enter it.

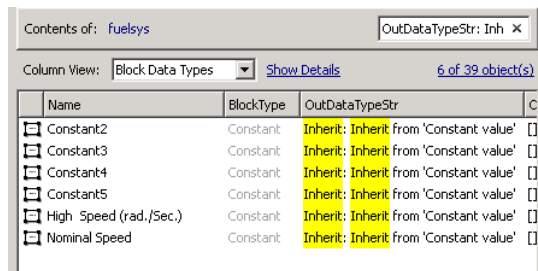
The text strings you enter must be in the format consistent with the guidelines described in the following sections.

**Case Sensitivity.** By default, the Model Explorer ignores case as it performs the filtering.

To specify that you want the Model Explorer to respect case sensitivity for a text string that you enter, put that text string in quotation marks. For example, if you want to restrict the filtering to display only objects that include the text Fuel (with a capital F), enter "Fuel" (with quotation marks).



**Specifying Property Values.** To restrict the filtering to apply to values for a specific property, specify the property name followed by a colon (:), and then the value. For example, to filter the contents to display only objects whose OutDataTypeStr property has a value that includes Inherit, enter OutDataTypeStr: Inherit (alternatively, you could put the whole string in quotation marks to enforce case sensitivity):



**Wildcards and MATLAB Expressions Not Supported.** The Model Explorer does not recognize wildcard characters, such as an asterisk (\*), as having any special meaning. For example, if you enter fuel\* in the **Filter Contents** text box, you get no results, even if several objects contain the text string fuel.

Also, if you specify a MATLAB expression, in the **Filter Contents** text box, the Model Explorer interprets that string as literal text, not as a MATLAB expression.

### **Clearing the Filtered Contents**

To redisplay the object property table as it appeared before you filtered the contents, click the **X** in the **Filter Contents** text box.

### **Filtering Removes Grouping**

If you have set up grouping on a column, then when you filtering contents, the Model Explorer does not retain that grouping.

## The Model Explorer: Working with Workspace Variables

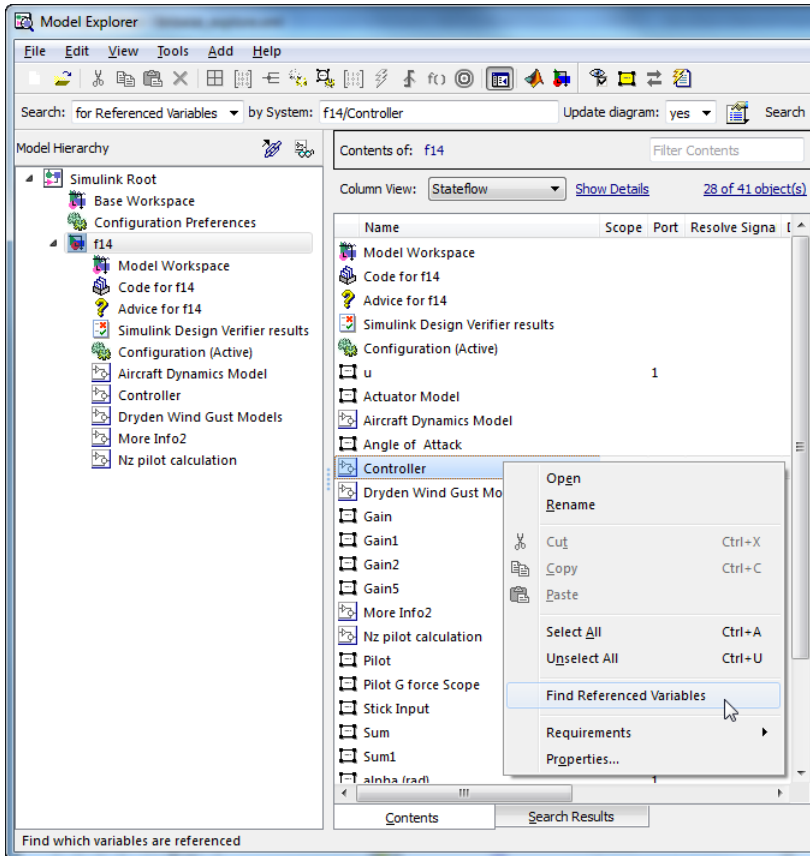
In this section...
“Finding Variables That Are Used by a Model or Block” on page 8-52
“Finding Blocks That Use a Specific Variable” on page 8-55
“Finding Unused Workspace Variables” on page 8-56
“Exporting Workspace Variables” on page 8-58
“Importing Workspace Variables” on page 8-60

### Finding Variables That Are Used by a Model or Block

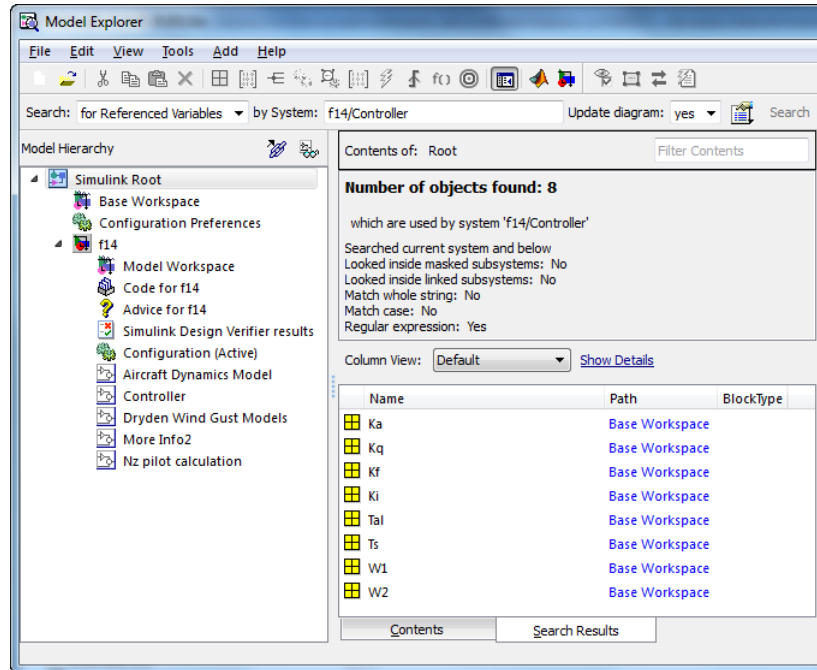
In the Model Explorer, you can get a list of variables that a model or block uses. The following approach is one way to get that list of variables:

- 1** In the **Contents** pane, right-click the block for which you want to find the variables that it uses.
- 2** Select the **Find Referenced Variables** menu item.





Model Explorer returns results similar to this:



For performance, Model Explorer uses cached information from the last compiled version of the model. If you want to recompile the model, either do so manually or, in the Model Explorer, set the **Update diagram** field to **yes** and repeat the search.

You can also use the following approaches to find variables that a model or block uses:

- In the Model Explorer, in the **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.

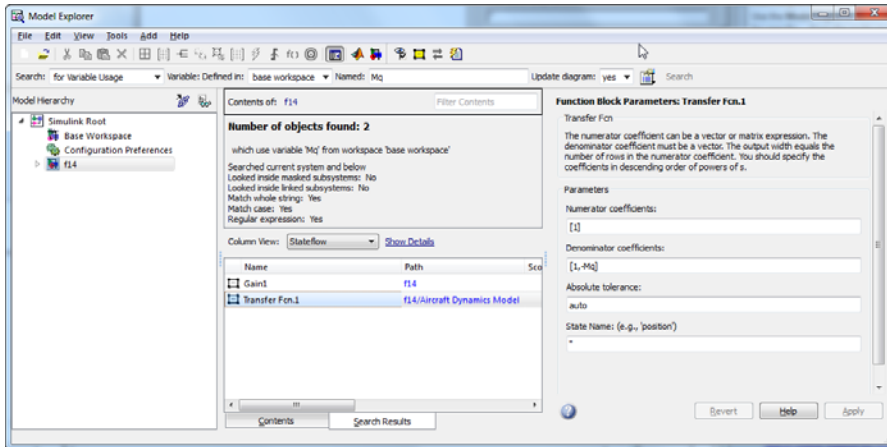
### Using the Set of Returned Variables

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 8-55). Also, you can export variables from the returned set of variables. For details, see “Exporting Workspace Variables” on page 8-58.

### 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.

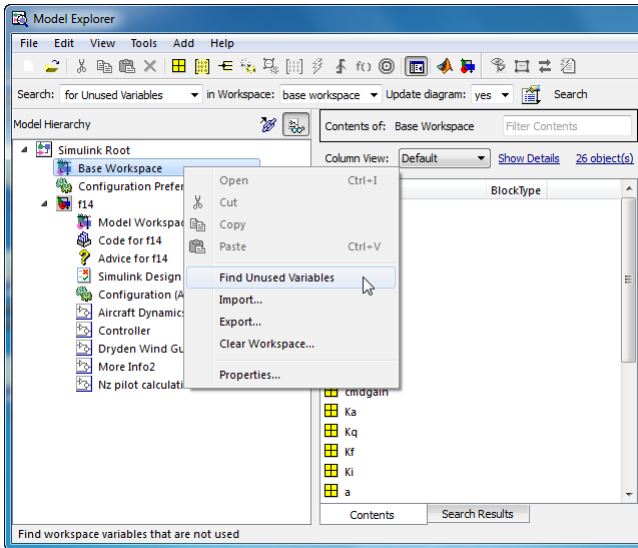
You can also find blocks that use a specific variable, by using one of these approaches:

- 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.

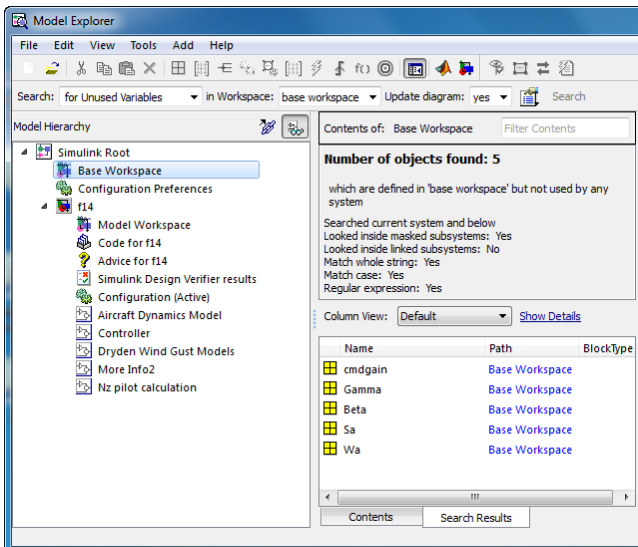
### Finding Unused Workspace Variables

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 **Model Hierarchy** pane, right-click the **Base Workspace** node and select the **Find Unused Variables** menu item.



4 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.

### Exporting Workspace Variables

You can export (save) a set of variables listed in the Model Explorer, exporting either individual variables or all the variables in the base or model workspace.

One possible workflow is to export the set of variables returned with the **Find Referenced Variables** option or the `Simulink.findVars` function. For details, see “Finding Variables That Are Used by a Model or Block” on page 8-52.

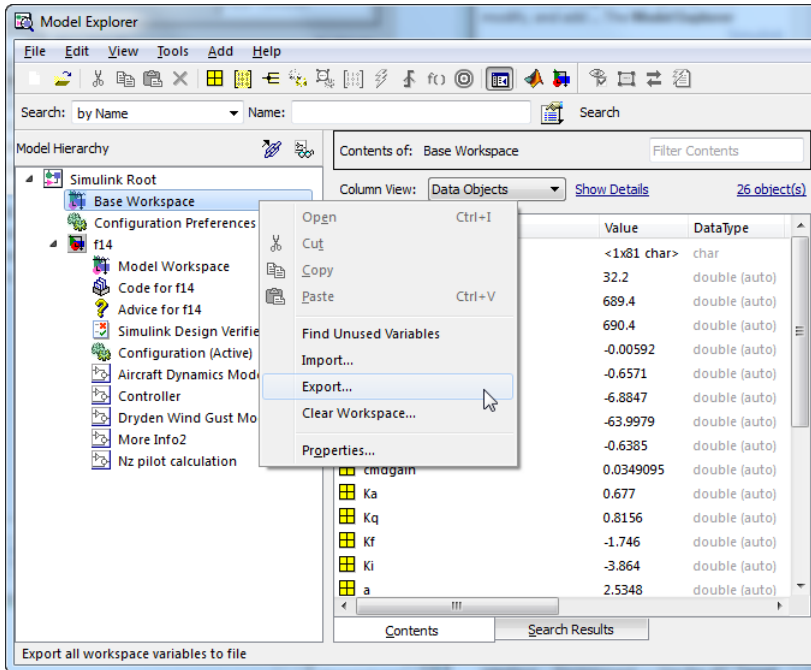
---

**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.
  - To select all the variables in a workspace, right-click the workspace node (for example, **Base Workspace**) and select the **Export** menu item. For example:



- b** To select individual variables, in the **Contents** pane, select the variables that you want to export. Right-click one of the highlighted variables and select the **Export Selected** menu item.

If the **Contents** pane has data grouped by a property, selecting the top line in a group does not select all the variables in that group. For details about grouped data, see “Grouping by a Property” on page 8-36.

- 2** Specify whether to save the variables in a MATLAB code file or a MAT-file.

The MATLAB code file format is easier to read, is editable, and supports version control. The MAT-file format is binary, which has performance advantages.

If you specify a MATLAB code file format, the Model Explorer may create an associated MAT-file, reflecting the name of the MATLAB code file, but with an extension of `.mat` instead of `.m`.

- 3** Specify a name and location for the file.

- 4** If the file already exists, Model Explorer displays a dialog box asking you to choose one of these options:
- **Overwrite entire file**
    - Replaces all variables in the target file with the selected variables, which are stored in alphabetical order.
  - **Update variables that exist in file and append new variables to file**
    - Updates existing variables in place and appends new variables.
  - **Only update variables that exist in file**
    - Updates existing variables, but does not add any new variables, which eliminates potentially extraneous variables.

### Importing Workspace Variables

You can import (load) a set of variables from a file into the base workspace or into a model workspace using the Model Explorer. When you import variables into a workspace, the Model Explorer overwrites existing variables and adds any new variables.

To import variables into a workspace:

- 1** In the **Model Hierarchy** pane, right-click the workspace into which you want to import variables.
- 2** Select the **Import** menu item.
- 3** In the Import from File dialog box, select a MATLAB code file or MAT-file for the variables that you want to import.

---

**Note** If you import a MATLAB code file, then Simulink also imports the associated MAT-file.

---



## The Model Explorer: Search Bar

### In this section...

“Searching in the Model Explorer” on page 8-61

“The Search Bar” on page 8-62

“Showing and Hiding the Search Bar” on page 8-62

“Search Bar Controls” on page 8-62

“Search Options” on page 8-64

“Search Button” on page 8-66

“Refining a Search” on page 8-66

### Searching in the Model Explorer

Use the Model Explorer search bar to search for specific objects from the node you select in the **Model Hierarchy** pane.

The Model Explorer displays search results in the **Search Results** tab of the **Contents** pane.

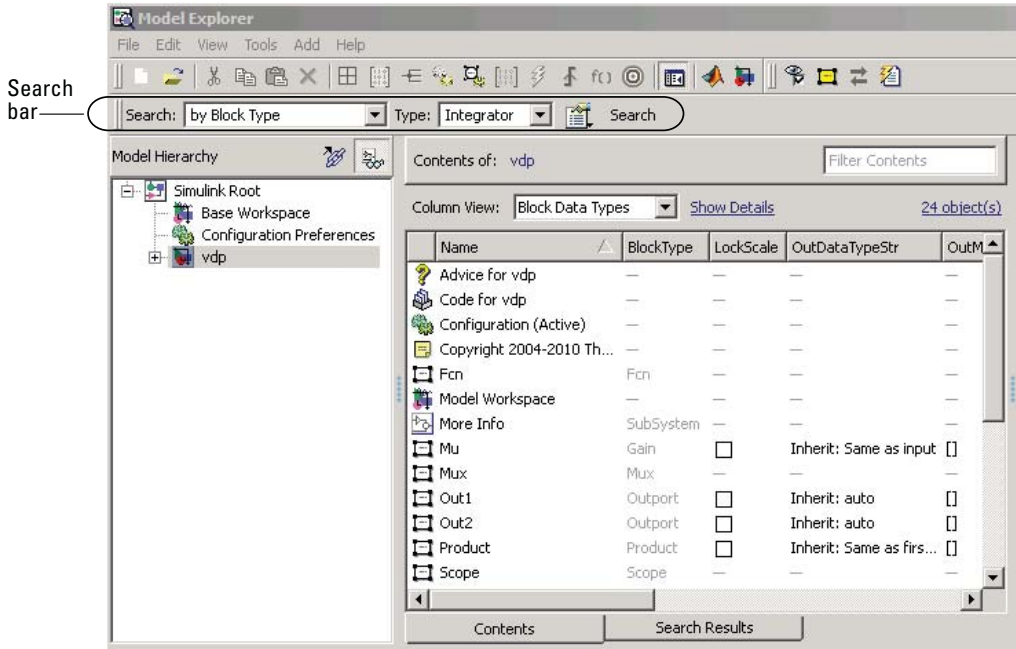
The search results appear in a table that is similar to the object property table in the **Contents** tab. The search results table uses the current column view (the object property table) definition as a starting point, and adds relevant properties that are not already included in the current view. Any additional property columns added to the **Search Results** pane do not affect the view definition.

If you modify the property columns in the search results table that also appear in the property table view, the changes you make affect both tables. For example, if you hide **OutMax** column in the search results table, and the **OutMax** column was also in the object property view table, then the **OutMax** column is hidden in both tables. However, if in the search results table you reorder where the **Complexity** column appears, if the view does not include the **Complexity** property, then that change to the search results table does not affect the view.

You can edit property values in the search results table.

## The Search Bar

The search bar appears at the top of the Model Explorer window.

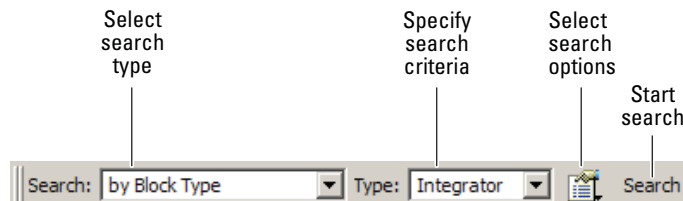


## Showing and Hiding the Search Bar

By default, the search bar is visible. To show or hide the search bar, select or clear the **View > Toolbars > Search Bar** option.

## Search Bar Controls

The search bar includes the following controls:



## Search Type

Use the **Search Type** control to specify the type of objects or properties to include in the search.

Search Type Option	Description
by Name	Searches a model or chart for all objects that have the specified string in the name of the object. See “Search Strings” on page 8-65.
by Property Name	Searches for objects that have a specified property. Specify the target property name from a list of properties that objects in the search domain can have.
by Property Value	Searches for objects with a property value that matches the value you specify. Specify the name of the property, the value to be matched, and the type of match (for example, equals, less than, or greater than). See “Search Strings” on page 8-65.
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 8-65.

Search Type Option	Description
for Referenced Variables	Searches for variables that a model or block uses. Specify the name of the model or block in the <b>by System</b> field. The model or block must be in the <b>Model Hierarchy</b> pane.
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 <b>in Workspace</b> 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 8-65.
by String	Searches a model for all objects in which the string you specify occurs. See “Search Strings” on page 8-65.

## Search Options

Use the **Search Options** control to specify the scope and how to apply search strings.

Search Option	Description
Search Current System and Below	Search the current system and the subsystems that it includes directly or indirectly.
Match Whole String	Do not allow partial string matches (for example, do not allow sub to match substring).
Match Case	Considers case when matching strings (for example, Gain does not match gain).
Regular Expression	Considers a string to be matched as a regular expression.
Evaluate Property Values During Search	Applies only for searches by property value. If enabled, the option causes the Model Explorer to evaluate the value of each property as a MATLAB expression and compare the result to the search value. If this option is disabled (the default), the Model Explorer compares the unevaluated property value to the search value.
Refine Search	Initiates a secondary search that provides additional search criteria to refine the initial search results. The second search operation searches for objects that meet both the original and the new search criteria (see “Refining a Search” on page 8-66).

## 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.

**Number of objects found: 39**

where Property SampleTime = -1


Searched current system and below  
 Looked inside masked subsystems: Yes  
 Looked inside linked subsystems: No  
 Match whole string: No  
 Match case: No  
 Regular expression: Yes

Column View: Data Objects [Show Details](#)

	Name	Path	Value	DataType	Min	Max	Dimensions	StorageClass	Complexity	InitialValue	SampleTime
	w	f14/Nz ...	—	—	—	—	—	—	—	—	-1
	q	f14/Nz ...	—	—	—	—	—	—	—	—	-1
	Gain1	f14/Nz ...	—	—	—	—	—	—	—	—	-1
	Gain2	f14/Nz ...	—	—	—	—	—	—	—	—	-1
	Product	f14/Nz ...	—	—	—	—	—	—	—	—	-1
	Sum1	f14/Nz ...	—	—	—	—	—	—	—	—	-1

You can edit the results displayed in the **Search Results** pane. For example, to change all objects found by a search to have the same property value, select the objects in the **Search Results** pane and change the property value of one of the objects.

## Refining a Search

To refine the previous search, in the search bar, click the **Select Search Options** button  and select **Refine Search**. A **Refine** button replaces the **Search** button on the search bar. Use the search bar to define new search criteria and then click the **Refine** button. The Model Explorer searches for objects that match both the previous search criteria and the new criteria.

## The Model Explorer: Dialog Pane

### In this section...

“What You Can Do with the Dialog Pane” on page 8-67

“Showing and Hiding the Dialog Pane” on page 8-67


“Editing Properties in the Dialog Pane” on page 8-67

### What You Can Do with the Dialog Pane

You can use the **Dialog** pane to view and change properties of objects that you select in the **Model Hierarchy** pane or in the **Contents** pane.

### Showing and Hiding the Dialog Pane

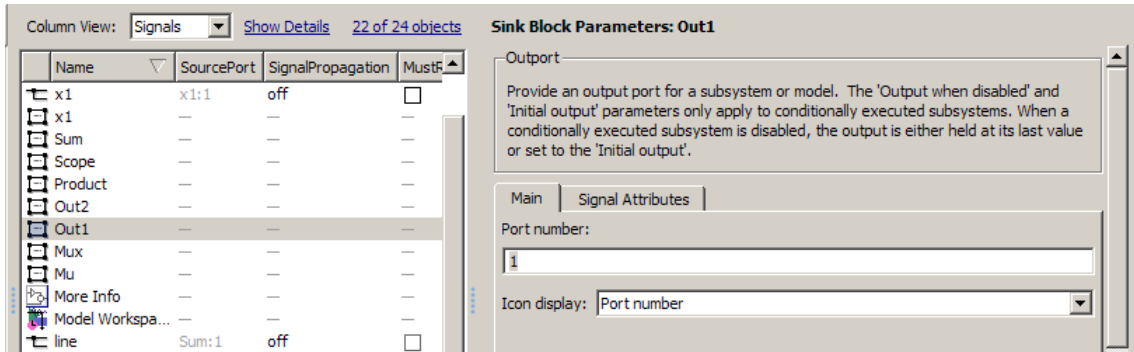
By default, the **Dialog** pane appears in the Model Explorer, to the right of the **Contents** pane. To show or hide the **Dialog** pane, use one of these approaches:

- From the **View** menu, select **Show Dialog Pane**.
- From the main toolbar, click the **Dialog View** button ()

### Editing Properties in the Dialog Pane

To edit property values using the **Dialog** pane:

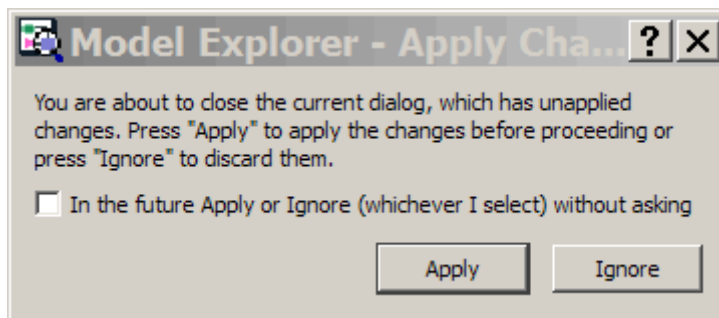
- 1 In the **Contents** pane, select an object (such as a block or signal). The **Dialog** pane displays the properties of the object you selected.



**2** Change a property (for example, the port number of an Outport block) in the **Dialog** pane.

**3** Click **Apply** to accept the change, or click **Revert** to return to the original value.

By default, clicking outside a dialog box with unapplied changes causes the Apply Changes dialog box to appear:



Click **Apply** to accept the changes or **Ignore** to revert to the original settings.

To prevent display of the **Apply Changes** dialog box:

**1** In the dialog box, click the **In the future Apply or Ignore (whichever I select) without asking** check box.



- 2** If you want Simulink to apply changes without warning you, press **Apply**.  
If you want Simulink to ignore changes without warning you, press **Ignore**.

To restore display of the **Apply Changes** dialog box, from the **Tools** menu, select **Prompt if dialog has unapplied changes**.

## The Finder

### In this section...

“Find Model Objects” on page 8-70

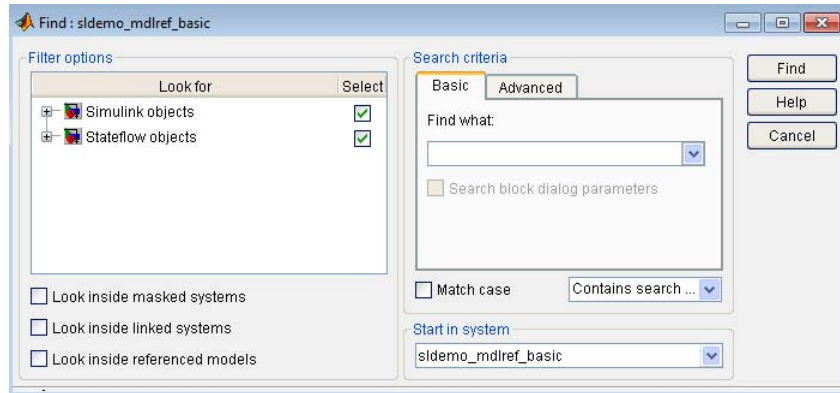
“Filter Options” on page 8-72

“Search Criteria” on page 8-73

## Find Model Objects

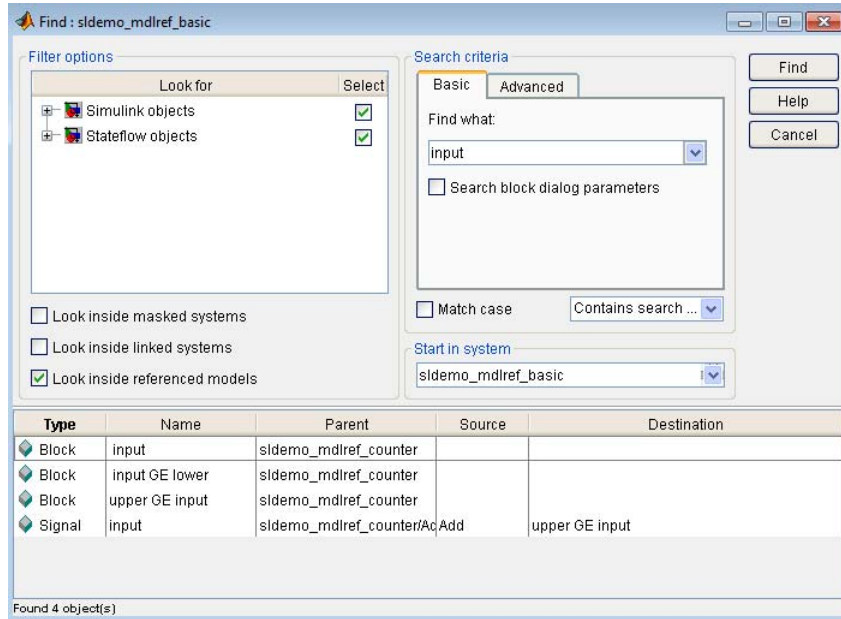
Use the Finder to locate blocks, signals, states, or other objects in a model.

- 1 Open the Finder. In the Simulink Model 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 8-72.
- 3 In the **Search criteria** area, specify the criteria that objects must meet to satisfy your search request. See “Search Criteria” on page 8-73.
- 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

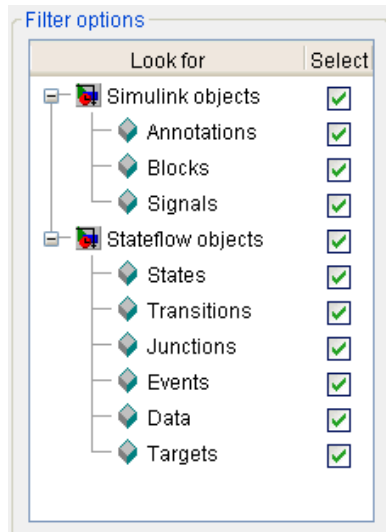
open an object that was in the Finder search results list, simply rerun the search by clicking the **Find** button.

### 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  <hr/> <b>Note</b> The Finder loads unopened referenced models. You can stop the search by using the pop-up cancel dialog box.  <hr/>

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:

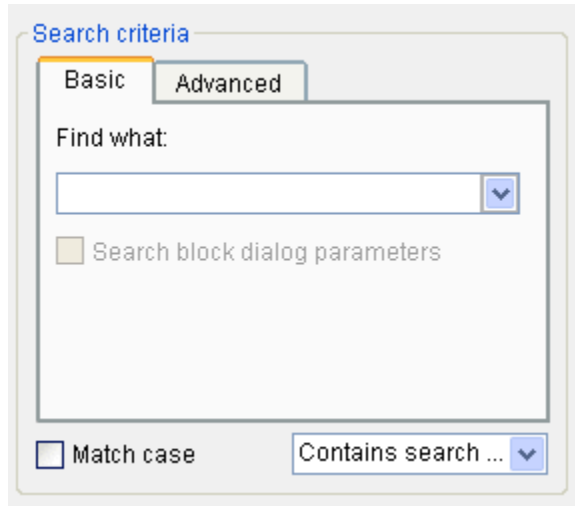
- Searches in linked library systems and referenced models that are not in a masked system
- Does *not* search inside:
  - Masked systems, including those that are in linked library systems or referenced models
  - Linked library systems or model referenced models, if the system or model is in a masked system

## Search Criteria

To specify the criteria that objects must meet to satisfy your search request, use the **Search criteria** panel.

### Basic

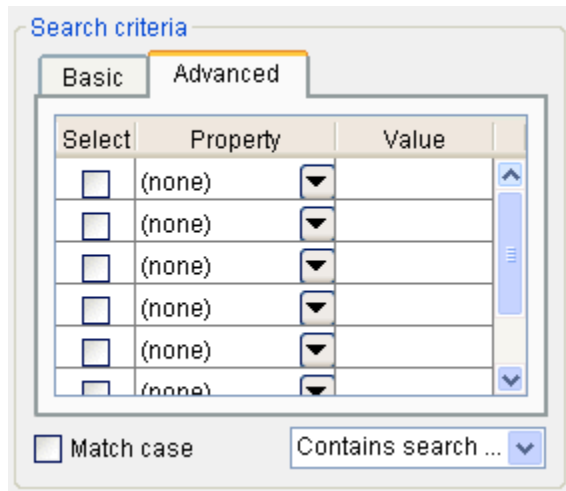
To search for an object whose name matches a specified text string, use the **Basic** panel. Enter search text in the **Find what** edit box. To reuse previous search text, select the appropriate search text from the dropdown list.



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, <code>ba*</code> matches <code>b</code> , <code>ba</code> , <code>baa</code> , and so on.
+	Matches one or more instances of the preceding character. For example, <code>ba+</code> matches <code>ba</code> , <code>baa</code> , 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, <code>[a-zA-Z0-9_]+</code> matches <code>foo_bar1</code> but not <code>foo\$bar</code> . A <code>^</code> indicates a match when the current character is not one of the following characters. For example, <code>[^0-9]</code> matches any character that is not a digit.
<code>\w</code>	Matches a word character (same as <code>[a-zA-Z0-9_]</code> ).
<code>\W</code>	Matches a nonword character (same as <code>[^a-zA-Z0-9_]</code> ).
<code>\d</code>	Matches a digit (same as <code>[0-9]</code> ).
<code>\D</code>	Matches a nondigit (same as <code>[^0-9]</code> ).
<code>\s</code>	Matches white space (same as <code>[\t\r\n\f]</code> ).
<code>\S</code>	Matches nonwhite space (same as <code>[^\t\r\n\f]</code> ).
<code>\&lt;WORD\&gt;</code>	Matches <code>WORD</code> where <code>WORD</code> is any string of word characters surrounded by white space.



## The Model Browser

In this section...
“About the Model Browser” on page 8-77
“Navigating with the Mouse” on page 8-79
“Navigating with the Keyboard” on page 8-79
“Showing Library Links” on page 8-79
“Showing Masked Subsystems” on page 8-79

### About the Model Browser

The Model Browser enables you to

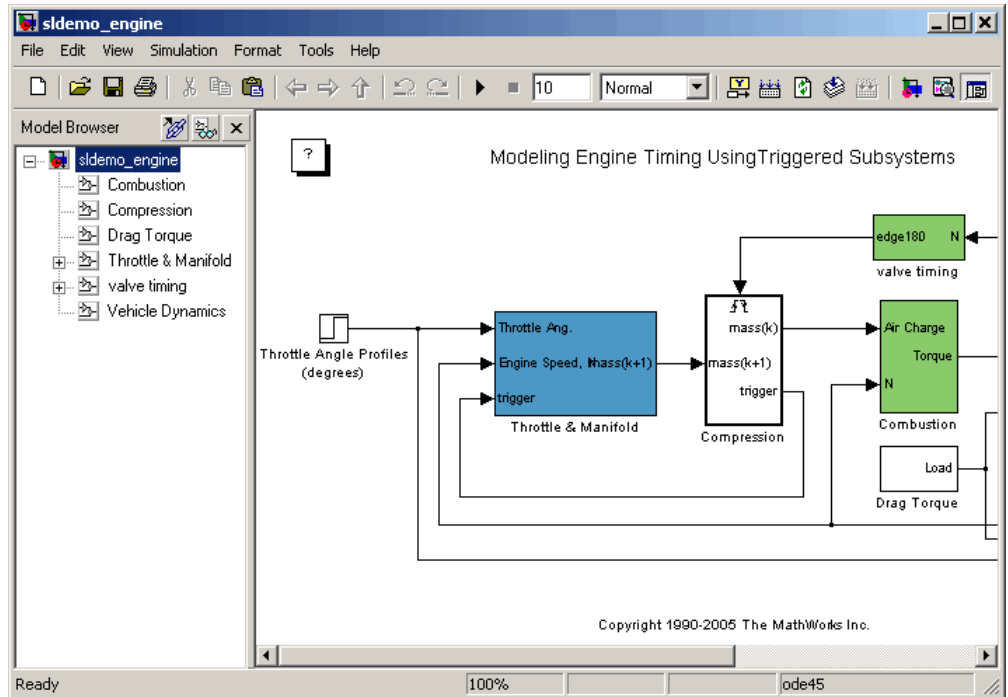
- Navigate a model hierarchically
- Open systems in a model
- Determine the blocks contained in a model

---

**Note** The browser is available only on Microsoft Windows platforms.

---

To display the Model Browser, select **Model Browser Options > Model Browser** from the Simulink **View** menu.



The model window splits into two panes. The left pane displays the browser, a tree-structured view of the block diagram displayed in the right pane.

---

**Note** The **Browser initially visible** preference causes Simulink to open models by default in the Model Browser. To set this preference, select **Preferences** from the Simulink **File** menu.

---

The top entry in the tree view corresponds to your model. A button next to the model name allows you to expand or contract the tree view. The expanded view shows the model's subsystems. A button next to a subsystem indicates that the subsystem itself contains subsystems. You can use the button to list the subsystem's children. To view the block diagram of the model or any subsystem displayed in the tree view, select the subsystem. You can use either the mouse or the keyboard to navigate quickly to any subsystem in the tree view.

## Navigating with the Mouse

Click any subsystem visible in the tree view to select it. Click the + button next to any subsystem to list the subsystems that it contains. Click the button again to contract the entry.

## Navigating with the Keyboard

Use the up/down arrows to move the current selection up or down the tree view. Use the left/right arrow or +/- keys on your numeric keypad to expand an entry that contains subsystems.

## Showing Library Links

The Model Browser can include or omit library links from the tree view of a model. Use the **Preferences** dialog box to specify whether to display library links by default. To toggle display of library links, select **Show Library Links** from the **Model Browser Options** submenu of the **View** menu.

## Showing Masked Subsystems

The Model Browser can include or omit masked subsystems from the tree view. If the tree view includes masked subsystems, selecting a masked subsystem in the tree view displays its block diagram in the diagram view. Use the **Preferences** dialog box to specify whether to display masked subsystems by default. To toggle display of masked subsystems, select **Show Masked Subsystems** from the **Model Browser Options** submenu of the **View** menu.

## Model Dependency Viewer

In this section...
“About Model Dependency Views” on page 8-80
“Opening the Model Dependency Viewer” on page 8-85
“Manipulating a Dependency View” on page 8-86
“Browsing Dependencies” on page 8-92
“Saving a Dependency View” on page 8-92
“Printing a Dependency View” on page 8-92

### 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 “Model Dependencies” on page 12-60.

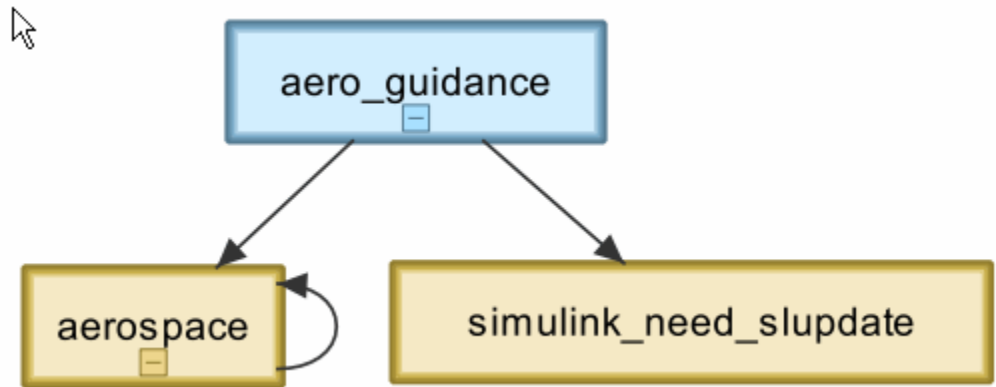
The Model Dependency Viewer allows you to choose between the following types of dependency views of a model reference hierarchy.

- “File Dependency View” on page 8-80
- “Referenced Model Instances View” on page 8-82
- “Processor-in-the-Loop Mode Indicator” on page 8-84
- “Warning Icon” on page 8-85

### File Dependency View

A *file dependency view* shows the model and library files referenced by a top model. A referenced model or library file appears only once in the view even if it is referenced more than once in the model hierarchy displayed in the view. A file dependency view consists of a set of blocks connected by arrows. Blue blocks represent model files; brown boxes, libraries. Arrows represent dependencies. For example, the arrows in the following view

indicate that the `aero_guidance` model references two libraries: `aerospace` and `simulink_need_slupdate`.



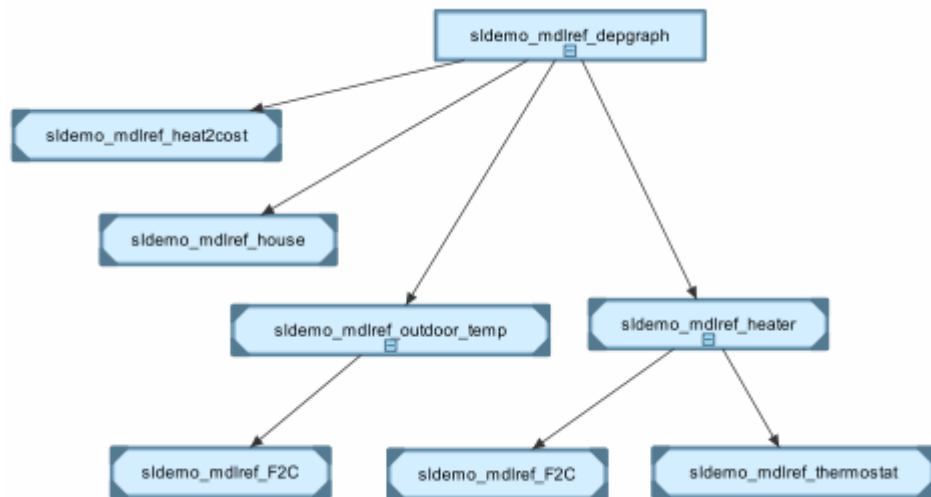
An arrow that points to the library from which it emerges indicates that the library references itself, i.e., blocks in the library reference other blocks in that same library. For example, the preceding view indicates that the `aerospace` library references itself.

A file dependency view optionally includes a legend that identifies the model in the view and the date and time the view was created.

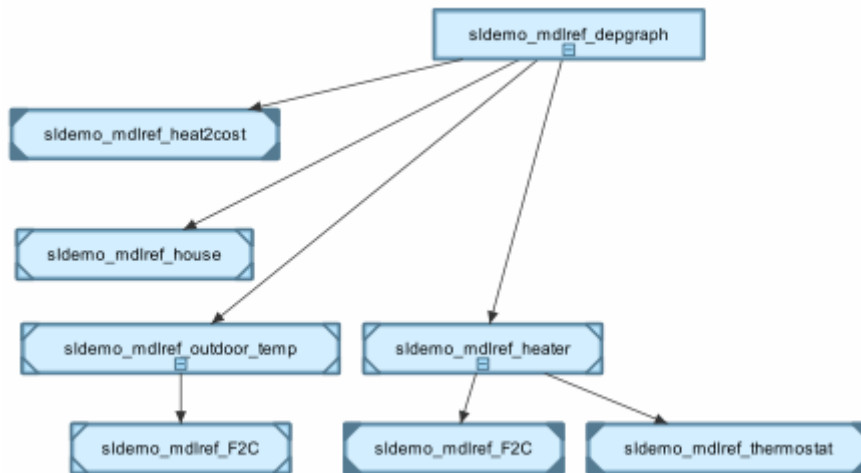


### Referenced Model Instances View

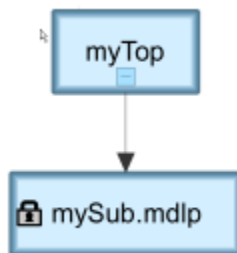
A *referenced model instances* view shows every reference to a model in a model reference hierarchy (see Chapter 5, “Referencing a Model”) rooted at the top model targeted by the view. If a model hierarchy references the same model more than once, the referenced model appears multiple times in the instance view, once for each reference. For example, the following view indicates that the model reference hierarchy rooted at `sldemo_md1ref_depgraph` contains two references to the model `sldemo_md1ref_F2C`.



In an instance view, boxes represent a top model and model references. Boxes representing accelerated-mode instances (see “Referenced Model Simulation Modes” on page 5-21) 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_mdref_F2C` operates in normal mode; the other, in accelerated mode.



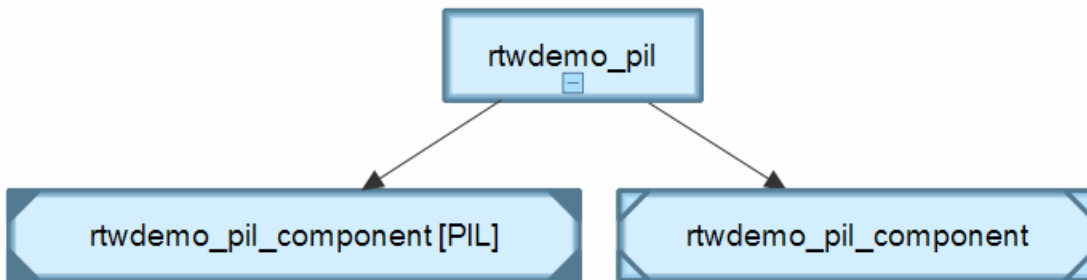
Boxes representing protected referenced models have a lock icon, and the model name has the .mdlP extension. Protected referenced model boxes have no expand(+)/collapse(-) button.



### Processor-in-the-Loop Mode Indicator


An instance view appends PIL to the names of models that run in Processor-in-the-Loop mode (see “Specifying the Simulation Mode” on page 5-23). 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 .

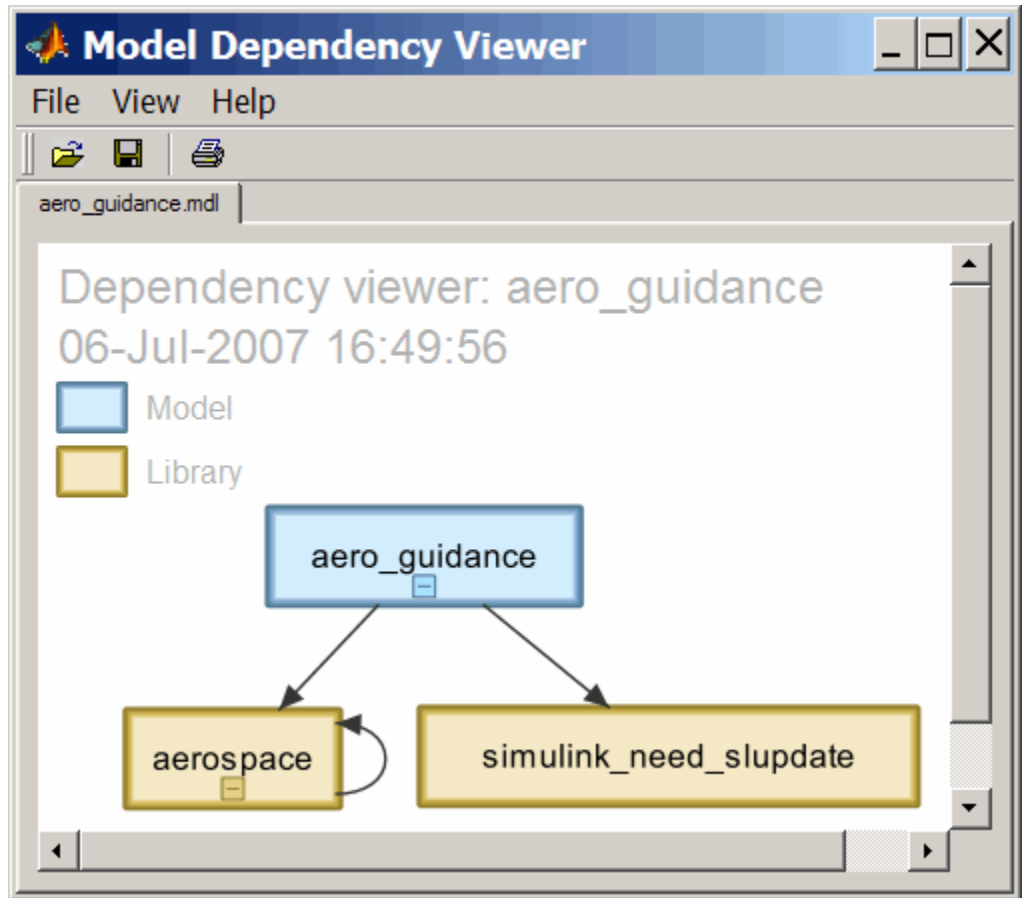
### Opening the Model Dependency Viewer

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 **Tools > Model Dependencies > Model Dependency Viewer**, then select the type of view you want to see:
  - **.mdl File Dependencies Including Libraries**
  - **.mdl File Dependencies Excluding Libraries**
  - **Referenced Model Instances**

The Model Dependency Viewer appears, displaying a dependency view of the model.



## Manipulating a Dependency View

The Model Dependency Viewer allows you to manipulate dependency views in various ways. See the following topics for more information:

- “Changing Dependency View Type” on page 8-87
- “Excluding Block Libraries from a File Dependency View” on page 8-87

- “Including Simulink Blocksets in a File Dependency View” on page 8-87
- “Changing View Orientation” on page 8-88
- “Expanding or Collapsing Views” on page 8-88
- “Zooming a Dependency View” on page 8-89
- “Moving a Dependency View” on page 8-89
- “Rearranging a Dependency View” on page 8-90
- “Displaying and Hiding a Dependency View’s Legend” on page 8-90
- “Displaying Full Paths of Referenced Model Instances” on page 8-90
- “Refreshing a Dependency View” on page 8-91

### **Changing Dependency View Type**

You can change the type of dependency view displayed in the viewer.

To change the type of dependency view:

- Select **View > Dependency Type > .mdl File Dependencies** (see “File Dependency View” on page 8-80 )
- or
- Select **View > Dependency Type > Referenced Model Instances** (see “Referenced Model Instances View” on page 8-82 ).

### **Excluding Block Libraries from a File Dependency View**

By default a file dependency view includes libraries on which a model depends.

To exclude block libraries:

- Deselect **View > Include Libraries**.

### **Including Simulink Blocksets in a File Dependency View**

By default, a file dependency view omits MathWorks block libraries when **View > Include Libraries** is selected.

To include libraries supplied by MathWorks:

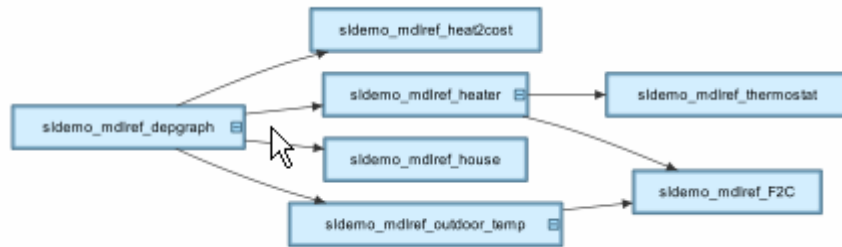
- Select **View > Show MathWorks Dependencies**.

### Changing View Orientation

By default the orientation of the dependency graph displayed in the viewer is vertical.

To change the orientation to horizontal:

- Select **View > Orientation > Horizontal**.

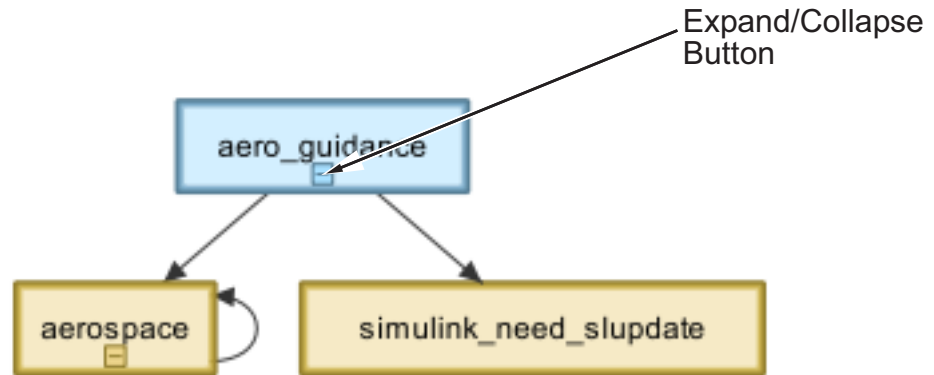


### Expanding or Collapsing Views

You can expand or collapse each model or library in the dependency view to display or hide the dependencies for that model or library.

To expand or collapse views:

- Click the expand(+)/collapse(-) button on the box representing the model or library to expand or collapse that view.



### Zooming a Dependency View

You can enlarge or reduce the size of the dependency graph displayed in the viewer.

To zoom a dependency view in or out, do either of the following:

- Press and hold down the **spacebar** key and then press the **+** or **-** key on the keyboard.
- Move the scroll wheel on your mouse forward or backward.

To fit the view to the viewer window:

- Press and release the **spacebar** key.

### Moving a Dependency View

You can move a dependency view to another location in the viewer window.

To move the dependency view:

- 1 Move the cursor over the view.
- 2 Press your keyboard's space bar and your mouse's left button simultaneously.
- 3 Move the cursor to drag the view to another location.

### **Rearranging a Dependency View**

You can rearrange a dependency view by moving the blocks representing models and libraries. This can make a complex view easier to read.

To move a block to another location:

- 1 Select the block you want to move by clicking it.
- 2 Drag and drop the block in the new location.

### **Displaying and Hiding a Dependency View's Legend**

The dependency view can display a legend that identifies the model in the view and the date and time the view was created.

To display or hide a dependency view's legend:

- Select **View > Show Legend** from the viewer's menu bar.

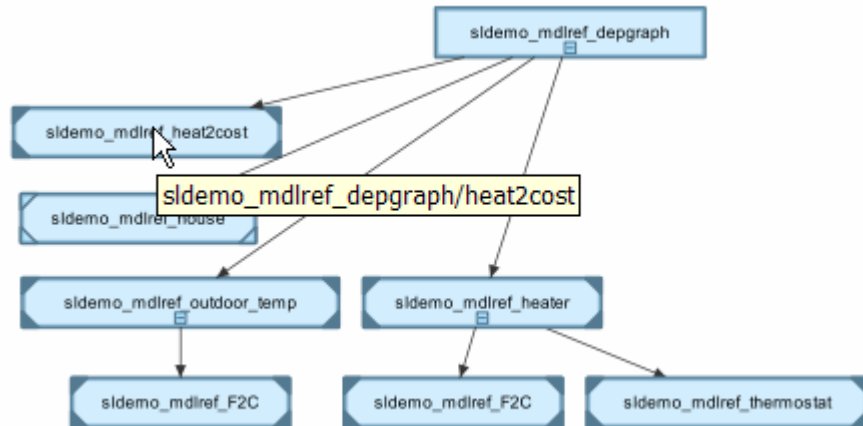
### **Displaying Full Paths of Referenced Model Instances**

In an instance view (see “Referenced Model Instances View” on page 8-82), you can display the full path of a model reference in a tooltip or in the box representing the reference.

To display the full path in a tooltip:

- Move the cursor over the box representing the reference in the view.

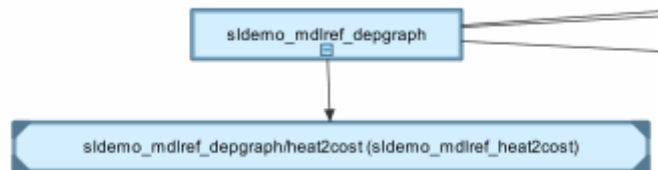
A tooltip appears, displaying the path displays the full path of the Model block corresponding to the instance.



To display full paths in the boxes representing the instances:

- Select **View > Show Full Path**.

Each box in the instance view now displays the path of the Model block corresponding to the instance. The name of the referenced model appears in parentheses as illustrated in the following figure.



## Refreshing a Dependency View

After changing a model displayed in a dependency view or any of its dependencies, you must update the view to reflect any dependency changes.

To update the view:

- Select **View > Refresh** from the dependency viewer's menu bar.

### Browsing Dependencies

You can use a dependency view to browse a model's dependencies:

- To open a model or library displayed in the view, double-click its block.
- To display the Model block corresponding to an instance in an instance view, right-click the instance and select **Highlight Block** from the menu that appears.
- To open all models displayed in the view, select **File > Open All Models** from the viewer's menu bar.
- To save all models displayed in the view, select **File > Save All Models**.
- To close all models displayed in the view, select **File > Close All Models**.

### Saving a Dependency View

You can save a dependency view for later viewing.

To save the current view:

- Select **File > Save As** from the viewer's menu bar, then enter a name for the view.

To reopen the view:

- Select **File > Open** from any viewer's menu bar, then select the view you want to open.

### Printing a Dependency View

To print a dependency view:

- Select **File > Print** from the dependency viewer's menu bar.



## Viewing Linked Requirements in Models and Blocks

In this section...
“Overview of Requirements Features in Simulink” on page 8-93
“Highlighting Requirements in a Model” on page 8-94
“Viewing Information About a Requirements Link” on page 8-96
“Navigating to Requirements from a Model” on page 8-97
“Filtering Requirements in a Model” on page 8-99

### 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 Model Editor and the Model Explorer provide this capability.

- “Highlighting a Model Using the Model Editor” on page 8-94
- “Highlighting a Model Using the Model Explorer” on page 8-96

---

**Note** If your model contains a Model block whose referenced model contains requirements, those requirements are not highlighted. You can view this information only in requirements reports. To generate requirements information for referenced models and then see highlighted snapshots of those requirements, follow the steps in “Reporting on Requirements in Model Blocks”.

---

### Highlighting a Model Using the Model Editor

If you are working in the Model Editor and want to see which model objects in the `slvnvdemo_fuelsys_officereq` model have requirements, follow these steps:

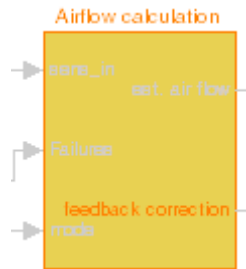
- 1 Open the demo model:

```
slvnvdemo_fuelsys_officereq
```

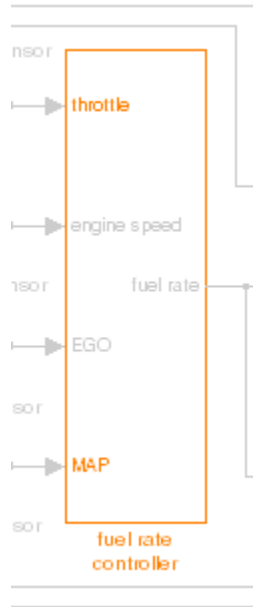
- 2 Select **Tools > Requirements > Highlight model**.

Two types of highlighting indicate model objects with requirements:

- Yellow 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 **Tools > Requirements > Unhighlight model**. Alternatively, you can right-click anywhere in the model, and select **Remove Highlighting**.

While a model is highlighted, you can still manage the model and its contents.

### 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 demo model:

```
slvndemo_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 `slvndemo_fuelsys_officereq` demo model, follow these steps:

- 1 Open the demo model:

```
slvndemo_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 `slvndemo_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 demo model:

```
slvndemo_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 `slvndemo_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 `slvndemo_fuelsys_officereq` model, and navigate to the requirements using the links inside the block.

- 1 Open the demo model:

```
slvndemo_fuelsys_officereq
```

- 2 Select **Tools > Requirements > Highlight model**.

- 3 In the `slvndemo_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 8-99
- “Filtering Options for Highlighting Requirements” on page 8-100

### Filtering Requirements Highlighting by User Tag

Some requirements links in your model can have one or more associated user tags. *User tags* are keywords that you create to categorize a requirement, for example, `design` or `test`.

For example, in the `slvnvdemo_fuelsys_officereq` model, the requirements link from the MAP sensor block has the user tag `test`.

To highlight only all the blocks that have a requirement with the user tag `test`:

- 1 Open the demo model:

```
slvnvdemo_fuelsys_officereq
```

- 2 In the Model Editor, select **Tools > Requirements > Settings**.

The Requirements Settings dialog box opens. If you do not have a Simulink Verification and Validation license, the **Filters** tab is the only option available.

By default, your model has no requirements filtering enabled.

**3** Select **Filter links by user tags when highlighting and reporting requirements**.

**4** In the **Include links with any of these tags** text box, delete design, and enter test.

**5** Press **Enter**.

**6** Highlight the slvndemo\_fuelsys\_officereq model for requirements. Select **Tools > Requirements > Highlight model**.

In the top-level model, only the MAP sensor block and the Test inputs block are highlighted.

**7** To disable the filtering by user tag, select **Tools > Requirements > Settings**, and clear **Filter links by user tags when highlighting and reporting requirements**.

The model highlighting updates immediately.

### Filtering Options for Highlighting Requirements

On the **Filters** tab, you select options that designate which objects with requirements are highlighted. The following table describes these settings, which apply to all requirements in your model for the duration of your MATLAB session.

Option	Description
<b>Filter links by user tags when highlighting and reporting requirements</b>	Enables filtering for highlighting and reporting, based on specified user tags.
<b>Include links with any of these tags</b>	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.



<b>Option</b>	<b>Description</b>
<b>Exclude links with any of these tags</b>	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.
<b>Apply same filters in context menus</b>	Disables navigation links in context menus for all objects whose requirements do not match at least one of the specified user tags.
<b>Under Link type filters, Disable DOORS surrogate item links in context menus</b>	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.



# Managing Model Configurations

---

- “About Model Configurations” on page 9-2
- “Multiple Configuration Sets in a Model” on page 9-3
- “Share a Configuration Set Across Models” on page 9-4
- “Share a Configuration Set Across Referenced Models” on page 9-6
- “Manage a Configuration Set” on page 9-8
- “Manage a Configuration Reference” on page 9-14
- “About Configuration Sets” on page 9-21
- “About Configuration References” on page 9-24
- “Model Configuration Command Line Interface” on page 9-28

## 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 9-23.

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 9-21. For examples on how to use configuration sets, see:

- “Multiple Configuration Sets in a Model” on page 9-3
- “Manage a Configuration Set” on page 9-8

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 9-24. For examples on how to use configuration references, see:

- “Share a Configuration Set Across Models” on page 9-4
- “Share a Configuration Set Across Referenced Models” on page 9-6
- “Manage a Configuration Reference” on page 9-14

## 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 Set Across 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:

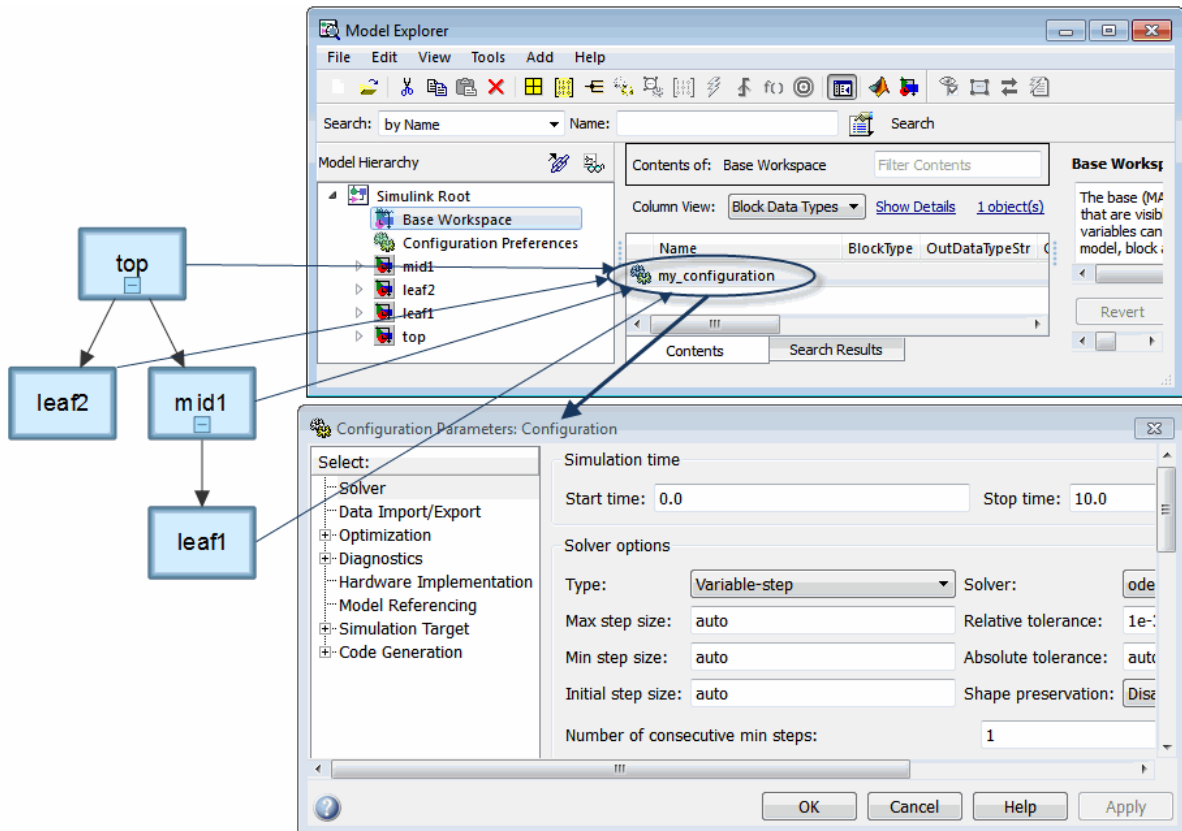
- 1 In the Model Hierarchy pane, right-click the model node.
- 2 In the context menu, select **Configuration > Add Configuration Reference**.

- 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 9-19. 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 “Using Callback Functions” on page 3-54.

## Share a Configuration Set Across Referenced Models

To use the same configuration for a model and all of its referenced models, use configuration references in each of the models to reference the same configuration set object in the base workspace.



In the diagram, each model 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`. The parameter values in `Configuration` therefore apply to all four models. Any parameter change in `Configuration` applies to all four models. To do share a configuration set across referenced model:




- 1** Open the Model Explorer.
- 2** In the Model Hierarchy pane, select **Base Workspace** and from the **Add** menu, select **Configuration**. A configuration set object is created in the base workspace.
- 3** In the Model Hierarchy pane, right-click the top model and select **Add > Configuration Reference**. The Create Configuration Reference dialog box opens.
- 4** Specify the **Configuration set name** of the configuration set object in the base workspace to be referenced. Click **OK**. You now have a configuration reference in your top model.
- 5** In the Model Hierarchy pane, right-click the configuration reference node and select **Activate**. The configuration reference is now the active configuration.
- 6** Under the top model node, right-click the active configuration reference node, and select **Propagate to Referenced Models**. The Propagate to Referenced Models dialog box opens.
- 7** Click **OK**. This action creates a copy of the configuration reference in each referenced model. The configuration references are already specified to point to the same configuration set object in the base workspace and are marked active.

## Manage a Configuration Set

### In this section...

- “Create a Configuration Set in a Model” on page 9-8
- “Create a Configuration Set in the Base Workspace” on page 9-8
- “Open a Configuration Set in the Configuration Parameters Dialog Box” on page 9-9
- “Activate a Configuration Set” on page 9-9
- “Set Values in a Configuration Set” on page 9-10
- “Copy, Delete, and Move a Configuration Set” on page 9-10
- “Save a Configuration Set” on page 9-11
- “Load a Saved Configuration Set” on page 9-12
- “Copy Configuration Set Components” on page 9-12

### 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**

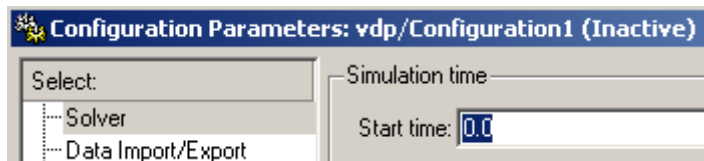
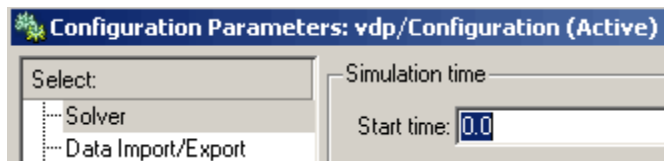
- In the toolbar, click the **Add Configuration** button 

**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 **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 9-9.

### 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” on page 9-14

“Resolve a Configuration Reference” on page 9-15

“Activate a Configuration Reference” on page 9-17

“Change Parameter Values in a Referenced Configuration Set” on page 9-18

“Save a Referenced Configuration Set” on page 9-19


“Load a Saved Referenced Configuration Set” on page 9-20

“Why is the Build Button Not Available for a Configuration Reference?”  
on page 9-20

### Create and Attach a Configuration Reference

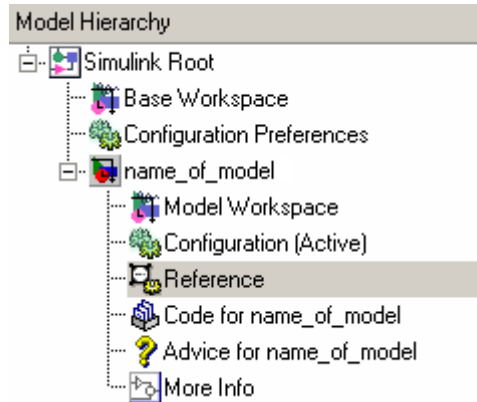
To use a configuration reference, it must point to freestanding configuration set. Create a freestanding configuration set before creating a configuration reference, see “Create a Configuration Set in the Base Workspace” on page 9-8.

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 9-25. Follow the instructions in “Resolve a Configuration Reference” on page 9-15.



- **No**, then the configuration reference is not created. Follow the instructions in “Create a Configuration Set in the Base Workspace” on page 9-8, 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**.



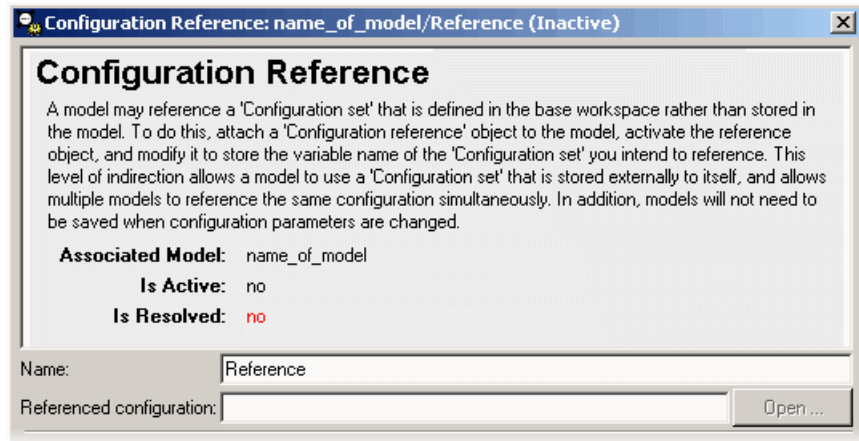
## Resolve a Configuration Reference

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 9-8.

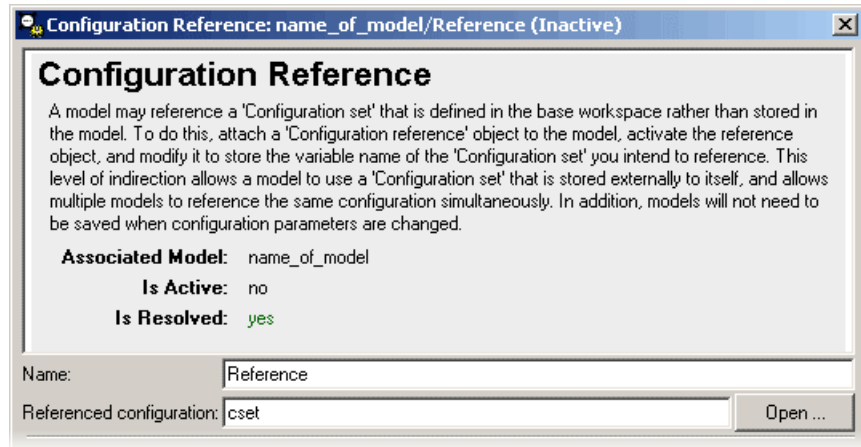
---

**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**.

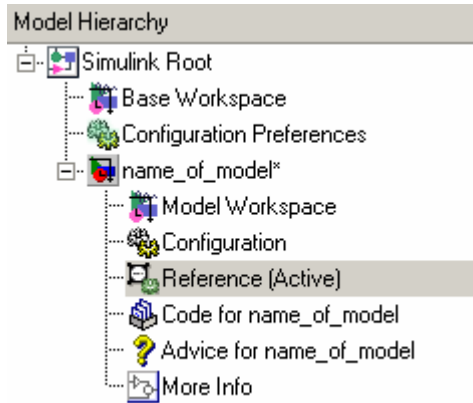


## Activate a Configuration Reference

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)**.



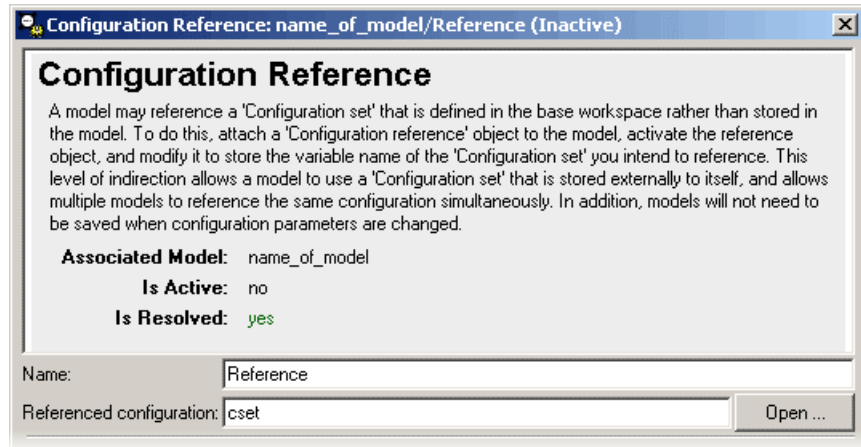
The freestanding configuration set of the active reference now provides the configuration parameters for the model.

### 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.
- 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 “Using Callback Functions” on page 3-54.

---

### 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 “Using Callback Functions” on page 3-54.

---

### 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?” on page 9-21
“What Is a Freestanding Configuration Set?” on page 9-22
“Model Configuration Preferences” on page 9-23

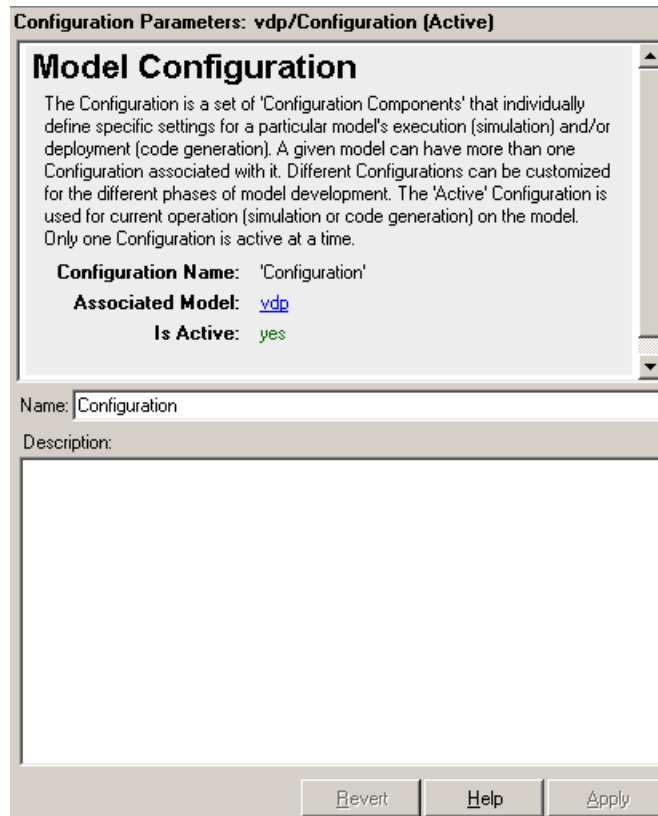
### What Is a Configuration Set?

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?” on page 9-24
“Why Use Configuration References?” on page 9-24
“Unresolved Configuration References” on page 9-25
“Configuration Reference Limitations” on page 9-26
“Configuration References for Models with Older Simulation Target Settings” on page 9-26

### 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 9-24. For an example on how to use configuration references, see “Share a Configuration Set Across Models” on page 9-4 or “Create and Attach a Configuration Reference” on page 9-14.

---

**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 “Using Callback Functions” on page 3-54.

---

### 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 9-15.

## 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 9-36.
- 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” on page 9-28

“Load and Activate a Configuration Set at the Command Line” on page 9-29

“Save a Configuration Set at the Command Line” on page 9-30

“Create a Freestanding Configuration Set at the Command Line” on page 9-30

“Create and Attach a Configuration Reference at the Command Line” on page 9-32

“Attach a Configuration Reference to Multiple Models at the Command Line” on page 9-32

“Get Values from a Referenced Configuration Set” on page 9-34

“Change Values in a Referenced Configuration Set” on page 9-34

“Obtain a Configuration Reference Handle” on page 9-35

“Use refresh When Replacing a Referenced Configuration Set” on page 9-36

### 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(mdl))
```

- 

```
cset = copy (getConfigSet(mdl, ConfigSetName))
```

*mdl* 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(mdl, 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 9-25.

## 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(mdl, ConfigSetRefName))
attachConfigSet (mdl, cref, true)
```

If you omit the copy operation, *cref* becomes a handle to the original configuration reference, rather than a copy of the reference. Any attempt to use *cref* causes an error. If you omit the argument true to attachConfigSet, the operation fails if a name conflict exists.

The following example shows code for obtaining a freestanding configuration set and attaching references to it 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('mdl1')
% Get handle to local cset
cset = getConfigSet('mdl1', 'Configuration')

% Create freestanding copy; original remains in model
cset1 = copy(cset)

% In the original model, create a configuration
% reference to the cset copy
cref1 = Simulink.ConfigSetRef
cref1.WSVarName = 'cset1'

% Attach the configuration reference to the model
attachConfigSet('mdl1', cref1, true)

% In a second model, create a configuration
% reference to the same cset
```

```
open_system('mdl2')
% Rename if name conflict occurs
attachConfigSetCopy('mdl2', cref1, true)

% Delete original cset from first model
detachConfigSet('mdl1', 'Configuration')
```

## 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 9-35.
- 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(md1, '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.





# Configuring Models for Targets with Multicore Processors

---

- “Introduction” on page 10-2
- “Design Considerations” on page 10-5
- “Modeling for Concurrent Execution” on page 10-11
- “Configure Your Model” on page 10-12
- “Baseline Analysis Using Configuration Defaults” on page 10-17
- “Customizing Concurrent Execution Settings” on page 10-19
- “Interpreting Simulation Results” on page 10-26
- “Building and Downloading the Model to a Multicore Target” on page 10-32
- “Concurrent Execution Example” on page 10-45
- “Command-Line Interface” on page 10-55

## Introduction

In this section...
“About Configuring Models for Concurrent Execution” on page 10-2
“Supported Targets” on page 10-3
“Helpful Terms” on page 10-3
“Software Requirements” on page 10-4

### 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” on page 10-5
“Simulation Limitations” on page 10-9

### 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.

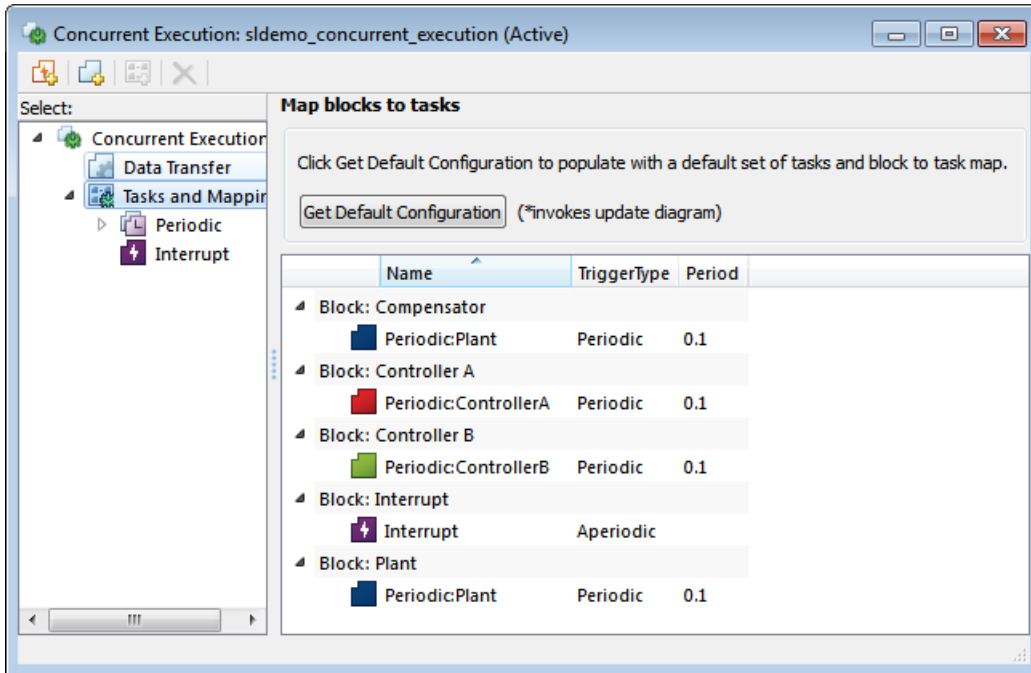
---

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:

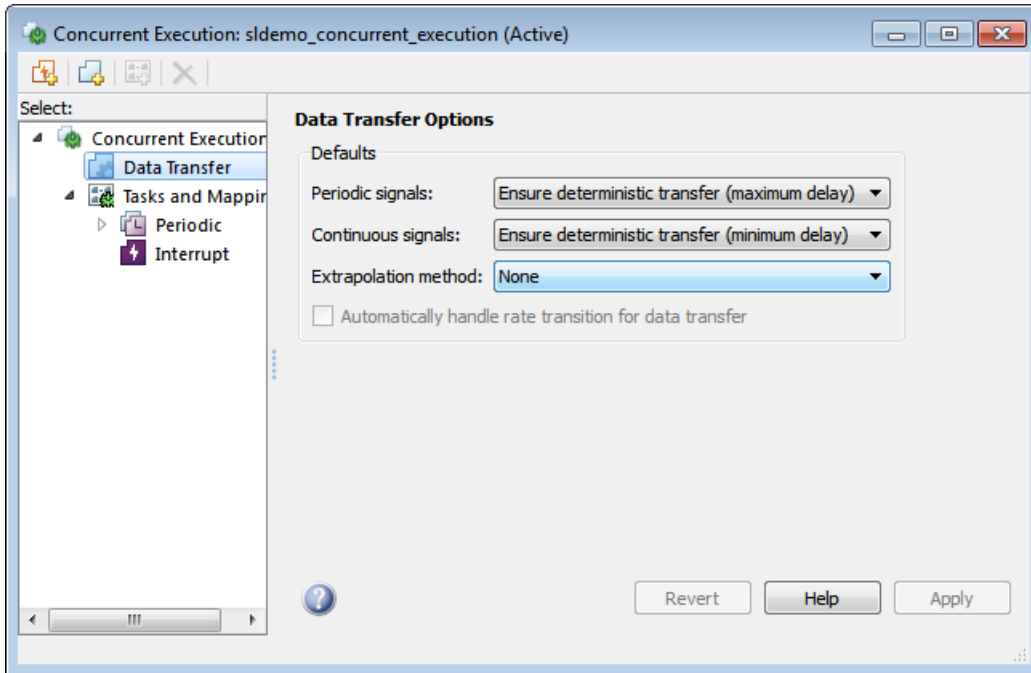
- A model that has identified blocks for concurrent execution
- A description of the available concurrency in terms of the number of tasks and their periodicities
- A mapping that places the identified blocks in the model into actual tasks for concurrent execution

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 for Concurrent Execution

## Workflow

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 10-5.

- 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 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 10-13.
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 10-12.

### 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 <b>Configuration</b> , then select the <b>Show Concurrent Execution</b> option.
Create new configuration settings, add a new concurrent execution configuration set.	Expand the node for the model. Right-click the model and select <b>Configuration &gt; Add Configuration for Concurrent Execution</b> .

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.

- 3 Activate the configuration set by right-clicking it and selecting **Activate**.

If you want to create a configuration reference, see “Creating and Propagating a Configuration Reference” on page 10-13. Otherwise, to begin configuring the model for concurrent execution, see “Baseline Analysis Using Configuration Defaults” on page 10-17.

## 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 10-12.

For more information on configuration references, see “About Configuration References” on page 9-24. This topic describes one way to create and propagate a configuration reference.

- 1 In the Simulink model editor, select **View > Model Explorer**.

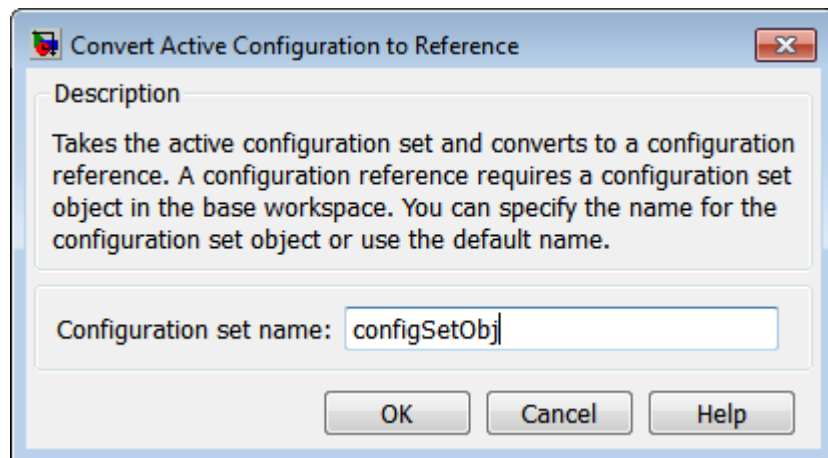
The Model Explorer window is displayed.

- 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 <b>Configuration &gt; Show Concurrent Execution options</b> .
Create new configuration settings, add a new concurrent execution configuration set.	Right-click and select <b>Configuration &gt; Add Configuration for Concurrent Execution</b> .

- 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.

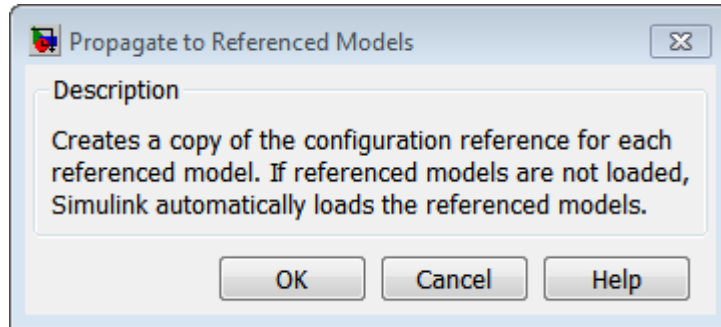


- 5 Click **OK** to accept the default name for the configuration reference.

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 **OK**.

The hierarchy of each referenced model is updated with the configuration reference.

- 8 In the left column, select the **Reference (Active)** node.

The right column changes to display the Configuration Parameters reference pane.

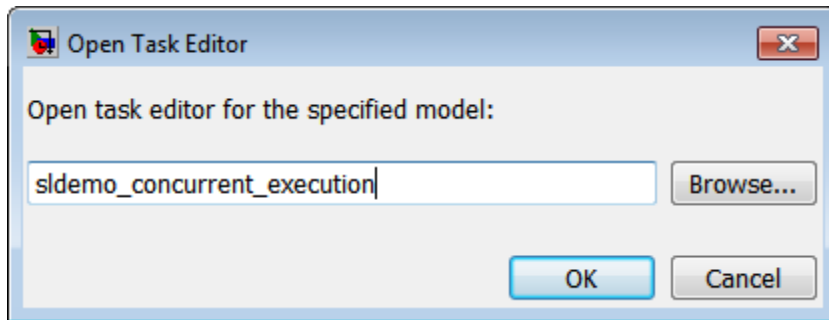
- 9 In the Configuration Parameters reference pane, click the **Open** button of the **Referenced configuration** parameter.

The Configuration Parameters dialog box is displayed.

- 10 Navigate to the Solver node.

- 11 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 10-17.



## 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.

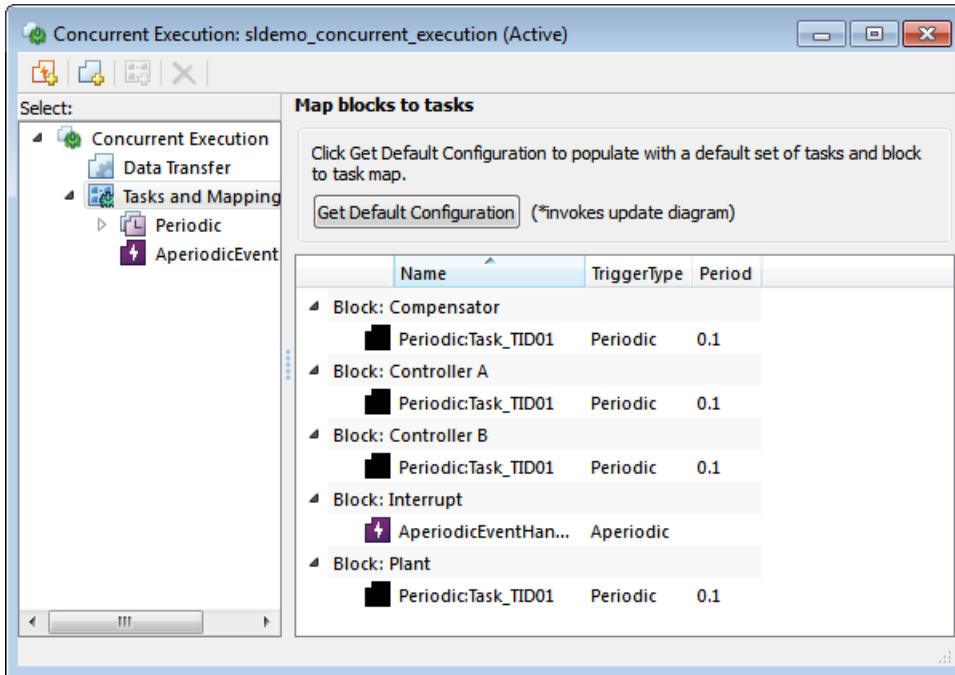
This button updates the diagram.

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.	"Customizing Concurrent Execution Settings" on page 10-19
Simulate the model.	"Interpreting Simulation Results" on page 10-26

## Customizing 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

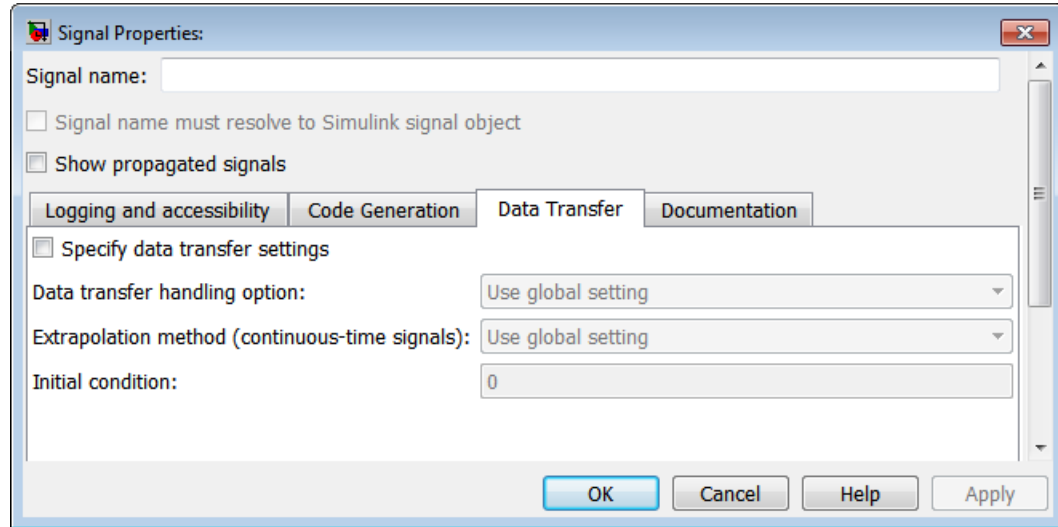
Use the **Data Transfer Options** pane to define communications between tasks.

#### Data Transfer Options

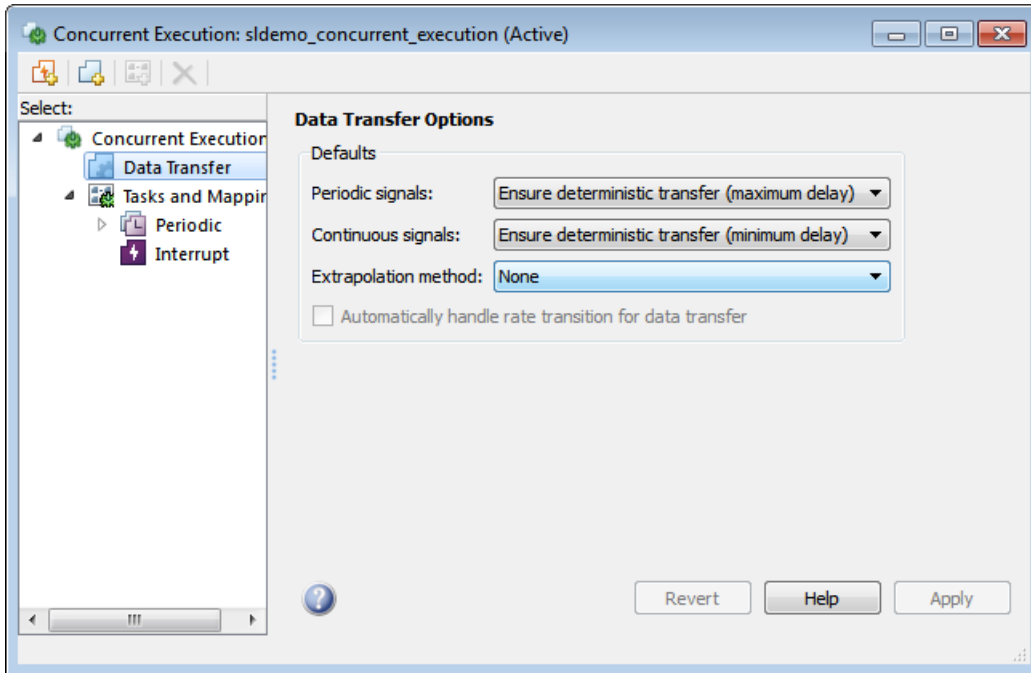
Data Transfer Type	Simulation	Deployment
Ensure data integrity only.	Data transfer is simulated using a one-step delay.	Simulink Coder ensures data integrity during data transfer. Data is transferred as soon as possible.
Ensure deterministic transfer (maximum delay).	Data transfer is simulated using 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 **Signal Properties** from the context menu. A dialog box like the following is displayed.



- 1 From the Data Transfer Options on page 10-19 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 10-24.

### Configuring Aperiodic Triggers and Tasks

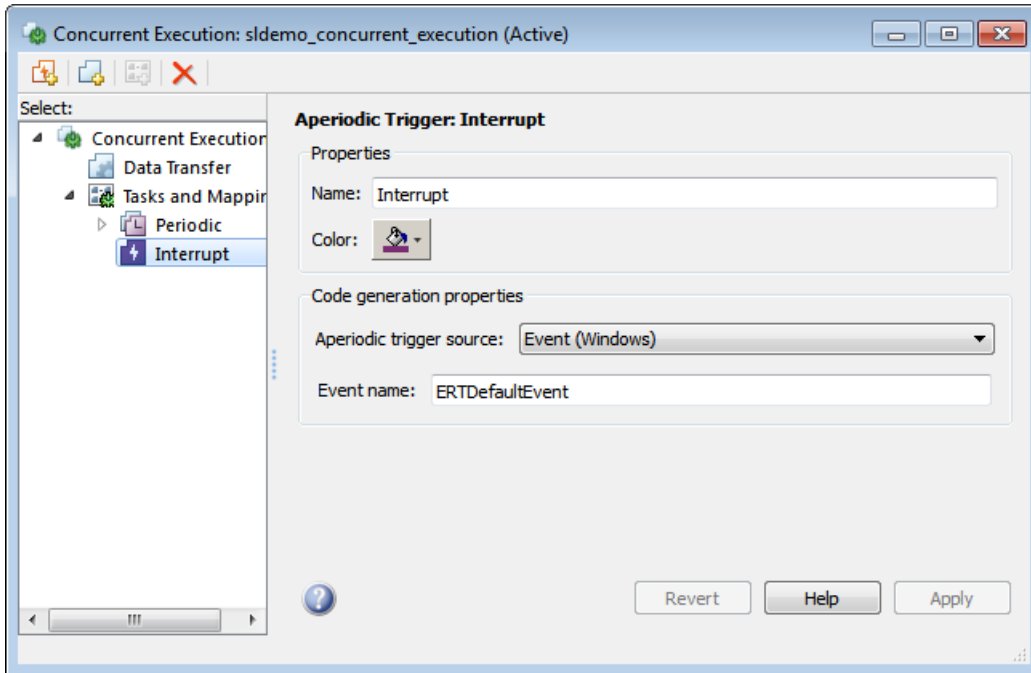
**1** To create an aperiodic trigger, in the Concurrent Execution dialog box, right-click the Concurrent Execution node and click the **Add aperiodic trigger** icon.

A node named **InterruptN** 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 and period 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 10-24.

### 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.

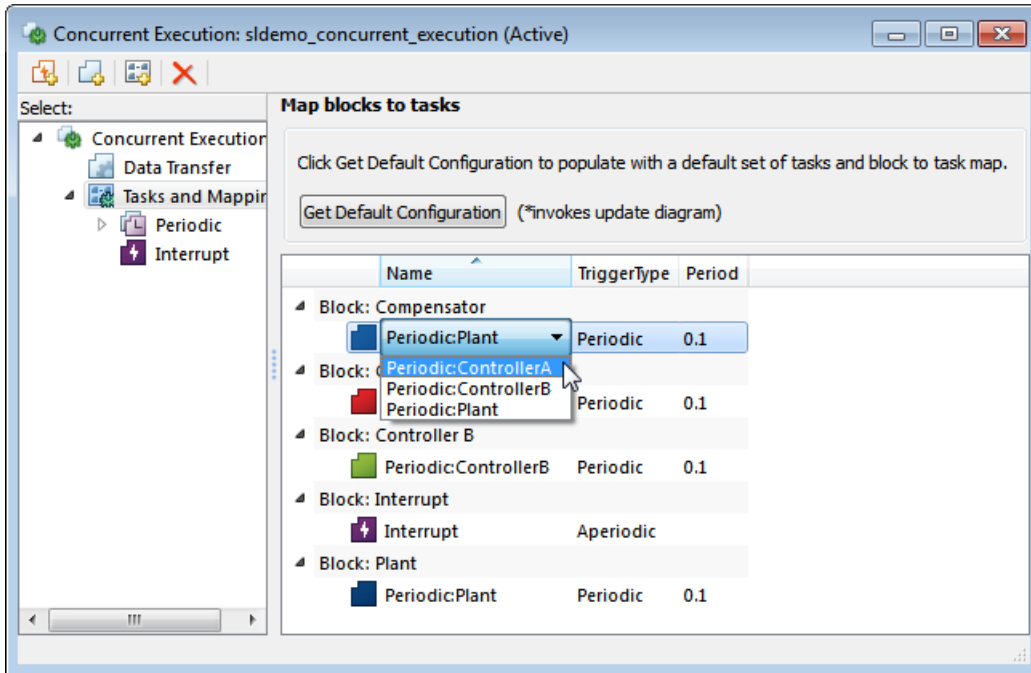
The **Map blocks to tasks** pane appears.

- 2 If you changed the model by adding or removing blocks, consider using automatic analysis by clicking the **Get Default Configuration** button.

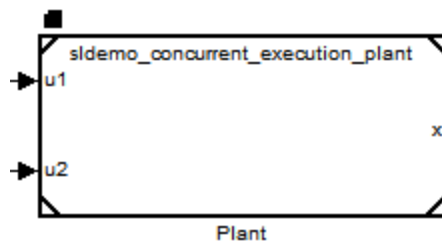
If you added a new Model block, a **select task** entry appears under the block.

- 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 “Interpreting Simulation Results” on page 10-26).

## Interpreting Simulation Results

### In this section...

“Introduction” on page 10-26

“Default Configuration” on page 10-27

“Sample Configured Model with Multiple Target Tasks” on page 10-28

“How Simulink Determines Data Transfer Requirements” on page 10-31

### 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.

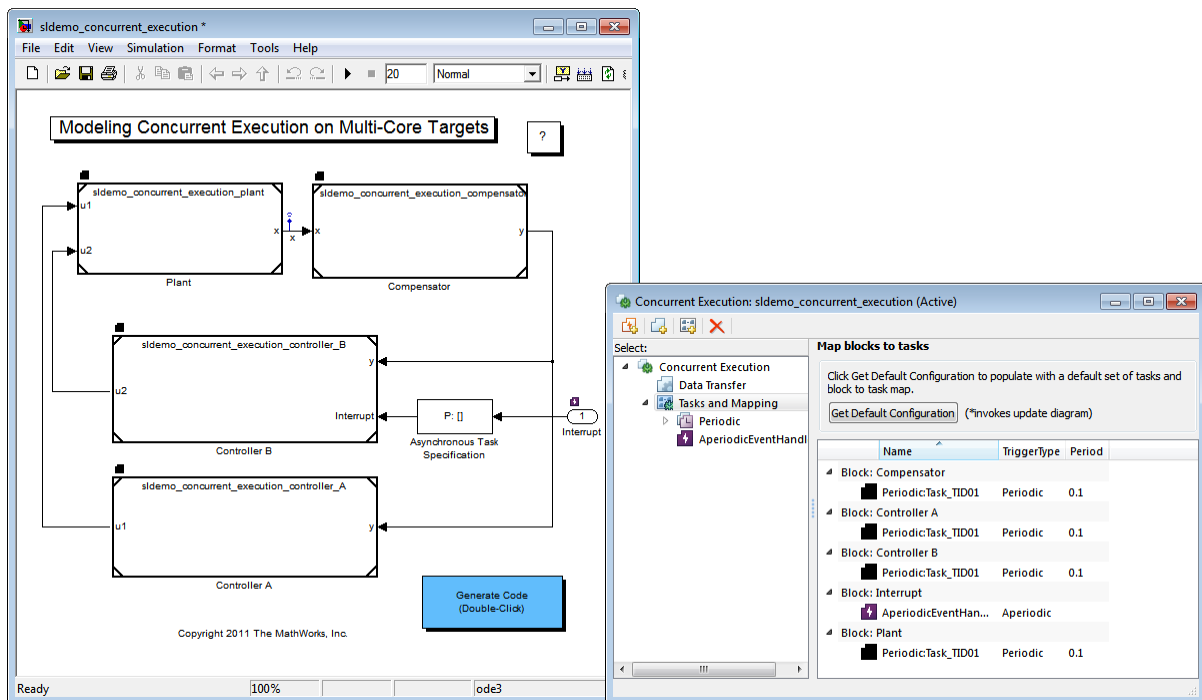
---

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 10-17. 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.



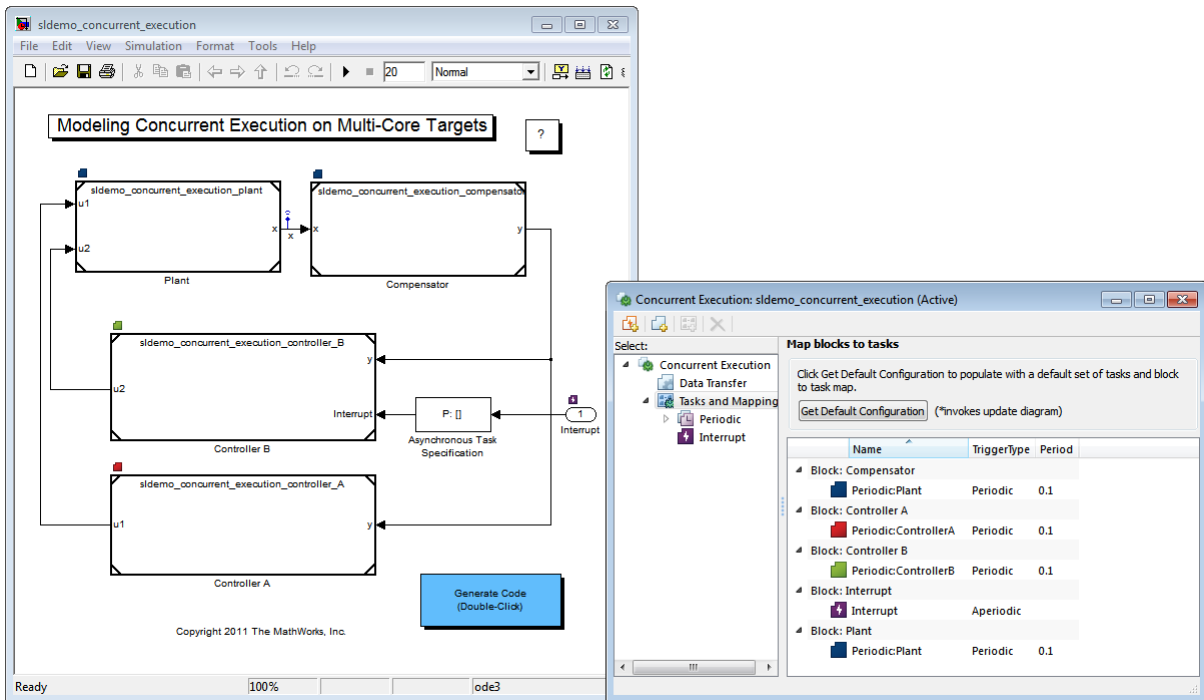
**Note** Configuring a model with automatic analysis always configures a model to minimize task-to-task communication requirements. In particular, only those communications that require rate transitions are included in the design.

Configure the model to inspect data using the Simulation Data Inspector from the **Data Input and Output** pane of the Configuration Execution dialog box. After you enable the Simulation Data Inspector, click **Simulate > Start** to simulate the model using the single task configuration. After simulation, the Simulation Data Inspector should automatically launch and record the simulation results for the signal labeled x.

### **Sample Configured Model with Multiple Target Tasks**

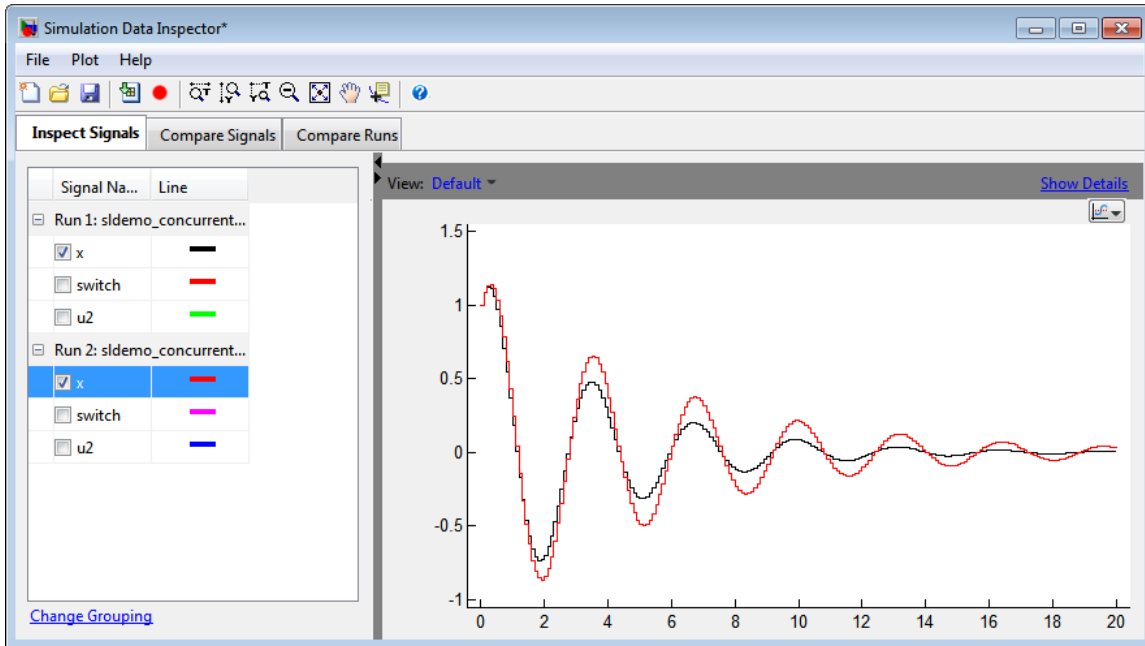
In the Concurrent Execution dialog box, create two additional tasks and map the ControllerA block to the first additional task and the ControllerB block to the second additional task.

- 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 10-19).

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 10-19). 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.

## Building and Downloading the Model to a Multicore Target

### In this section...

“Generating Code” on page 10-32

“Configuring Embedded Coder for Native Threads Example” on page 10-42

“Build and Download” on page 10-43

“Profile and Evaluate” on page 10-44

### 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 10-19.

## 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 **Tools > Code Generation > 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<sup>®</sup> 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.
    TaskTransAtControllerB0ut1_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 B0ut1' */
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.

<b>Aspect of Concurrent Execution</b>	<b>Linux Implementation</b>	<b>Windows Implementation</b>	<b>Mac OS Implementation</b>
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

<b>Aspect of Concurrent Execution</b>	<b>Linux Implementation</b>	<b>Windows Implementation</b>	<b>Mac OS Implementation</b>
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 10-19. 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**

<b>API</b>	<b>Linux Implementation</b>	<b>Windows Implementation</b>	<b>Mac OS Implementation</b>
Data protection API	<ul style="list-style-type: none"> <li>• pthread_mutex_init</li> <li>• pthread_mutex_ - destroy</li> <li>• pthread_mutex_lock</li> <li>• pthread_mutex_ - unlock</li> </ul>	<ul style="list-style-type: none"> <li>• CreateMutex</li> <li>• CloseHandle</li> <li>• WaitForSingleObject</li> <li>• ReleaseMutex</li> </ul>	<ul style="list-style-type: none"> <li>• pthread_mutex_init</li> <li>• pthread_mutex_ - destroy</li> <li>• pthread_mutex_lock</li> <li>• pthread_mutex_ - unlock</li> </ul>
Synchronization API	<ul style="list-style-type: none"> <li>• sem_init</li> <li>• sem_destroy</li> </ul>	<ul style="list-style-type: none"> <li>• CreateSemaphore</li> <li>• CloseHandle</li> </ul>	<ul style="list-style-type: none"> <li>• sem_open</li> <li>• sem_unlink</li> </ul>



## Data Protection and Synchronization APIs that Embedded Coder and Generic Real-Time Targets Use (Continued)

API	Linux Implementation	Windows Implementation	Mac OS Implementation
	<ul style="list-style-type: none"> <li>• sem_wait</li> <li>• sem_post</li> </ul>	<ul style="list-style-type: none"> <li>• WaitForSingle-Object</li> <li>• ReleaseSemaphore</li> </ul>	<ul style="list-style-type: none"> <li>• sem_wait</li> <li>• sem_post</li> </ul>

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();
}

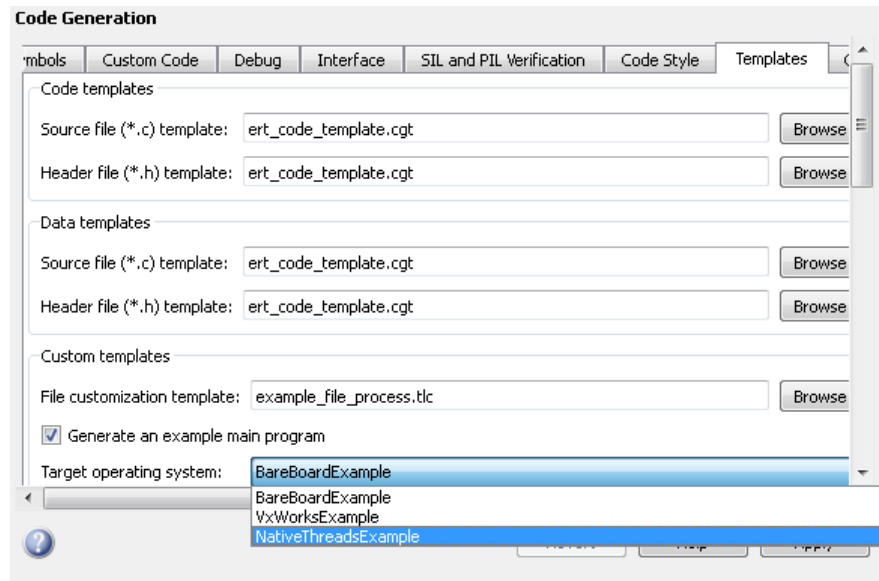
Aperiodic_Task()
{
    Wait_for_aperiodic_event();
    Run the appropriate aperiodic_task();
}

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 10-24).

## Concurrent Execution Example

For an interactive example of a model that has been configured to work in a concurrent execution environment:

- 1 In the MATLAB Command Window, type

```
demom
```

The Help window opens.

- 2 In the Demos pane on the left, select **Simulink > Demos > Modeling Features > Modeling Concurrency > Modeling Concurrent Execution on Multi-Core Targets**.

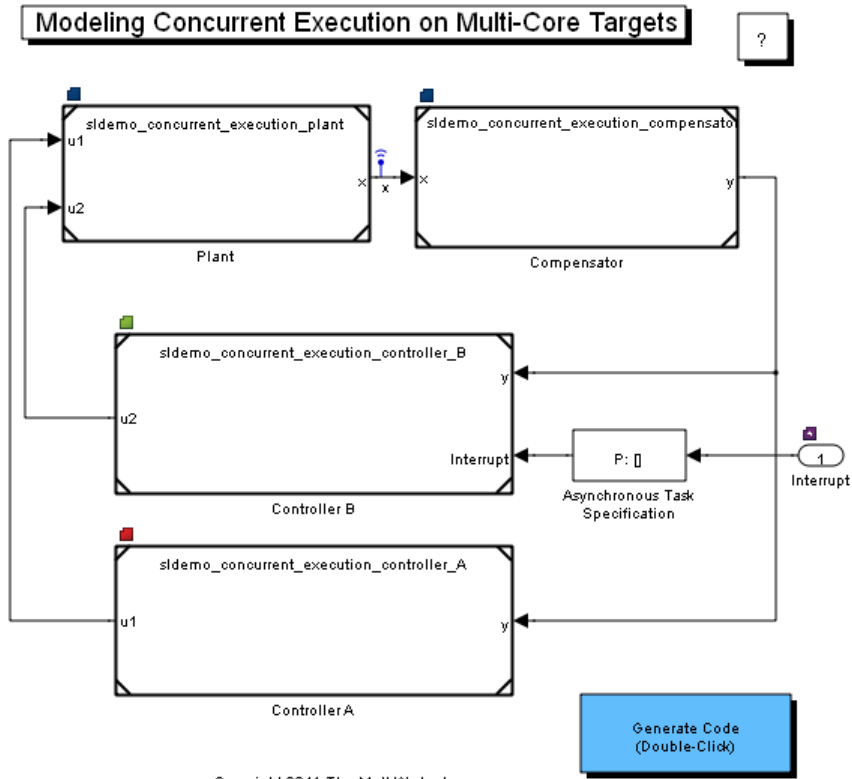
### Modeling Concurrent Execution on Multi-Core Targets

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**

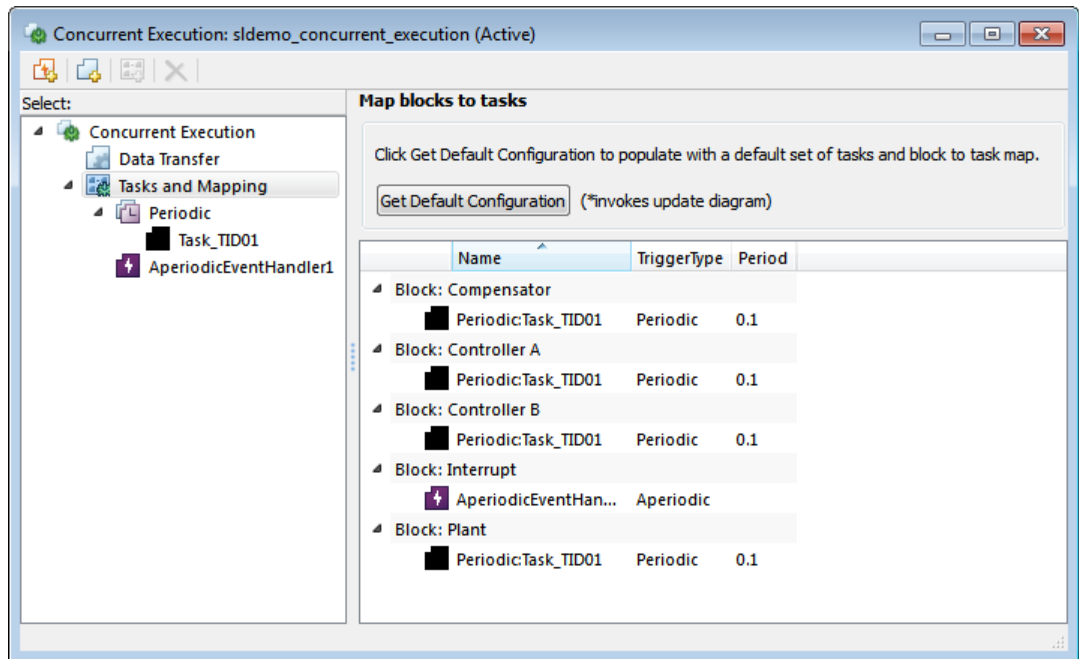
This model has been configured for concurrent execution on a target. For more information, see the documentation.

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`.



### 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.

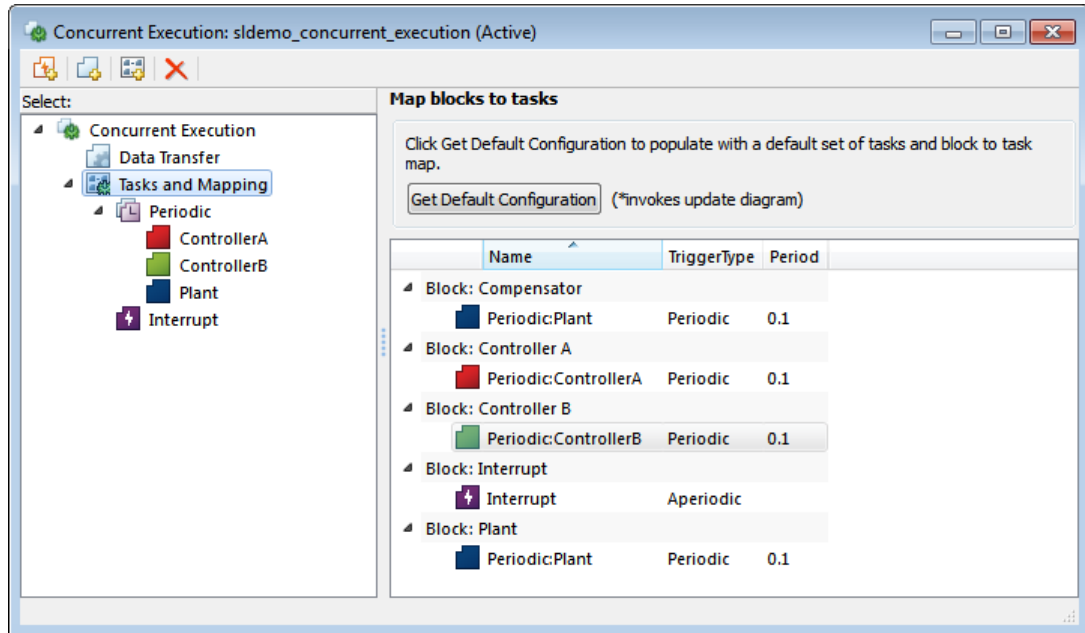
Assume that you have significant computation in all four Model blocks which needs to be mapped to separate tasks on a multicore target platform. To experiment with a different mapping for the Model blocks, change the task configuration to create new tasks, and map the blocks to the newly created tasks. 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 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');

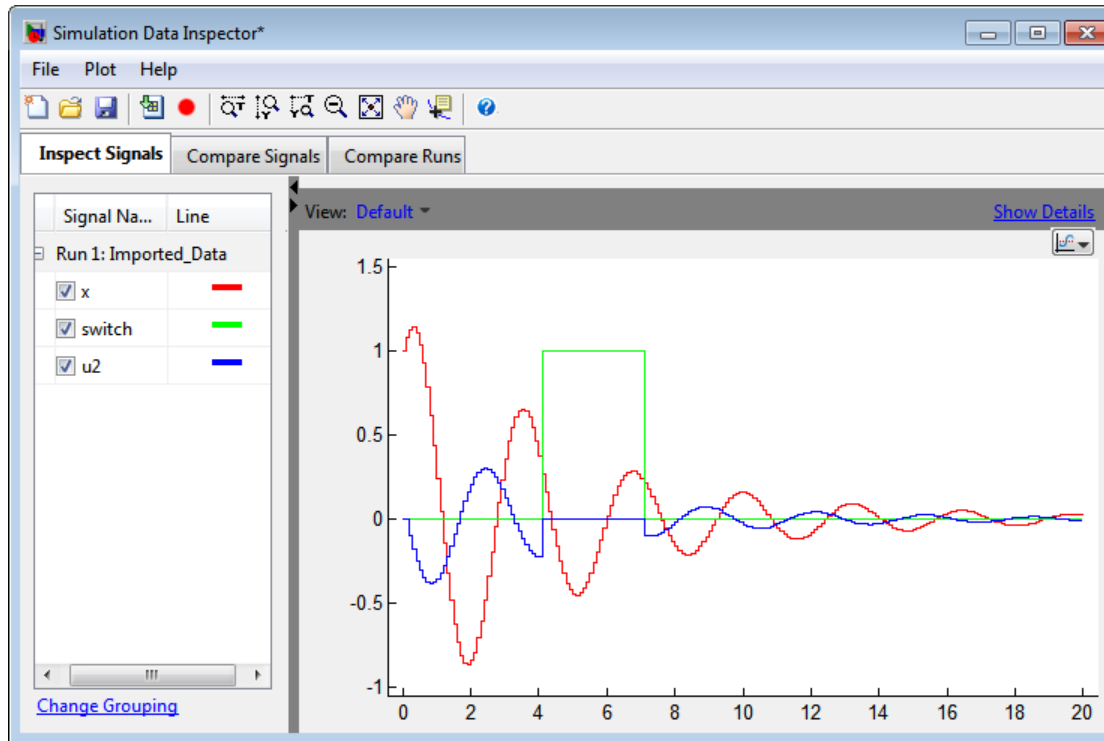
sim(topmdl);

```

### 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	<code>Simulink.SoftwareTarget.concurrentExecution</code>
Specify aperiodic trigger	<code>Simulink.SoftwareTarget.AperiodicTrigger</code>
Specify periodic trigger	<code>Simulink.SoftwareTarget.PeriodicTrigger</code>
Specify aperiodic trigger for POSIX targets	<code>Simulink.SoftwareTarget.PosixSignalHandler</code>
Specify task that models unit of concurrent execution	<code>Simulink.SoftwareTarget.Task</code>
Configure model for concurrent execution	<code>Simulink.SoftwareTarget.TaskConfiguration</code>
Specify base class for <code>PeriodicTrigger</code> and <code>AperiodicTrigger</code>	<code>Simulink.SoftwareTarget.WindowsEventHandler</code>
Describe aperiodic trigger for Windows target	<code>Simulink.SoftwareTarget.Trigger</code>





# Modeling Best Practices

---

- “General Considerations when Building Simulink Models” on page 11-2
- “Modeling a Continuous System” on page 11-8
- “Best-Form Mathematical Models” on page 11-11
- “Example: Converting Celsius to Fahrenheit” on page 11-15
- “Componentization Guidelines” on page 11-17

## General Considerations when Building Simulink Models

### In this section...

“Avoiding Invalid Loops” on page 11-2

“Shadowed Files” on page 11-4

“Model Building Tips” on page 11-6

### Avoiding Invalid Loops

You can connect the output of a block directly or indirectly (i.e., via other blocks) to its input, thereby, creating a loop. Loops can be very useful. For example, you can use loops to solve differential equations diagrammatically (see “Modeling a Continuous System” on page 11-8) or model feedback control systems. However, it is also possible to create loops that cannot be simulated. Common types of invalid loops include:

- Loops that create invalid function-call connections or an attempt to modify the input/output arguments of a function call (see “Function-Call Subsystems” on page 6-26 for a description of function-call subsystems)
- Self-triggering subsystems and loops containing non-latched triggered subsystems (see “Triggered Subsystems” on page 6-17 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:

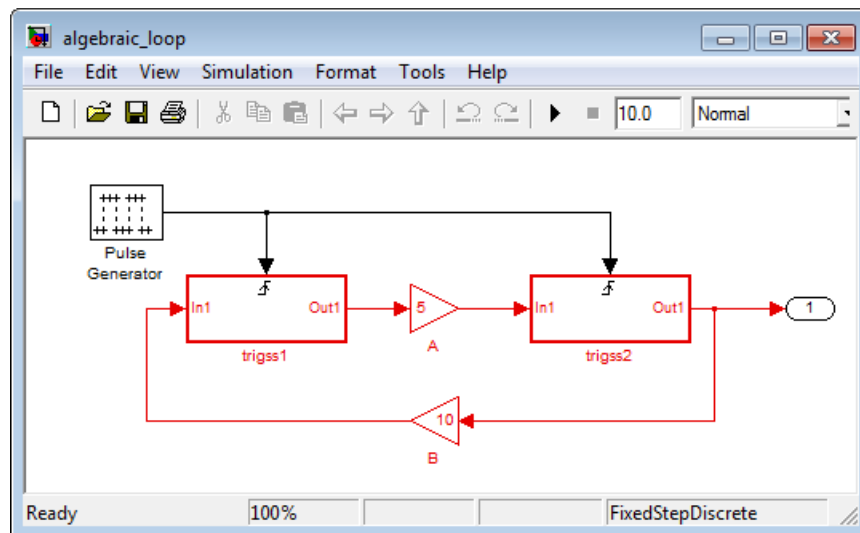
- `simulink/Ports&Subsystems/sl_subsys_semantics/Triggered subsystem/sl_subsys_trigerr1(sl_subsys_trigerr1)`
- `simulink/Ports&Subsystems/sl_subsys_semantics/Triggered subsystem/sl_subsys_trigerr2(sl_subsys_trigerr2)`

- `simulink/Ports&Subsystems/sl_subsys_semantics/Function-call systems/sl_subsys_fcncallerr3 (sl_subsys_fcncallerr3)`

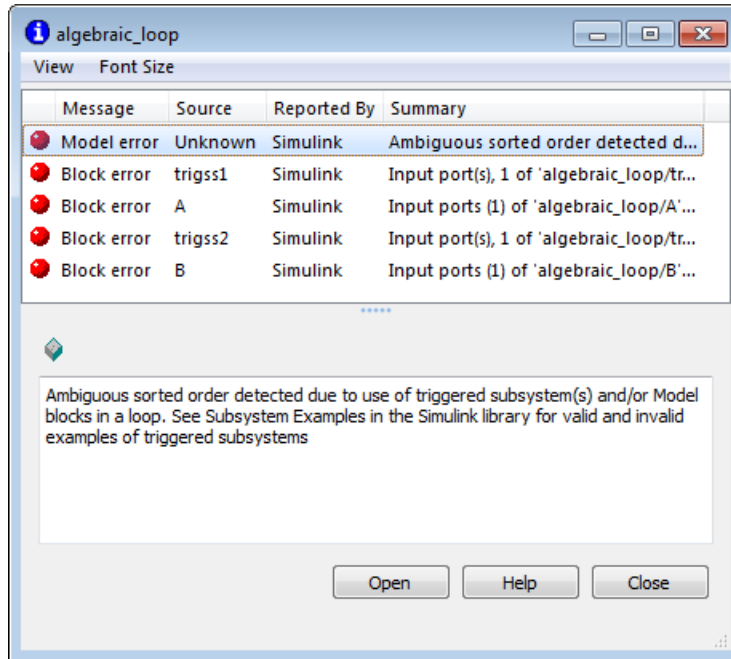
You might find it useful to study these examples to avoid creating invalid loops in your own models.

## Detecting Invalid Loops

To detect whether your model contains invalid loops, select **Update Diagram** from the model's **Edit** menu. If the model contains invalid loops, the invalid loops are highlighted. This is illustrated in the following model ,



and displays an error message in the Simulation Diagnostics Viewer.



## Shadowed Files

If there are two Model files with the same name (e.g. `mylibrary.mdl`) on the MATLAB path, the one higher on the path is loaded, and the one lower on the path is said to be "shadowed".

The rules Simulink software uses to find Model files are similar to those used by MATLAB software. See "How the Search Path Determines Which Function to Use" in the MATLAB documentation. However, there is an important difference between how Simulink block diagrams and MATLAB functions are handled: a loaded block diagram takes precedence over any unloaded ones, regardless of its position on the MATLAB path. This is done for performance reasons, as part of the Simulink software's incremental loading methodology.

The precedence of a loaded block diagram over any others can have important implications, particularly since a block diagram can be loaded without the corresponding Simulink window being visible.

## Making Sure the Correct Block Diagram Is Loaded

When using libraries and referenced models, a block diagram may be loaded without showing its window. If the MATLAB path or the current MATLAB folder changes while block diagrams are in memory, these block diagrams may interfere with the use of other files of the same name. For example, after a change of folder, a loaded but invisible library may be used instead of the one the user expects.

To see an example:

- 1 Enter `sldemo_hydcy14` to open the Simulink demo model `sldemo_hydcy14`.
- 2 Use the `find_system` command to see which block diagrams are in memory:

```
find_system('type','block_diagram')
```

```
ans =
```

```
    'hydlib'  
    'sldemo_hydcy14'
```

Note that a Simulink library, `hydlib`, has been loaded, but is currently invisible.

- 3 Now close `sldemo_hydcy14`. Run the `find_system` command again, and you will see that the library is still loaded.

If you change to another folder which contains a different library called `hydlib`, and try to run a model in that folder, the library in that folder would not be loaded because the block diagram of the same name in memory takes precedence. This can lead to problems including:

- Simulation errors
- "Bad Link" icons on blocks which are library links
- Wrong results

To prevent these conditions, it is necessary to close the library explicitly as follows:

```
close_system('hydlib')
```

Then, when the Simulink software next needs to use a block in a library called `hydlib` it will use the file called `hydlib.mdl` which is highest on the MATLAB path at the time. Alternatively, to make the library visible, enter:

```
open_system('hydlib')
```

### **Detecting and Fixing Problems**

When updating a block diagram, the Simulink software checks the position of its file on the MATLAB path and will issue a warning if it detects that another file of the same name exists and is higher on the MATLAB path. The warning reads:

```
The file containing block diagram 'mylibrary' is shadowed  
by a file of the same name higher on the MATLAB path.
```

This may indicate that the wrong file called `mylibrary.mdl` is being used. To see which file called `mylibrary.mdl` is loaded into memory, enter:

```
which mylibrary  
  
C:\work\Model1\mylibrary.mdl
```

To see all the files called `mylibrary` which are on the MATLAB path, including MATLAB scripts, enter:

```
which -all mylibrary  
  
C:\work\Model1\mylibrary.mdl  
C:\work\Model2\mylibrary.mdl % Shadowed
```

To close the block diagram called `mylibrary` and let the Simulink software load the file which is highest on the MATLAB path, enter:

```
close_system('mylibrary')
```

### **Model Building Tips**

Here are some model-building hints you might find useful:

- Memory issues

In general, more memory will increase performance.

- Using hierarchy

More complex models often benefit from adding the hierarchy of subsystems to the model. Grouping blocks simplifies the top level of the model and can make it easier to read and understand the model. For more information, see “Creating Subsystems” on page 3-37. The Model Browser provides useful information about complex models (see “The Model Browser” on page 8-77).

- 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 31-19 and “Annotating Diagrams” on page 3-26.

- Modeling strategies

If several of your models tend to use the same blocks, you might find it easier to save these blocks in a model. Then, when you build new models, just open this model and copy the commonly used blocks from it. You can create a block library by placing a collection of blocks into a system and saving the system. You can then access the system by typing its name in the MATLAB Command Window.

Generally, when building a model, design it first on paper, then build it using the computer. Then, when you start putting the blocks together into a model, add the blocks to the model window before adding the lines that connect them. This way, you can reduce how often you need to open block libraries.

## Modeling a Continuous System

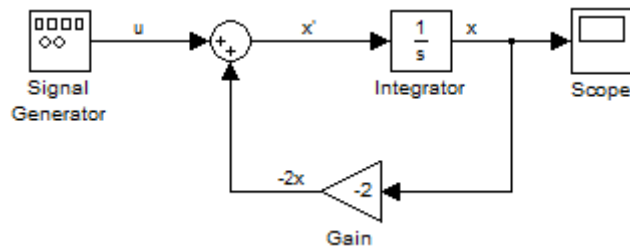
To model the differential equation

$$x' = -2x(t) + u(t),$$

where  $u(t)$  is a square wave with an amplitude of 1 and a frequency of 1 rad/sec, use an integrator block and a gain block. The Integrator block integrates its input  $x'$  to produce  $x$ . Other blocks needed in this model include a Gain block and a Sum block. To generate a square wave, use a Signal Generator block and select the Square Wave form but change the default units to radians/sec. Again, view the output using a Scope block. Gather the blocks and define the gain.

In this model, to reverse the direction of the Gain block, select the block, then use the **Flip Block** command from the **Format** menu. To create the branch line from the output of the Integrator block to the Gain block, hold down the **Ctrl** key while drawing the line. For more information, see “Drawing a Branch Line” on page 3-19.

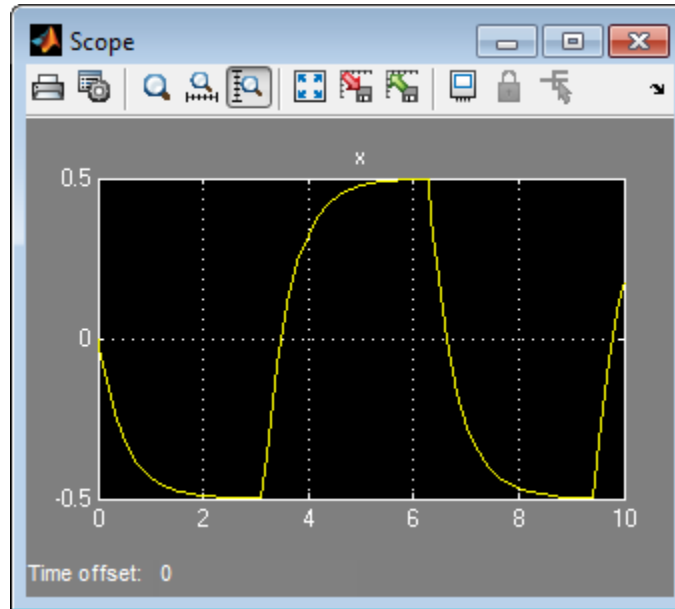
Now you can connect all the blocks.



An important concept in this model is the loop that includes the Sum block, the Integrator block, and the Gain block. In this equation,  $x$  is the output of the Integrator block. It is also the input to the blocks that compute  $x'$ , on which it is based. This relationship is implemented using a loop.



The Scope displays  $x$  at each time step. For a simulation lasting 10 seconds, the output looks like this:



The equation you modeled in this example can also be expressed as a transfer function. The model uses the Transfer Fcn block, which accepts  $u$  as input and outputs  $x$ . So, the block implements  $x/u$ . If you substitute  $sx$  for  $x'$  in the above equation, you get

$$sx = -2x + u.$$

Solving for  $x$  gives

$$x = u/(s + 2)$$

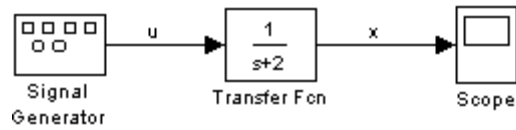
or,

$$x/u = 1/(s + 2).$$

The Transfer Fcn block uses parameters to specify the numerator and denominator coefficients. In this case, the numerator is 1 and the denominator

is  $s+2$ . Specify both terms as vectors of coefficients of successively decreasing powers of  $s$ .

In this case the numerator is  $[1]$  (or just  $1$ ) and the denominator is  $[1 \ 2]$ .



The results of this simulation are identical to those of the previous model.

## Best-Form Mathematical Models

### In this section...

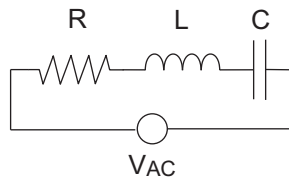
“Series RLC Example” on page 11-11

“Solving Series RLC Using Resistor Voltage” on page 11-12

“Solving Series RLC Using Inductor Voltage” on page 11-13

### 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

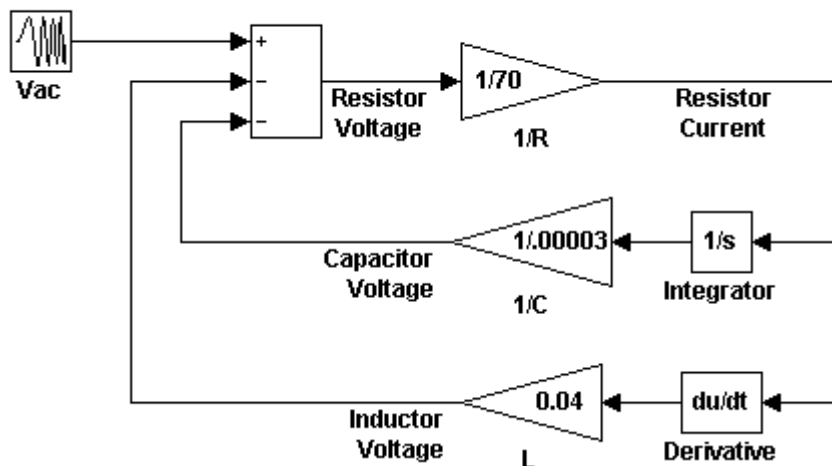
$$V_R = Ri$$

$$Ri = V_{AC} - L \frac{di}{dt} - \frac{1}{C} \int_{-\infty}^t i(t) dt$$

### 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  $L$ .

Series RLC Circuit: Formulated to solve for resistor current



This formulation contains a Derivative block associated with the inductor. Whenever possible, you should avoid mathematical formulations that require Derivative blocks as they introduce discontinuities into your system. Numerical integration is used to solve the model dynamics though time.

These integration solvers take small steps through time to satisfy an accuracy constraint on the solution. If the discontinuity introduced by the Derivative block is too large, it is not possible for the solver to step across it.

In addition, in this model the Derivative, Sum, and two Gain blocks create an algebraic loop. Algebraic loops slow down the model's execution and can produce less accurate simulation results. See "Algebraic Loops" on page 2-40 for more information.

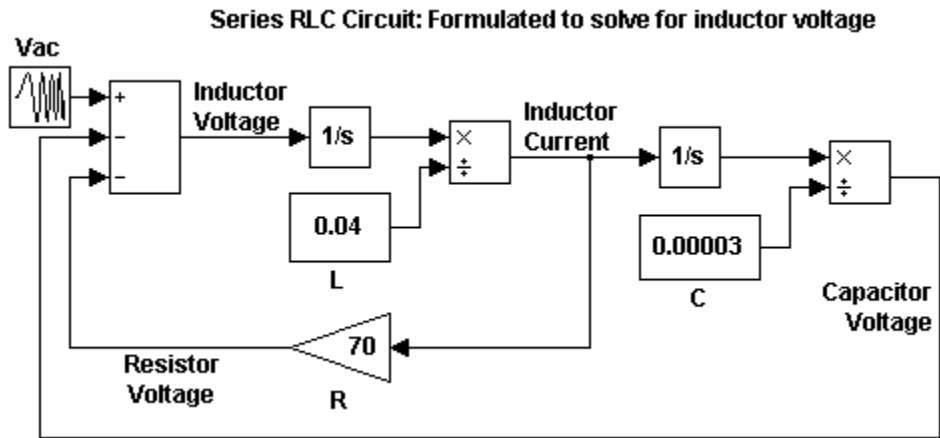
## Solving Series RLC Using Inductor Voltage

To avoid using a Derivative block, formulate the equation to solve for the inductor voltage.

$$V_L = L \frac{di}{dt}$$
$$L \frac{di}{dt} = V_{AC} - Ri - \frac{1}{C} \int_{-\infty}^t i(t) dt$$

### Circuit Model

The following diagram shows this equation modeled in Simulink. The inductor voltage is the sum of the voltage source, the resistor voltage, and the capacitor voltage. You need the current in the circuit to calculate the resistor and capacitor voltages. To calculate the current, integrate the inductor voltage and divide by  $L$ . Calculate the capacitor voltage by integrating the current and dividing by  $C$ . Calculate the resistor voltage by multiplying the current by a gain of  $R$ .



This model contains only integrator blocks and no algebraic loops. As a result, the model simulates faster and more accurately.

## Example: Converting Celsius to Fahrenheit

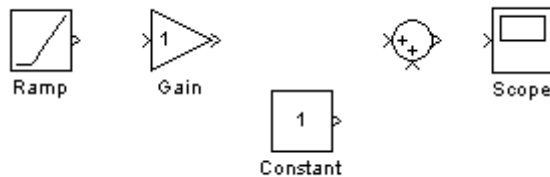
To model the equation that converts Celsius temperature to Fahrenheit

$$T_F = 9/5(T_C) + 32$$

First, consider the blocks needed to build the model:

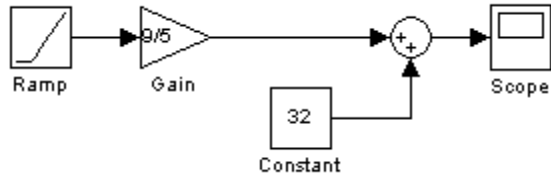
- A Ramp block to input the temperature signal, from the Sources library
- A Constant block to define a constant of 32, also from the Sources library
- A Gain block to multiply the input signal by 9/5, from the Math Operations library
- A Sum block to add the two quantities, also from the Math Operations library
- A Scope block to display the output, from the Sinks library

Next, gather the blocks into your model window.



Assign parameter values to the Gain and Constant blocks by opening (double-clicking) each block and entering the appropriate value. Then, click the **OK** button to apply the value and close the dialog box.

Now, connect the blocks.



The Ramp block inputs Celsius temperature. Open that block and change the **Initial output** parameter to 0. The Gain block multiplies that temperature by the constant  $9/5$ . The Sum block adds the value 32 to the result and outputs the Fahrenheit temperature.

Open the Scope block to view the output. Now, choose **Start** from the **Simulation** menu to run the simulation. The simulation runs for 10 seconds.



# Componentization Guidelines

## Componentization

The “Large-Scale Modeling for Embedded Applications” paper by Kerry Grand, Vinod Reddy, Gen Sasaki, and Eric Dillaber defines a component as follows:

“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.”

---

**Tip** The “Large-Scale Modeling for Embedded Applications” paper provides additional information to help you to decide how to componentize your 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.

<b>Componentization Technique</b>	<b>Modeling Goals for Which the Technique Is Well Suited</b>
Subsystems	<ul style="list-style-type: none"> <li>• Add hierarchy to organize and visually simplify a model.</li> <li>• Maximize design reuse with inherited attributes for context-dependent behavior.</li> </ul>
Libraries	<ul style="list-style-type: none"> <li>• Provide a frequently used, and infrequently changed, modeling utility.</li> <li>• Reuse components repeatedly in a model or in multiple models.</li> </ul>
Model referencing	<ul style="list-style-type: none"> <li>• Develop a referenced model independently from the models that use it.</li> </ul>

Componentization Technique	Modeling Goals for Which the Technique Is Well Suited
	<ul style="list-style-type: none"> <li>• Obscure the contents of a referenced model, allowing you to distribute it without revealing the intellectual property that it embodies.</li> <li>• Reference a model multiple times without having to make redundant copies.</li> <li>• Facilitate changes by multiple people, with defined interfaces for top-level components.</li> <li>• 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).</li> <li>• Perform unit testing.</li> <li>• Simplify debugging for large models.</li> <li>• Generate code that reflects the model structure.</li> </ul>

For a more detailed comparison of these modeling techniques, see “Summary of Componentization Techniques” on page 11-19.

## 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.

<b>Modeling Requirement or Feature</b>	<b>Subsystems</b>	<b>Libraries</b>	<b>Model Referencing</b>
<b>Development Process</b>			
Component reuse	Not supported	Well suited	Well suited
Team-based development	Not supported	Supported, with limitations	Well suited
Intellectual property protection	Not supported	Not supported	Well suited
Unit testing	Supported, with limitations	Supported, with limitations	Well suited
<b>Performance</b>			
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
<b>Features</b>			
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

<b>Modeling Requirement or Feature</b>	<b>Subsystems</b>	<b>Libraries</b>	<b>Model Referencing</b>
Buses	Well suited	Well suited	Supported, with limitations
S-functions	Well suited	Well suited	Supported, with limitations
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 11-21
- “Libraries Summary” on page 11-25
- “Model Referencing Summary” on page 11-29

## **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 11-19.

For additional information about subsystems, see:

- Creating Subsystems
- Creating Conditional Subsystems

<b>Modeling Requirement or Feature</b>	<b>Guidelines for Subsystems</b>
<b>Development Process</b>	
Component reuse	<p><b>Not supported</b></p> <ul style="list-style-type: none"> <li>• Copy a subsystem to reuse it in a model.</li> <li>• Subsystem copies are independent of each other.</li> <li>• Save a subsystem by saving the model that contains the subsystem.</li> <li>• Configuration management for subsystems is difficult.</li> </ul>
Team-based development	<p><b>Not supported</b></p> <ul style="list-style-type: none"> <li>• For subsystems in a model, Simulink provides no direct interface with source control tools.</li> <li>• 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.</li> </ul>
Intellectual property protection	<p><b>Not supported</b></p> <p>Use model referencing protected models instead.</p>
Unit testing	<p><b>Supported, with limitations</b></p> <ul style="list-style-type: none"> <li>• For coverage testing, use Signal Builder and source blocks.</li> <li>• Each time a subsystem changes, you need to copy the subsystem to a harness model.</li> <li>• The test harness may have different Simulink sort orders, due to virtual boundaries.</li> <li>• Test harness files require configuration management overhead.</li> </ul>
<b>Performance</b>	

<b>Modeling Requirement or Feature</b>	<b>Guidelines for Subsystems</b>
Model loading speed	<p><b>Supported, with limitations</b></p> <p>Loading a model loads all subsystems at one time. There is no incremental loading.</p>
Simulation speed for large models	<p><b>Supported, with limitations</b></p> <ul style="list-style-type: none"> <li>• To speed simulation, use Accelerator or Rapid Accelerator simulation mode.</li> <li>• Simulation mode applies to the whole model. Model referencing provides a finer level of control for simulation modes.</li> </ul>
Memory	<p><b>Supported, with limitations</b></p> <p>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.</p>
Artificial algebraic loop avoidance	<p><b>Well suited</b></p> <ul style="list-style-type: none"> <li>• Virtual subsystems avoid artificial algebraic loops.</li> <li>• For nonvirtual subsystems, consider enabling the Subsystem block parameter <b>Minimize algebraic loop occurrences</b>.</li> </ul>
<b>Features</b>	
Signal property inheritance	<p><b>Well suited</b></p> <ul style="list-style-type: none"> <li>• Inheriting signal properties from outside of the subsystem boundary avoids your having to specify properties for every signal.</li> <li>• Propagation of signal properties can lead to Simulink using signal properties that you did not anticipate.</li> </ul>

<b>Modeling Requirement or Feature</b>	<b>Guidelines for Subsystems</b>
State initialization	<p><b>Well suited</b></p> <p>You can initialize states of subsystems.</p>
Tunability	<p><b>Well suited</b></p> <ul style="list-style-type: none"> <li>• Tune subsystems using a block parameterization or masked subsystems.</li> <li>• Control tunability using <b>Configuration Parameters &gt; Optimization &gt; Signals and Parameters &gt; Inline parameters</b>.</li> </ul>
Buses	<p><b>Well suited</b></p> <p>Subsystems do not require the use of bus objects for virtual buses.</p>
S-functions	<p><b>Well suited</b></p> <p>Subsystems support inlined or noninlined S-functions.</p>
Model configuration settings	<p><b>Well suited</b></p> <p>A subsystem uses the model configuration settings of the model that contains the subsystem.</p>
Tools	<p><b>Well suited</b></p> <p>Subsystems provide extensive support for Simulink tools.</p>
Code generation	<p><b>Supported, with limitations</b></p> <ul style="list-style-type: none"> <li>• To generate code for a subsystem by itself, right-click the Subsystem block and select a code generation option.</li> <li>• 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.</li> </ul>



<b>Modeling Requirement or Feature</b>	<b>Guidelines for Subsystems</b>
	<ul style="list-style-type: none"> <li>• For virtual subsystems, you cannot specify file or function code partitions for code generation.</li> </ul>

## 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 11-19.

For additional information about libraries, see [Working with Block Libraries](#).

<b>Modeling Requirement or Feature</b>	<b>Guidelines for Libraries</b>
<b>Development Process</b>	
Component reuse	<p><b>Well suited</b></p> <ul style="list-style-type: none"> <li>• Access a collection of well-defined utility blocks.</li> <li>• Create a component once and reuse it in models.</li> <li>• Link to the same library block multiple times without creating multiple copies.</li> <li>• Link to the same library block from multiple models.</li> <li>• Restrict write access to library components.</li> <li>• Maintain one truth: propagate changes from a single library block to all blocks that link to that library.</li> <li>• Disable a link to allow independent changes to a linked block.</li> <li>• Managing library links adds some overhead.</li> </ul>

<b>Modeling Requirement or Feature</b>	<b>Guidelines for Libraries</b>
	<ul style="list-style-type: none"> <li>• Save library in a file similar to a Simulink model, but you cannot simulate the file contents.</li> </ul>
Team-based development	<p><b>Supported, with limitations</b></p> <ul style="list-style-type: none"> <li>• Place library files in source control for version control and configuration management.</li> <li>• Maintain one truth: propagate changes from a single library block to all blocks that link to that library.</li> <li>• To reduce file contention, use one subsystem per library.</li> <li>• Link to the same library block from multiple models.</li> <li>• Restrict write access to library component.</li> <li>• See General Reusability Limitations.</li> </ul>
Intellectual property protection	<p><b>Not supported</b></p> <p>Use model referencing protected models instead.</p>
Unit testing	<p><b>Supported, with limitations</b></p> <ul style="list-style-type: none"> <li>• For coverage testing, use Signal Builder and source blocks.</li> <li>• Test harness may have different Simulink sort orders, due to virtual boundaries.</li> <li>• Test harness files require configuration management overhead.</li> </ul>
<b>Performance</b>	

<b>Modeling Requirement or Feature</b>	<b>Guidelines for Libraries</b>
Model loading speed	<p><b>Well suited</b></p> <p>Simulink incrementally loads a library at the point needed during editing, updating a diagram, or simulating a model.</p>
Simulation speed for large models	<p><b>Supported, with limitations</b></p> <ul style="list-style-type: none"> <li>• To speed simulation, use Accelerator or Rapid Accelerator simulation mode.</li> <li>• Simulation mode applies to the whole model. Model referencing provides a finer level of control for simulation modes.</li> </ul>
Memory	<p><b>Supported, with limitations</b></p> <ul style="list-style-type: none"> <li>• Simulink incrementally loads libraries at the point needed during editing, updating a diagram, or simulating a model.</li> <li>• Simulink duplicates library block instances during block update.</li> <li>• 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.</li> </ul>
Artificial algebraic loop avoidance	<p><b>Well suited</b></p> <ul style="list-style-type: none"> <li>• Virtual subsystems avoid artificial algebraic loops.</li> <li>• For nonvirtual subsystems, consider enabling the Subsystem block parameter <b>Minimize algebraic loop occurrences</b>.</li> </ul>
<b>Features</b>	

<b>Modeling Requirement or Feature</b>	<b>Guidelines for Libraries</b>
Signal property inheritance	<p><b>Well suited</b></p> <ul style="list-style-type: none"> <li>• Inheriting signal properties from outside of the library block boundary avoids your having to specify properties for every signal.</li> <li>• Propagation of signal properties can lead to Simulink using signal properties that you did not anticipate.</li> </ul>
State initialization	<p><b>Well suited</b></p> <p>You can initialize states of library blocks.</p>
Tunability	<p><b>Well suited</b></p> <ul style="list-style-type: none"> <li>• Tune library blocks using block parameterization or masked subsystems.</li> <li>• Control tunability using <b>Configuration Parameters &gt; Optimization &gt; Signals and Parameters &gt; Inline parameters</b>.</li> </ul>
Buses	<p><b>Well suited</b></p> <p>Libraries do not require the use of bus objects for virtual buses.</p>
S-functions	<p><b>Well suited</b></p> <p>Libraries support inlined and noninlined S-functions.</p>
Model configuration settings	<p><b>Well suited</b></p> <ul style="list-style-type: none"> <li>• Library models do not have model configuration settings.</li> <li>• A referenced library block uses the model configuration setting of the model that contains that block.</li> </ul>

<b>Modeling Requirement or Feature</b>	<b>Guidelines for Libraries</b>
Tools	<p><b>Supported, with limitations</b></p> <p>There are some limitations for using some Simulink tools, such as the Model Advisor, with libraries.</p>
Code generation	<p><b>Supported, with limitations</b></p> <ul style="list-style-type: none"> <li>• 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.</li> <li>• For virtual subsystems, you cannot specify file or function code partitions for code generation.</li> </ul>

## 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 11-19.

For additional information about model referencing, see:

- Referencing a Model
- Simulink Model Referencing Requirements
- Model Referencing Limitations

<b>Modeling Requirement or Feature</b>	<b>Guidelines for Model Referencing</b>
<b>Development Process Requirements</b>	
Component reuse	<p><b>Well suited</b></p> <ul style="list-style-type: none"> <li>• Create a standalone component once and reuse it in multiple models.</li> <li>• Reference the same model multiple times without creating multiple copies.</li> <li>• Reference the same model from multiple models.</li> <li>• Model referencing uses specified boundaries for preserving component integrity.</li> </ul>
Team-based development	<p><b>Well suited</b></p> <ul style="list-style-type: none"> <li>• For version control and configuration management, you can place model reference files in a source control system.</li> <li>• Design, create, simulate, and test a referenced model independently from the model that references it.</li> <li>• Link to the same model reference from multiple models.</li> <li>• Changes made to a referenced model apply to all instances of that referenced model.</li> <li>• Simulink does not limit access for changing a model reference.</li> <li>• You save a referenced model in a separate file from the model that references it. Using separate files helps to avoid file contention.</li> </ul>

<b>Modeling Requirement or Feature</b>	<b>Guidelines for Model Referencing</b>
Intellectual property protection	<p><b>Well suited</b></p> <ul style="list-style-type: none"> <li>• Use the protected model feature to obscure contents of a referenced model in a distributed model.</li> <li>• Creating a protected model feature requires a Simulink Coder license. Using a protected model does <i>not</i> require a Simulink Coder license.</li> </ul>
Unit testing	<p><b>Well suited</b></p> <ul style="list-style-type: none"> <li>• Test components independently to isolate behaviors, by simulating them standalone.</li> <li>• You can eliminate unit retest for unchanged components.</li> <li>• Use a data-defined test harness, with MATLAB test vectors and direct coverage collection.</li> <li>• For coverage testing, use root inports and outports.</li> </ul>
<b>Performance</b>	
Model loading speed	<p><b>Well suited</b></p> <ul style="list-style-type: none"> <li>• Simulink incrementally loads a referenced model at the point needed during editing, updating a diagram, or simulating a model.</li> <li>• If a simulation target build is required, first-time loading can be slow.</li> </ul>

<b>Modeling Requirement or Feature</b>	<b>Guidelines for Model Referencing</b>
Simulation speed for large models	<p><b>Well suited</b></p> <ul style="list-style-type: none"> <li>• Simulate a referenced model standalone.</li> <li>• The Model block has an option for specifying the simulation mode.</li> <li>• You can improve rebuild performance by selecting the appropriate setting for the <b>Configuration Parameters &gt; Model Referencing &gt; Rebuild</b> parameter.</li> <li>• Simulation through code generation can have a slow start-up time, which might be undesirable during prototyping.</li> <li>• See “Limitations on Normal Mode Referenced Models” on page 5-90, “Limitations on Accelerator Mode Referenced Models” on page 5-91, and “Limitations on PIL Mode Referenced Models” on page 5-94.</li> </ul>
Memory	<p><b>Well suited</b></p> <ul style="list-style-type: none"> <li>• Simulink loads a referenced model at the point that model is needed for navigation during editing, updating a diagram, or simulating a model.</li> <li>• Use model reference Accelerator mode to reduce memory usage, incrementally loading a compiled version of a referenced model.</li> </ul>
Artificial algebraic loop avoidance	<p><b>Supported, with limitations</b></p> <p>Consider enabling <b>Configuration Parameters &gt; Model Referencing &gt; Minimize algebraic loop occurrences</b>.</p>
<b>Features</b>	



<b>Modeling Requirement or Feature</b>	<b>Guidelines for Model Referencing</b>
Signal property inheritance	<p><b>Supported, with limitations</b></p> <ul style="list-style-type: none"> <li>• 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.</li> <li>• Model block is context-independent, so it cannot inherit signal properties. Explicitly set input and output signal properties.</li> <li>• Use a bus object to define the signal data type of a bus signal that is passed into a referenced model.</li> <li>• Goto and From block lines cannot cross model referencing boundaries.</li> <li>•</li> <li>• See Index Base Limitations.</li> </ul>
State initialization	<p><b>Supported, with limitations</b></p> <ul style="list-style-type: none"> <li>• You can initialize states from the top model.</li> <li>• Use either the structure format or structure with time format to initialize the states of a top model and the models that it references.</li> <li>• To use the SimState (simulation state) feature with model referencing, simulate all Model blocks in Normal mode.</li> <li>• See “Importing and Exporting State Information for Referenced Models” on page 29-101.</li> </ul>

<b>Modeling Requirement or Feature</b>	<b>Guidelines for Model Referencing</b>
Tunability	<p><b>Supported, with limitations</b></p> <ul style="list-style-type: none"> <li>• To have each instance of a referenced model use different values, use model arguments in the Model block.</li> <li>• To have each instance of a referenced model use the same values, use <code>Simulink.Parameter</code> objects.</li> <li>• To have each instance of a referenced model use the same values, use <code>Simulink.Parameter</code> objects.</li> </ul> <p>By default, all other parameters are inlined.</p>
Buses	<p><b>Supported, with limitations</b></p> <p>You must use bus objects for bus signals that cross referenced model boundaries (for example, global data stores, root inports, root outports).</p>
S-functions	<p><b>Supported, with limitations</b></p> <p>Model referencing generally supports inlined or noninlined S-functions. See “S-Function Limitations” on page 5-93.</p>
Model configuration settings	<p><b>Supported, with limitations</b></p> <ul style="list-style-type: none"> <li>• To apply the same model configuration settings to all models in a model hierarchy, use a referenced configuration set.</li> <li>• 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.</li> </ul>

<b>Modeling Requirement or Feature</b>	<b>Guidelines for Model Referencing</b>
Tools	<b>Supported, with limitations</b> <ul style="list-style-type: none"><li>• There are some limitations for using some Simulink tools, such as the Simulink Debugger, with model referencing.</li><li>• For details, see “Simulink Tool Limitations” on page 5-89.</li></ul>
Code generation	<b>Well suited</b> <ul style="list-style-type: none"><li>• By default, model referencing generates code incrementally.</li><li>• You can improve rebuild performance by selecting the appropriate setting for the <b>Configuration Parameters &gt; Model Referencing &gt; Rebuild</b> parameter.</li><li>• 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”.</li></ul>



# Managing Projects

---

- “Organize Large Modeling Projects” on page 12-2
- “Create a New Project” on page 12-9
- “Add Files and Discover Required Project Files” on page 12-16
- “Manage Project Files” on page 12-23
- “Create Shortcuts to Set Up Projects and Run Frequent Tasks” on page 12-29
- “Interface with Source Control from Projects” on page 12-34
- “Retrieve and Check Out Files Under Source Control” on page 12-42
- “Review Changes and Commit Modified Files” on page 12-48
- “Use Templates to Create Standard Project Settings” on page 12-54
- “Export Projects” on page 12-59
- “Model Dependencies” on page 12-60

## Organize Large Modeling Projects

In this section...
“Tools for Managing Project Files” on page 12-2
“Getting Started with Your Project” on page 12-2
“Example Project” on page 12-4

### Tools for Managing Project Files

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:

- Find all the files that belong with your project
- Share projects using built-in integration with the Apache™ Subversion® client, an external source control tool
- View and label modified files for peer review workflows
- Create standard ways to initialize and shutdown 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 and video demos.

### Getting Started with Your Project

You can use projects to manage:

- Your design (.mdl, .m, .mat, and other files, source code for S-functions, data)
- A set of actions to use with your project (e.g., run setup code; open models, simulate; build; run shutdown code).

- Working with files under source control (such as check out, compare revisions, tag or label, and check in)

To get started with managing your files with a project:

- 1** Open the Simulink Project Tool from the MATLAB command line, by entering:

```
simulinkproject
```

Alternatively,

- From the MATLAB Desktop, select **File > New > Simulink Project or Start > Simulink > Simulink Project**.
- From the Library Browser or Simulink Editor, select **View > Simulink Project**.

The Project Tool opens. In the Project Tool you can create, load, and explore projects; discover and manage required files; interact with source control; and save tasks.

- 2** Try an example project to see how the tools can help you organize your work. See “Example Project” on page 12-4.
- 3** Create a new project by selecting **Simulink Project > New**. See “Create a New Project” on page 12-9.
- 4** Add files to your project from the All Files view, and use the Dependency Analysis view to check required files. See “Add Files and Discover Required Project Files” on page 12-16
- 5** Explore views of your files. See “Manage Project Files” on page 12-23.
- 6** Create shortcuts from the file views to save and run frequent tasks. See “Create Shortcuts to Set Up Projects and Run Frequent Tasks” on page 12-29
- 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 “Interface with Source Control from Projects” on page 12-34.

### Example Project

Try an example project to see how the tools can help you organize your work.

In the Simulink Demos, under Modeling Features, see Model Management. The example `sldemo_slproject_airframe` describes how to:

- 1 Set up and browse some example project files, under local revision control.
- 2 Examine project shortcuts to run set up and shut down 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 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 these steps to explore the example project:

- 1 Run this command to create a working copy of the project files and open the project:

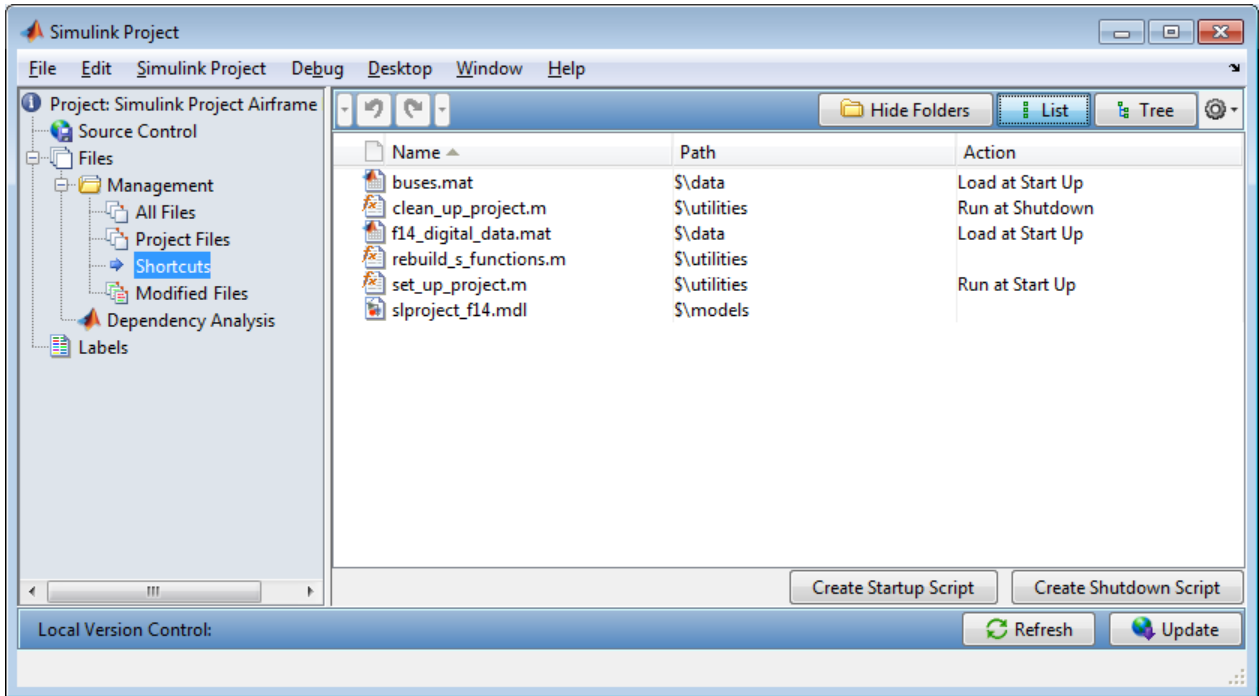
```
sldemo_slproject_airframe
```

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.

- 2 Click the Shortcuts node to view the startup tasks and other shortcuts.
- 3 Click the **List** button at the top right of the Project Tool to view the shortcuts as a list of files.

You can use shortcuts to run startup or shutdown tasks, and to easily find files within a large project.





In this example you can see shortcuts for the following tasks:

- Some files are set as **Run at Start Up** shortcuts. Startup shortcut files are automatically run (.m files), loaded (.mat files), and opened (Simulink models) when you open the project. You can use these shortcuts to set up the environment for your project. In this example, 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;
```

- **Run at Shutdown** shortcuts run before the current project closes. In this example, the file `clean_up_project.m` resets the environment changes made by `set_up_project.m`.

- You can use shortcuts to make scripts easier to find in a large project. The script that regenerates S-Functions is a shortcut so that a new user of the project can easily find it.
- You can use shortcuts to make the top-level model, or models, within a project easier to find. In this example, the top-level model `slproject_f14` is a shortcut.

#### 4 Use the example shortcuts:

- a 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.
- b Right-click the shortcut `rebuild_s_functions.m` and select **Run** to generate the S-Function. Open this file to view how it works. You may need to run `mex -setup` if you have not previously used the `mex` command.

To create new 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**.

#### 5 Run a file dependency analysis on the files within your project to check that all the files that are required by the project are stored within it.

- a Click the Dependency Analysis node.
- b Click the Analyze button.
- c Review files reported in the Problems tab.
- d Observe that the S-Function binary, `timesthree`, is required by the project but is not currently part of it. Click a file in the Problem Files table to view where it is used in the table below.

You may 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.

- e Right-click a problem file and select **Add External File**. The next time you run dependency analysis, this file will not be marked as a problem file.

#### 6 Modify a file and review changes.

- a Open and make changes to one of the utility MATLAB files, or one of the models. You can double-click to open files for editing from the Simulink Project, or right-click and select **Open**.
- b Click the Modified Files node to see the files that you have modified.
- c To review changes, right-click a file in the Modified File 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.

- d To commit your changes to source control, click the **Commit Modified Files** button.

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, 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 12-49.

- 7 You can dock and undock the Simulink Project Tool into the MATLAB Desktop. When docked, the Project menus (such as the **Simulink Project** menu and **Help** menu items) integrate into the menus of the MATLAB Desktop, and the **Simulink Project** menu is visible only when the Simulink Project Tool has focus. If you cannot see the **Simulink Project** menu, click the Simulink Project Tool.
- 8 Click the 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. You can use the check box to set the current working folder to the project root when you open the project.
- 9 Click the **Source Control** node to see information about the source control tool being used by the current project. This 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 file management views.

- 10** Click the Project Files view to manage the files within your project. Only the files that are in your project are shown.
- 11** Click the All Files view to see all the files in your sandbox. This 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.
- 12** In any file view, click the List button at the top right to view the files as a list. Click the "cog" icon Actions button at the top right (as in the Current Folder Browser) to customize the views and to group files.

## Create a New Project

In this section...
“Create a New Project to Manage Existing Files” on page 12-9
“Open Recent Projects” on page 12-13
“Change the Project Name, Root, Description, and Startup Folder” on page 12-14

### 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.

---

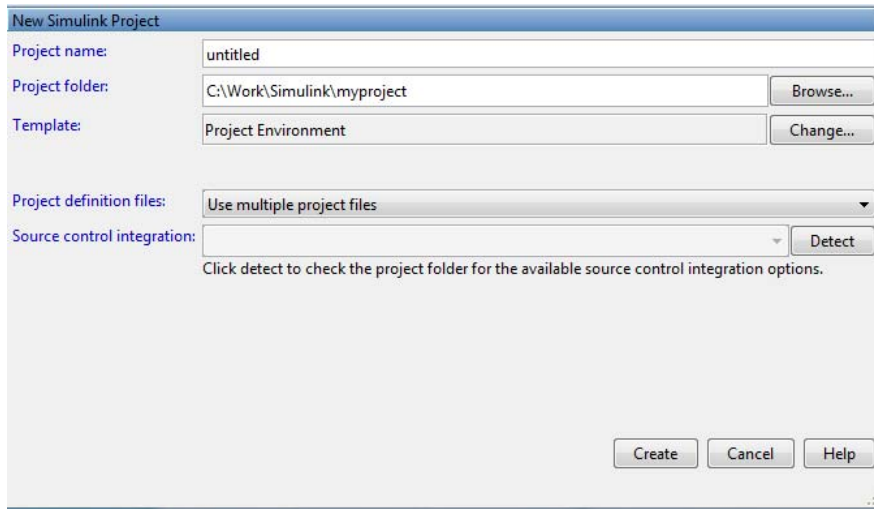
**Note** If you want to retrieve your project from a source control repository, see instead “Retrieve a Working Copy of a Project from Source Control” on page 12-42.

---

To create a new project to manage your files:

- 1 Select **Simulink Project > New**.

The Create Simulink Project dialog box appears.



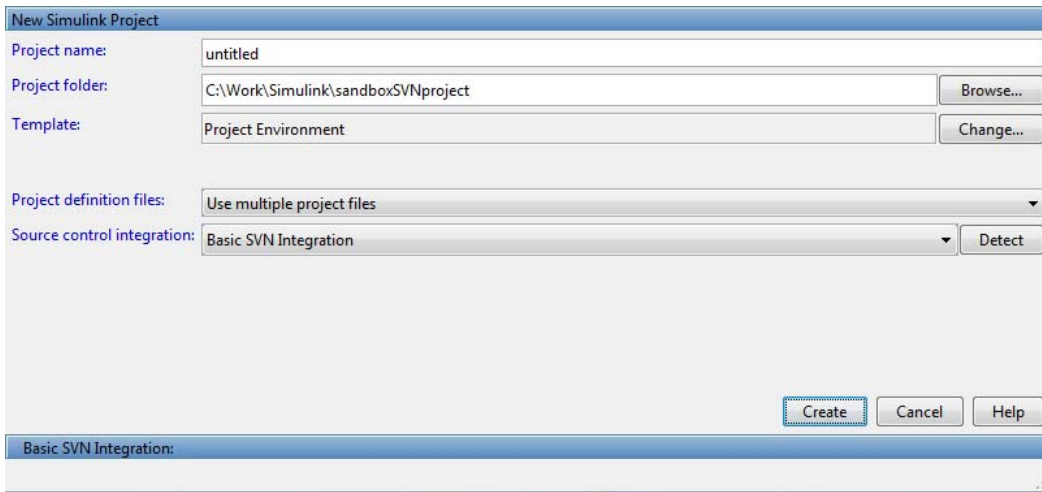
- 2** Enter the project name.
- 3** Select a project folder. The default is your current folder.
- 4** (Optional) Click **Detect** to check the project folder for source control integration options. If your selected folder is under source control that the project can recognize, the **Source control integration** field reports this. 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 “Interface with Source Control from Projects” on page 12-34.

---

The next example shows the project has detected SVN in the selected project folder, and so the project selects Basic SVN Integration.



#### 5 (Optional) Change the template.

- Leave the default template to create a project with some preconfigured settings to guide you with setting up your project. By default, the **Project Environment** template is selected to 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 view information about the default template settings, click **Change** and read the description for the **Project Environment** template.

- If you want to create a blank project without any preconfigured structure or utilities, click **Change** next to **Template** to open a dialog box and select the **Blank Project** template.
- 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 12-54.

Note you will be warned if there are collisions with the chosen template that will overwrite any files in your chosen location.

#### 6 (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 two users both submit changes in the same project to a source control tool. See “Project Definition Files” on page 12-49.

**7** 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 and Discover Required Project Files” on page 12-16.



## Open Recent Projects

After you create projects, you can open recent projects from the **Simulink Project** menu. You need to open the Project Tool to access the **Simulink Project** menu.

- 1 To open the Project Tool from the command line, enter:

```
simulinkproject
```

Alternatively, to open the Project Tool, from the Library Browser or Simulink Editor, select **View > Simulink Project**.

- 2 Select a recent project to open from the **Simulink Project** menu.

---

**Note** You can have only a single project open. If you open another project with the **Simulink Project** menu, any currently open project closes. You cannot have multiple projects open because it could cause conflicts.

---

If you cannot see the **Simulink Project** menu, click the Simulink Project Tool.

You can dock and undock the Project Tool into the MATLAB Desktop and navigate all desktop tools using the standard MATLAB **Desktop** and **Window** menus. As with all desktop tools when docked, the Project Tool menus (such as the **Simulink Project** menu and **Help** menu items) integrate into the menus of the MATLAB Desktop.

---

**Tip** Create a MATLAB shortcut for opening the Project Tool by dragging this command to the toolbar from the Command History or Command Window:

```
simulinkproject
```

---

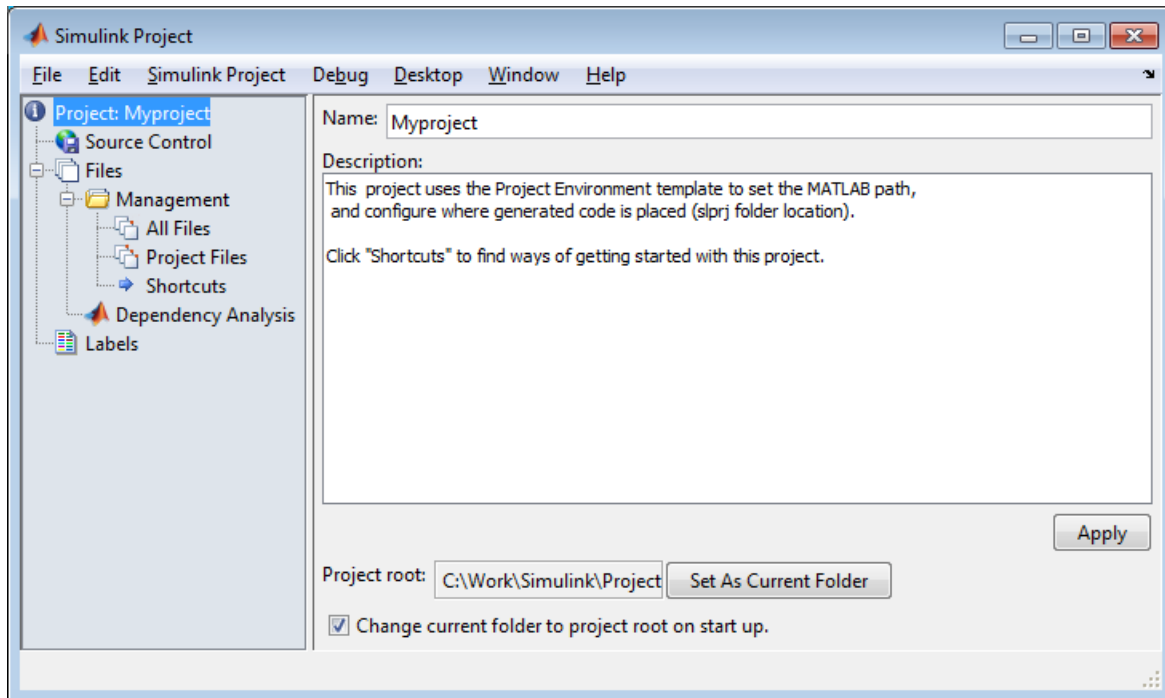
### **Change the Project Name, Root, Description, and Startup Folder**

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 startup** 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 “Create Shortcuts to Set Up Projects and Run Frequent Tasks” on page 12-29.



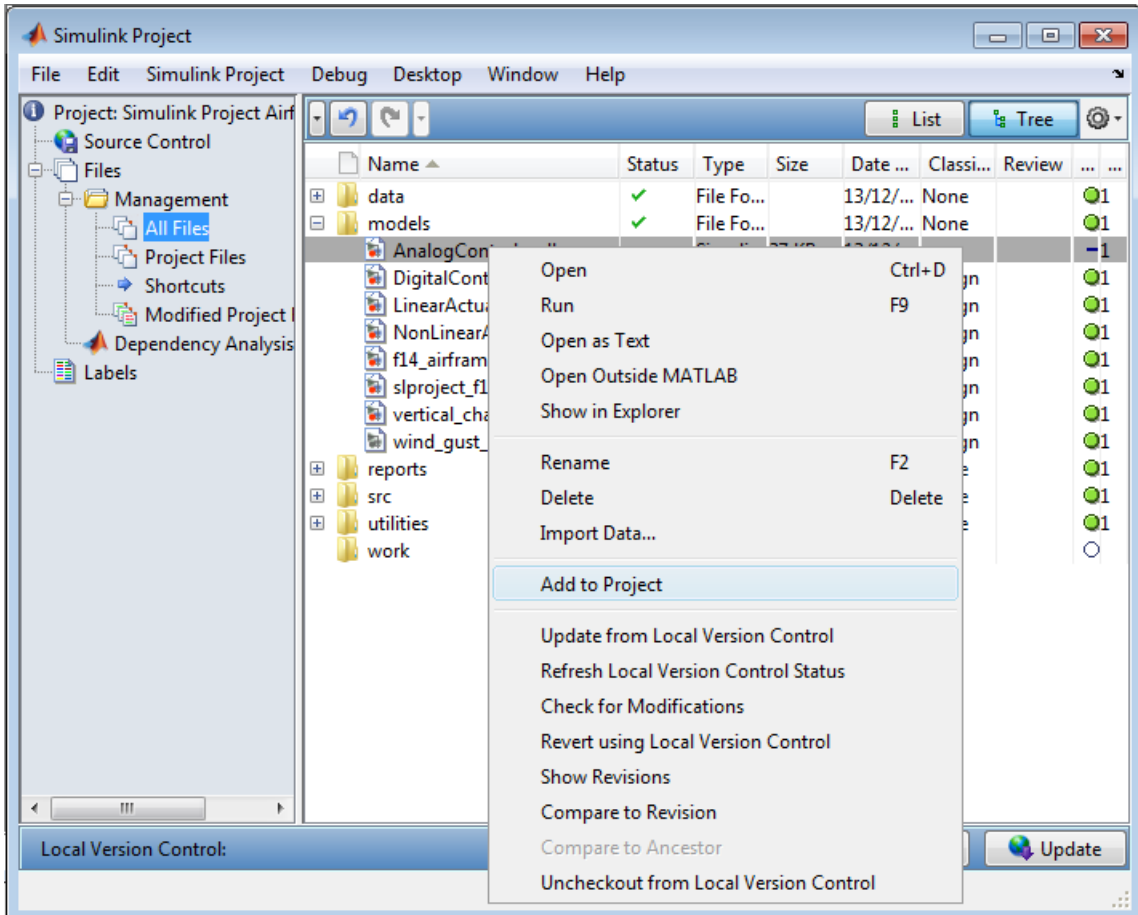
# Add Files and Discover Required Project Files

In this section...
“Add Files” on page 12-16
“Discover Required Files” on page 12-18

## Add Files

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 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.

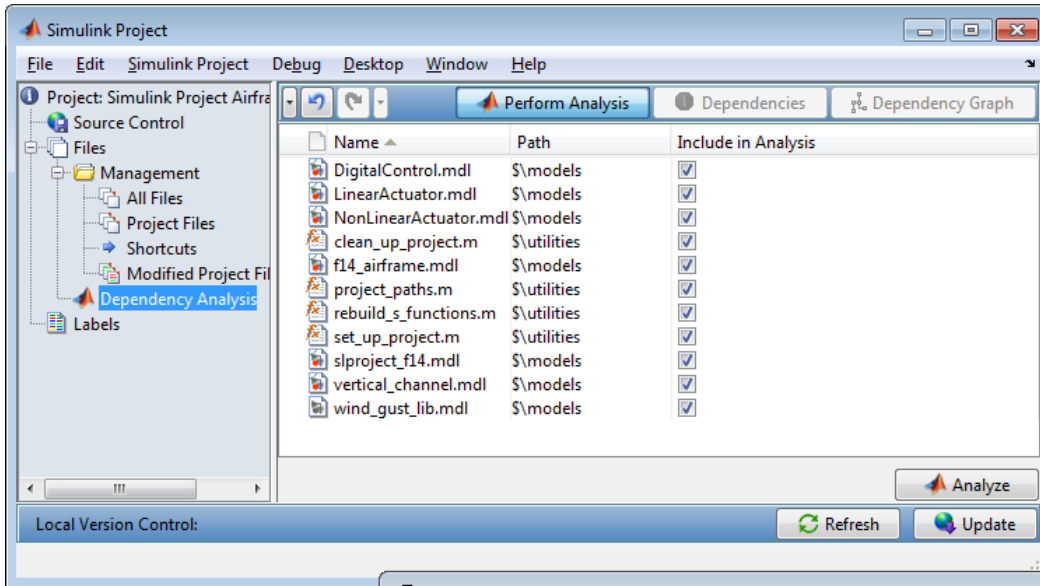
To help you set up your project with all required files, see “Discover Required Files” on page 12-18.

To configure your project to automatically run startup and shutdown tasks, see “Create Shortcuts to Set Up Projects and Run Frequent Tasks” on page 12-29.

### Discover Required Files

You can discover files required by your project with the Dependency Analysis view.

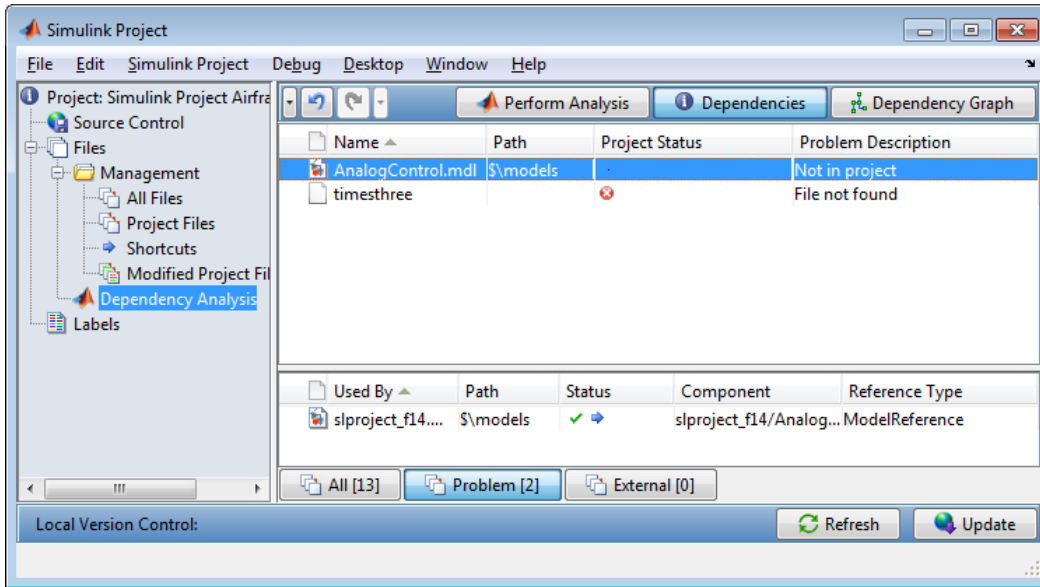
- You can use dependency analysis to help you set up your project with all required files. For example, you can add a top-level model to your project, analyze the model dependencies, and then add all dependent files to your project.
  - You can run dependency analysis at any point in your workflow when you want to check that all required files are in the project. For example, you could check dependencies again before submitting a version of your project to source control.
- 1** 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 models you want to analyze, right-click and select **Add to Project**.
  - 2** In the Project tree, click Dependency Analysis.  
Files in your project are shown in the Perform Analysis tab.
  - 3** Select the check boxes to specify which files to analyze.



- 4 Click **Analyze** to discover required files.

The view changes to the Dependencies tab to show your results.

- 5 If any problems are found, the Project Tool displays the Problem tab. The Problem tab shows dependent files that you should review because they are required by the project but not currently in the project. 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.

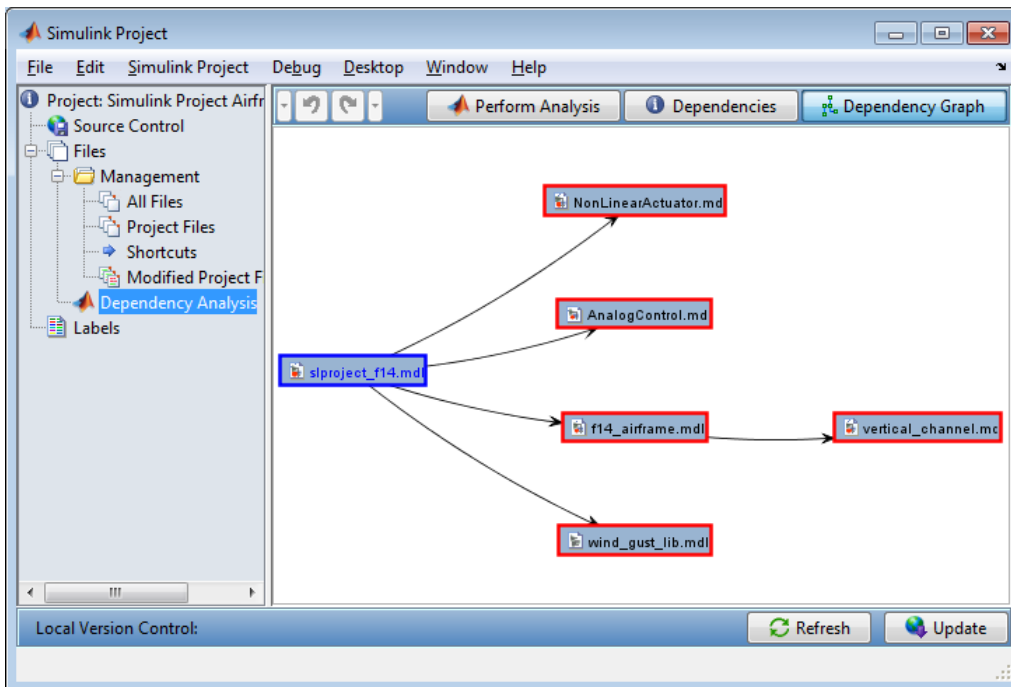


- 6 Check the Problem Description and Project Status of dependent files, and if desired right-click to add any required files that are not in the project. You can select multiple files. For example, press **Ctrl+A** to select all files in the Dependent Files list, right-click, and select **Add to Project**.
- 7 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 moves to the list on the External tab. Next time you run dependency analysis, this file will not appear in the Problem list.

You may not want to add all required files to the project. For example, you might want to exclude derived S-Function binary files that are generated from source code that is part of the project. 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 may not indicate any problem if the dependent file is on your path and is a utility or other resource that is not part of your project. Use dependency analysis to ensure you understand your design's dependencies.



- 8 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.
- 9 Click the All tab to view all identified dependencies. Click files to view where they are used.
- 10 To investigate dependencies visually, click Dependency Graph at top right.
  - To highlight dependencies, right-click the graph and select **Highlight Dependencies > Upstream >** or **Downstream** , then click graph items to view their highlighted dependencies, as shown in the following example.



- Right-click the graph to try different graph options, change zoom, and filter files. You can also control zoom with a mouse wheel.
- To save the graph as an image, right-click and select **Save**.

You can use the 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 “Model Dependencies” on page 12-60.

## Manage Project Files

### In this section...

“Choose Views of Files to Manage” on page 12-23

“Group and Sort File Views” on page 12-24

“Work With Project Files” on page 12-24

“Back Out Changes” on page 12-25

“Label Files” on page 12-26

### Choose Views of Files to Manage

Use the Project File Management view to explore project files, interact with source control, view modified or labeled files, and save tasks or shortcuts.

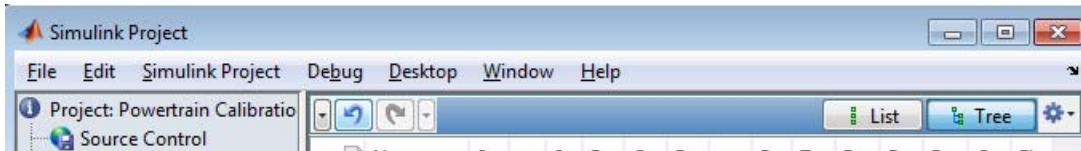
- 1 Click Management in the Project tree.
- 2 Use the nodes in the tree to choose the view with the files you want to manage:
  - **All Files** — View all files within your project folder (or projectroot). This list can be different from the list in the Project Files node. For example, you might want 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.
  - **Modified Files**— View only files with changes in your project. 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 12-48.
  - **Shortcuts** — View files you have specified as shortcuts for frequent tasks, such as opening top-level models, running startup or shutdown code, 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 “Create Shortcuts to Set Up Projects and Run Frequent Tasks” on page 12-29.

## Group and Sort File Views

To group and sort the views in all File Management nodes:

- Use the **List** or **Tree** 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 only want to view files.



- Click the Actions button (next to the Tree button) to select the columns to display and select groupings, for example, to sort by Review Status labels or any labels you have defined.

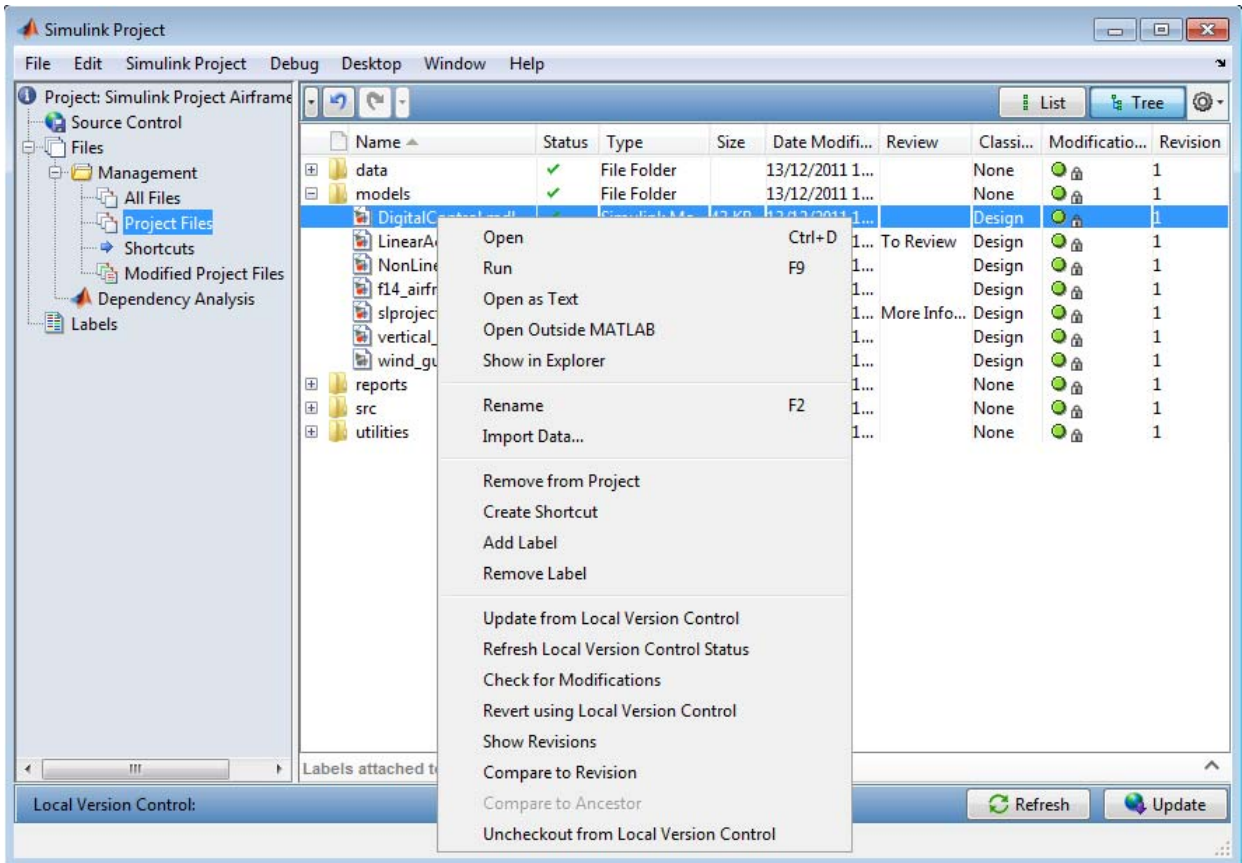
## Work With Project Files

In all File Management 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 12-26.
  - Create entry point shortcuts (for example, code to run at start up or shut down, open models, simulate or generate code). See “Create Shortcuts to Set Up Projects and Run Frequent Tasks” on page 12-29.
  - If a source control interface is enabled you can also:
    - Refresh source control status
    - Update from source control
    - Check for modifications
    - Revert

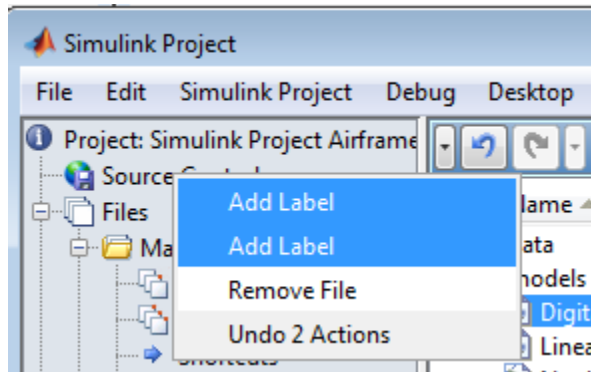
- Compare against revision (select a version to compare)

See “Interface with Source Control from Projects” on page 12-34.



## 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.

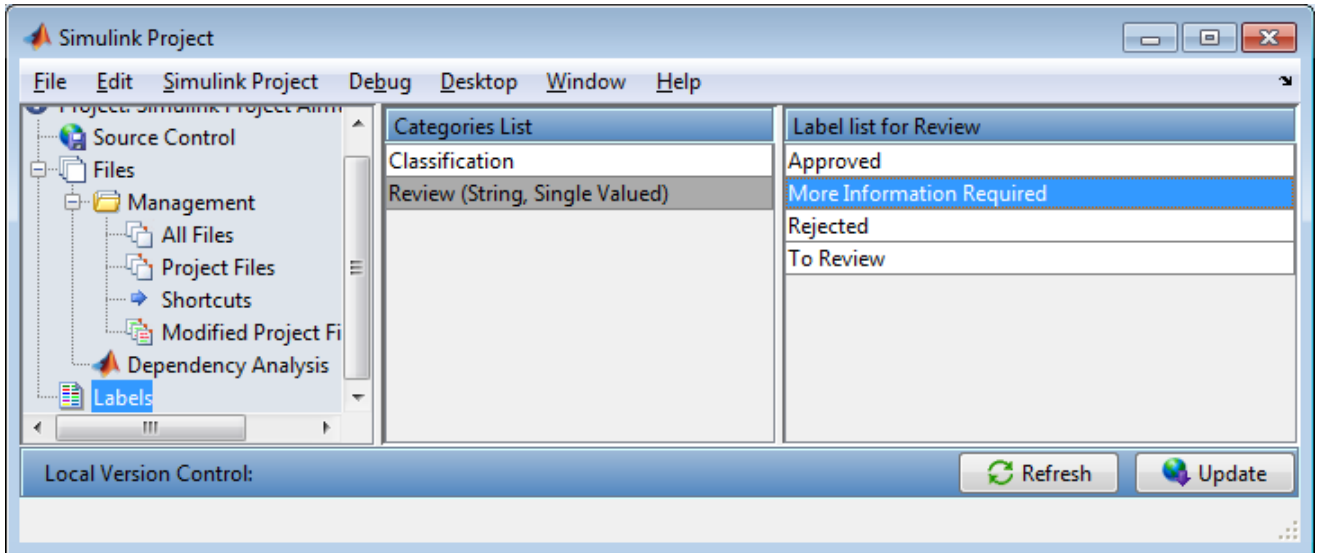


### Label Files

Use labels to organize your files. The Project automatically applies built-in labels for File categories. You can create your own labels.

- In the File Management 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 File Management views, you can organize lists by labels. Use the Actions button (cog icon at top right) and select Group By.
- Use the Labels tree node to create new label categories.

The Labels view:



- 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 only want to apply 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 to **Remove** selected user-defined categories and labels. You cannot delete built-in labels.

To add labels at the command line, see the `Simulink.ModelManagement.Project.CurrentProject` reference page.



## Create Shortcuts to Set Up Projects and Run Frequent Tasks

### In this section...

“Create Shortcuts” on page 12-29

“Use Shortcuts to Find and Run Frequent Tasks” on page 12-30

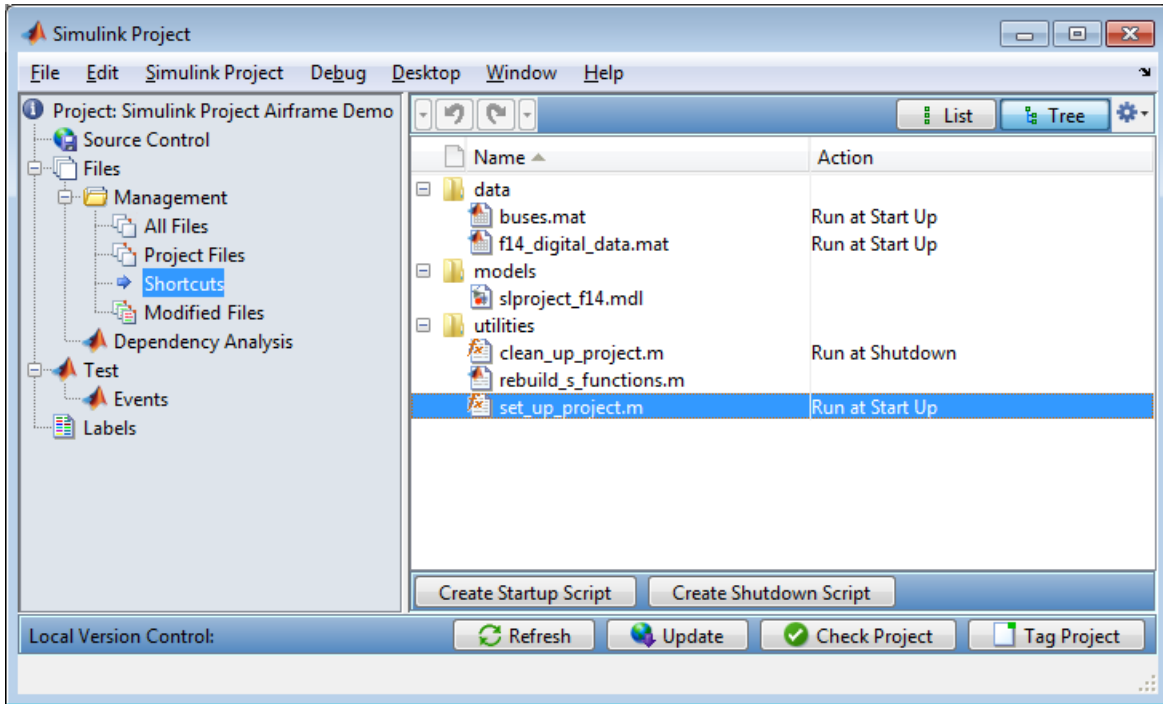
“Automate Startup Tasks with Shortcuts” on page 12-31

“Automate Shutdown Tasks with Shortcuts” on page 12-33

### 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 File Management Shortcuts node is blank until you add shortcuts. You can create shortcuts from the File Management nodes All Files or Project Files.

- 1 To add a shortcut, right-click a file in the All Files or Project Files node 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** 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`.

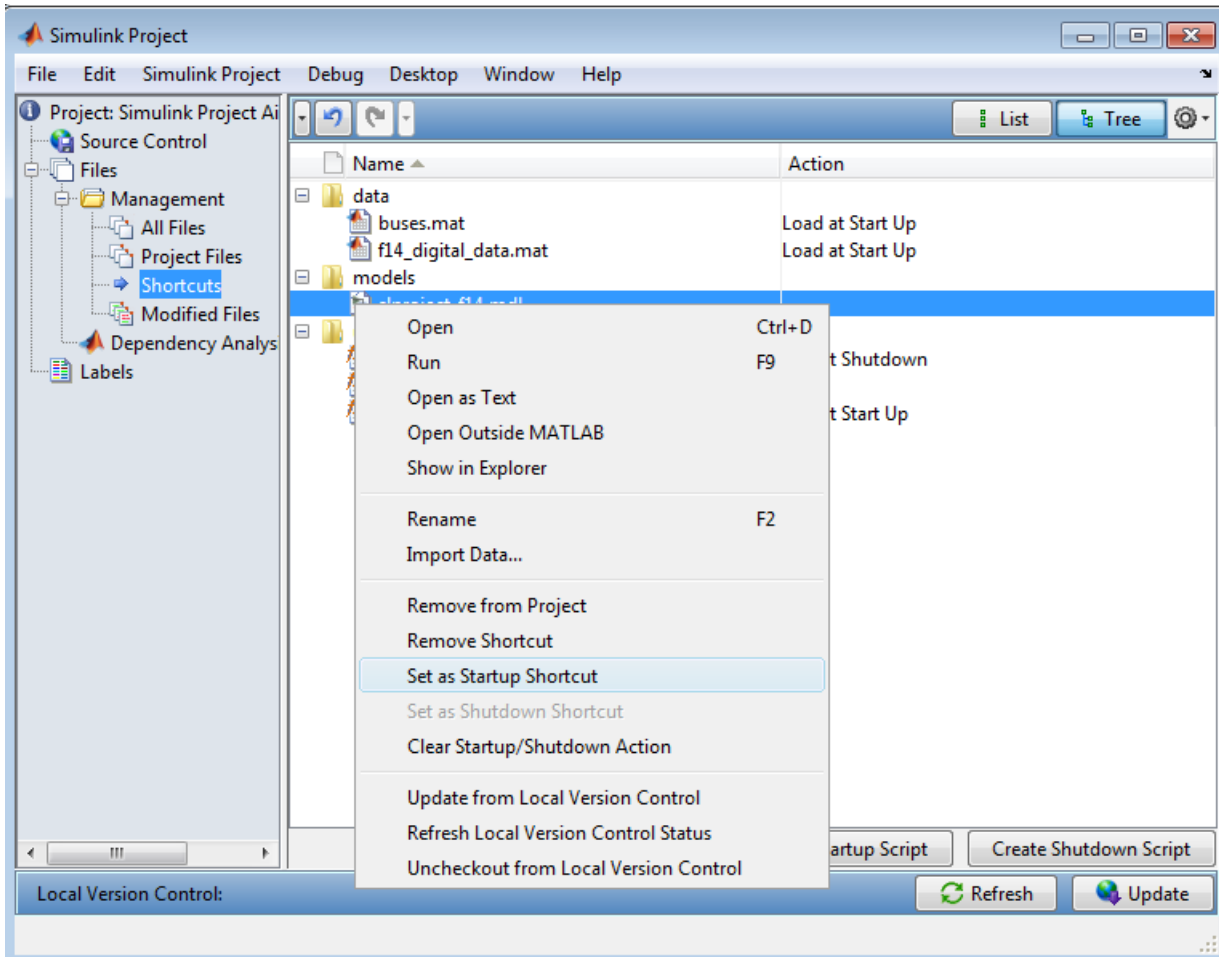
---

**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.

---

## Interface with Source Control from Projects

### In this section...

“Set Up Source Control with Projects” on page 12-34

“Register Model Files with Source Control Tools” on page 12-35

“Set Up Subversion” on page 12-35

“Set Up Local Version Control” on page 12-37

“Add or Change Project Source Control” on page 12-39

“Write a Source Control Adapter with the SDK” on page 12-40

### Set Up Source Control with Projects

Many capabilities of the Simulink Project Tool enable you to work with an external source control tool.

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:

- Apache Subversion (SVN) — Client must support the command-line interface. See “Set Up Subversion” on page 12-35.
- A built-in Local Version Control tool.

Project examples use the light-weight local version control tool so you can try out source control operations. The local version control tool is designed for a single user for demonstration purposes only. See “Set Up Local Version Control” on page 12-37.

If your project is under a supported source control tool, you can use these project features:

- “Add or Change Project Source Control” on page 12-39
- “Retrieve and Check Out Files Under Source Control” on page 12-42
- “Review Changes and Commit Modified Files” on page 12-48

## 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 automerger. This 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 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 12-36

## Set Up Subversion

- “Install Subversion” on page 12-35
- “Register Model Files with Subversion” on page 12-36
- “Create Subversion Repository Structure” on page 12-36
- “Use Projects with Subversion” on page 12-37

## Install Subversion

Projects contain an interface to any Apache Subversion (SVN) client that supports the command-line interface. Install an SVN client that supports the command-line interface, then you can use SVN 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 1.5, or SVN 1.6 etc.

You can find Subversion clients on this Web page:  
<http://subversion.apache.org/packages.html>.

### Register Model Files with Subversion

If you do not register your model file extension as binary, Apache Subversion may add annotations to conflicted Simulink files and attempt automerger. 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.
- 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 automerger.  

```
*.mdl = svn:mime-type= application/octet-stream  
*.mat = svn:mime-type=application/octet-stream  
*.slx = svn:mime-type= application/octet-stream
```

### Create Subversion Repository Structure

To enable tagging within projects when using SVN, create your repository with the standard tags, trunk, and branch folders, and check out 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>.

If you have installed the TortoiseSVN client for use with Microsoft Windows Explorer, you can follow these steps:

- 1 In Windows Explorer, right-click the folder where you want the repository and select **TortoiseSVN > Create repository here**. TortoiseSVN reports successful repository creation.
- 2 Right-click the repository folder and select **TortoiseSVN > Repo-browser**.
- 3 In the Repository Browser, right-click and select **Create folder** to add folders.

Add folders named tags, trunk, and branch.



- 4 When you check out files to your sandbox from the repository, check out from `trunk`. When you use either **SVN Checkout** in Windows, or **Retrieve from Source Control** in the project tool, select `/trunk` in the repository path, e.g., `file:///C:/Work/repository/trunk`.

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.

## Use Projects with Subversion

After you install an SVN client that supports the command-line interface, then the Simulink Project Tool can interface to SVN. To use SVN in your project:

- Create a new project in a folder under SVN source control and click **Detect**. See “Create a New Project to Manage Existing Files” on page 12-9.
- Alternatively, put the project under SVN source control later by using the Source Control node in the Project tree. Under **Available Source Control Integrations**, select **Basic SVN Integration** and click **Reload**. See “Add or Change Project Source Control” on page 12-39.

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.

## Set Up Local Version Control

The Simulink Project Tool includes a light-weight local version control tool so you can try out source control operations.

---

**Note** The Local Version Control tool is designed for a single user.

---

To add the local version 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**, select **Local Version Control** and click **Reload**.

To create a repository using Local Version Control,

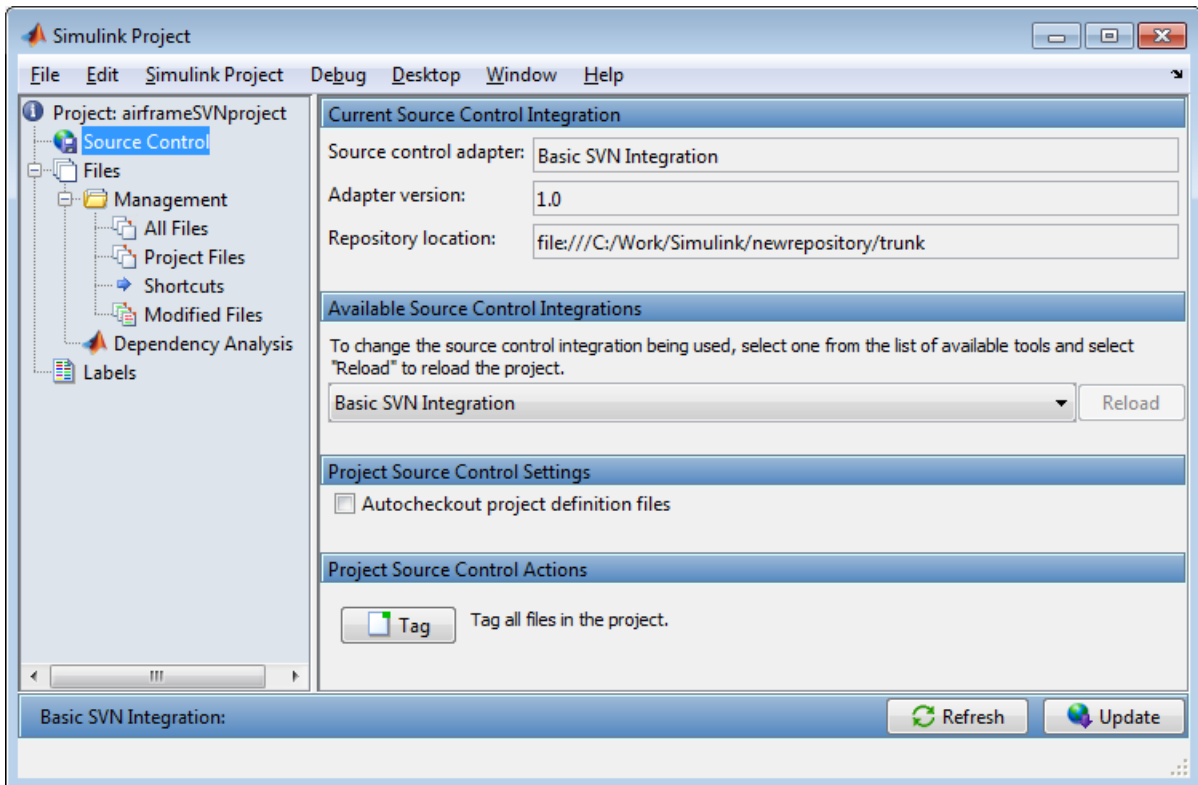
- 1** Select **Simulink Project > Retrieve from Source Control**
- 2** In the Project Retriever, select the **Source control integration Local Version Control**.
- 3** Next to **Repository path** click **Change**.

The Select a Repository dialog box opens.

- 4** Next to **Create a new repository**, click **Create**.
- 5** In the file browser, choose a location for your Local Version Control repository, specify a file name for your database .db file and click **Save**.
- 6** (Optional) In the Select a Repository dialog box, click **Validate** to check your new repository path is valid.
- 7** Click **OK** to close the dialog box and return to the Project Retriever.
- 8** To use your new repository, create a project sandbox and check files into the repository as follows:
  - a** Specify a new **Sandbox** folder in the Project Retriever, leave your new repository in the **Repository path** field and click **Retrieve**. You can use a sandbox folder that already contains files or add files to the folder later.
  - b** You are prompted to create a new project in the folder. Name your project and click **Detect** to put the project under Local Version Control.
  - c** If you don't already have files in the sandbox folder, create or copy the files you want in the project to the folder.
  - d** In the Project Tool All Files view, select files and right-click to **Add to Project**.
  - e** When you are ready to check in files to your Local Version Control repository, select the Modified Files view and click **Commit Modified Files**. Enter a comment if desired and click **Submit**. The project checks in the modified files to your new repository.

## Add or Change Project Source Control

- “Viewing Source Control Type and Repository” on page 12-39
- “Adding, Changing or Removing Source Control” on page 12-40
- “Using Source Control Settings” on page 12-40
- “Tagging Files” on page 12-40



### Viewing Source Control Type and Repository

The Source Control node in the project tree shows details of the detected source control tool, the adapter interfacing to source control in your current project, and the repository location.

### **Adding, Changing or Removing Source Control**

You can add source control to a newly created project or an existing one, by selecting an available source control tool from the list and clicking **Reload**.

Use this control to remove a project from source control by selecting **No source control integration**. For example this might be useful when you are preparing a project to create a template from it.

### **Using Source Control Settings**

**Autocheckout project definition files** You can select the check box if you want the project to automatically check out project definition files, but there is a risk of unintentionally checking out files.

---

**Caution** To avoid unintentionally checking out files, do not select this checkbox. Instead, let the project notify you and offer to check out definition files only when you need to.

---

### **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 adds your tag to every project file.

Not every source control has the concept of tags. To use tags with SVN, see “Create Subversion Repository Structure” on page 12-36

### **Write a Source Control Adapter with the SDK**

Simulink provides a Software Development Kit (SDK) 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” on page 12-42

“Check Source Control Status of Project Files” on page 12-46

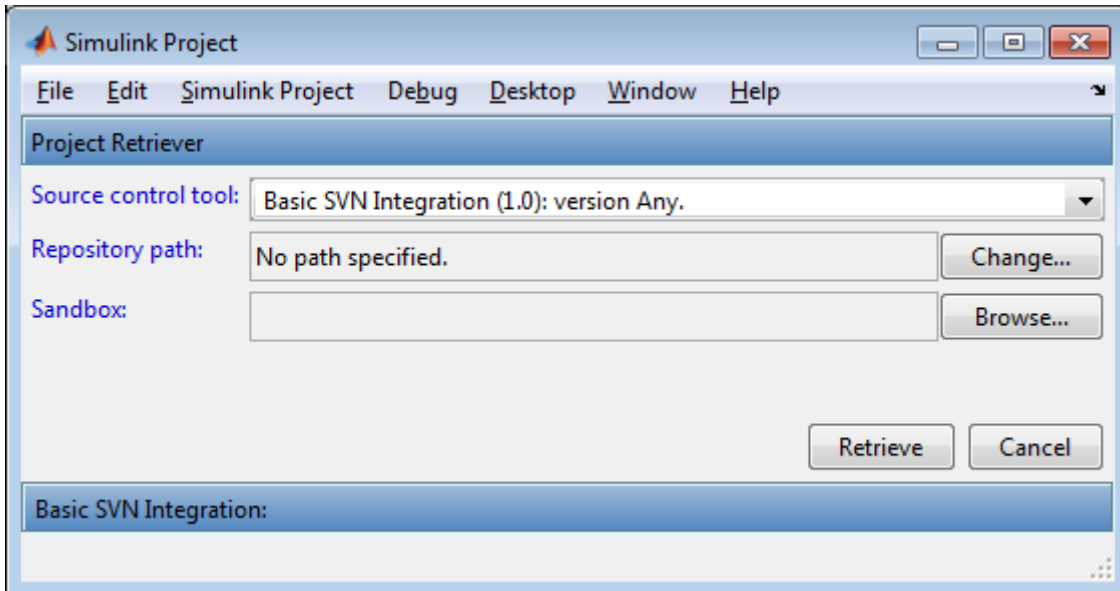
“Check Out Files” on page 12-46

### Retrieve a Working Copy of a Project from Source Control

To create a new local copy of a project by retrieving files from source control:

- 1 Select **Simulink Project > Retrieve From Source Control**.

The Project Retriever appears.



- 2 (Optional) Select your source control interface from the **Source Control Adapters** drop-down list.

Leave the default SVN to use the basic SVN integration with your project.

- 3** Click **Change** to select the Repository Path that you want to retrieve files from.

The Specify Repository URL dialog box opens.

- a** Click **Browse** next to **Generate URL from folder** 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.

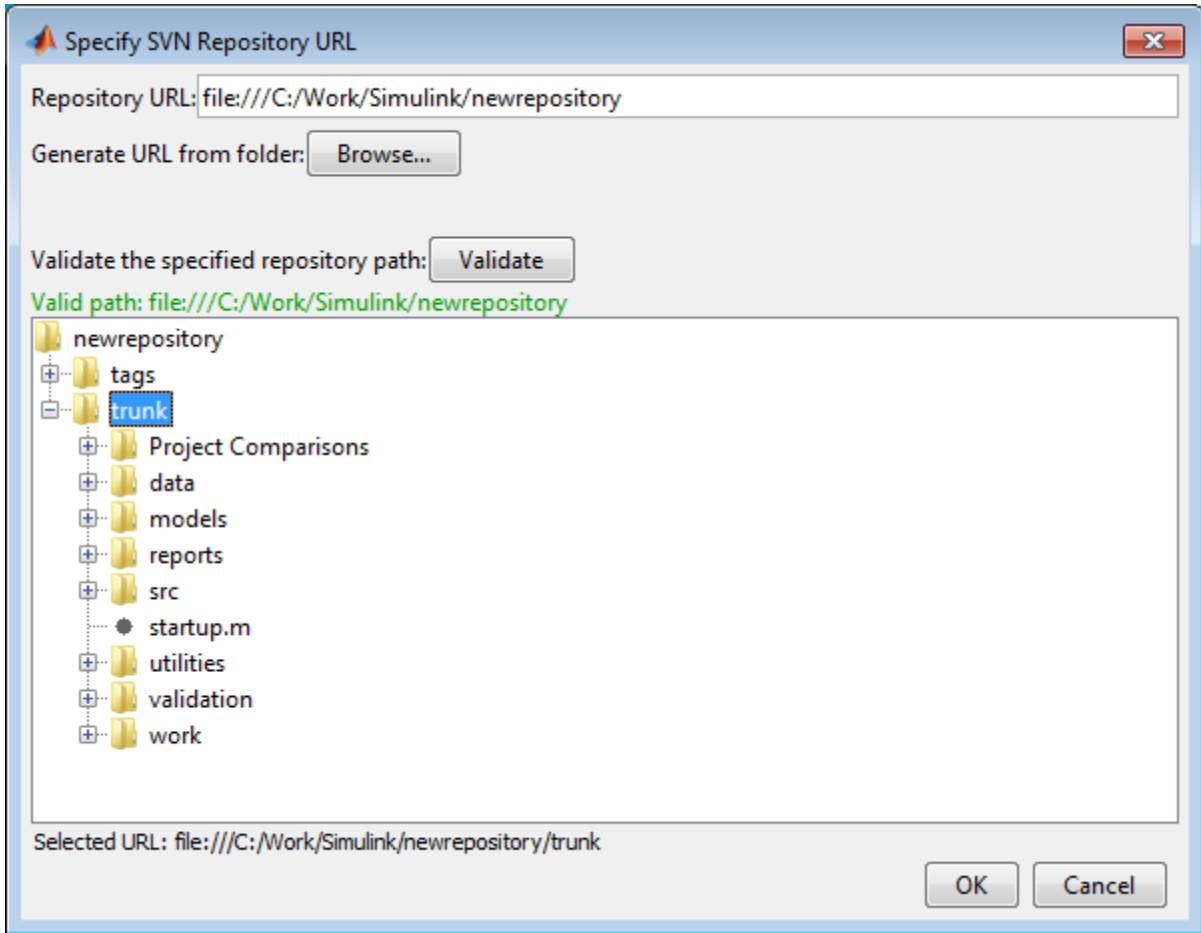
Alternatively, manually enter or paste the **Repository URL**.

- b** Click **Validate** to check the repository path.

If the path is invalid, check the URL against your source control repository browser.

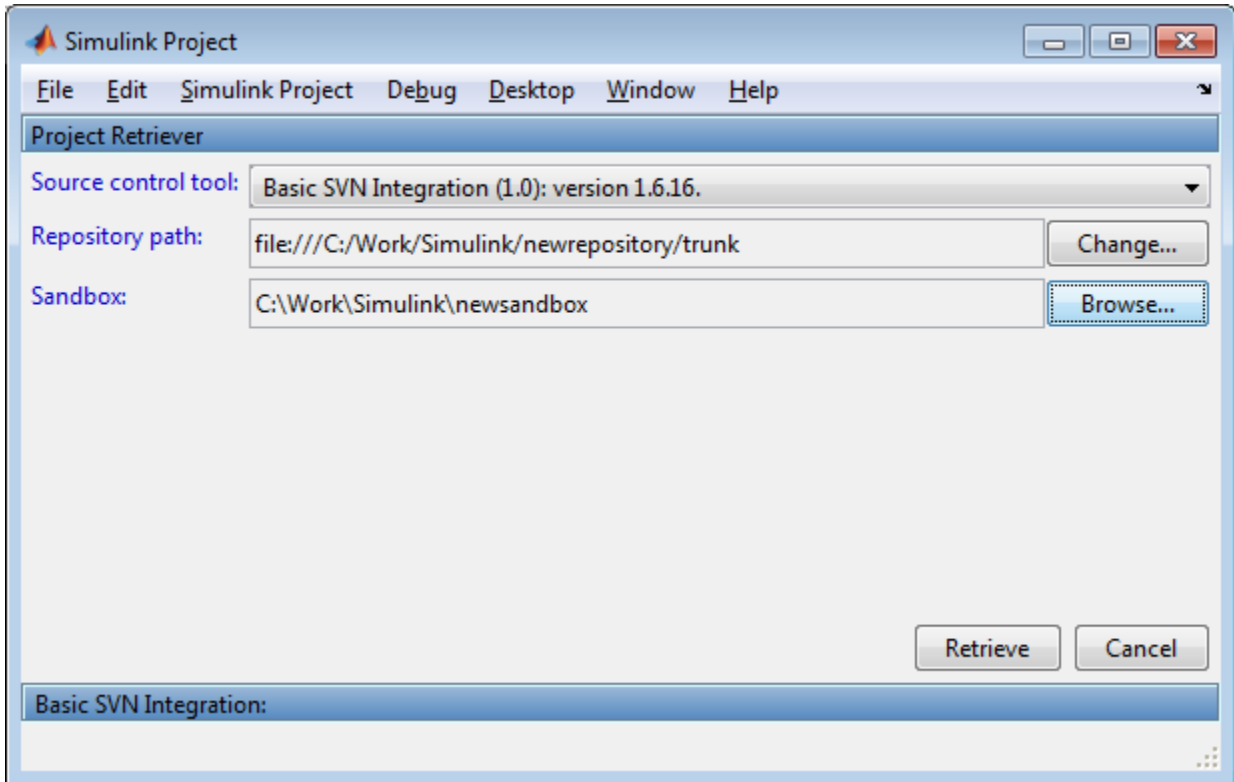
- c** If necessary, select a deeper folder in the repository tree. The example shows **trunk** selected, and the **Selected URL** displays at the bottom of the dialog box.

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.





- 5 Click **Retrieve**.
- 6 Watch the **Basic SVN Integration** status bar for messages as the project retrieves your files from source control.
- 7 A dialog appears to report the files in the repository have been checked out to your selected sandbox folder, and to check 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 and Discover Required Project Files” on page 12-16.

## Check Source Control Status of Project Files

### Refresh Source Control Status

To check the status of individual files, right-click files in any management view to select **Refresh**. This queries the local sandbox state and checks for changes made with another tool. For Subversion, **Refresh** does not contact the repository.

To check source control status of *all* project files, click the **Refresh** button in the source control status bar. The status bar reports source control messages, and the buttons in the status bar apply to the whole project.

**Refresh** refreshes the view of the source control status for all files under projectroot. **Refresh** updates the columns **Revision** 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)**.

### Update Revisions

Click the **Update** button to get the latest revisions from the source control repository.

### Check Out Files

To check out files,

- 1 In any file management view, click to select a file, or **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 Basic SVN Integration Repository**.

For next steps, see “Review Changes and Commit Modified Files” on page 12-48.

## Review Changes and Commit Modified Files

### In this section...

“View Modified Files” on page 12-48

“Review Changes” on page 12-50

“Precommit Actions” on page 12-50

“Commit Modified Files” on page 12-52

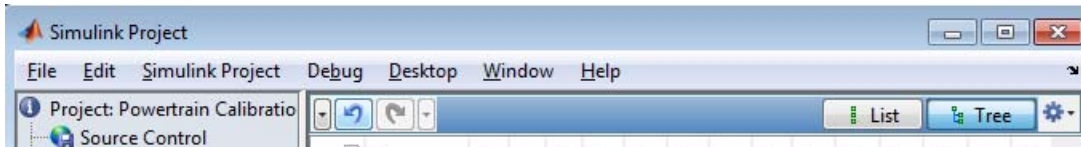
“Resolve Conflicts” on page 12-52

### View Modified Files

The Modified Files node is visible only if you are using a 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.

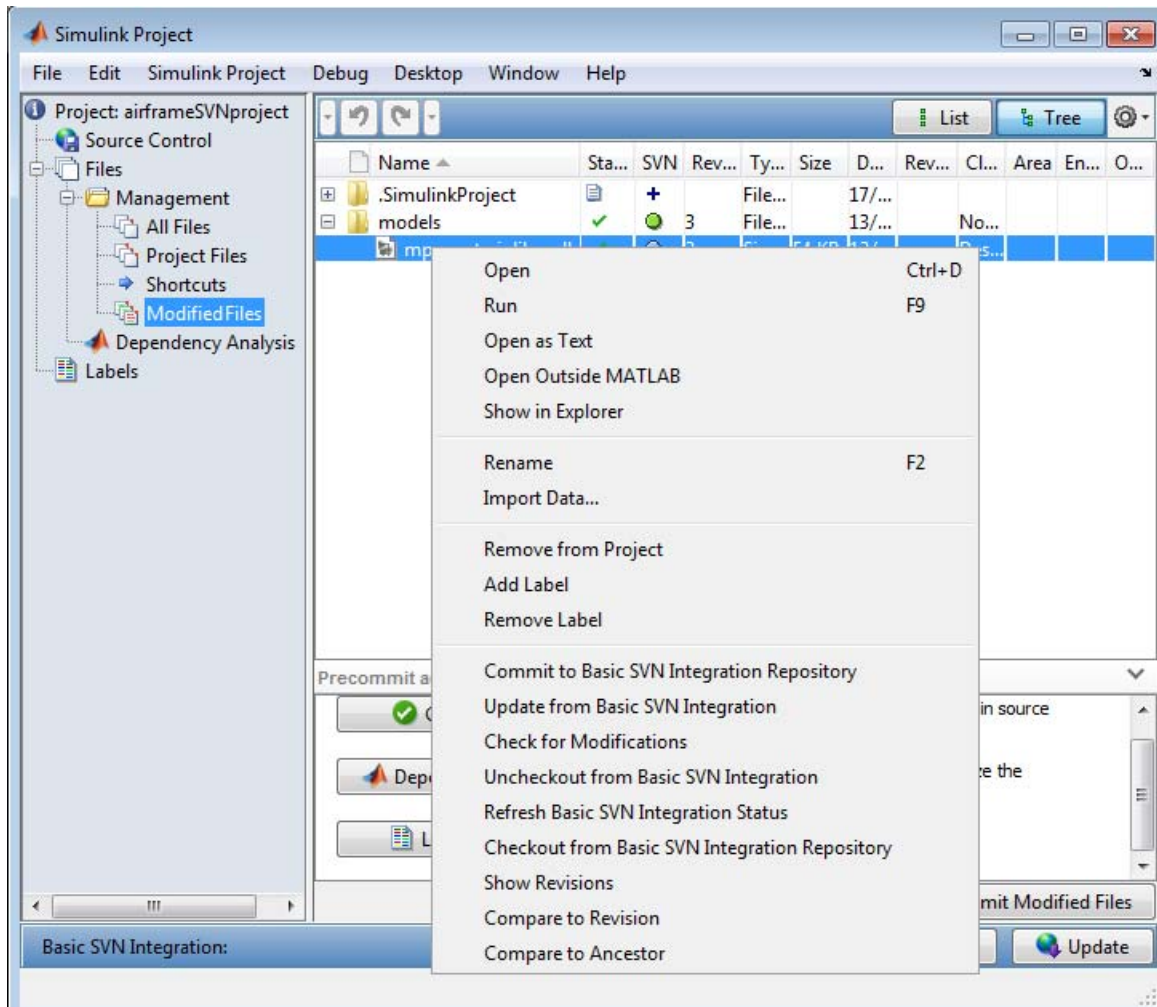
In the Modified Files view, it can be useful to switch to List view. Use the **List** or **Tree** buttons at top right.



As in the other Management 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



## 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 12-52

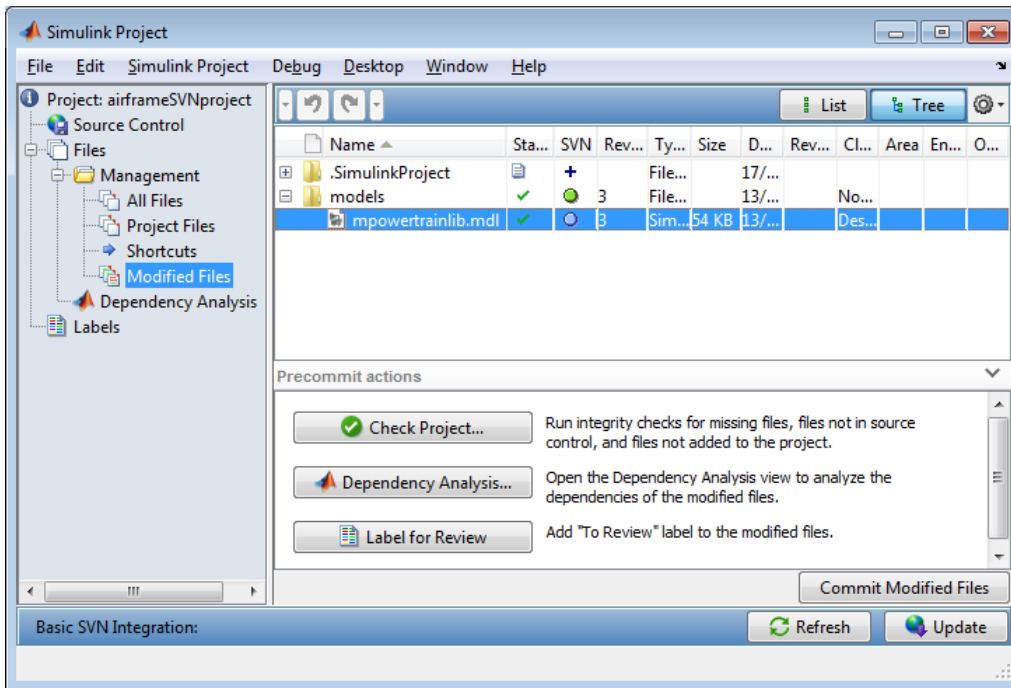
### Review Changes

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.

### 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.

This function is also in the **Simulink Project** menu (**Run Integrity Checks**) so you can run the checks from any project view.

- 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**.
- If you want to add the label To Review to all files in your changeset, click the **Label Changeset 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 12-49.

---

## Commit Modified Files

To commit your changes to source control,

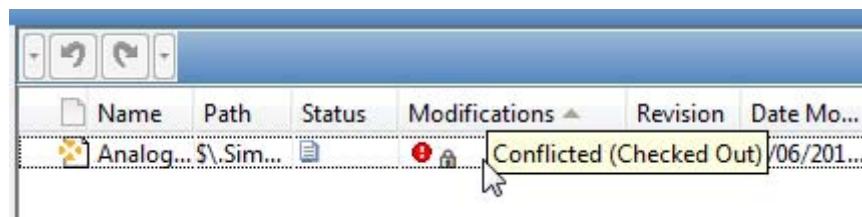
- 1 Click the **Commit Modified Files** button to check in all files in the modified files list.
- 2 A dialog prompts you to enter comments for your submission.
- 3 Click **Submit** or **Cancel**.

## 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** at the top right.
- 3 Check the source control status column (e.g., **SVN** or **Modifications** column) for files with a red cross 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 manually change labels, see “Label Files” on page 12-26, 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.

## Use Templates to Create Standard Project Settings

In this section...
“Use Templates for Standard Project Setup” on page 12-54
“Create a Template from Your Current Project” on page 12-54
“View and Validate Templates” on page 12-56
“Create a New Project Using a Template” on page 12-57
“Import New Templates” on page 12-57

### 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, then use the template to create new projects.

To create a template from your current project, select **Simulink Project > Templates > Create Template**.

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, as described next.

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 12-42.
- 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 may 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** Select **Simulink Project > Templates > Create Template**.
- 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:

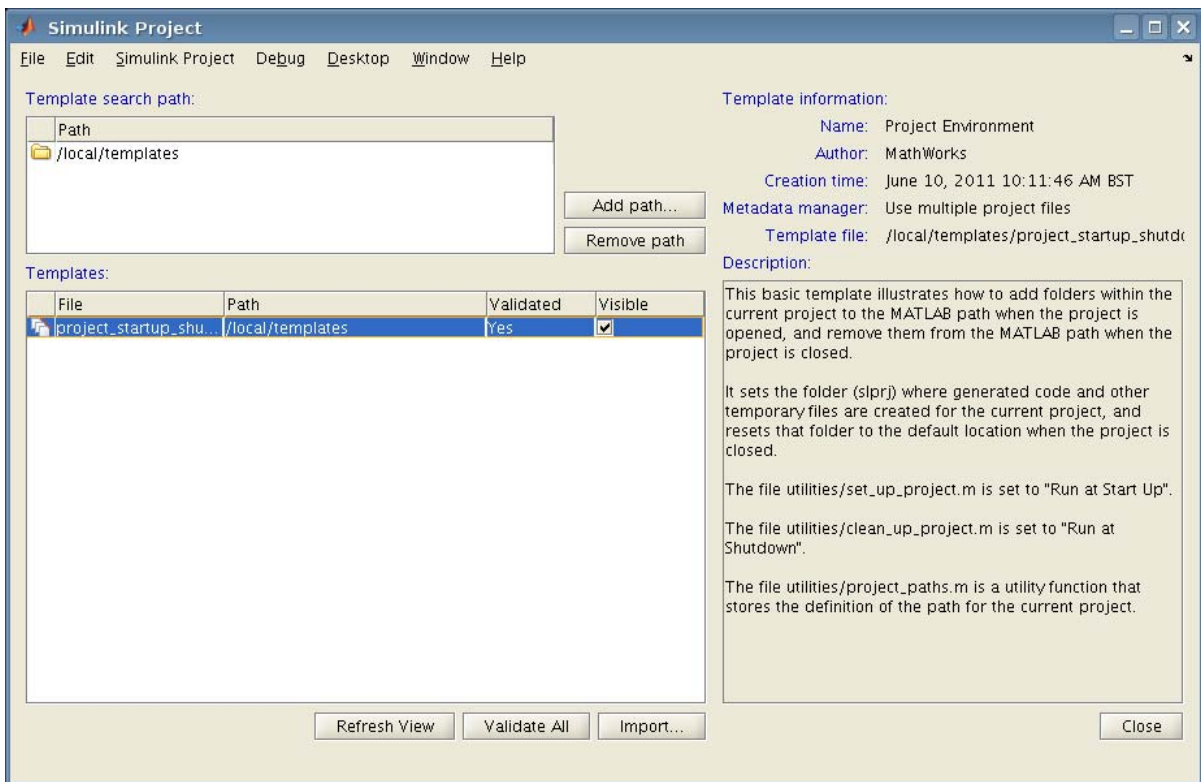
- 1** Create a new empty project using the template you want to modify.
- 2** Make the desired changes to the project.
- 3** Select **Simulink Project > Templates > Create Template**.

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. Select **Simulink Project > Templates > Template Manager**.

Click the default template in the **Templates** pane to view the **Description**.



The default 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 (s1prj) for generated code and other temporary files.
- Run standard scripts at start up and shut down.
- Include information in a template about names, authors, and description

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 default template, leave it selected 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 could be created by you, your colleagues, or downloaded from MATLAB Central.

You need to import a new template to make it available for use in new projects.

- 1** Select **Simulink Project > Templates > Template 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.

## Export Projects

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** Select **Simulink Project > Export to Zip**. 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 export command exports a complete project.

To extract and load a zipped project,

- 1** Extract the project files from the Zip file (for example, using the MATLAB `unzip` function).
- 2** In the Simulink Project Tool, select **Simulink Project > Open**. A file browser opens.
- 3** Navigate to the folder containing the `.SimulinkProject` folder, and click **OK** to load the project.

## Model Dependencies

### In this section...

“What Are Model Dependencies?” on page 12-60

“Generate Manifests” on page 12-61

“Command-Line Dependency Analysis” on page 12-67

“Edit Manifests” on page 12-69

“Compare Manifests” on page 12-72

“Export Files in a Manifest” on page 12-73

“Scope of Dependency Analysis” on page 12-75

“Best Practices for Dependency Analysis” on page 12-78

“Use the Model Manifest Report” on page 12-79

### 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*.

You can analyze file dependencies from the Simulink project to discover required files for your entire project. See “Discover Required Files” on page 12-18.

For detailed dependency analysis of a specific model, use the manifest tools to control more options. 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
- Control the scope of dependency analysis
- Identify required toolboxes



After you analyze 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 8-80.

## 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.

---

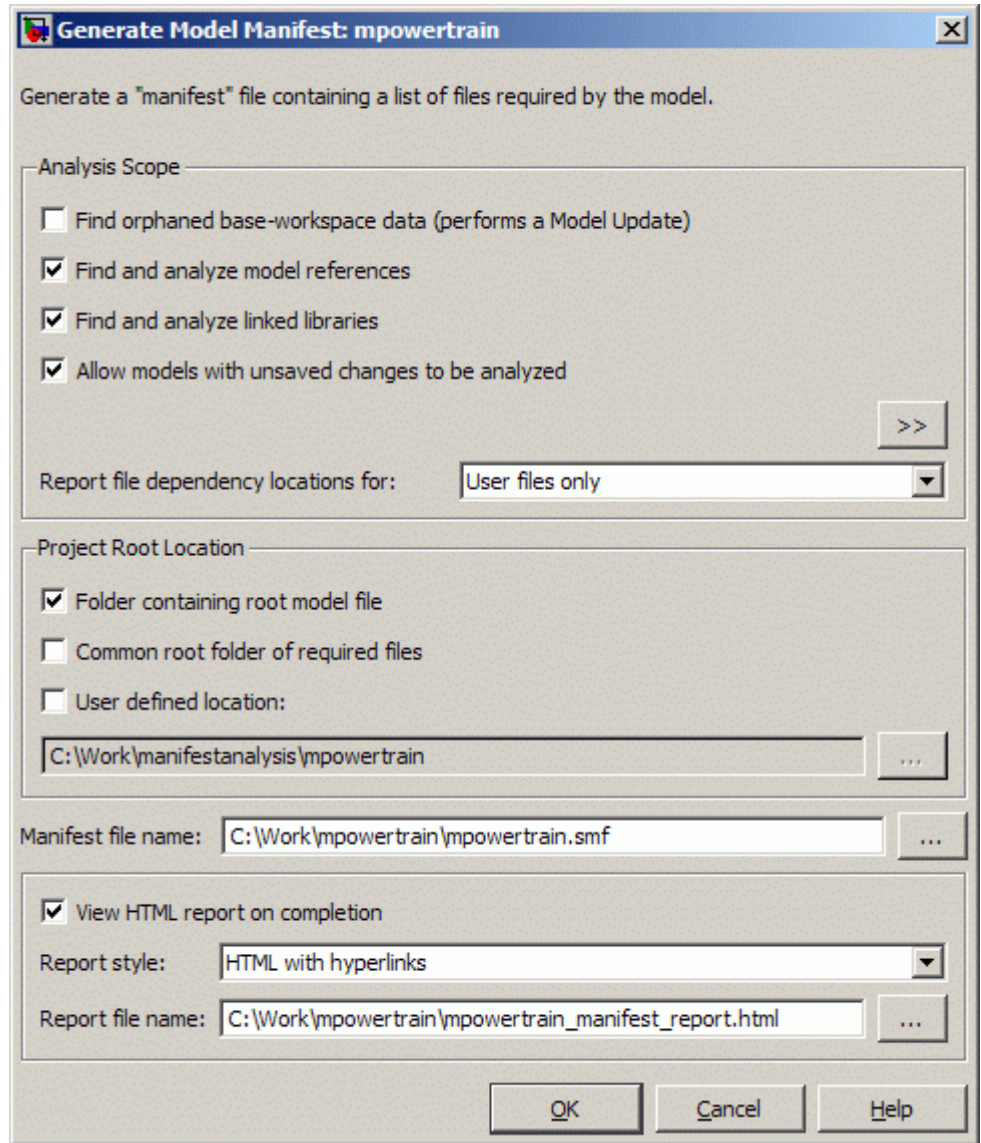
**Note** The model dependencies identified in a manifest depend upon the *Analysis Scope* you specify. For example, performing an analysis without selecting **Find Library Links** may not find all the Simulink Blocksets that your model requires, since these are often included in a model as library links. See “Manifest Analysis Scope Options” on page 12-64.

---

To generate a manifest:

- 1 Select **Tools > Model Dependencies > Generate Manifest**.

The Generate Model Manifest dialog box appears.



**2** Click **OK** to generate a manifest and report using the default settings.

Alternatively you can first change the following settings:

- Select the **Analysis scope** check boxes to specify the type of dependencies you want to detect (see “Manifest Analysis Scope Options” on page 12-64).
- 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 12-79 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
<b>Find orphaned base workspace data (performs a Model Update)</b>	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).
<b>Find and analyze model references</b>	Searches for Model blocks in the model, and identifies any referenced models as dependencies.
<b>Find and analyze linked libraries</b>	Searches for links to library blocks in the model, and identifies any library links as dependencies.
<b>Allow models with unsaved changes to be analyzed</b>	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.	

<b>Check Box Option</b>	<b>Description</b>
<b>Find S-functions</b>	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 12-77.
<b>Analyze model and block callbacks (including Interpreted MATLAB Function blocks)</b>	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 12-76.
<b>Find files required for code generation</b>	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 <i>STF_make_rtw_hook</i> functions, and locates system target files and Code Replacement Library definition files (.m or .mat). See also “Required Toolboxes” on page 12-81, and the source code item in “Special Cases” on page 12-77.
<b>Find data files (e.g. in “From File” blocks)</b>	Searches for explicitly referenced data files, such as those in From File blocks, and identifies those files as dependencies. See “Special Cases” on page 12-77.
<b>Analyze Stateflow charts</b>	Searches for file dependencies introduced through the use of syntax such as <code>ml.mymean(myvariable)</code> in models that use Stateflow.

<b>Check Box Option</b>	<b>Description</b>
<b>Analyze code in MATLAB Functions blocks</b>	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.
<b>Find requirements documents</b>	Searches for requirements documents linked using the Requirements Management Interface. Note that requirements links created with Telelogic® DOORS software are not included in manifests. For more information, see “Requirements Traceability” in the Simulink Verification and Validation documentation. This option is disabled if you do not have a Simulink Verification and Validation license, and Simulink ignores any requirements links in your model.
<b>Analyze files in “user toolboxes”</b>	Searches for file dependencies introduced by files in user-defined toolboxes. See “Special Cases” on page 12-77.
<b>Analyze MATLAB files</b>	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 12-76.
<b>Store MATLAB code analysis warnings in manifest</b>	Saves any warnings in the manifest.

See also “Scope of Dependency Analysis” on page 12-75 for more information.

## Command-Line Dependency Analysis

- “Check File Dependencies” on page 12-67
- “Check Toolbox Dependencies” on page 12-67

### 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 12-69.
- *manifestfile* — (optional input) specify the name of the manifest file to create. Note that the suffix `.smf` is always added to the user-specified name.

If you specify the optional input, *manifestfile*, then the command creates a manifest file with the specified name and path *manifestfile*. *manifestfile* can be a full-path or just a file name (in which case the file is created in the current folder).

If you try this analysis on a demo model, it returns an empty list of required files because the standard MathWorks installation includes all the files required for the demo models.

### Check Toolbox Dependencies

To check which toolboxes are required, 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 .mdl files on the MATLAB path. Simulink model names (without .mdl extension) are also allowed

This returns the following:

- *names* — a cell-array of toolbox names required by the files in *files\_in*.
- *dirs* — a cell-array of the toolbox folders.

---

**Note** The method `toolboxDependencyAnalysis` looks for toolbox dependencies of the files in `files_in` but does *not* analyze any subsequent dependencies.

---

If you want to find all detectable toolbox dependencies of your model *and* the files it depends on:

- 1 Call `fileDependencyAnalysis` on your model.

For example:

```
[files, missing, depfile, manifestfile] = dependencies.fileDependencyAnalysis('mymodel')

files =
    'C:\Work\manifest\foo.m'
    'C:\Work\manifest\mymodel.mdl'
missing =
    []
depfile =
    []
manifestfile =
    []
```

- 2 Call `toolboxDependencyAnalysis` on the files output of step 1.

For example:



```
tbxes = dependencies.toolboxDependencyAnalysis(files)

tbxes =
[1x24 char]    'MATLAB'    '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 12-81 for more examples of how your installed products and analysis scope settings can affect reported toolbox requirements.

## Edit Manifests

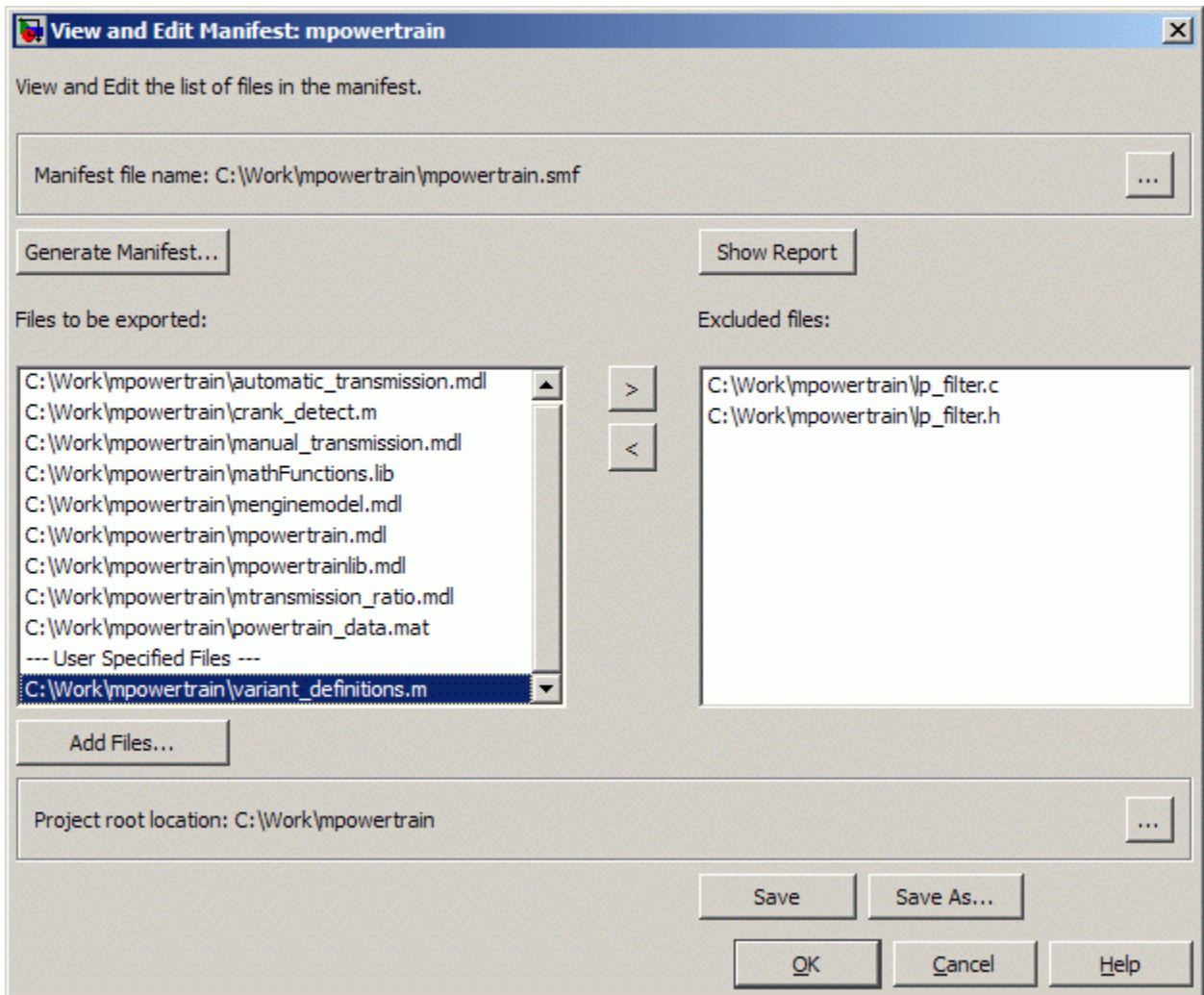
After you generate a manifest, you can view the list of files identified as dependencies, and manually add or delete files from the list.

To edit the list of required files in a manifest:


- 1 Select **Tools > Model Dependencies > View/Edit Manifest Contents**.

Alternatively, if you are viewing a manifest report you can click **Edit** in the top **Actions** box, or you can click **View and Edit Manifest** in the Export Manifest dialog box.

The View and Edit Manifest dialog box appears, showing the latest manifest for the current model.



---

**Note** You can open a different manifest by clicking the Browse for manifest file button . If you have not generated a manifest, select **Generate Manifest** to open the Generate Model Manifest dialog box (see “Generate Manifests” on page 12-61).

---

**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 12-79 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 **Tools > Model Dependencies > Compare Manifests**.

The dialog box Select Files or Folders for Comparison appears.

- 2** In the dialog box Select Files or Folders for Comparison, select files to compare, and the comparison type.
  - a** Use the drop-down lists or browse to select manifest files to compare.

- b** Select the **Comparison type**. For two manifests you can select:
  - **Simulink manifest comparison** — Select for a manifest file list comparison reporting new, removed and changed files. The report contains links to open files and compare files that differ. You can use a similar file **List comparison** for comparing a manifest to a folder or a ZIP file.
  - **Simulink manifest comparison (printable)** — Select for a printable **Model Manifest Differences Report** without links. The report provides details about each manifest file, and lists the differences between the files.
- 3** View the report in the Comparison Tool comparing the file names, dates, and sizes stored in the manifests.

Be aware the details stored in the manifest may differ from the files on disk. If you click a “compare” link in the report, you see warnings if there are problems such as size mismatches, or if the tool cannot find those files on disk.

For more information on the Comparison Tool, see “Comparing Files and Folders” in the MATLAB Desktop Tools and Development Environment documentation.

## Export Files in a Manifest

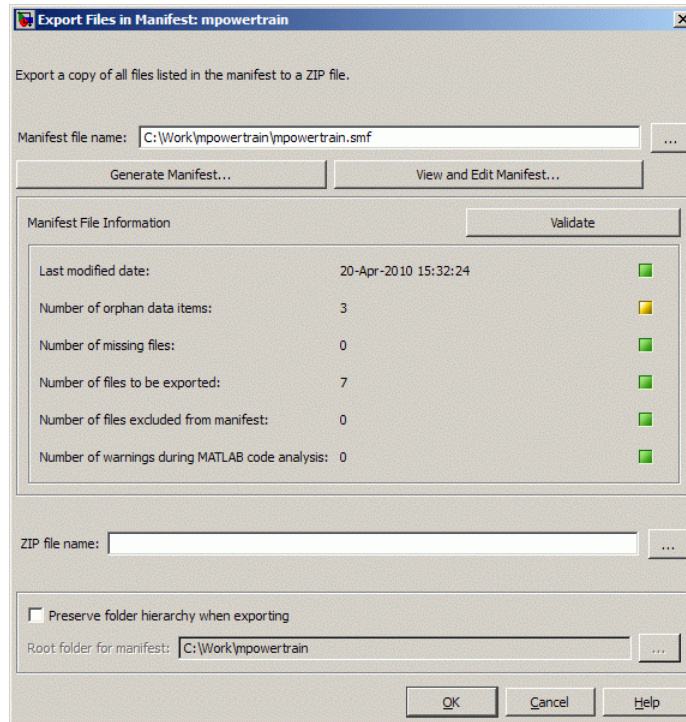
You can export copies of the files listed in the manifest to a ZIP file. Exporting the files allows you to package the model with its required files into a single ZIP file, so you can easily send it to another user or save it in a revision control system.


To export your model with its required files:

- 1** Select **Tools > Model Dependencies > Export Files in Manifest**.

Alternatively, if you are viewing a manifest report you can click **Export** in the top **Actions** box.

The Export Files in Manifest dialog box appears, showing the latest manifest for the current model.



**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 12-61).

- 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 12-69. When you close the View and Edit Manifest dialog box, you return to the Export Files in Manifest dialog box.
- 3 Click **Validate** to check the manifest. Validation reports information about possible problems such as missing files, warnings, and orphaned base workspace data.

- 4 Enter the ZIP file name to which you want to export the model.
- 5 Select **Preserve folder hierarchy when exporting** if you want to keep folder structure for your exported model and files. Then, select the root folder to use for this structure (usually the same as the **Project Root Location** on the Generate Manifest dialog box).

---

**Note** You must select **Preserve folder hierarchy** if you are exporting a model that uses an `.m` file inside a MATLAB class (to maintain the folder structure of the class), or if the model refers to files in other folders (to ensure the exported files maintain the same relative paths).

---

- 6 Click **OK**.

The model and its file dependencies are exported to the specified ZIP file.

## Scope of Dependency Analysis

The Simulink Manifest Tools identify required files and list them in an XML file called a *manifest*. When Simulink generates a manifest file, it performs a static analysis on your model, which means that the model does not need to be capable of performing an “update diagram” operation (see “Updating a Block Diagram” on page 1-32). 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 12-64.

For more information on what the tool analyzes, refer to the following sections:

- “Analysis Limitations” on page 12-76
- “Code Analysis” on page 12-76
- “Special Cases” on page 12-77

## Analysis Limitations

The analysis might not find all files required by your model (for examples, see “Code Analysis” on page 12-76).

The analysis might not report certain blocksets or toolboxes required by a model. You should be aware of this limitation when sending a model to another user. Blocksets that do not introduce dependence on any files (such as Simulink Fixed Point™) cannot be detected.

To include dependencies that the analysis cannot detect, you can add additional file dependencies to a manifest file using the View/Edit Manifest Contents option (see “Edit Manifests” on page 12-69).

## 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 12-81 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 12-69).

- 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 12-76).

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” on page 12-80
- “Required Toolboxes” on page 12-81
- “Example Model Manifest Report” on page 12-81

## 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 12-81.
- **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 12-61. 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 12-81.

## 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.mdl*, and so no dependence is reported upon the block set.
- If you clear the **Analyze MATLAB files** option, then the analysis cannot find a dependence upon *fuzzy.m*, and so no dependence is reported upon the Fuzzy Logic Toolbox™.

## Example Model Manifest Report

You should always check the **Dependency analysis settings** section in the Model Manifest Report to see the scope of analysis settings used to generate it.

Following are portions of a sample report.

**Model Manifest Report: mpowertrain**

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](#)

**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 ( <a href="#">open</a> )	32283 bytes	2010-04-20 13:26:04	true
\$projectroot/automatic_transmission.mdl ( <a href="#">open</a> )	11613 bytes	2009-06-03 10:26:38	true
\$projectroot/lp_filter.c ( <a href="#">open</a> )	17 bytes	2006-10-27 17:11:58	true
\$projectroot/lp_filter.h ( <a href="#">open</a> )	20 bytes	2006-10-27 17:12:00	true
\$projectroot/manual_transmission.mdl ( <a href="#">open</a> )	32277 bytes	2010-04-20 13:25:54	true
\$projectroot/mathFunctions.lib ( <a href="#">open</a> )	4 bytes	2006-10-27 17:12:00	true
\$projectroot/menginemodel.mdl ( <a href="#">open</a> )	19260 bytes	2006-08-08 14:13:10	true
\$projectroot/mpowertrain.mdl ( <a href="#">open</a> )	57595 bytes	2010-04-20 13:29:06	true
\$projectroot/mpowertrainlib.mdl ( <a href="#">open</a> )	34759 bytes	2006-08-08 14:13:14	true
\$projectroot/mtransmission_ratio.mdl ( <a href="#">open</a> )	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 <a href="#">(show)</a>	Sprojectroot/automatic_transmission.mdl <a href="#">(open)</a>	(not in a toolbox)
ModelReference	mpowertrain/Model Variants <a href="#">(show)</a>	Sprojectroot/manual_transmission.mdl <a href="#">(open)</a>	(not in a toolbox)
ModelReference	mpowertrain/engine model <a href="#">(show)</a>	Sprojectroot/menginemodel.mdl <a href="#">(open)</a>	(not in a toolbox)
LibraryLink	mpowertrain/Library Shift Logic <a href="#">(show)</a>	Sprojectroot/mpowertrainlib.mdl <a href="#">(open)</a>	(not in a toolbox)
ModelCallback,PreLoadFcn	mpowertrain <a href="#">(show)</a>	Sprojectroot/powertrain_data.mat	(not in a toolbox)
RealTimeWorkshop,Configuration,CustomCode	automatic_transmission <a href="#">(show)</a>	Sprojectroot/lp_filter.c <a href="#">(open)</a>	(not in a toolbox)
RealTimeWorkshop,Configuration,CustomCode	automatic_transmission <a href="#">(show)</a>	Sprojectroot/lp_filter.h <a href="#">(open)</a>	(not in a toolbox)
RealTimeWorkshop,Configuration,CustomCode	automatic_transmission <a href="#">(show)</a>	Sprojectroot/mathFunctions.lib <a href="#">(open)</a>	(not in a toolbox)
LibraryLink	automatic_transmission/Grouped Unit Delay <a href="#">(show)</a>	Sprojectroot/mpowertrainlib.mdl <a href="#">(open)</a>	(not in a toolbox)
LibraryLink	automatic_transmission/Torque Converter/Torque Conversion <a href="#">(show)</a>	Sprojectroot/mpowertrainlib.mdl <a href="#">(open)</a>	(not in a toolbox)
ModelReference	automatic_transmission/transmission ratio <a href="#">(show)</a>	Sprojectroot/mtransmission_ratio.mdl <a href="#">(open)</a>	(not in a toolbox)
MSFunction	mtransmission_ratio/CrankSpeedSmoothing <a href="#">(show)</a>	Sprojectroot/crank_detect.m <a href="#">(open)</a>	(not in a toolbox)
RealTimeWorkshop,Configuration,CustomCode	manual_transmission <a href="#">(show)</a>	Sprojectroot/lp_filter.c <a href="#">(open)</a>	(not in a toolbox)
RealTimeWorkshop,Configuration,CustomCode	manual_transmission <a href="#">(show)</a>	Sprojectroot/lp_filter.h <a href="#">(open)</a>	(not in a toolbox)
RealTimeWorkshop,Configuration,CustomCode	manual_transmission <a href="#">(show)</a>	Sprojectroot/mathFunctions.lib <a href="#">(open)</a>	(not in a toolbox)
LibraryLink	manual_transmission/Grouped Unit Delay <a href="#">(show)</a>	Sprojectroot/mpowertrainlib.mdl <a href="#">(open)</a>	(not in a toolbox)
LibraryLink	manual_transmission/Torque Converter/Torque Conversion <a href="#">(show)</a>	Sprojectroot/mpowertrainlib.mdl <a href="#">(open)</a>	(not in a toolbox)
ModelReference	manual_transmission/transmission ratio <a href="#">(show)</a>	Sprojectroot/mtransmission_ratio.mdl <a href="#">(open)</a>	(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 ( <a href="#">show</a> )
trans_type_auto	Simulink.Variant	mpowertrain/Model Variants ( <a href="#">show</a> )
trans_type_manual	Simulink.Variant	mpowertrain/Model Variants ( <a href="#">show</a> )

## 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

---

- Chapter 13, “Running Simulations”
- Chapter 14, “Running a Simulation Programmatically”
- Chapter 15, “Visualizing and Comparing Simulation Results”
- Chapter 16, “Analyzing Simulation Results”
- Chapter 17, “Improving Simulation Performance and Accuracy”
- Chapter 18, “Simulink Debugger”
- Chapter 19, “Accelerating Models”



# Running Simulations

---

- “Simulation Basics” on page 13-2
- “Controlling Execution of a Simulation” on page 13-3
- “Specifying a Simulation Start and Stop Time” on page 13-8
- “Choosing a Solver” on page 13-9
- “Interacting with a Running Simulation” on page 13-31
- “Saving and Restoring the Simulation State as the SimState” on page 13-32
- “Diagnosing Simulation Errors” on page 13-39

## Simulation Basics

You can simulate a model at any time simply by clicking the **Start** button on the Model Editor displaying the model (see “Starting a Simulation” on page 13-3). However, before starting the simulation, you might want to specify various simulation options, such as the simulation’s start and stop time and the type of solver used to solve the model at each simulation time step. Specifying simulation options is called “configuring the model”. With the Simulink software you can create multiple model configurations, called configuration sets, modify existing configuration sets, and switch configuration sets with a click of a mouse button (see “Manage a Configuration Set” on page 9-8 for information on creating and selecting configuration sets).

Once you have defined or selected a model configuration set that meets your needs, you can start the simulation. The simulation runs from the specified start time to the specified stop time. While the simulation is running, you can interact with the simulation in various ways, stop or pause the simulation (see “Pausing or Stopping a Simulation” on page 13-5), and launch simulations of other models. If an error occurs during a simulation, Simulink halts the simulation and the Simulation Diagnostics Viewer pops up that helps you to determine the cause of the error.

## Controlling Execution of a Simulation

### In this section...

“Starting a Simulation” on page 13-3

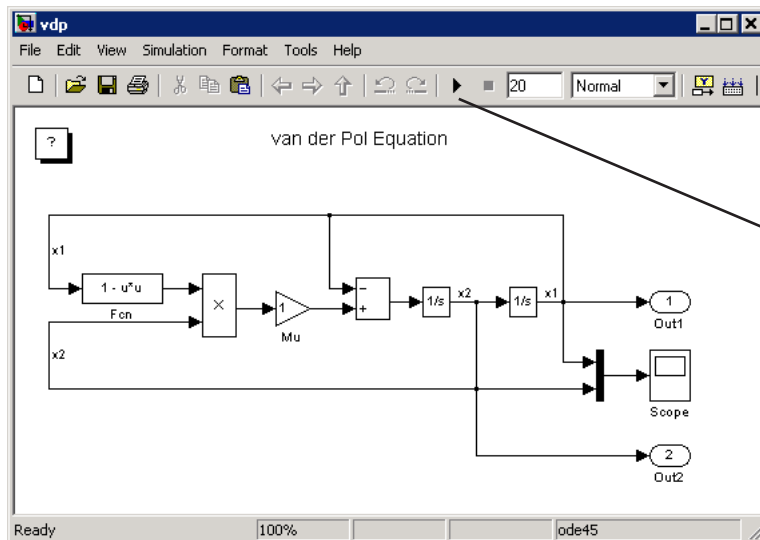
“Pausing or Stopping a Simulation” on page 13-5

“Using Blocks to Stop or Pause a Simulation” on page 13-5

### Starting a Simulation

This section explains how to run a simulation interactively using this model. See Chapter 14, “Running a Simulation Programmatically” for information on running a simulation from a program, an S-function, or the MATLAB command line.

To start the execution of a model, from the **Simulation** menu of the Model Editor, select **Start** or click the **Start** button on the model toolbar.

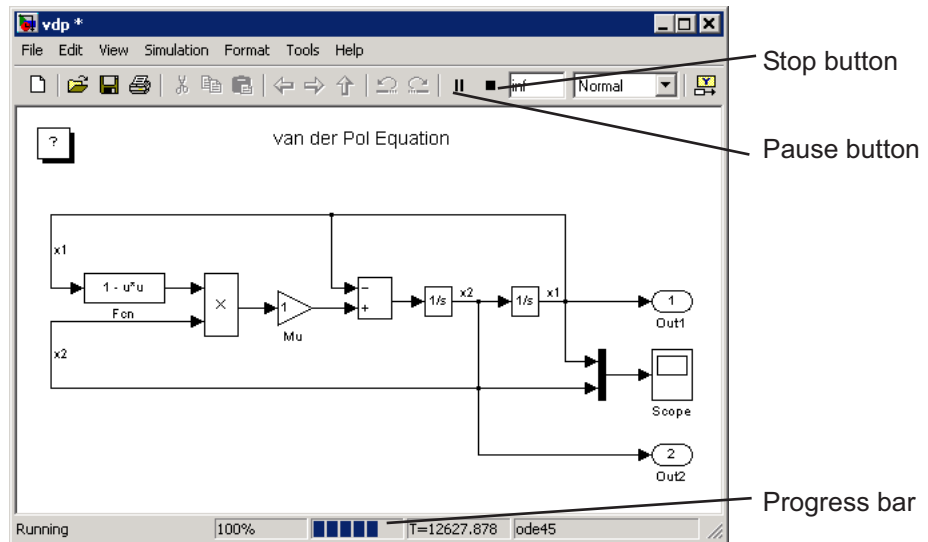


Start button

**Note** A common mistake is to start a simulation while the Simulink block library is the active window. Make sure that your model window is the active window before starting a simulation.

The model execution begins at the start time that you specify on the Configuration Parameters dialog box. Execution continues until an error occurs, until you pause or terminate the simulation, or until the simulation reaches the stop time as specified on the Configuration Parameters dialog box (see “Configuration Parameters Dialog Box”).

While the simulation is running, a progress bar at the bottom of the model window shows how far the simulation has progressed. A **Stop** command replaces the **Start** command on the **Simulation** menu. A **Pause** command appears on the menu and replaces the **Start** button on the model toolbar.



Your computer beeps to signal the completion of the simulation.

## Pausing or Stopping a Simulation

Select the **Pause** command or button to pause the simulation. Once Simulink completes the execution of the current time step, it suspends the simulation. When you select **Pause**, the menu item and the button change to **Continue**. (The button has the same appearance as the **Start** button). You can resume a suspended simulation at the next time step by choosing **Continue**.

To terminate execution of the model, select the **Stop** button or the **Stop Simulation** menu item. Simulink completes the execution of the current time step and then terminates the simulation. Subsequently selecting the **Start** menu item or button restarts the simulation at the first time step specified on the Configuration Parameters dialog box.

If the model includes any blocks that write output to a file or to the workspace, or if you select output options on the Configuration Parameters dialog box, the Simulink software writes the data when the simulation is terminated or suspended.

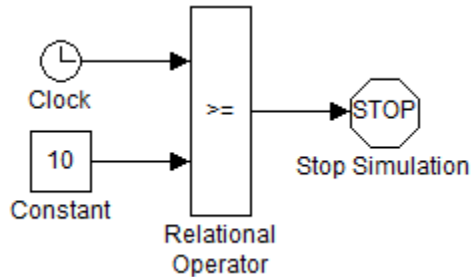
## Using Blocks to Stop or Pause a Simulation

### Using Stop Blocks

You can use the Stop Simulation block to terminate a simulation when the input to the block is nonzero. To use the Stop Simulation block:

- 1 Drag a copy of the Stop Simulation block from the Sinks library and drop it into your model.
- 2 Connect the Stop Simulation block to a signal whose value becomes nonzero at the specified stop time.

For example, this model stops the simulation when the input signal reaches 10.



If the block input is a vector, any nonzero element causes the simulation to terminate.

## Creating Pause Blocks

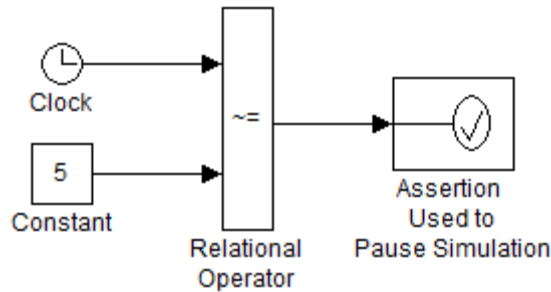
You can use an Assertion block to pause the simulation when the input signal to the block is zero. To create a pause block:

- 1 Drag a copy of the Assertion block from the Model Verification library and drop it into your model.
- 2 Connect the Assertion block to a signal whose value becomes zero at the desired pause time.
- 3 Open the Block Parameters dialog box of the Assertion block .
  - Enter the following commands into the **Simulation callback when assertion fails** field:
 

```
set_param(bdroot, 'SimulationCommand', 'pause'),
disp(sprintf('\nSimulation paused.'))
```
  - Uncheck the **Stop simulation when assertion fails** option.
- 4 Click **OK** to apply the changes and close this dialog box.

The following model uses a 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 Chapter 14, “Running a Simulation Programmatically” for more information on using the `set_param` command to control the execution of a Simulink model.

---

## Specifying a Simulation Start and Stop Time

By default, simulations start at 0.0 s and end at 10.0 s.

---

**Note** In the Simulink software, time and all related parameters (such as sample times) are implicitly in seconds. If you choose to use a different time unit, you must scale all parameters accordingly.

---

The **Solver** configuration pane allows you to specify other start and stop times for the currently selected simulation configuration. See “Solver Pane” for more information. On computers running the Microsoft Windows operating system, you can also specify the simulation stop time in the **Simulation** menu.

---

**Note** Simulation time and actual clock time are not the same. For example, if running a simulation for 10 s usually does not take 10 s as measured on a clock. The amount of time it actually takes to run a simulation depends on many factors including the complexity of the model, the step sizes, and the computer speed.

---

## Choosing a Solver

In this section...
“What Is a Solver?” on page 13-9
“Choosing a Solver Type” on page 13-10
“Choosing a Fixed-Step Solver” on page 13-13
“Choosing a Variable-Step Solver” on page 13-17
“Choosing a Jacobian Method for an Implicit Solver” on page 13-24

### 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 13-10 provides background on the different types of solvers while “Choosing a Fixed-Step Solver” on page 13-13 and “Choosing a Variable-Step Solver” on page 13-17 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 13-14	Not Applicable
	Implicit	Not Applicable	“Implicit Fixed-Step Continuous Solvers” on page 13-16	Not Applicable

		<b>Discrete</b>	<b>Continuous</b>	<b>Variable-Order</b>
Variable-Step	Explicit	“Choosing a Variable-Step Solver” on page 13-17	“Explicit Continuous Variable-Step Solvers” on page 13-18	“Variable-Order Solvers” on page 13-13
	Implicit		“Implicit Continuous Variable-Step Solvers” on page 13-19	“Variable-Order Solvers” on page 13-13

---

## 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 13-12
  - 2** Every solver in the Simulink library can perform on models that contain algebraic loops.
- 

For information on tailoring the selected solver to your model, see “Improving Simulation Accuracy” on page 17-11.

## 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

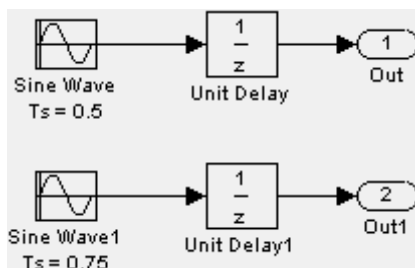
Both fixed-step and variable-step solvers compute the next simulation time as the sum of the current simulation time and a quantity known as the *step size*. With a fixed-step solver, the step size remains constant throughout the simulation. In contrast, with a variable-step solver, the step size can 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 13-24 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 13-20.

## 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 13-12 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.

<b>Solver</b>	<b>Integration Technique</b>	<b>Order of Accuracy</b>
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 13-22.
- 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 13-10 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.

<b>ODE Solver</b>	<b>One-Step Method</b>	<b>Multistep Method</b>	<b>Order of Accuracy</b>	<b>Method</b>
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-Moulton

ODE Solver	Tips on When to Use
ode45	<p>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.</p> <p>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.</p>
ode23	<p>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.</p>
ode113	<p>For problems with stringent error tolerances or for computationally intensive problems, the Adams-Bashforth-Moulton PECE solver can be more efficient than ode45.</p>

### Implicit Continuous Variable-Step Solvers

If your problem is stiff, try using one of the implicit variable-step solvers: ode15s, ode23s, ode23t, or ode23tb.

ODE Solver	One-Step Method	Multistep Method	Order of Accuracy	Solver Reset Method	Max. Order	Method
ode15s		X	Variable, Low to Medium	X	X	Numerical Differentiation Formulas (NDFs)
ode23s	X		Low			Second-order, modified Rosenbrock formula

ODE Solver	One-Step Method	Multistep Method	Order of Accuracy	Solver Reset Method	Max. Order	Method
ode23t	X		Low	X		Trapezoidal rule using a “free” interpolant
ode23tb	X		Low	X		TR-BDF2

**Solver Reset Method.** For three of the stiff solvers — ode15s, ode23t, and ode23tb— a drop-down menu for the Solver reset method appears on the Solver Configuration pane. This parameter controls how the solver treats a reset caused, for example, by a zero-crossing detection. The options allowed are Fast and Robust. The former setting specifies that the solver does not recompute the Jacobian for a solver reset, whereas the latter setting specifies that the solver does. Consequently, the Fast setting is faster computationally but might use a small step size for certain cases. To test for such cases, run the simulation with each setting and compare the results. If there is no difference, you can safely use the Fast setting and save time. If the results differ significantly, try reducing the step size for the fast simulation.

**Maximum Order.** For the ode15s solver, you can choose the maximum order of the numerical differentiation formulas (NDFs) that the solver applies. Since the ode15s uses first- through fifth-order formulas, the Maximum order parameter allows you to choose 1 through 5. For a stiff problem, you may want to start with order 2.

**Tips for Choosing a Variable-Step Implicit Solver.** The following table provides tips relating to the application of variable-step implicit solvers. For a demonstration comparing the behavior of these solvers, see sldemo\_solvers.

ODE Solver	Tips on When to Use
ode15s	ode15s is a variable-order solver based on the numerical differentiation formulas (NDFs). NDFs are related to, but are more efficient than the backward differentiation formulas (BDFs), which are also known as Gear's method. The ode15s solver numerically generates the Jacobian matrices. If you suspect that a problem is stiff, or if ode45 failed or was highly inefficient, try ode15s. As a rule, start by limiting the maximum order of the NDFs to 2.
ode23s	ode23s is based on a modified Rosenbrock formula of order 2. Because it is a one-step solver, it can be more efficient than ode15s at crude tolerances. Like ode15s, ode23s numerically generates the Jacobian matrix for you. However, it can solve certain kinds of stiff problems for which ode15s is not effective.
ode23t	The ode23t solver is an implementation of the trapezoidal rule using a "free" interpolant. Use this solver if your model is only moderately stiff and you need a solution without numerical damping. (Energy is not dissipated when you model oscillatory motion.)
ode23tb	ode23tb is an implementation of TR-BDF2, an implicit Runge-Kutta formula with two stages. The first stage is a trapezoidal rule step while the second stage uses a backward differentiation formula of order 2. By construction, the method uses the same iteration matrix in evaluating both stages. Like ode23s, this solver can be more efficient than ode15s at crude tolerances.

---

**Note** For a *stiff* problem, solutions can change on a time scale that is very small as compared to the interval of integration, while the solution of interest changes on a much longer time scale. Methods that are not designed for stiff problems are ineffective on intervals where the solution changes slowly because these methods use time steps small enough to resolve the fastest possible change. For more information, see Shampine, L. F., *Numerical Solution of Ordinary Differential Equations*, Chapman & Hall, 1994.

---

## Support for Zero-Crossing Detection

Both the variable-step discrete and continuous solvers use zero-crossing detection (see “Zero-Crossing Detection” on page 2-24) to handle continuous signals.

## Specifying Error Tolerances for Variable-Step Solvers

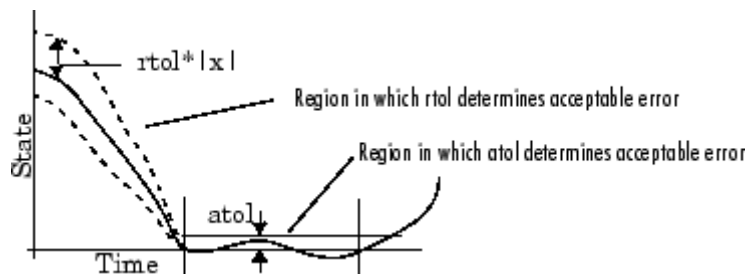
**Local Error.** The variable-step solvers use standard control techniques to monitor the local error at each time step. During each time step, the solvers compute the state values at the end of the step and determine the *local error*—the estimated error of these state values. They then compare the 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:

$$e_i \leq \max(\text{rtol} \times |x_i|, \text{atol}_i).$$

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:

$$\begin{aligned}\dot{x} &= f(x, t, u) \\ y &= g(x, t, u).\end{aligned}$$

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:

$$\dot{x}_1 = f_1(x_1, x_3)$$

$$\dot{x}_2 = f_2(x_2)$$

$$\dot{x}_3 = f_3(x_2).$$

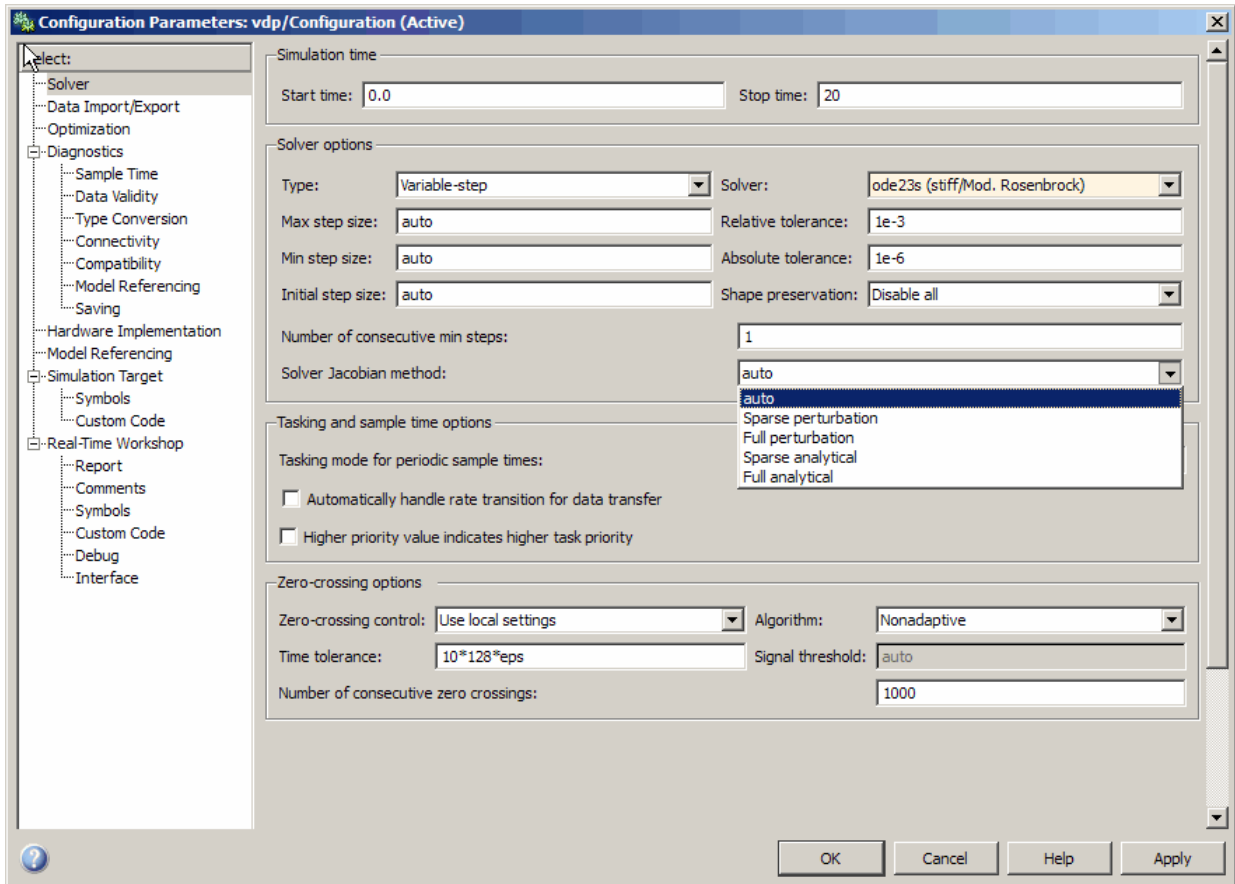
From this system, you can derive a sparsity pattern that reflects the structure of the equations. The pattern, a Boolean matrix, has a 1 for each  $x_i$  that appears explicitly on the right-hand side of an equation. You thereby attain:

$$J_{x,pattern} = \begin{pmatrix} 1 & 0 & 1 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \end{pmatrix}$$

As discussed in “Full and Sparse Perturbation Methods” on page 13-28 and “Full and Sparse Analytical Methods” on page 13-30 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**.



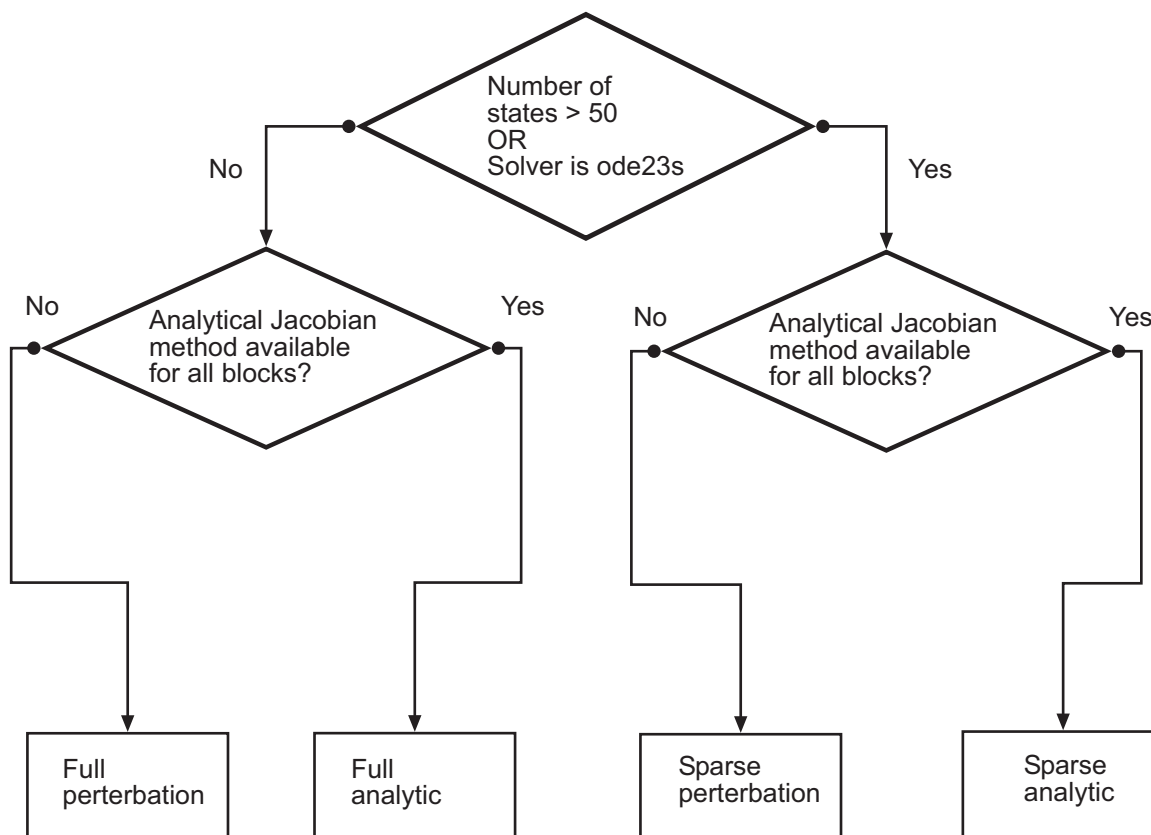
**Note** If you set **Automatic solver parameter selection** to warning or error in the Solver Diagnostics pane, and you choose a different solver method than Simulink, you might receive a warning or an error.

**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,

$$\begin{aligned}\dot{x}_1 &= f_1(x_1, x_3) \\ \dot{x}_2 &= f_2(x_2) \\ \dot{x}_3 &= f_3(x_2).\end{aligned}$$

The solver Jacobian is:

$$\begin{aligned}
 J_x &= \begin{pmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} & \frac{\partial f_1}{\partial x_3} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} & \frac{\partial f_2}{\partial x_3} \\ \frac{\partial f_3}{\partial x_1} & \frac{\partial f_3}{\partial x_2} & \frac{\partial f_3}{\partial x_3} \end{pmatrix} \\
 &= \begin{pmatrix} \frac{f_1(x_1 + \Delta x_1, x_2, x_3) - f_1}{\Delta x_1} & \frac{f_1(x_1, x_2 + \Delta x_2, x_3) - f_1}{\Delta x_2} & \frac{f_1(x_1, x_2, x_3 + \Delta x_3) - f_1}{\Delta x_3} \\ \frac{f_2(x_1 + \Delta x_1, x_2, x_3) - f_2}{\Delta x_1} & \frac{f_2(x_1, x_2 + \Delta x_2, x_3) - f_2}{\Delta x_2} & \frac{f_2(x_1, x_2, x_3 + \Delta x_3) - f_2}{\Delta x_3} \\ \frac{f_3(x_1 + \Delta x_1, x_2, x_3) - f_3}{\Delta x_1} & \frac{f_3(x_1, x_2 + \Delta x_2, x_3) - f_3}{\Delta x_2} & \frac{f_3(x_1, x_2, x_3 + \Delta x_3) - f_3}{\Delta x_3} \end{pmatrix}
 \end{aligned}$$

It is, therefore, necessary to perturb each of the three states three times and to evaluate the derivative function three times. For a system with  $n$  states, this method perturbs the states  $n$  times.

By applying the sparsity pattern and perturbing states  $x_1$  and  $x_2$  together, this matrix reduces to:

$$J_x = \begin{pmatrix} \frac{f_1(x_1 + \Delta x_1, x_2 + \Delta x_2, x_3) - f_1}{\Delta x_1} & 0 & \frac{f_1(x_1, x_2, x_3 + \Delta x_3) - f_1}{\Delta x_3} \\ 0 & \frac{f_2(x_1 + \Delta x_1, x_2 + \Delta x_2, x_3) - f_2}{\Delta x_2} & 0 \\ 0 & \frac{f_3(x_1 + \Delta x_1, x_2 + \Delta x_2, x_3) - f_3}{\Delta x_2} & 0 \end{pmatrix}$$

The solver can now solve columns 1 and 2 in one sweep. While the sparse perturbation method saves significant computation, it also adds overhead to compilation. It might even slow down the simulation if the system does not have a large number of continuous states. A tipping point exists for which you

obtain increased performance by applying this method. In general, systems having a large number of continuous states are usually sparse and benefit from the sparse method.

The sparse perturbation method, like the sparse analytical method, uses UMFPACK to perform linear algebraic operations. Also, the sparse perturbation method supports both RSim and Rapid Accelerator mode.

### **Full and Sparse Analytical Methods**

The full and sparse analytical methods attempt to improve performance by calculating the Jacobian using analytical equations rather than the perturbation equations. The sparse analytical method, also uses the sparsity information to accelerate the linear algebraic operations required to solve the ordinary differential equations.

### **Sparsity Pattern**

For details on how to access and interpret the sparsity pattern in MATLAB, see `sldemo_metro`.

### **Support for Code Generation**

While the sparse perturbation method supports RSim, the sparse analytical method does not. Consequently, regardless of which sparse method you select, any generated code uses the sparse perturbation method.



## Interacting with a Running Simulation

You can perform certain operations interactively while a simulation is running. You can do the following:

- Modify some configuration parameters, including the stop time and the maximum step size
- Click a line to see the signal carried on that line on a floating (unconnected) Scope or Display block
- Modify the parameters of a block, as long as you do not cause a change in the:
  - Number of states, inputs, or outputs
  - Sample time
  - Number of zero crossings
  - Vector length of any block parameters
  - Length of the internal block work vectors
  - Dimension of any signals
- Display block data tips (see “Block Data Tips” on page 20-2)

You cannot make changes to the structure of the model, such as adding or deleting lines or blocks, during a simulation. To make these kinds of changes, stop the simulation, make the change, then start the simulation again to see the results of the change.

## Saving and Restoring the Simulation State as the SimState

### In this section...

“Overview of the SimState” on page 13-32

“How to Save the SimState” on page 13-33

“How to Restore the SimState” on page 13-35

“How to Change the States of a Block within the SimState” on page 13-37

“Using the SimState Interface Checksum Diagnostic” on page 13-37

“Limitations of the SimState” on page 13-38

“Using SimState within S-Functions” on page 13-38

### Overview of the SimState

In real-world applications, you simulate a Simulink model repeatedly to analyze the behavior of a system for different input, boundary conditions, or operating conditions. In many applications, a start-up phase with significant dynamic behavior is common to multiple simulations. For example, the cold start take-off of a gas turbine engine occurs before each set of aircraft maneuvers. Ideally, you would simulate this start-up phase once, save the simulation state at the end of the start-up phase, and then use this simulation state or *SimState* as the initial state for each set of conditions or maneuvers.

The Simulink `SimState` feature allows you to save all run-time data necessary for restoring the simulation state of a model. A `SimState` includes both the logged and internal state of every block (e.g., continuous states, discrete states, work vectors, zero-crossing states) and the internal state of the Simulink engine (e.g., the data of the ODE solver).

You can save a `SimState`:

- At the final **Stop time**
- When you interrupt a simulation with the **Pause** or **Stop** button
- When you use a block (e.g., the Stop block) to stop a simulation

At a later time, you can restore the `SimState` and use it as the initial conditions for any number of simulations.

---

**Note** The **Final states** option of the **Data Import/Export** pane in Simulink saves only *logged* states—the continuous and discrete states of blocks—which are a subset of the complete simulation state of the model. Hence you cannot use the **Final states** to save and restore the complete simulation state as the initial state of a new simulation.

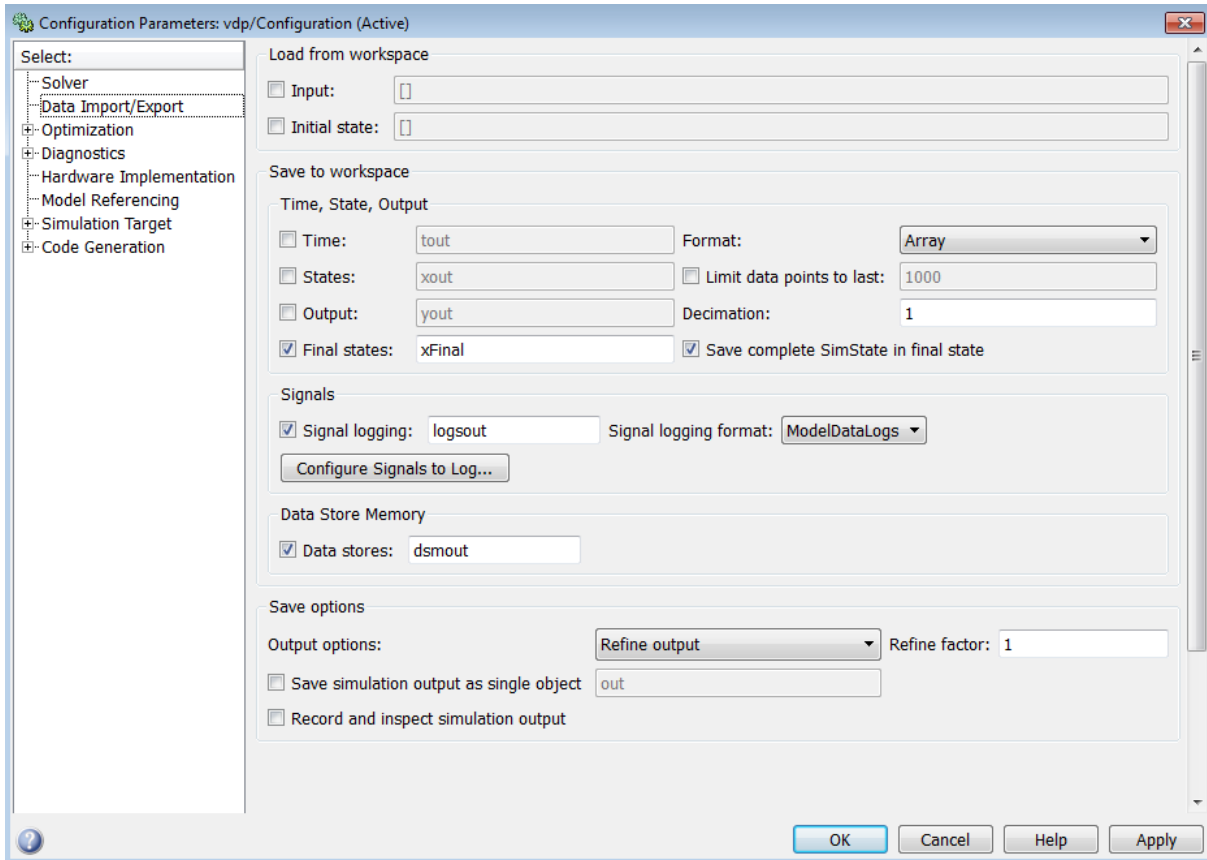
---

## How to Save the SimState

### Saving the SimState Interactively

To save the complete `SimState` at the beginning of the final step:

- 1** In the Simulink model window, select **Simulation > Configuration Parameters**.
- 2** Navigate to the **Data Import/Export** pane.
- 3** Select the **Final states** check box. The **Save complete SimState in final state** check box becomes active.
- 4** Select the **Save complete SimState in final state** check box.
- 5** In the adjacent field, enter a variable name for the `SimState`.
- 6** Simulate the model by selecting **Simulation > Start**.



### Saving the SimState Programmatically

You can save the `SimState` at the beginning of the final step programmatically using the `sim` command in conjunction with the `set_param` command with the `SaveCompleteFinalSimState` parameter set to on:

```
set_param mdl, 'SaveFinalState', 'on', 'FinalStateName', ...
    [mdl 'SimState'], 'SaveCompleteFinalSimState', 'on')
simOut = sim mdl, 'StopTime', tstop)
set_param mdl, 'SaveFinalState', 'off')
```

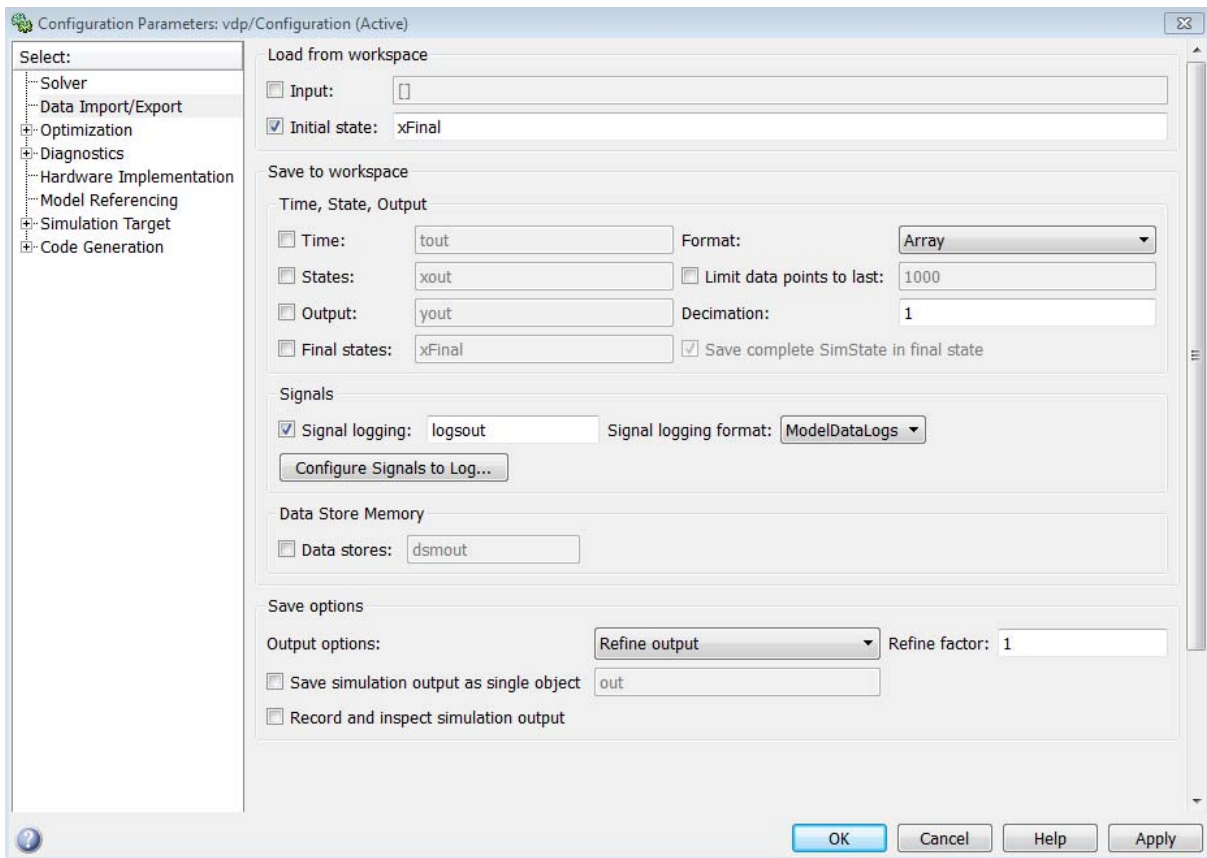
## How to Restore the SimState

### Restoring the SimState Interactively

You can restore the SimState interactively.

In the **Data Import/Export** pane:

- 1 Under **Load from workspace**, select the check box next to **Initial state**. The adjacent field becomes active.
- 2 Enter the name of the variable containing the SimState in the field.



In the **Solver** pane of the **Configuration Parameters** window:

- 1** Keep the **Start time** set to its original value.
- 2** Set the **Stop time** to the sum of the original simulation time plus the new additional simulation time.
- 3** Click **OK**.

The **Start time** must maintain its original value because it is a reference value for all time and time-dependent variables in both the original and the current simulations. For example, a block may save and restore the number of sample time hits that occurred since the beginning of simulation as the `SimState`. For clarity, consider a model that you ran from 0 s to 100 s and that you now wish to run from 100 s to 200 s. The **Start time** is 0 s for both the original simulation (0 s to 100 s) and for the current simulation (100 s to 200 s). And 100 s is the initial time of the current simulation. Also, if the block had ten sample time hits during the original simulation, Simulink recognizes that the next sample time hit will be the eleventh relevant to 0 s (not 100 s).

### **Restoring the SimState Programmatically**

Use the `set_param` command to specify the initial condition as the `SimState`.

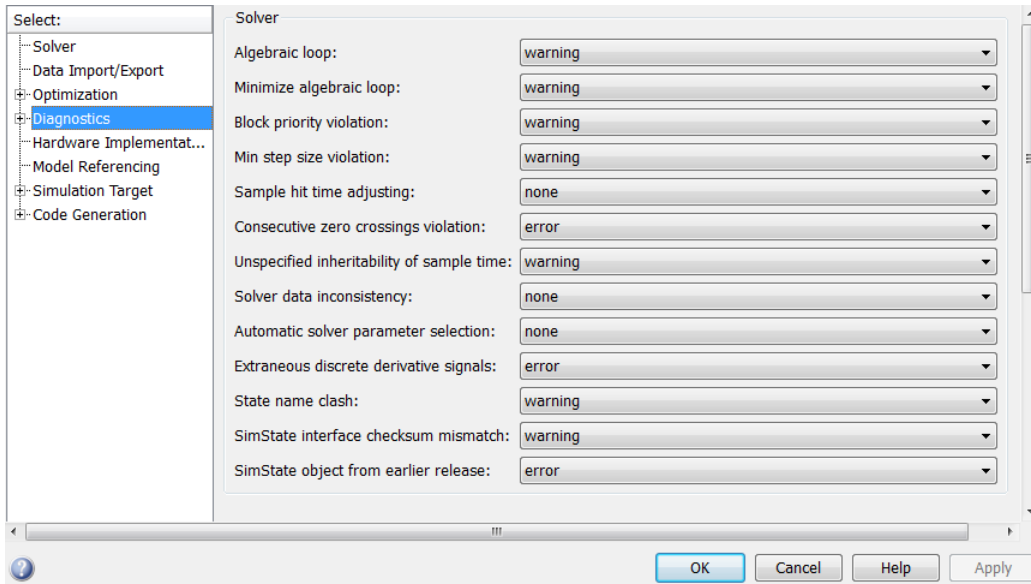
```
set_param mdl, 'LoadInitialState', 'on', 'InitialState', ...  
[mdl 'SimState'];  
simOut = sim mdl, 'StopTime', tstop)
```

### **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');
```



## How to Change the States of a Block within the SimState

You can use the `loggedStates` to get or set the `SimState`. The `loggedStates` field has the same structure as `xout.signals` if `xout` is the state log that Simulink exports to the workspace.

## Using the SimState Interface Checksum Diagnostic

The `SimState` interface checksum is primarily based upon the configuration settings of your model. A diagnostic, 'SimState interface checksum mismatch', resides on the Diagnostics pane of the Configuration Parameters dialog box. You can set this diagnostic to 'none', 'warning', or 'error' to receive a warning or an error if the interface checksum of the restored `SimState` does not match the current interface checksum of the model. Such mismatches may occur when you try to simulate using a solver that is different from the one that

generated the saved `SimState`. Simulink permits such solver changes. For example, you can use a solver such as `ode15s`, to solve the initial stiff portion of a simulation, save the final `SimState`, and then continue the simulation with the restored `SimState` and using `ode45`. In other words, this diagnostic is purely to serve your own purposes for detecting solver changes.

## Limitations of the SimState

Several limitations exist for the `SimState`:

- You can use only the Normal or the Accelerator mode of simulation.
- You cannot save the `SimState` in Normal mode and restore it in Accelerator mode, or vice versa.
- You can save the `SimState` only at the final stop time or at the execution time at which you pause or stop the simulation.
- By design, Simulink does not save user data, run-time parameters, or logs of the model.
- The `SimState` feature does not support code generation, including Model Reference in accelerated modes.
- You cannot make any structural changes to the model between the time at which you save the `SimState` and the time at which you restore the simulation using the `SimState`. For example, you cannot add or remove a block after saving the `SimState` without repeating the simulation and saving the new `SimState`.
- You cannot input the `SimState` to model functions.

## Using SimState within S-Functions

Special APIs for C and Level-2 MATLAB S-functions are available, which enable the S-functions to work with the `SimState`. For information on how to implement these APIs within S-functions, see “S-Function Compliance with the `SimState`”.



## Diagnosing Simulation Errors

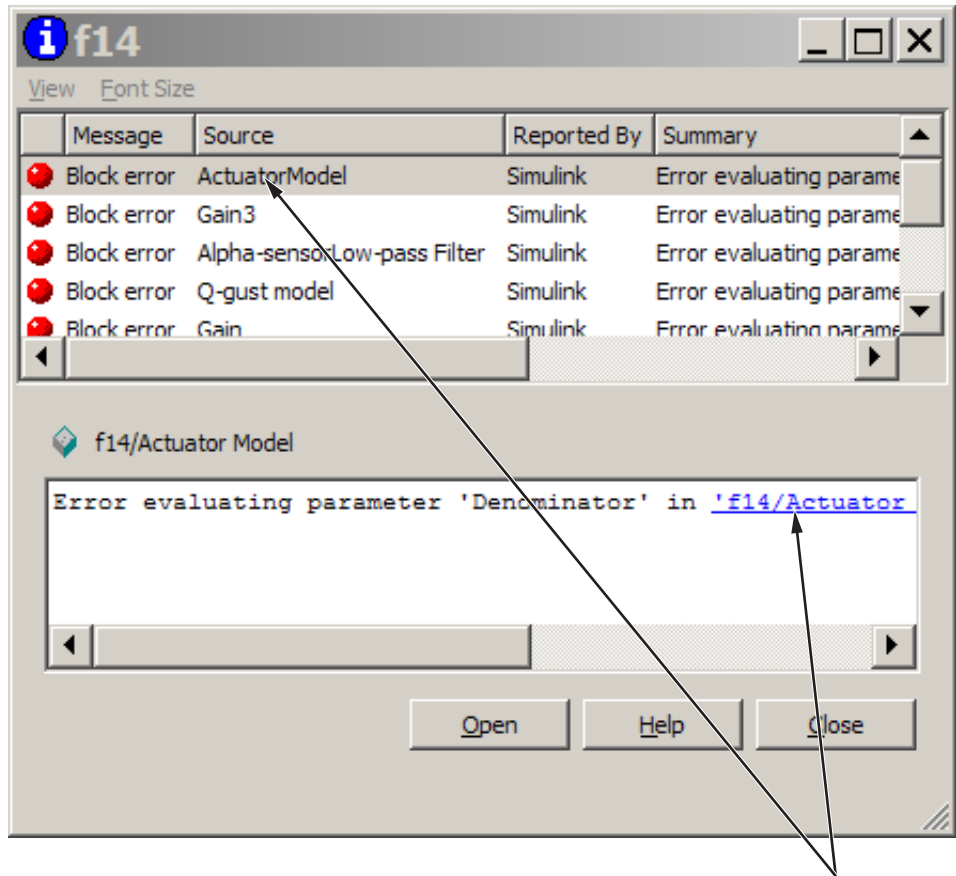
In this section...
“Response to Run-Time Errors” on page 13-39
“Simulation Diagnostics Viewer” on page 13-39
“Creating Custom Simulation Error Messages” on page 13-41

### 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.



Click to display error source.

### 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).

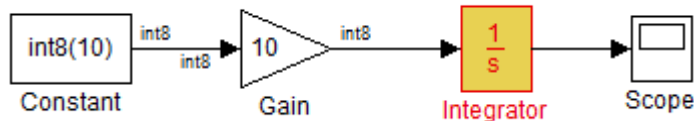
**Summary.** Error message, abbreviated to fit in the column

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.

### Creating Custom Simulation Error Messages

The Simulation Diagnostics Viewer displays the output of any instance of the MATLAB error function executed during a simulation. Such instances include those invoked by block or model callbacks, or by S-functions that you create or that the Interpreted MATLAB Function block executes.

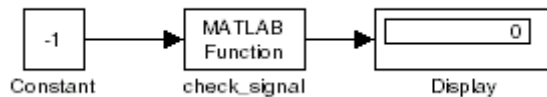
You can use the MATLAB error function in callbacks, S-functions or the Interpreted MATLAB Function block to create custom error messages specific to your application. Capabilities available for messages include:

- 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.

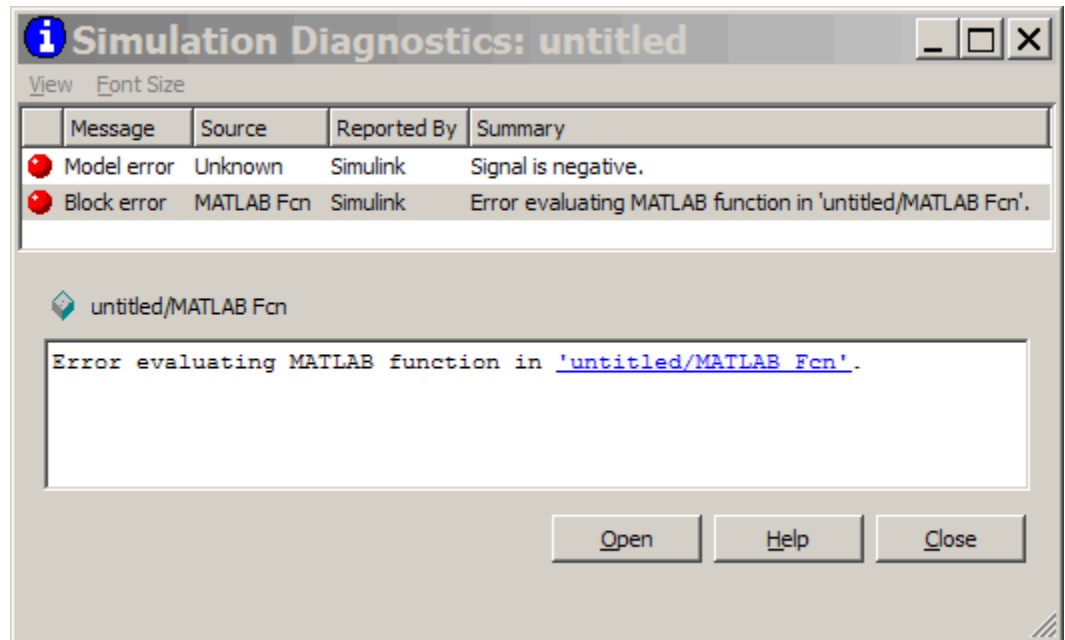
The following example shows how you can make the user-created function `check_signal` display the string `Signal is negative`.



The Interpreted 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 displays the error message in the Simulation Diagnostics Viewer.



## Creating Hyperlinks to Files, Directories, or Blocks

To include a hyperlink to a block, file, or folder in the error message, include the path to the item enclosed in quotation marks.

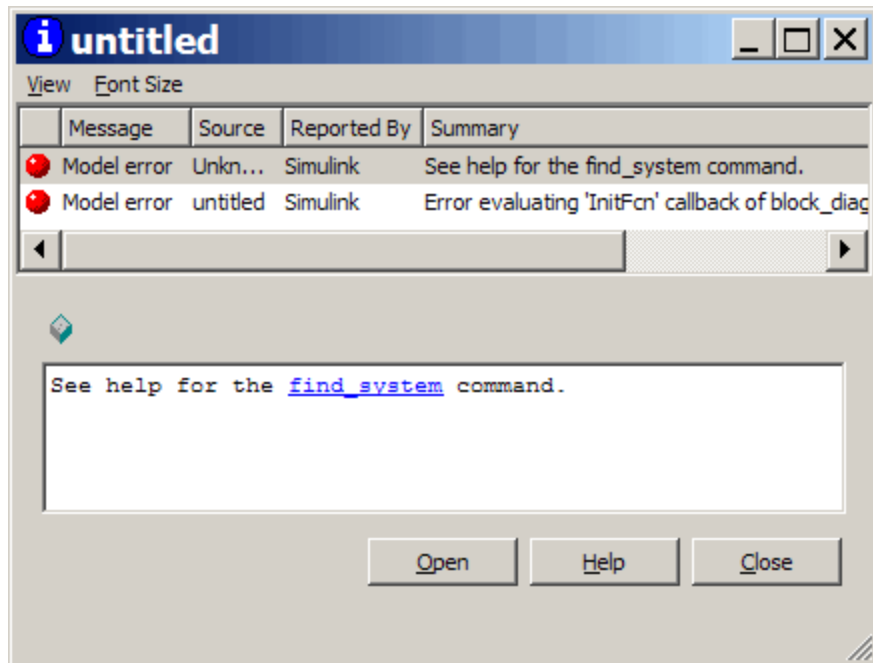
- `error ('Error evaluating parameter in block "mymodel/Mu"')`  
displays a text hyperlink to the block Mu in the model "mymodel". Clicking the hyperlink displays the block in the model window.
- `error ('Error reading data from "c:/work/test.data"')`  
displays a text hyperlink to the file test.data in the error message. Clicking the link displays the file in your preferred MATLAB editor.
- `error ('Could not find data in folder "c:/work"')`  
displays a text hyperlink to the c:/work folder. Clicking the link opens a system command window (shell) and sets its working folder to c:/work.

## Creating Programmatic Hyperlinks

You can create a hyperlink that, when clicked, causes the evaluation of a MATLAB expression. For example, the following model `InitFcn` callback displays an error, when the model starts, with a hyperlink to help for the `find_system` command.

```
error('See help for the <a href="matlab:doc  
find_system">find_system</a>
```

In this example, the Simulation Diagnostics Viewer displays a hyperlink labeled `find_system`. Clicking the link opens the documentation for the `find_system` command in the MATLAB Help browser.



# Running a Simulation Programmatically

---

- “About Programmatic Simulation” on page 14-2
- “Using the sim Command” on page 14-3
- “Using the set\_param Command” on page 14-7
- “Running Parallel Simulations” on page 14-8
- “Error Handling in Simulink Using MSLException” on page 14-15

### About Programmatic Simulation

Entering simulation commands in the MATLAB Command Window or from a MATLAB file enables you to run unattended simulations. You can perform Monte Carlo analysis by changing the parameters randomly and executing simulations in a loop. You can use either the `sim` command or the `set_param` command to run a simulation programmatically. To run simulations simultaneously, you can call `sim` from within a `parfor` loop under specific conditions.



## Using the sim Command

### In this section...

“Single-Output Syntax for the sim Command” on page 14-3

“Examples of Implementing the sim Command” on page 14-4

“Calling sim from within parfor” on page 14-5

“Backwards Compatible Syntax” on page 14-5

### Single-Output Syntax for the sim Command

The general form of the command syntax for running a simulation is:

```
SimOut = sim('model', Parameters)
```

where *model* is the name of the block diagram and *Parameters* can be a list of parameter name-value pairs, a structure containing parameter settings, or a configuration set. The `sim` command returns, `SimOut`, a single `Simulink.SimulationOutput` object that contains all of the simulation outputs (logged time, states, and signals). This syntax is the “single-output format” of the `sim` command.

```
SimOut = sim('model', 'Param1', Value1, 'Param2', Value2...);
SimOut = sim('model', ParameterStruct);
SimOut = sim('model', ConfigSet);
```

During simulation, the specified parameters override the values in the block diagram configuration set. The original configuration values are restored at the end of simulation. If you wish to simulate the model without overriding any parameters, and you want the simulation results returned in the single-output format, then you must do one of the following:

- select **Return as single object** on the Data Import/Export pane of the Configuration Parameters dialog box
- specify the `ReturnWorkspaceOutputs` parameter value as `'on'` in the `sim` command:

```
SimOut = sim('model', 'ReturnWorkspaceOutputs', 'on');
```

To log the model time, states, or outputs, use the Configuration Parameters Data Import/Export dialog box. To log signals, either use a block such as the To Workspace block or the Scope block, or use the **Signal and Scope Manager** to log results directly.

For complete details of the `sim` command syntax, see the `sim` reference page. For information about the configuration parameters, see “Configuration Parameters Dialog Box”.

## Examples of Implementing the `sim` Command

Following are examples that demonstrate the application of each of the three formats for specifying parameter values using the single-output format of the `sim` command.

### Specifying Parameter Name-Value Pairs

In the following example, the `sim` syntax specifies the model name, `vdp`, followed by consecutive pairs of parameter name and parameter value. For example, the value of the `SimulationMode` parameter is `rapid`.

```
simOut = sim('vdp','SimulationMode','rapid','AbsTol','1e-5',...
            'SaveState','on','StateSaveName','xoutNew',...
            'SaveOutput','on','OutputSaveName','youtNew');
simOutVars = simOut.who;
yout = simOut.get('youtNew');
```

### Specifying a Parameter Structure

The following example shows how to specify parameter name-value pairs as a structure to the `sim` command.

```
paramNameValStruct.SimulationMode = 'rapid';
paramNameValStruct.AbsTol         = '1e-5';
paramNameValStruct.SaveState      = 'on';
paramNameValStruct.StateSaveName  = 'xoutNew';
paramNameValStruct.SaveOutput     = 'on';
paramNameValStruct.OutputSaveName = 'youtNew';
simOut = sim('vdp',paramNameValStruct);
```

## Specifying a Configuration Set

The following example shows how to create a configuration set and use it with the `sim` syntax.

```
mdl = 'vdp';
load_system(mdl)
simMode = get_param(mdl, 'SimulationMode');
set_param(mdl, 'SimulationMode', 'rapid')
cs = getActiveConfigSet(mdl);
mdl_cs = cs.copy;
set_param(mdl_cs, 'AbsTol', '1e-5', ...
            'SaveState', 'on', 'StateSaveName', 'xoutNew', ...
            'SaveOutput', 'on', 'OutputSaveName', 'youtNew')
simOut = sim(mdl, mdl_cs);
set_param(mdl, 'SimulationMode', simMode)
```

The block diagram parameter, `SimulationMode`, is not part of the configuration set, but is associated with the model. Therefore, the `set_param` command saves and restores the original simulation mode by passing the model rather than the configuration set.

## Calling sim from within parfor

For information on how to run simultaneous simulations by calling `sim` from within `parfor`, see “Running Parallel Simulations” on page 14-8.

## 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.

<i>T</i>	The time vector returned.
<i>X</i>	The state returned in matrix or structure format. The state matrix contains continuous states followed by discrete states.
<i>Y</i>	The output returned in matrix or structure format. For block diagram models, this variable contains all root-level blocks.
<i>Y1,...,Yn</i>	The outputs, which can only be specified for diagram models. Here <i>n</i> must be the number of root-level blocks. Each output will be returned in the <i>Y1,...,Yn</i> variables.
' <i>model</i> '	The name of a block diagram model.
<i>Timespan</i>	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 <i>T</i> , but in general <i>T</i> will include additional time points.
<i>Options</i>	Optional simulation parameters created in a structure by the <code>simset</code> command using name-value pairs.
<i>UT</i>	Optional external inputs. For supported expressions, see "Enabling Data Import" on page 29-74.

Simulink only requires the first parameter. Simulink takes all defaults from the block diagram, including unspecified options. If you specify any optional arguments, your specified settings override the settings in the block diagram.

Specifying the right-hand side argument of `sim` as the empty matrix, `[]`, causes Simulink to use the default for the argument.

To specify the single-output format for `sim(model, Timespan, Options, UT)`, set the 'ReturnWorkspaceOutputs' option of the options structure to 'on'.

See also `simset` and `simget`.

## Using the set\_param Command

You can use the `set_param` command to start, stop, pause, or continue a simulation, to update a block diagram, or to write all data logging variables to the base workspace. The format of the `set_param` command is:

```
set_param('sys', 'SimulationCommand', 'cmd')
```

where `'sys'` is the name of the system and `'cmd'` is `'start'`, `'stop'`, `'pause'`, `'continue'`, `'update'`, or `'WriteDataLogs'`. See Chapter 29, “Importing and Exporting Simulation Data” for information about data logging.

Similarly, you can use the `get_param` command to check the status of a simulation. The format of the `get_param` function call for this use is

```
get_param('sys', 'SimulationStatus')
```

The Simulink software returns `'stopped'`, `'initializing'`, `'running'`, `'paused'`, `'updating'`, `'terminating'`, or `'external'` (used with the Simulink Coder product).

---

**Note** If you use `matlab -nodisplay` to start a session, then you cannot use `set_param` to run your simulation session.

---

## Running a Simulation from an S-Function

S-functions can use the `set_param` command to control simulation execution. A C MEX S-function can use the `mexCallMATLAB` macro to call the `set_param` command itself.

## Running Parallel Simulations

### In this section...

“Overview of Calling sim from within parfor” on page 14-8

“sim in parfor with Rapid Accelerator Mode” on page 14-9

“Workspace Access Issues” on page 14-10

“Resolving Workspace Access Issues” on page 14-10

“Data Concurrency Issues” on page 14-12

“Resolving Data Concurrency Issues” on page 14-12

### 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 19-10 for details on selecting a simulation mode and “Designing Your Model for Effective Acceleration” on page 19-15 for optimizing simulation run times.) For other simulation modes, you need to address any workspace access issues and data concurrency issues in order to produce useful results. Specifically, the simulations need to create separately named output files and workspace variables; otherwise, each simulation will overwrite the same workspace variables and files, or possibly have collisions trying to write variables and files simultaneously.

For details about the `parfor` command, see `parfor`.

---

**Note** All simulation modes require a homogeneous file system. The workers and the callers must be on the same operating system and have the same type of file system (for example, NTFS or FAT).

---

## sim in parfor with Rapid Accelerator Mode

Running Rapid Accelerator simulations in `parfor` combines speed with automatic distribution of a prebuilt executable to the `parfor` workers. As a result, this mode eliminates duplication of the update diagram phase.

To run parallel simulations in Rapid Accelerator simulation mode using the `sim` and `parfor` commands, you must:

- Configure the model to run in Rapid Accelerator simulation mode
- Ensure that the Rapid Accelerator target is already built and up to date
- Disable the Rapid Accelerator target up-to-date check by setting the `sim` command option `RapidAcceleratorUpToDateCheck` to 'off'.

To satisfy the second condition, you can only change parameters between simulations that do not require a model rebuild. In other words, the structural checksum of the model must remain the same. Hence, you can change only tunable block diagram parameters and tunable run-time block parameters between simulations. For a discussion on tunable parameters that do not require a rebuild subsequent to their modifications, see “Determining If the Simulation Will Rebuild” on page 19-7.

As for the third condition, the following sample code demonstrates how to disable the up-to-date check using the `sim` command.

```
matlabpool open
% Load the model and set parameters
mdl = 'vdp';
load_system(mdl)
% Build the Rapid Accelerator target
rtp = Simulink.BlockDiagram.buildRapidAcceleratorTarget(mdl);
% Run parallel simulations
parfor i=1:4
    simOut{i} = sim(mdl,'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 demonstration of this method of running parallel simulations, refer to the Rapid Accelerator Simulations Using PARFOR demo.

## Workspace Access Issues

In order to run `sim` in `parfor`, you must first open a MATLAB pool of workers using the `matlabpool` command. The `parfor` command then runs the code within the `parfor` loop in these MATLAB worker sessions. The MATLAB workers, however, do not have access to the workspace of the MATLAB client session where the model and its associated workspace variables have been loaded. Hence, if you load a model and define its associated workspace variables outside of and before a `parfor` loop, then neither is the model loaded, nor are the workspace variables defined in the MATLAB worker sessions where the `parfor` iterations are executed. This is typically the case when you define model parameters or external inputs in the base workspace of the client session. These scenarios constitute workspace access issues.

## Resolving Workspace Access Issues

When a Simulink model is loaded into memory in a MATLAB client session, it is only visible and accessible in that MATLAB session; it is not accessible in the memory of the MATLAB worker sessions. Similarly, the workspace variables associated with a model that are defined in a MATLAB client session (such as parameters and external inputs) are not automatically available in the worker sessions. You must therefore ensure that the model is loaded and that the workspace variables referenced in the model are defined in the MATLAB worker session by using the following two methods.



- In the `parfor` loop, use the `sim` command to load the model and to set parameters that change with each iteration. (Alternative: load the model and then use the `g(s)et_param` command(s) to set the parameters in the `parfor` loop)
- In the `parfor` loop, use the MATLAB `evalin` and `assignin` commands to assign data values to variables.

Alternatively, you can simplify the management of workspace variables by defining them in the model workspace. These variables will then be automatically loaded when the model is loaded into the worker sessions. There are, however, limitations to this method. For example, you cannot have tunable parameters in a model workspace. For a detailed discussion on the model workspace, see “Using Model Workspaces” on page 3-67.

### Specifying Parameter Values Using the `sim` Command

Use the `sim` command in the `parfor` loop to set parameters that change with each iteration.

```
% Run parallel simulations of a model that does not
% result in data concurrency issues
mdl = 'vdp';
paramName = 'StopTime';
paramValue = {'10', '20', '30', '40'};
parfor i=1:4
    simOut{i} = sim(mdl, ...
                   paramName, paramValue{i}, ...
                   'SaveTime', 'on');
end
```

An equivalent method is to load the model and then use the `set_param` command to set the `paramName` in the `parfor` loop.

### Specifying Variable Values Using the `assignin` Command

You can pass the values of model or simulation variables to the MATLAB workers by using the `assignin` or the `evalin` command. The following example illustrates how to use this method to load variable values into the appropriate workspace of the MATLAB workers.

```
parfor i = 1:4
    assignin('base', 'extInp', externalInput{i})
    % 'extInp' is the name of the variable in the base
    % workspace which contains the External Input data
    simOut{i} = sim mdl, 'ExternalInput', 'extInp');
end
```

For further details, see the Rapid Accelerator Simulations Using PARFOR demo.

## Data Concurrency Issues

Data concurrency issues refer to scenarios for which software makes simultaneous attempts to access the same file for data input or output. In Simulink, they primarily occur as a result of the nonsequential nature of the `parfor` loop during simultaneous execution of Simulink models. The most common incidences arise when code is generated or updated for a simulation target of a Stateflow, Model 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 (mdl) 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(mdl)
    % set the block parameters, e.g., filename of To File block
    set_param(someBlkInMdl, blkParamName, blkParamValue{i})
```

```
% set the model parameters by passing them to the sim command
out{i} = sim mdl, mdlParamName, mdlParamValue{i});
cd(cwd)
rmdir(tmpdir,'s')
rmpath(cwd)
end
```

Note that you can also avoid other concurrency issues due to file I/O errors by using a temporary folder for each iteration of the `parfor` body.

### A Model with To File Blocks

If you simulate a model with To File blocks from inside of a `parfor` loop, the nonsequential nature of the loop may cause file I/O errors. To avoid such errors during parallel simulations, you can either use the temporary folder idea above or use the `sim` command in Rapid Accelerator mode with the option to append a suffix to the file names specified in the model To File blocks. By providing a unique suffix for each iteration of the `parfor` body, you can avoid the concurrency issue.

```
parfor i=1:4
    sim mdl, ...
        'ConcurrencyResolvingToFileSuffix', num2str(i),...
        'SimulationMode', 'rapid');
end
```

# Error Handling in Simulink Using MSLException

## Error Reporting in a Simulink Application

Simulink allows you to report an error by throwing an exception using the `MSLException` object, which is a subclass of the MATLAB `MException` class. As with the MATLAB `MException` object, you can use a try-catch block with a `MSLException` object construct to capture information about the error. The primary distinction between the `MSLException` and the `MException` objects is that the `MSLException` object has the additional property of `handles`. These handles allow you to identify the object associated with the error.

## The MSLException Class

The `MSLException` class has five properties: `identifier`, `message`, `stack`, `cause`, and `handles`. The first four of these properties are identical to those of `MException`. For detailed information about them, see “Error Handling”. The fifth property, `handles`, is a cell array with elements that are double array. These elements contain the handles to the Simulink objects (blocks or block diagrams) associated with the error.

## Methods of the MSLException Class

The methods for the `MSLException` class are identical to those of the `MException` class. For details of these methods, see `MException`.

## Capturing Information about the Error

The structure of the Simulink try-catch block for capturing an exception is:

```
try
    Perform one or more operations
catch E
    if isa(E, 'MSLException')
        ...
    end
```

If an operation within the try statement causes an error, the catch statement catches the exception (*E*). Next, an `if isa` conditional statement tests to

determine if the exception is Simulink specific, i.e., an `MSLException`. In other words, an `MSLException` is a type of `MException`.

The following code demonstrates how to get the handles associated with an error.

```
errHndls = [];  
try  
    sim('modelName', ParamStruct);  
catch e  
    if isa(e,'MSLException')  
        errHndls = e.handles{1}  
    end  
end
```

You can see the results by examining `e`. They will be similar to the following output:

```
e =  
  
MSLException  
  
Properties:  
    handles: {[7.0010]}  
 identifier: 'Simulink:Parameters:BlkParamUndefined'  
  message: [1x87 char]  
    cause: {0x1 cell}  
    stack: [0x1 struct]
```

Methods, Superclasses

To identify the name of the block that threw the error, use the `getfullname` command. For the present example, enter the following command at the MATLAB command line:

```
getfullname(errHndls)
```

If a block named `Mu` threw an error from a model named `vdp`, MATLAB would respond to the `getfullname` command with:

```
ans =
```

vdp/Mu





# Visualizing and Comparing Simulation Results

---

- “About Scope Blocks, Signal Viewers, Signal Logging, and Test Points” on page 15-2
- “Signal Viewer Tasks” on page 15-6
- “Scope Signal Viewer Tasks” on page 15-12
- “Scope Signal Viewer Characteristics” on page 15-15
- “Signal Generator Tasks” on page 15-23
- “Signal and Scope Manager” on page 15-25
- “Signal Selector” on page 15-29
- “Inspecting and Comparing Logged Signal Data” on page 15-33

## About Scope Blocks, Signal Viewers, Signal Logging, and Test Points

### In this section...

“What Are Scope Blocks, Signal Viewers, Test Points and Data Logging?” on page 15-2

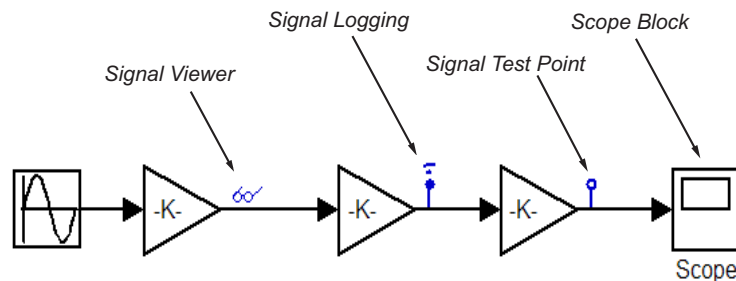
“Scope Block and Scope Signal Viewer Differences” on page 15-3

“Why Use Signal Generators and Signal Viewers Instead of Source Blocks and Scope Blocks?” on page 15-4

### 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 15-6 and “Scope Signal Viewer Tasks” on page 15-12.
- For detailed information on signal viewers, see “Signal and Scope Manager” on page 15-25.
- For information on signal logging, see “Exporting Signal Data Using Signal Logging” on page 29-19.
- For information on signal Test Points, see “Working with Test Points” on page 31-59.

- For information on Scope Blocks, see “Sinks”.

## 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 15-29  See “Scope Signal Viewer Context Menu” on page 15-16	Drag from Library Browser
Scope of Control	All viewers centrally managed from Signal and Scope Manager  See “Signal and Scope Manager” on page 15-25.	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 15-12	Multiple
Data handling	Save data to a signal logging object	Save variable data to workspace as structures or arrays

<b>Characteristic</b>	<b>Scope signal Viewer</b>	<b>Scope Block</b>
Data logging	Log data to model-wide data object See <code>Simulink.SimulationData.Dataset</code> and <code>Simulink.ModelDataLogs</code>	None
Scrolling display data capability	Yes	No
Display	<ul style="list-style-type: none"> <li>• Data markers</li> <li>• Legends</li> <li>• Color and line codes distinguish signals</li> </ul>	Color and line codes distinguish signals
Graph Refresh Period	Adjustable	Fixed
Display of Minor Steps	The viewer does not display minor steps regardless of the value of the Refine parameter setting.	The scope displays minor steps if the Refine parameter is greater than 1. The value of the Refine parameter indicates the number of intermediate steps displayed.

## **Why Use 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 “Working with Test Points” on page 31-59 for more information.

## Signal Viewer Tasks

### In this section...

- “About Signal Viewers” on page 15-6
- “Attaching a Signal Viewer” on page 15-6
- “Adding Signals to a Signal Viewer” on page 15-8
- “Displaying a Signal Viewer” on page 15-9
- “Zooming In On Graph Regions” on page 15-10
- “How to Save Data to MATLAB Workspace” on page 15-10
- “Plotting the Viewer Data” on page 15-11

### 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 15-3.
- Signal viewers do not show signal labels on the axis
- Signal viewers do not work with Report Generator
- Signal viewers do not display the simulation minor time step values
- Not all signal viewer features are supported when you simulate your model in Rapid Accelerator mode. For more information, see “Behavior of Scopes and Viewers with Rapid Accelerator Mode” on page 19-17.
- 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 15-17 .

### 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,

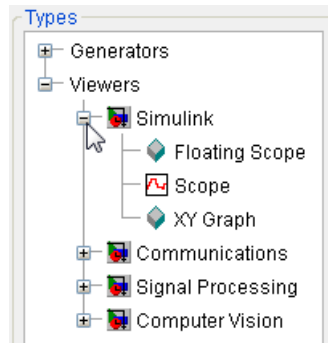
- 1 On your Simulink block diagram, right-click a signal, and then from the context menu, select **Create & Connect Viewer**.
- 2 From the list that appears, select the type of signal viewer you want to attach.

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.

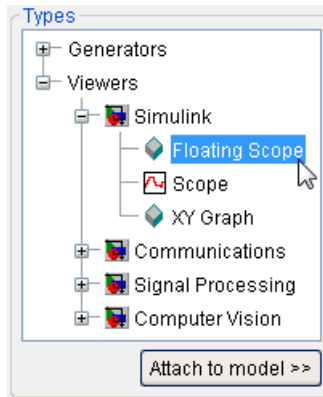


---

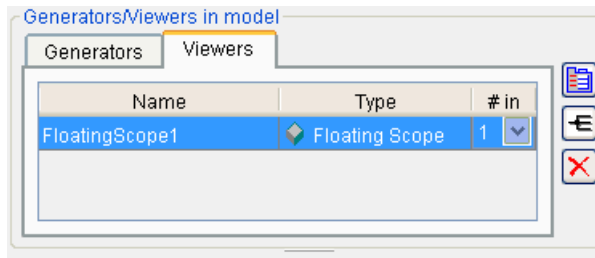
**Note** The Simulink Scope displayed in the Signal and Scope Manager Types pane is not the same as the Simulink Scope Block. For an explanation of the differences, see “Scope Block and Scope Signal Viewer Differences” on page 15-3.

---

- 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,

- In your block diagram, right-click a signal.



- 2 From the signal context menu, select **Connect to existing viewer**.

A list of signal viewers that were added to your model is displayed.

- 3 From the list, select the signal viewer to attach the signal.

You can also add signals to signal viewers with the Signal and Scope Manager. See “Signal and Scope Manager” on page 15-25.

---

**Note** The simulation must be run again for the new trace to be displayed in the viewer.

---



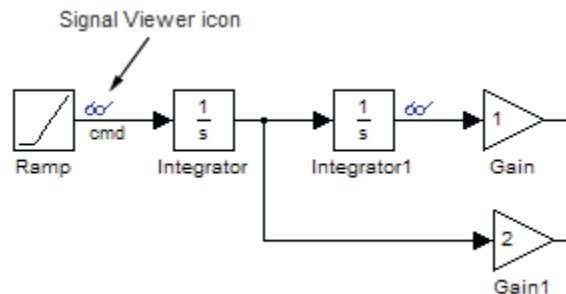
---

**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.


## Zooming In On Graph Regions

- To zoom in on a region (simultaneously zooming in on the  $x$  and  $y$




directions), select from the Scope Viewer toolbar, and left-click within the graph. While holding down the mouse button, define the region of interest.


To zoom, click and hold the left mouse button, and drag the mouse to define the zoom region bounding box. Release the mouse button to effect the change.

- Select  and use the mouse to zoom only in the  $x$  direction.

Define the zoom region by positioning the pointer at one end of the region, pressing and holding down the left mouse button, then moving the pointer to the other end of the region. Release the mouse button to effect the change. To zoom, click and hold the left mouse button, and drag the mouse to define the zoom region bounding box. Release the mouse button to effect the change.

- Select  and use the mouse to zoom only the  $y$  direction.


---

**Tip** Use Autoscale () to restore the display if you mistakenly zoom in too much.

---

## How to Save 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 properties icon  .
- 2 Click the **History** tab.
- 3 Select **Save to model signal logging object (logout)**.
- 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:

```
logout.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 “Inspecting and Comparing Logged Signal Data” on page 15-33.
- **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” on page 15-12
“Creating a Multiple Axes Scope Signal Viewer” on page 15-12

### 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.

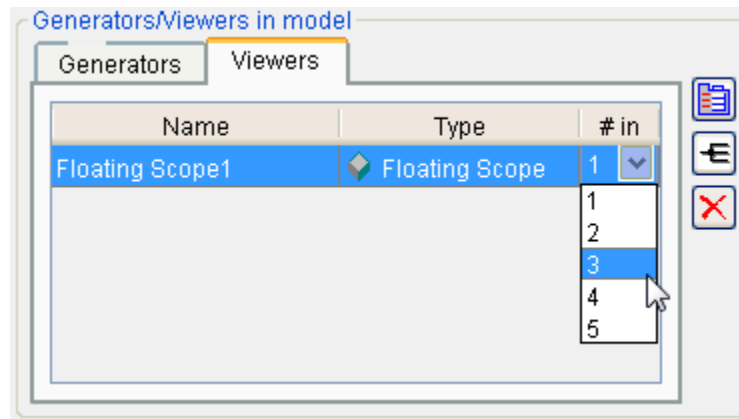
For information about the color and line styles in the Viewer window, see “How a Scope Signal Viewer Determines Trace Color Coding and Line Styles” on page 15-20.

### Creating a Multiple Axes Scope Signal Viewer

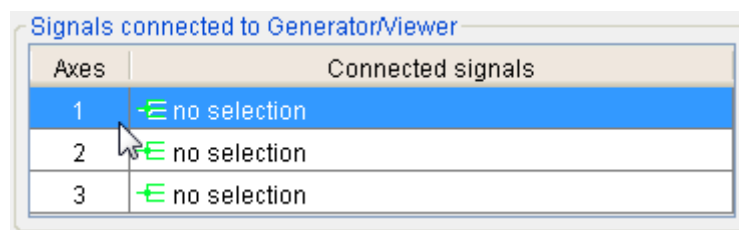
You can add multiple plots (called *axes*) to a scope signal viewer. Each axes can have different *y*-axis settings.



To create a viewer with more than one axes.

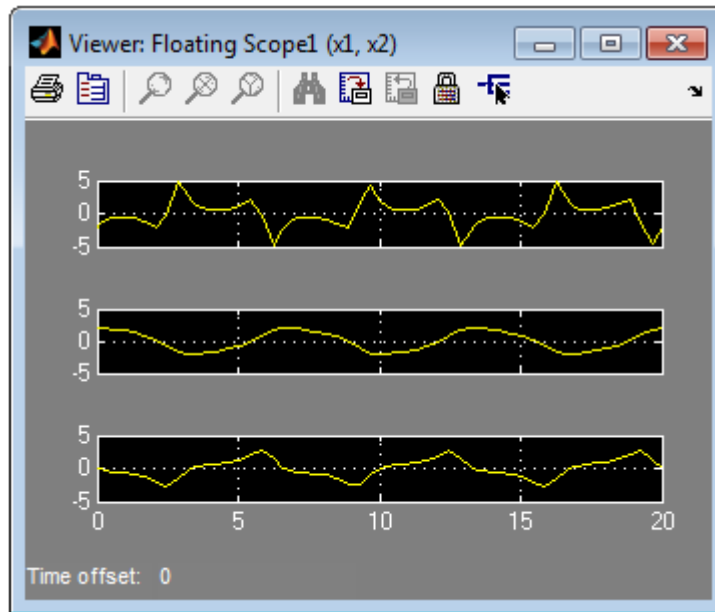
- 1 Open the Signal and Scope manager. Add a signal Scope or Floating Scope signal viewer to your model. See “Attaching a Signal Viewer” on page 15-6.
- 2 From the **# in** drop-down list, select the total number of axes for the graph.



- 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.













## Scope Signal Viewer Characteristics

In this section...
“Scope Signal Viewer Toolbar” on page 15-15
“Scope Signal Viewer Context Menu” on page 15-16
“Scope Signal Viewer Parameters Dialog Box” on page 15-17
“How a Scope Signal Viewer Determines Trace Color Coding and Line Styles” on page 15-20
“How Scope Signal Viewer Parameter Settings Can Affect Performance” on page 15-21

### 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 15-17.
	Simultaneously zooms in on the $x$ and $y$ axes. The zoom feature is not active while the simulation is running.  For more information, see “Zooming In On Graph Regions” on page 15-10.
	Use this button to zoom in on the $x$ axis only. The zoom feature is not active while the simulation is running.  For more information, see “Zooming In On Graph Regions” on page 15-10.

Icon	Function
	<p>Use this button to zoom in on the y axis only. The zoom feature is not active while the simulation is running.</p> <p>For more information, see “Zooming In On Graph Regions” on page 15-10.</p>
	<p>Automatically scales the axis to fully display all signals.</p>
	<p>Stores the current axis settings so you can apply them to the next simulation.</p>
	<p>Restores the graph setting values saved by the most recent <b>Save axes settings</b> command.</p>
	<p>Activates the Signal Selector. For more information, see “Signal Selector” on page 15-29.</p>
	<p>Docks and undocks the Scope Viewer. When you dock the Scope Viewer, it is placed within the MATLAB Command Window and automatically resized.</p>

### 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	<p>Displays the Signal Selector dialog.</p> <p>For information, see “Signal Selector” on page 15-29</p>



Control	Function
<b>Axes properties</b>	Displays the Axis Properties dialog. You can manually set the minimum and maximum range for the y axis here.
<b>Scope parameters</b>	Displays the Scope parameters dialog. For information, see “Scope Signal Viewer Parameters Dialog Box” on page 15-17.
<b>Tick labels</b>	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 15-8.

**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
<code>all</code>	Places ticks on the outside of all axes
<code>inside</code>	Places tick labels inside all axes (available only on signal viewers)
<code>bottom axis only</code>	Places tick labels outside the bottom axes

**Scroll.** When you select this option, the scope continuously scrolls the displayed signals to the left to keep as much data in view as will fit on the screen at any one time.

In contrast, when this option is not selected, the scope draws a screen full of data from left to right until the screen is full, erases the screen, and draws the next screen full of data. This loop is repeated until the end of simulation time. The effects of this option are discernible only when drawing is slow, for example, when the model is very large or has a very small step size.

---

**Note** In some cases, the simulation slows when the simulation runs with the scroll option selected. See “How Scope Signal Viewer Parameter Settings Can Affect Performance” on page 15-21.

---

**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 “Exporting Signal Data Using Signal Logging” on page 29-19 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’s **Configuration Parameters** dialog box.

**Logging Name.** Specifies the name under which to store the viewer's data in the model's `Simulink.ModelDataLogs` object. The name must be different from the log names specified by other signal viewers or for other signals, subsystems, or model references logged in the model's `Simulink.ModelDataLogs` object.

### Performance Tab

Controls how frequently the Scope 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 “How Scope Signal Viewer Parameter Settings Can Affect Performance” on page 15-21.

---

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.

### How a Scope Signal Viewer Determines Trace Color Coding and Line Styles

The Scope signal viewer displays each signal as a separate, color-coded trace, in the following order:

- 1 Blue

**2** Red

**3** Magenta

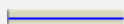
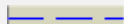
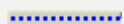
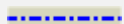
**4** Cyan

**5** Yellow

**6** Green

The viewer cycles through the colors if the axis is displaying more than six signals.

If a signal contains multiple elements (such as a vector or matrix), the viewer distinguishes the elements with different line styles. If a signal has more than four elements, the viewer cycles through the line styles. The line styles retain the color of the signal.

Signal Element	Scope Viewer
1	
2	
3	
4	

## How Scope Signal Viewer Parameter Settings Can Affect Performance

In some cases, when a Scope signal viewer needs to display a large number of data points, the simulation slows. When this happens, you can improve simulation performance by adjusting the settings of some of the viewer parameters. Try one or a combination of the following until you are satisfied with the simulation performance.

- Turn off scroll mode.

- 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.” on page 15-23
“Removing a Generator” on page 15-24

### 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 attach a Signal Generator using the context menu,

- 1 Right-click the input to a block (such as a gain block), and from the signal context menu select **Create & Connect Generator**.
- 2 From the list that appears, select the type of scope to be attached.

The generator will appear in the block diagram as a small rectangle that lists the generator type you have chosen. Double-click this region to display a dialog from where you can change the generators properties.

### 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 (such as a gain block), and 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” on page 15-25

“Opening the Signal and Scope Manager” on page 15-26

“Changing Generator or Viewer Parameters” on page 15-27

“Adding Signals to a Viewer” on page 15-27

“Removing a Generator or Viewer from a Simulink Model” on page 15-27

“Viewing Test Point Data” on page 15-27

## 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.

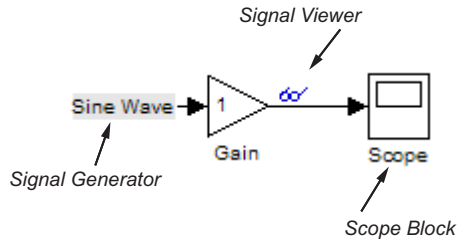
---

**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

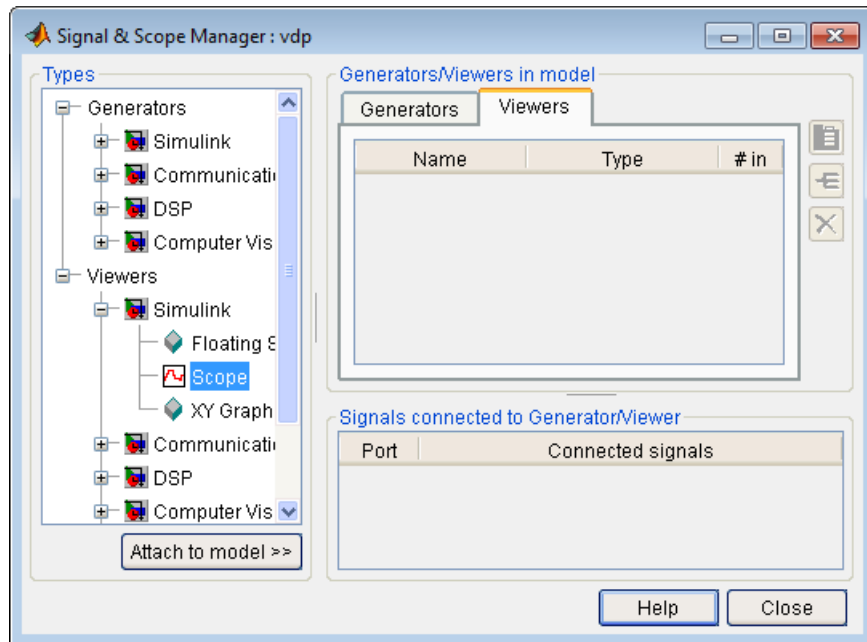
The small icons identifying a viewer or generator are called Viewer and Generator Objects. These objects are not the same as scope blocks or signal blocks. Generator and Viewer Objects are managed by the Signal and Scope Manager, and are placed on signals. Blocks are dragged from the Library browser and are not managed by the Signal and Scope manager.



## Opening the Signal and Scope Manager

- 1 In the Model Editor window, and from the **Tools** menu, select **Signal & Scope Manager**.

The Signal & Scope Manager window opens.



Alternatively within your model, right click and from the context menu, select **Signal & Scope Manager**.

## Changing Generator or Viewer Parameters


- 1 To the right side of the Generators/Viewers pane, click the Parameters button 

The parameters dialog box opens for the selected generator or viewer.

- 2 Review and change object 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 “Working with Test Points” on page 31-59 and Chapter 5, “Referencing a Model”.

## Signal Selector

### In this section...

“About the Signal Selector” on page 15-29

“Select signals for object” on page 15-30

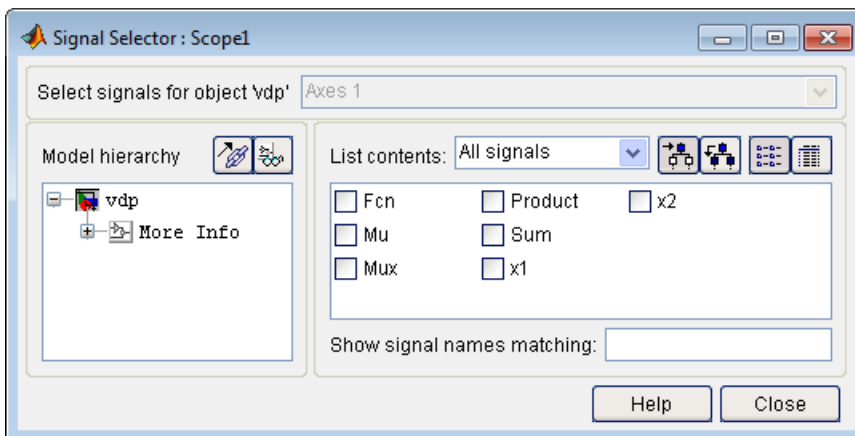
“Model Hierarchy” on page 15-30

“Inputs/Signals List” on page 15-30

### About the Signal Selector

The Signal Selector allows you to connect a generator or viewer object (see “Attaching a Signal Viewer” on page 15-6 and “Attaching a Signal Generator.” on page 15-23) 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.



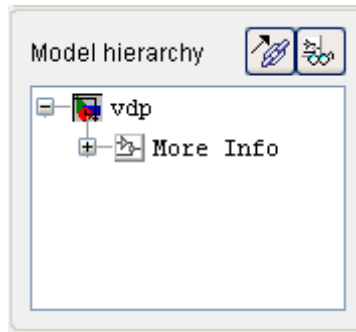
## Select signals for object

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.

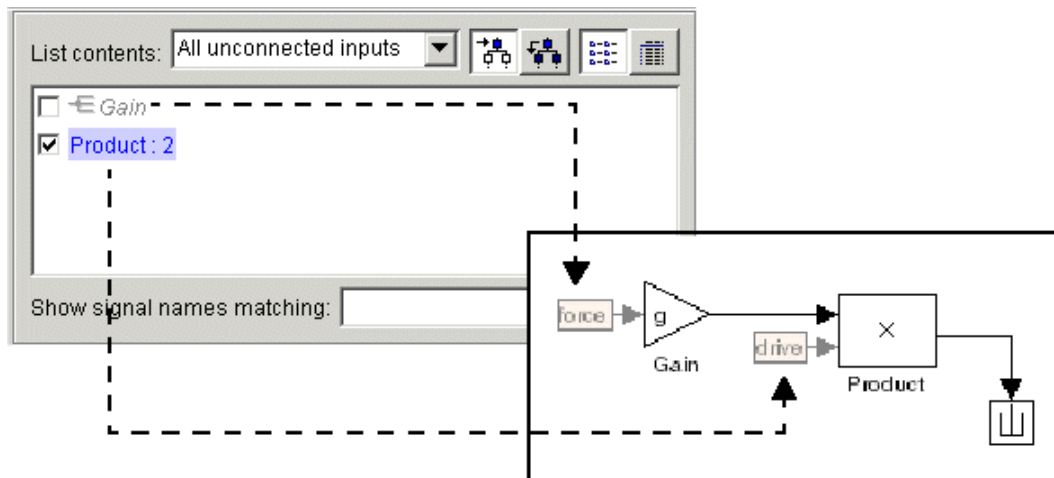


Selecting a subsystem causes the adjacent port list to display the ports available for connection in the selected subsystem. To display subsystems included as library links in your model, click the **Follow links** button at the top of the **Model hierarchy** control. To display subsystems contained 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 Selector's 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.

---



## Inspecting and Comparing Logged Signal Data

### In this section...

“Overview” on page 15-33

“Record or Import Data into the Simulation Data Inspector Tool” on page 15-36

“Visual Inspection of Signal Data in the Simulation Data Inspector Tool” on page 15-42

“Comparison of Signal Data” on page 15-54

“Comparison of One Signal From Multiple Simulations” on page 15-56

“Comparison of All Logged Signal Data From Multiple Simulations” on page 15-59

“Create Simulation Data Inspector Report” on page 15-63

“Export Results in the Simulation Data Inspector Tool” on page 15-64

“How the Simulation Data Inspector Tool Aligns Signals” on page 15-65

“How the Simulation Data Inspector Tool Compares Time Series Data” on page 15-67

“Understanding the Simulation Data Inspector Interface” on page 15-68

“Limitations of the Simulation Data Inspector Tool” on page 15-84

“Record and Inspect Signal Data Programmatically” on page 15-85

### Overview

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 15-65 describes how signals are aligned between runs. “How the Simulation Data Inspector Tool Compares Time Series Data” on page 15-67 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 “Exporting Signal Data Using Signal Logging” on page 29-19.
- 2** Open the Simulation Data Inspector tool, as described in “Open the Simulation Data Inspector Tool” on page 15-69.
- 3** Simulate your model and record simulation data or import logged signal data, as described in “Record or Import Data into the Simulation Data Inspector Tool” on page 15-36.
- 4** Configure the Signal Browser table and specify how you want to graph the data, as described in “Understanding the Simulation Data Inspector Interface” on page 15-68.
- 5** Inspect signals to quickly determine if the run satisfies requirements, as described in “Visual Inspection of Signal Data in the Simulation Data Inspector Tool” on page 15-42.
- 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 “Comparison of Signal Data” on page 15-54.
- 9** Compare all of the imported signal data from multiple runs, as described in “Comparison of All Logged Signal Data From Multiple Simulations” on page 15-59.

- 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 15-64.

The Simulation Data Inspector software provides a command-line interface. For more information, see “Record and Inspect Signal Data Programmatically” on page 15-85

## Record or Import Data into the Simulation Data Inspector Tool

- “Data Requirements” on page 15-36
- “Record Simulation Data into the Simulation Data Inspector Tool” on page 15-37
- “Import Logged Signal Data into the Simulation Data Inspector Tool” on page 15-38
- “Load Previously Recorded Data from a MAT-file” on page 15-40

### Data Requirements

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

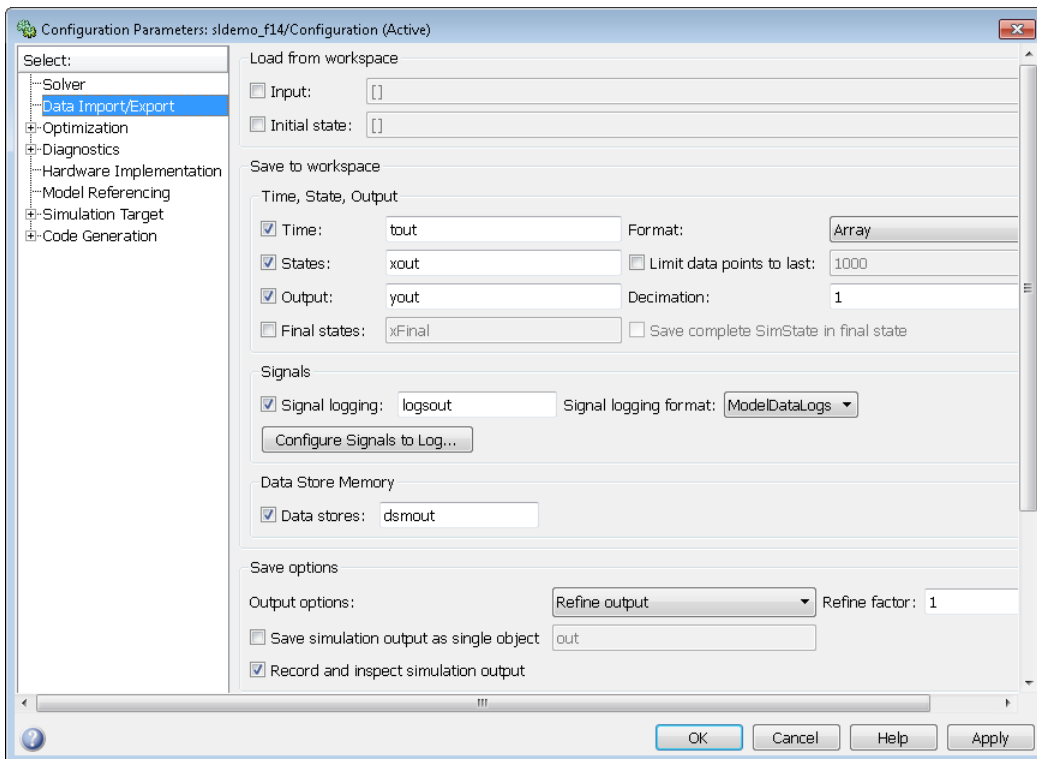
The Simulation Data Inspector supports output from the following blocks:

- Scope (`Structure` with `time` and `Array` format)
- To File (`Timeseries` format)
- To Workspace (`Timeseries` or `Structure With Time` format)


## Record Simulation Data into the Simulation Data Inspector Tool

**Record Signal Data Automatically After Simulation.** You can configure your model to automatically open the Simulation Data Inspector tool and record simulation data every time you run or pause a simulation.

- 1 Select **Simulation > Configuration Parameters** to open the Configuration Parameters dialog box.
- 2 Select the **Data Import/Export** pane.
- 3 Select the **Signal logging** parameter.
- 4 Select the **Record and inspect simulation output** parameter.
- 5 Select a **Signal logging** format.




**Record Signal Data Interactively With Simulations.** To set the Simulation Data Inspector to automatically import data after a simulation run:

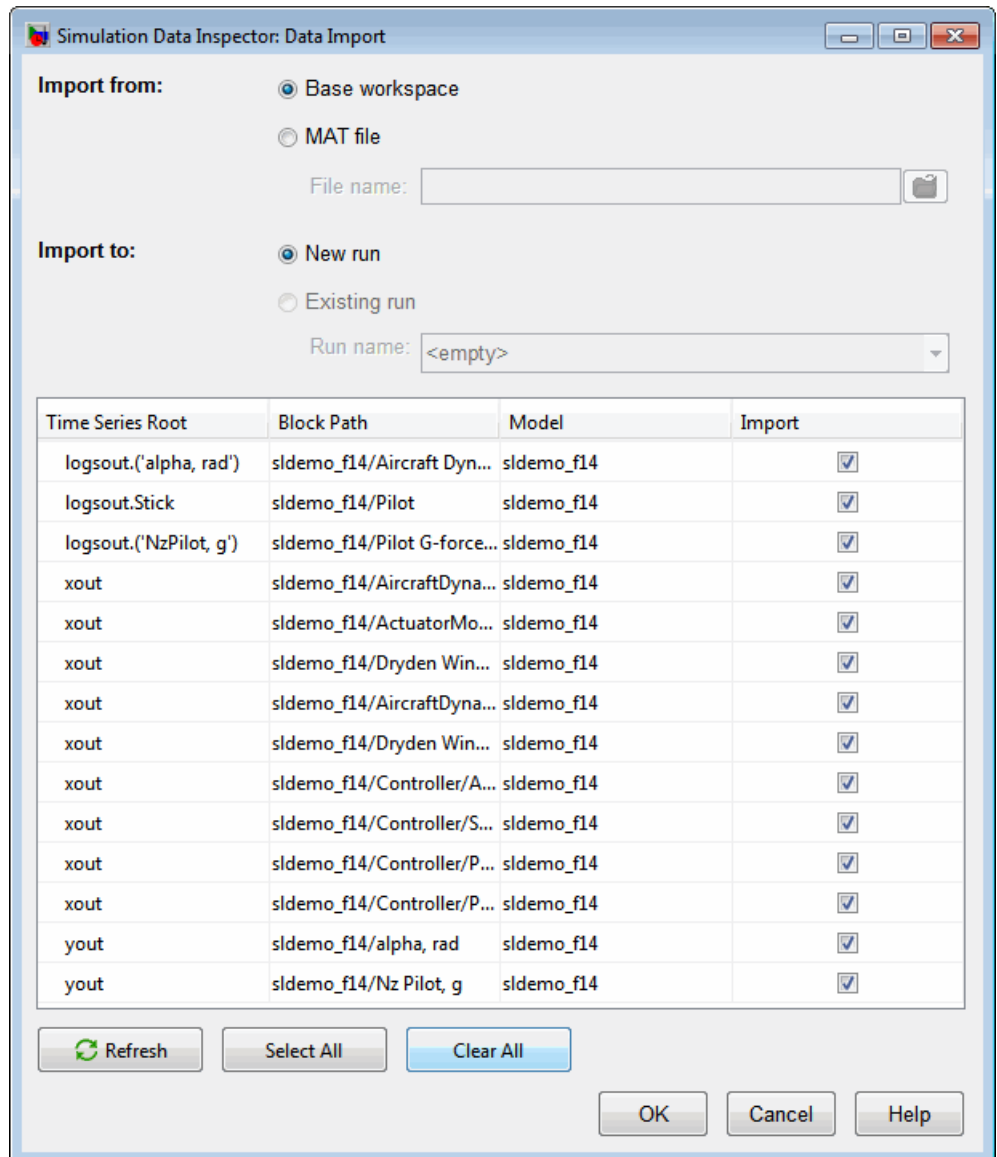
- 1 Open the Simulation Data Inspector tool.
- 2 Click the **Record** button .
- 3 In the model diagram window, simulate your model. When the simulation is done, the data automatically appears within a new run in the Simulation Data Inspector tool. To modify the run name, see “Rename a Run” on page 15-75.
- 4 To import another simulation run, leave the **Record** button selected, and simulate your model again. When the simulation is done, the data appears as another new run.
- 5 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.

### **Import Logged Signal Data into the Simulation Data Inspector Tool**

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 “Exporting Signal Data Using Signal Logging” on page 29-19.

**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 logouts, xouts, and youts appear in the table.

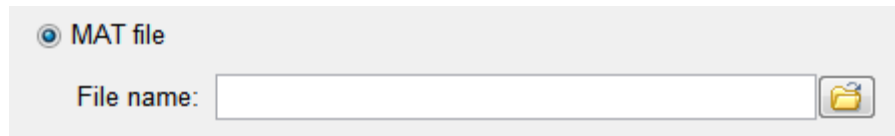


- 3 Select the **Import** check box to import a signal. Clear the **Import** check box for signals that you do not want. You can also use the **Select All** and **Clear All** buttons for mass selection or clearing of all signals.

**4** Select **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.




The screenshot shows a dialog box with a radio button selected next to the text "MAT file". Below this, there is a text input field labeled "File name:" followed by a folder icon button.

- 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** Select **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.

## Visual Inspection of Signal Data in the Simulation Data Inspector Tool


### Overview

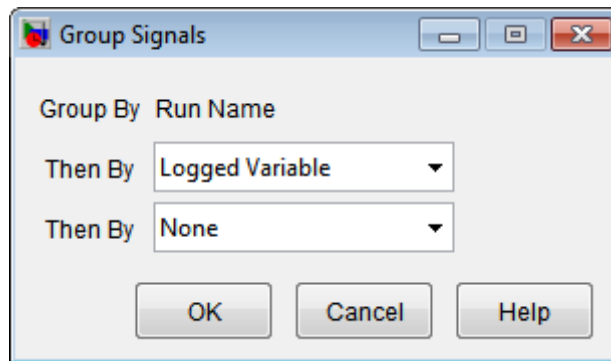
On the **Inspect Signals** tab you can inspect logged signal data. On the left pane you can open the Signal Browser table to view and configure signal and run properties (see “Understanding the Simulation Data Inspector Interface” on page 15-68). On the right pane you can create different plot views. 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. These examples demonstrate how to work with views for inspecting your data:

- “View Signal Data” on page 15-42
- “Create a View of Multiple Plots” on page 15-45
- “Explore Signal Data in a Multiple Plot View” on page 15-47
- “Replace a Run in a View” on page 15-48
- “Copy a View in the Inspect Signals Tab” on page 15-51
- “Delete a View in the Inspect Signals Tab” on page 15-52
- “Export a View in the Inspect Signals Tab” on page 15-53
- “Import a View in the Inspect Signals Tab” on page 15-53

### View Signal Data

- 1** Configure a model to log signal data. This example uses the `sldemo_f14` demo model configured to log signals: `q`, `rad/sec`, `Stick`, and `NzPilot`, `g`. For more information, see “Exporting Signal Data Using Signal Logging” on page 29-19.
- 2** Open the Simulation Data Inspector. In the **Model Diagram window**, select **Tools > Inspect Logged Signals**. For more information, see “Open the Simulation Data Inspector Tool” on page 15-69.

- 3 Click the **Record** button  to record simulation data. From the **Model Diagram window**, simulate your model. The Simulation Data Inspector tool records and displays the simulation data. To import signal data from previous simulation runs, see “Import Logged Signal Data into the Simulation Data Inspector Tool” on page 15-38.
- 4 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 “Understanding the Simulation Data Inspector Interface” on page 15-68.
- 5 Right-click the Signal Browser table title bar. Select **Columns** and uncheck **Block Name** and **Block Path**.
- 6 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**.



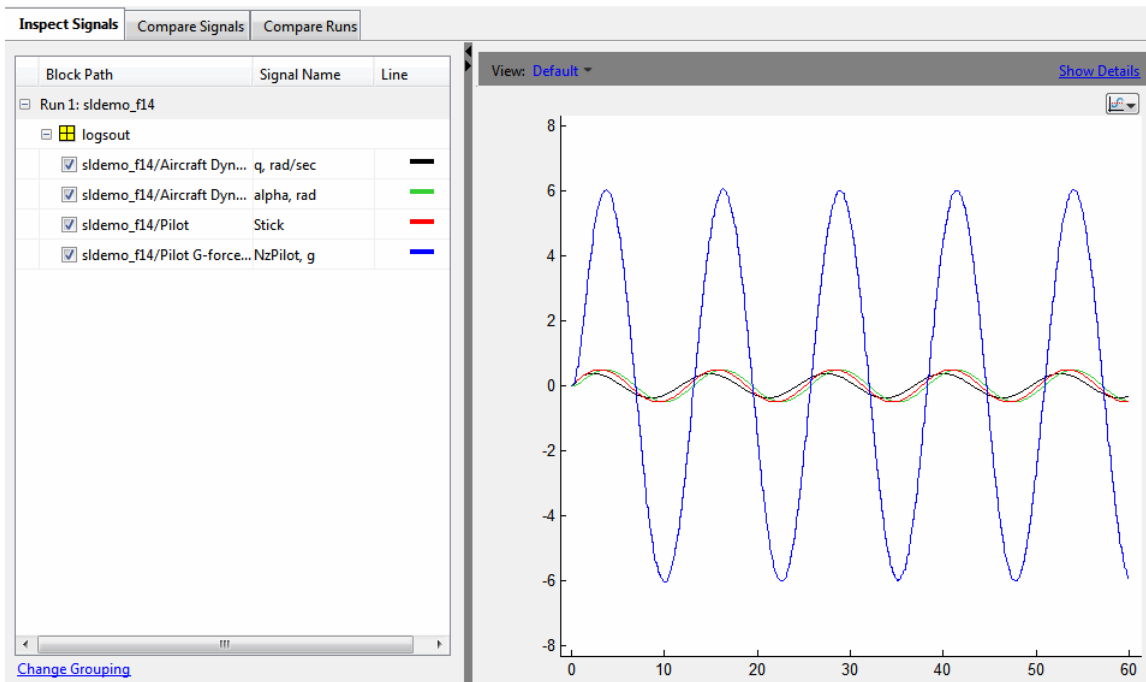
- 7 Expand logouts to view the logged signals.
- 8 “Specify the Line Configuration” on page 15-76 for each signal.
- 9 To specify the synchronization method, right-click the Signal Browser table title bar. Select **Columns** and check **Synchronization Method**. The **Sync Method** column is displayed 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.

**10** Repeat step 5 for the **Interpolation Method**.

**11** 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.

**12** 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.



**13** To create a report of the results, see “Create Simulation Data Inspector Report” on page 15-63.

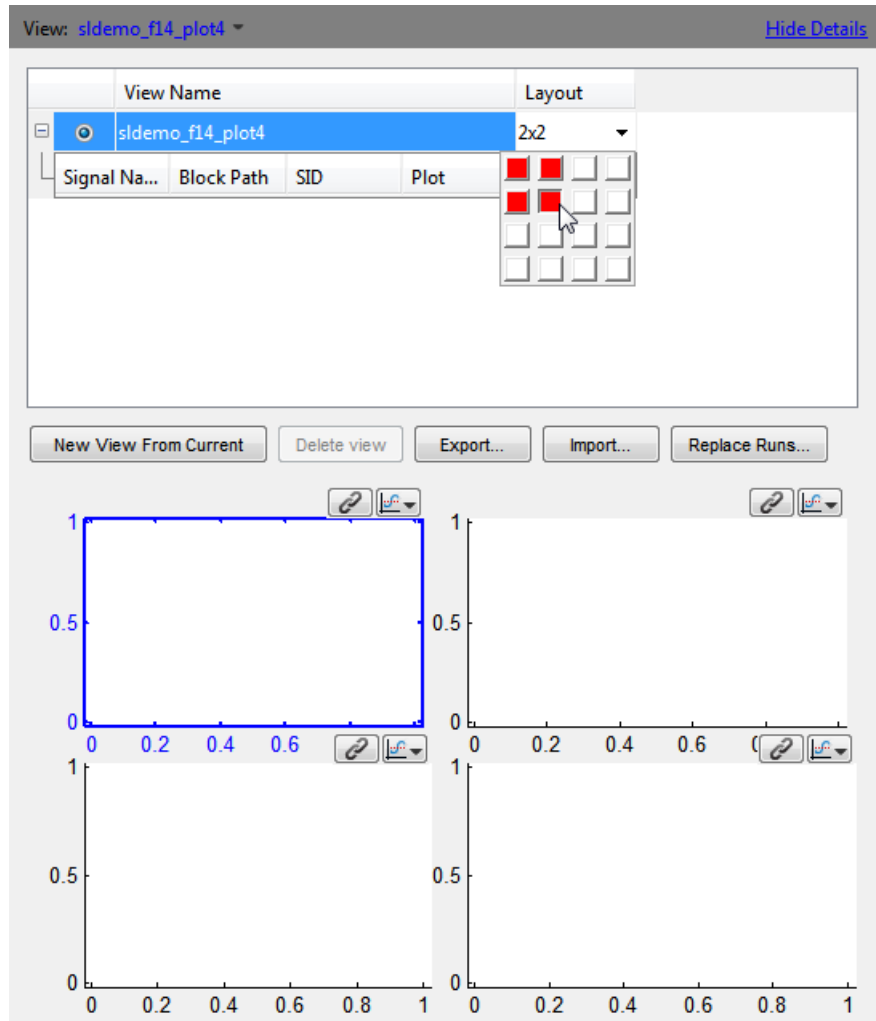
## Create a View of Multiple Plots

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 into the Simulation Data Inspector Tool” on page 15-37 or “Import Logged Signal Data into the Simulation Data Inspector Tool” on page 15-38.

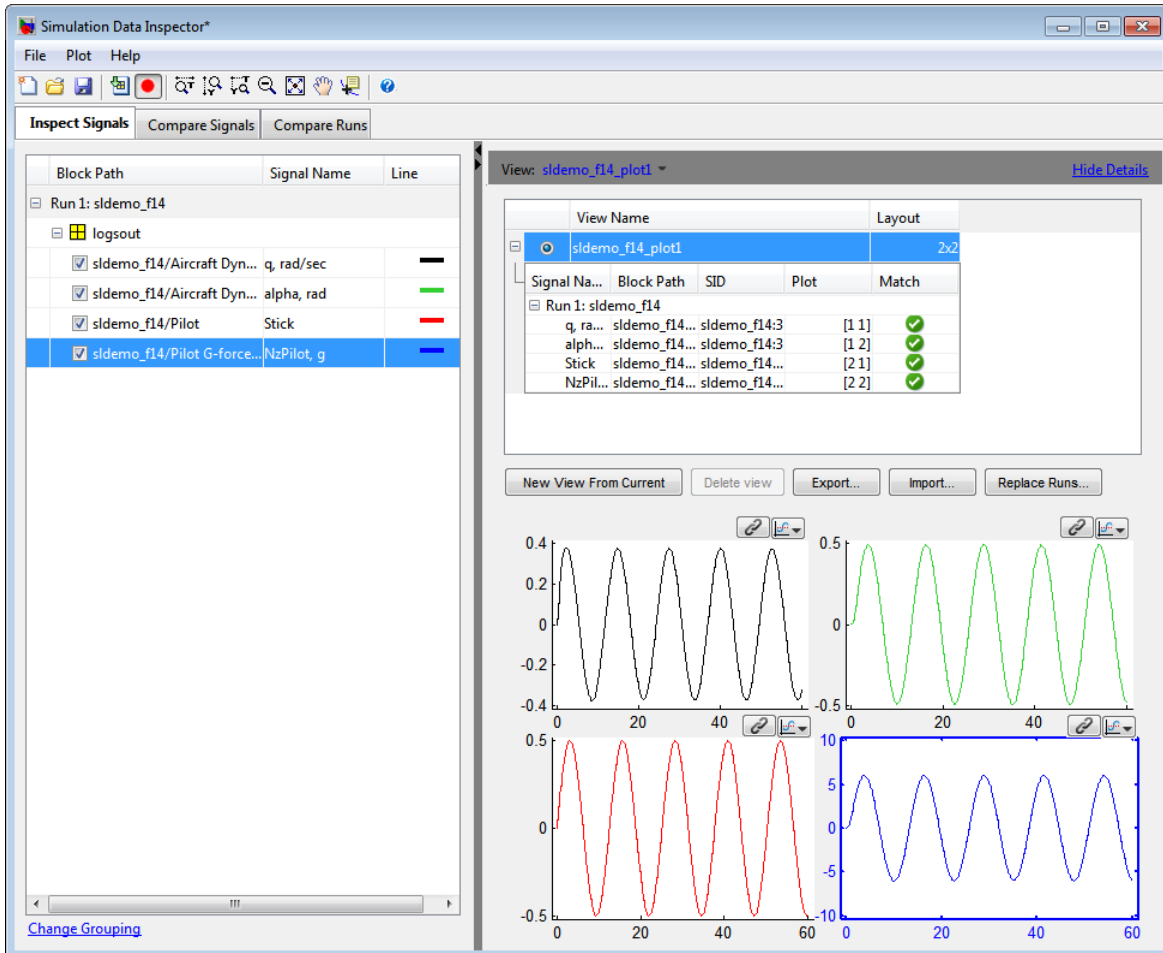
- 1 On the right pane, on the **View** toolbar, click **Show Details**.



- 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.

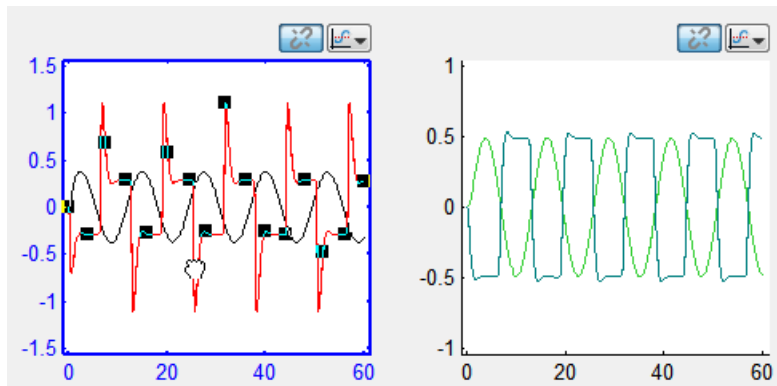
## Explore Signal Data in a Multiple Plot View

**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 15-79.

## 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.

The screenshot shows the Simulation Data Inspector (SDI) interface. The 'Replace Runs' dialog box is open, displaying the following content:

**Simulation Data Inspector: Replace Runs**

Use the "Replace Runs" tool to replace signals in one run with those of another.

1. Select a run to be replaced under "Runs in current view".
2. Select a run to replace it with under "Replace with".

To control and understand how the signals of one run will be replaced with another, select "Advanced Options".

1. Runs in current view:

- Run 1: sldemo\_f14
- Run 2: sldemo\_f14**

2. Replace with:

- Run 3: sldemo\_f14

Advanced options

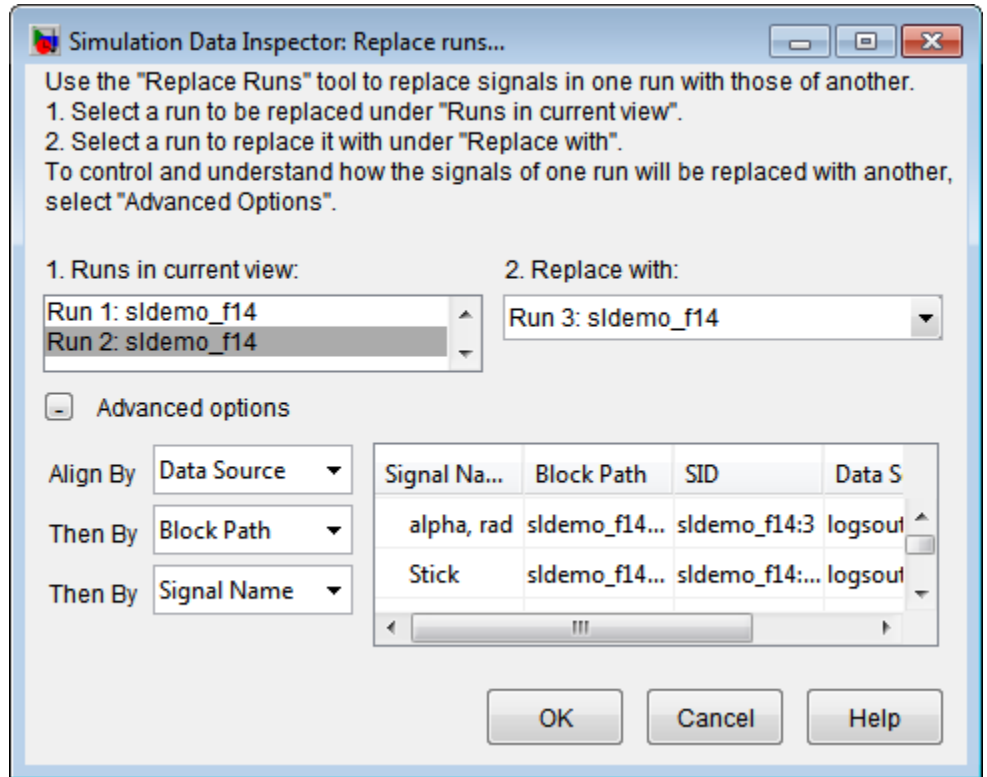
Buttons: OK, Cancel, Help

The background interface shows a tree view of signal data for 'Run 1: sldemo\_f14' and 'Run 2: sldemo\_f14'. The 'Replace Runs...' button is visible in the top right of the main interface.

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 15-65.





6 Click **OK**. The data from Run 2 is replaced with data from Run 3.

The screenshot shows the 'Inspect Signals' tab with three runs of data. The 'View Details' table for 'sldemo\_f14\_plot1' is as follows:

Signal Name	Block Path	SID	Plot	Match
Run 1: sldemo_f14				
q, ra...	sldemo_f14...	sldemo_f14:3	[1 1]	✓
alph...	sldemo_f14...	sldemo_f14:3	[1 2]	✓
NzPil...	sldemo_f14...	sldemo_f14...	[2 2]	✓
Stick	sldemo_f14...	sldemo_f14...	[2 1]	✓
Run 3: sldemo_f14				
q, ra...	sldemo_f14...	sldemo_f14:3	[1 1]	✓
alph...	sldemo_f14...	sldemo_f14:3	[1 2]	✓
Stick	sldemo_f14...	sldemo_f14...	[2 1]	✓
NzPil...	sldemo_f14...	sldemo_f14...	[2 2]	✓

Below the table are four plots showing signal waveforms for different runs. The top-left plot shows a signal with a blue box highlighting a specific region. The top-right plot shows a signal with a green box highlighting a specific region. The bottom-left plot shows a signal with a red box highlighting a specific region. The bottom-right plot shows a signal with a blue box highlighting a specific region.

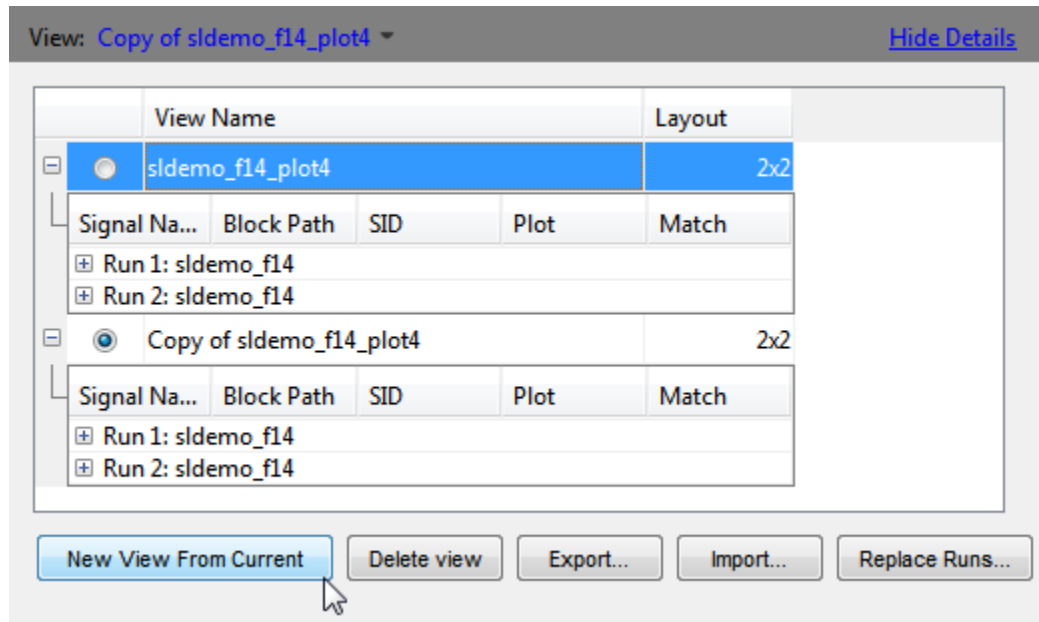
The View Details table now includes Run 3 instead of Run 2. Run 3 lists signals from Run 2. The **Match** column displays a  for a signal that aligned with a signal in Run 3. If a signal did not align, the **Match** column displays a .

## 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 15-64.

### **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 into the Simulation Data Inspector Tool” on page 15-37), or import data (see “Import Logged Signal Data into the Simulation Data Inspector Tool” on page 15-38).

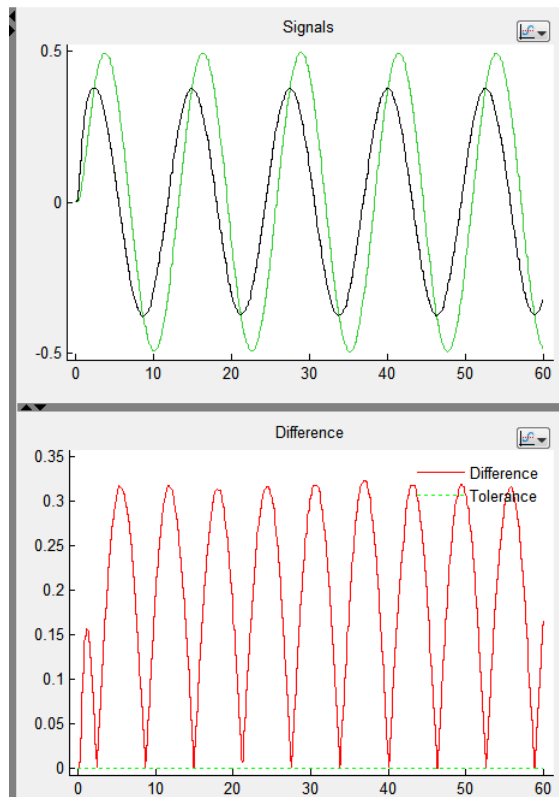
## Comparison of Signal Data

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 15-69.
- 2 Record simulation data or import data into the Simulation Data Inspector tool. See “Record Simulation Data into the Simulation Data Inspector Tool” on page 15-37 or “Import Logged Signal Data into the Simulation Data Inspector Tool” on page 15-38.
- 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 “Understanding the Simulation Data Inspector Interface” on page 15-68.
- 4 “Specify the Line Configuration” on page 15-76 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.

Inspect Signals		Compare Signals	Compare Runs	
Sig 1	Sig 2	Signal Name	Line	
[-] Run 1: sldemo_f14				
[-] [grid icon] logout				
<input type="radio"/>	<input type="radio"/>	q, rad/sec		—
<input checked="" type="radio"/>	<input checked="" type="radio"/>	alpha, rad		—
<input type="radio"/>	<input type="radio"/>	Stick		—
<input type="radio"/>	<input type="radio"/>	NzPilot, g		—

The **Signals** graph displays the signal data and the **Difference** graph displays the difference and tolerance values.



For information on manipulating the graphs, see “Understanding the Simulation Data Inspector Interface” on page 15-68.

- 7 To create a report of the results, see “Create Simulation Data Inspector Report” on page 15-63.

## Comparison of One Signal From Multiple Simulations

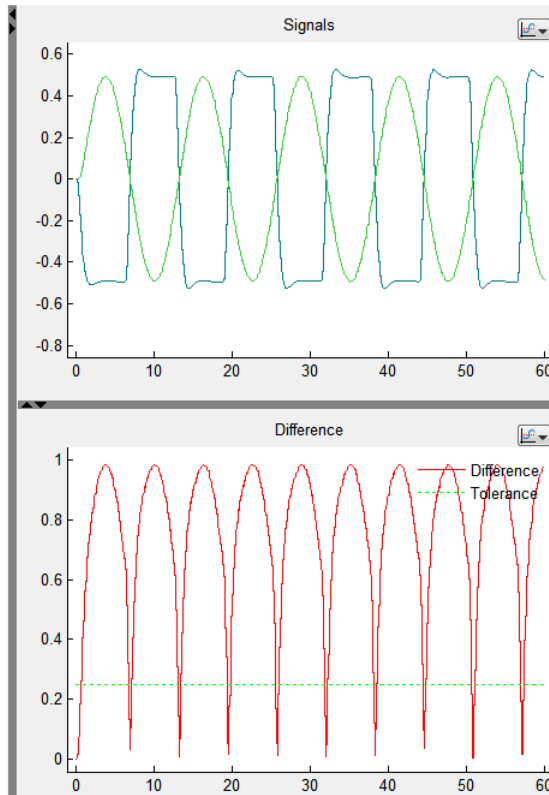
In the Simulation Data Inspector tool, you can use the **Compare Signals** tab to compare the same signal from two different simulation runs. To compare two data runs for a signal:

- 1** Open the Simulation Data Inspector tool. See “Open the Simulation Data Inspector Tool” on page 15-69.
- 2** Record simulation data or import data for two simulation runs. For more information, see “Record Simulation Data into the Simulation Data Inspector Tool” on page 15-37 or “Import Logged Signal Data into the Simulation Data Inspector Tool” on page 15-38.
- 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 “Understanding the Simulation Data Inspector Interface” on page 15-68.
- 4** “Specify the Line Configuration” on page 15-76 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.



Inspect Signals		Compare Signals	Compare Runs			
Sig 1	Sig 2	Signal Name	Line	Abs Tol	Rel Tol	
[-] Run 1: sldemo_f14						
[-] [X] logout						
<input type="radio"/>	<input type="radio"/>	q, rad/sec	—	0	0	
<input checked="" type="radio"/>	<input type="radio"/>	alpha, rad	—	.25	.05	
<input type="radio"/>	<input type="radio"/>	Stick	—	0	0	
<input type="radio"/>	<input type="radio"/>	NzPilot, g	—	0	0	
[-] Run 2: sldemo_f14						
[-] [X] logout						
<input type="radio"/>	<input type="radio"/>	q, rad/sec	—	0	0	
<input type="radio"/>	<input checked="" type="radio"/>	alpha, rad	—	.25	.05	
<input type="radio"/>	<input type="radio"/>	Stick	—	0	0	
<input type="radio"/>	<input type="radio"/>	NzPilot, g	—	0	0	

Once two signals are selected, the **Signals** graph displays the signal data and the **Difference** graph displays the difference and tolerance values.



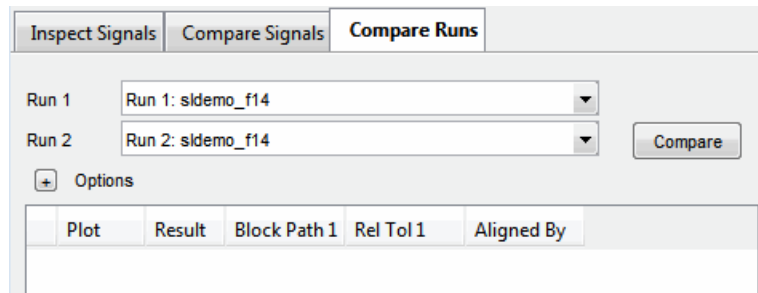
For information on manipulating the graphs, see “Understanding the Simulation Data Inspector Interface” on page 15-68.

- 8 To create a report of the results, see “Create Simulation Data Inspector Report” on page 15-63.

## Comparison of 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 15-69.
- 2 Record simulation data or import data from multiple simulation runs, for more information, see “Record Simulation Data into the Simulation Data Inspector Tool” on page 15-37 or “Import Logged Signal Data into the Simulation Data Inspector Tool” on page 15-38.
- 3 Select the **Compare Runs** tab.
- 4 From the **Run 1** and **Run 2** drop-down lists, select two different runs.

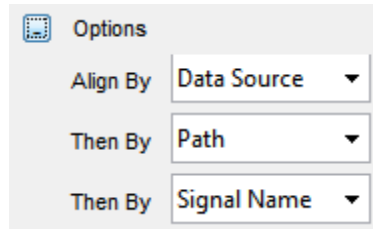



---

**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**.

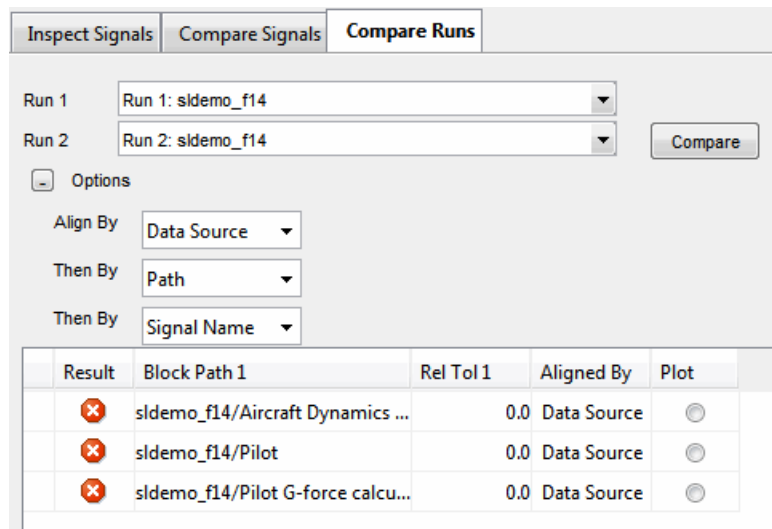
---

- 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 15-65.

- 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 ⚠.

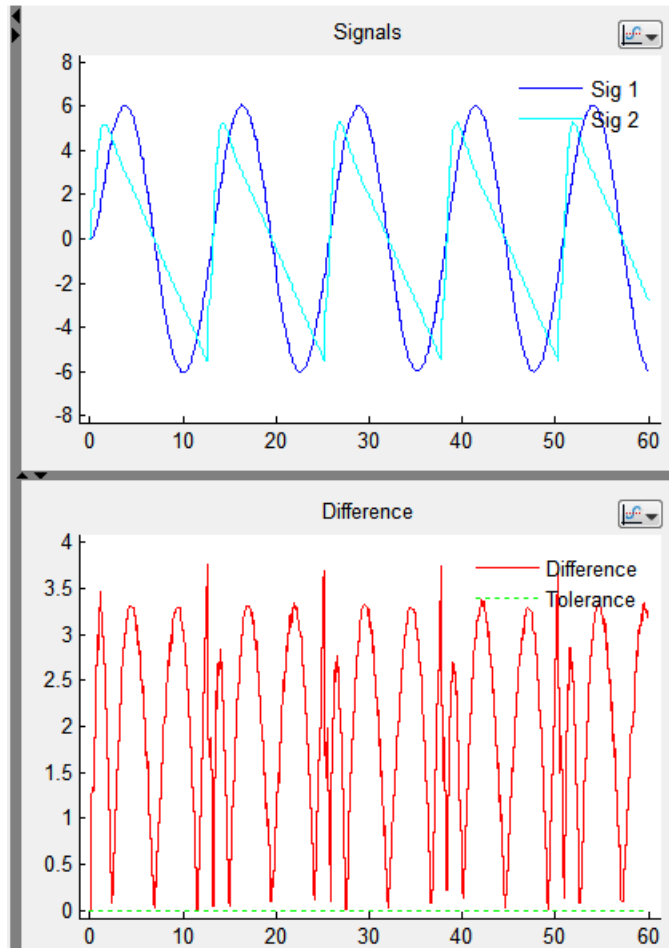
- To modify the relative tolerance and absolute tolerance, add the **Abs Tol 1** column to the Signal Browser table. Double-click the corresponding fields for a signal and type in a value.

**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**.

Result	Block Path 1	Abs Tol 1	Rel Tol 1	Aligned By
✓	sldemo_f14/Aircraft Dynamics ...	.35	0.0	Data Source
✗	sldemo_f14/Pilot	0.0	0.0	Data Source
✗	sldemo_f14/Pilot G-force calcu...	0.0	0.0	Data Source

- 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.



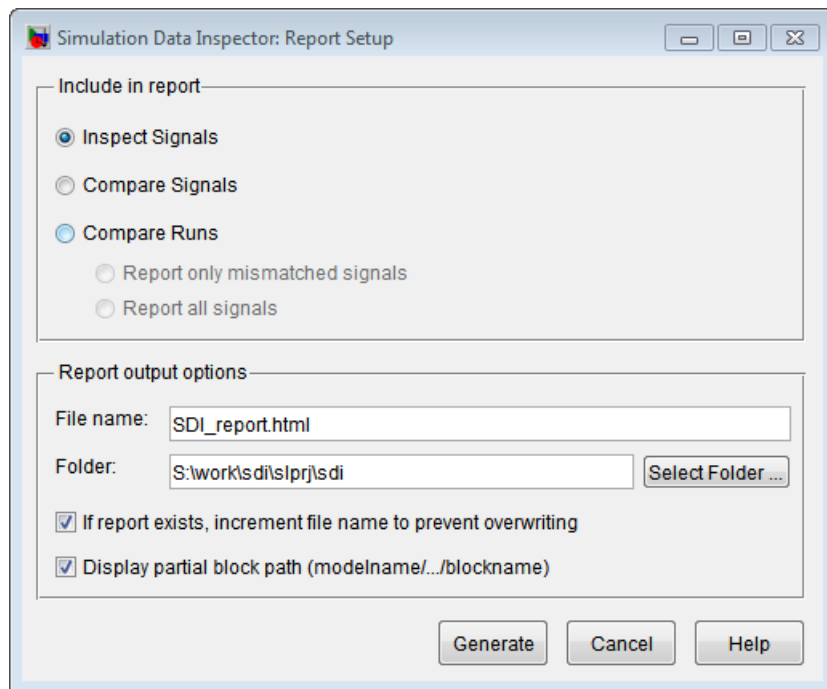
For information on manipulating the graph, see “Understanding the Simulation Data Inspector Interface” on page 15-68.

- 10** To create a report of the results, see “Create Simulation Data Inspector Report” on page 15-63.

## 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 15-65 or “Compare Runs: Aligning Signals for Comparing Signal Data” on page 15-66.

### 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
	<ul style="list-style-type: none"> <li>• Signal aligned</li> <li>• Signal data is replaced in the view</li> </ul>
	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
	<ul style="list-style-type: none"> <li>• Signal aligned</li> <li>• Signal data from two runs matched within the tolerance</li> </ul>
	<ul style="list-style-type: none"> <li>• Signal aligned</li> <li>• Signal data from two runs did not match within the tolerance</li> </ul>
	Signal from <b>Run 1</b> did not align with a signal from <b>Run 2</b>

## 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 15-67.

### 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:

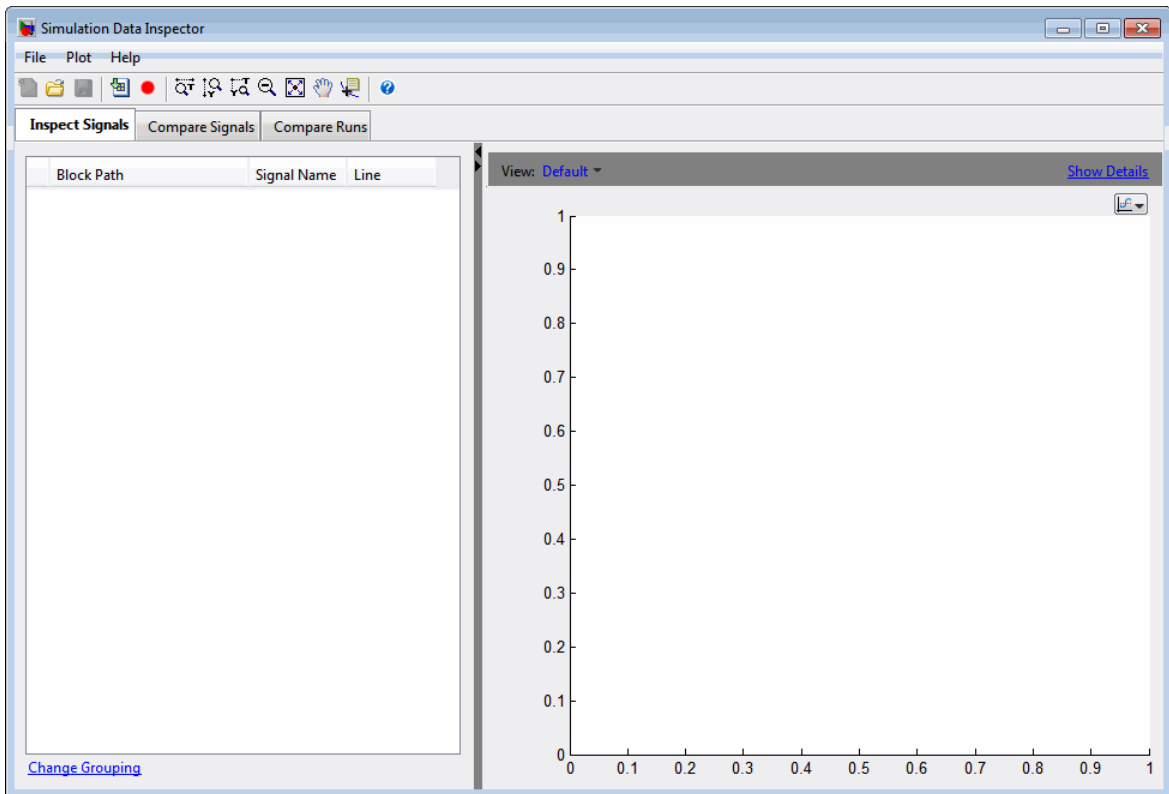
```
tolerance = max(absoluteTolerance, relativeTolerance*abs(baselineData));
```

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.

## Understanding 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 15-69 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 15-81
- 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 15-70
- “Modify Grouping in Signal Browser Table” on page 15-73
- “Rename a Run” on page 15-75
- “Select a Run or Signal Option in the Signal Browser Table” on page 15-76
- “Display Run Properties” on page 15-79

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 15-76
- “Modify a Plot in the Simulation Data Inspector Tool” on page 15-79

For more information on how to import, inspect, and compare your signal data, see “Inspecting and Comparing Logged Signal Data” on page 15-33.

## 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`
- **Model Diagram window:** Select **Tools > Inspect Logged Signals**
- **Configuration Parameters Dialog Box:** To configure your model to automatically launch the Simulation Data Inspector tool when a simulation is stopped or paused, see “Record Signal Data Automatically After Simulation” on page 15-37.

### **Why Is the Simulation Data Inspector Tool Empty?**

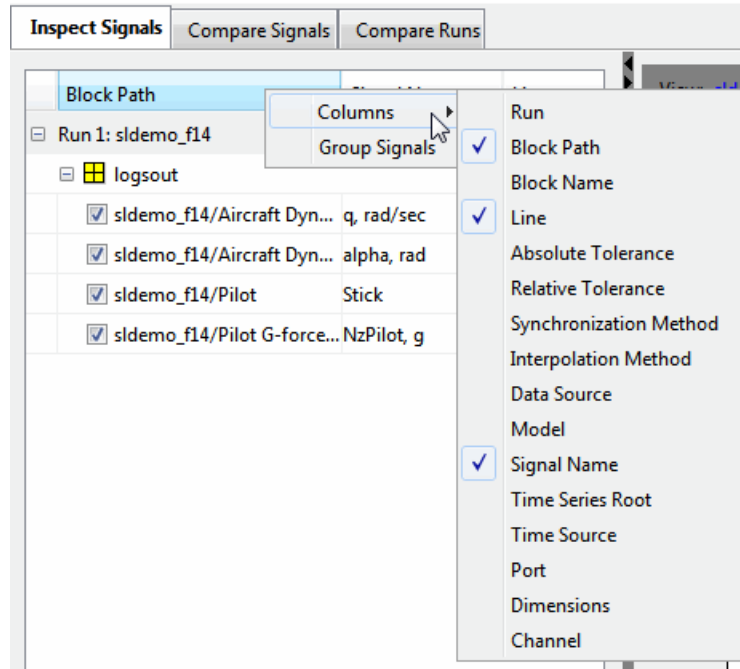
There are several methods for populating the Simulation Data Inspector with data.

- If you are using the record button to simulate and record data, your model must be setup to export signal data. For more information, see:
  - “Exporting Simulation Data” on page 29-4
  - “Exporting Signal Data Using Signal Logging” on page 29-19After your model is configured to export signal data, see “Record Simulation Data into the Simulation Data Inspector Tool” on page 15-37.
- If you want to view previously logged signal data, see “Import Logged Signal Data into the Simulation Data Inspector Tool” on page 15-38.

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 15-84.

### **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: <b>union, intersection, uniform</b> (user-specified)

**Column Options for the Inspect Signals and Compare Signals Tabs (Continued)**

<b>Column Option</b>	<b>Value</b>
<b>Interpolation Method</b>	Method to align data: <b>zoh</b> , <b>linear</b> (user-specified)
<b>Data Source</b>	Name for the data (logout.Stick.Data)
<b>Model</b>	Model name for the signal data
<b>Signal</b>	Signal name for the data (Stick)
<b>Time Series Root</b>	String signifying the name of the Simulink.Timeseries object (logout.Stick.Time)
<b>Time Source</b>	String signifying the array containing the time data (logout.Stick.Time)
<b>Port</b>	Index of the output port that emits the signal logged
<b>Dimensions</b>	Number of dimensions of the signal
<b>Channel</b>	Channel of matrix data

**Column Options for Compare Runs Tab**

<b>Column Option</b>	<b>Value</b>
<b>Result</b>	Result of the comparison for the signal across the specified runs
<b>Block Path</b>	<ul style="list-style-type: none"> <li>• <b>Run 1: Block Path</b></li> <li>• <b>Run 2: Block Path</b></li> </ul>
<b>Data Source</b>	String identifying the data source <ul style="list-style-type: none"> <li>• <b>Run 1: Data Source</b></li> <li>• <b>Run 2: Data Source</b></li> </ul>



### Column Options for Compare Runs Tab (Continued)

Column Option	Value
SID	“Simulink Identifier” <ul style="list-style-type: none"> <li>• Run 1: SID</li> <li>• Run 2: SID</li> </ul>
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

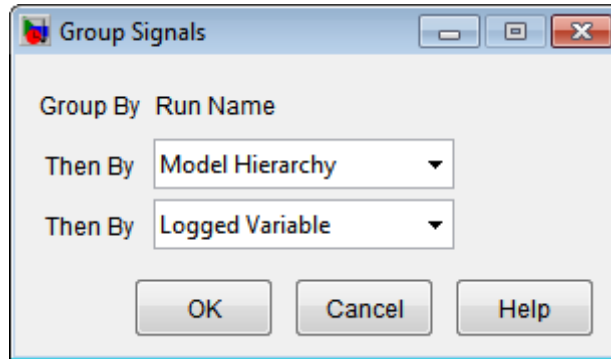
After selecting a column option, the new column is added to the table in the order that it appears in the options list.

### 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:

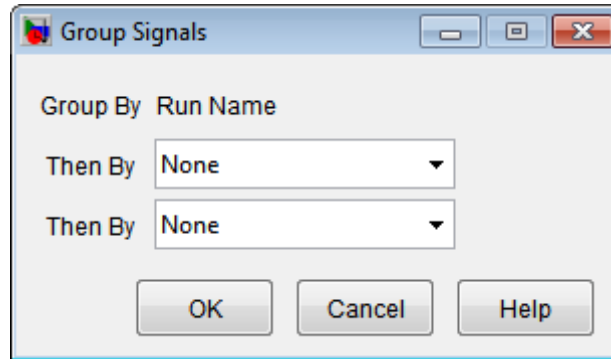
- 1 Right-click the Signal Browser table and select **Group Signals**.
- 2 In the Group Signals dialog box, in the first **Then By** list, select Model Hierarchy.
- 3 In the second **Then By** list, select Logged Variable.



- 4 Click **OK**. The Signal Browser table groups the signal data by model and then by the logged variables.

Block Name	Signal Name	Line
Run 1: sldemo_mdref_dsm		
sldemo_mdref_dsm		
yout		
Out1		—
Out1		—
logout		
A	bot_out	—
A1	bot2_out	—
Switch	swich_out	—
sldemo_mdref_dsm_bot		
dsmout		
DSM	RefSignalVal	—

To remove the hierarchy and display a simple list of logged signals, you can select None in the Group Signals dialog box.



The Signal Browser table displays the logged signals as follows:

	Block Name	Signal Name	Line
[-]	Run 1: sldemo_f14		
<input checked="" type="checkbox"/>	Aircraft Dynamics Model	q, rad/sec	—
<input checked="" type="checkbox"/>	Aircraft Dynamics Model	alpha, rad	—
<input checked="" type="checkbox"/>	Pilot	Stick	—
<input checked="" type="checkbox"/>	Pilot G-force calculation	NzPilot, g	—

## 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.

Block Path	Signal Name	Line
Run 1: sldemo_f14		
logout		
✓ sldemo_f14/Aircraft D...	q, rad/sec	—
✓ sldemo_f14/Aircraft D...	alpha, rad	—
✓ sldemo_f14/Pilot	Stick	—
✓ sldemo_f14/Pilot G-for...	NzPilot, g	—

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.

Block Path	Signal Name	Line
Run 1: sldemo_f14		
logout		
✓ sldemo_f14/Aircraft D...	q, rad/sec	—
✓ sldemo_f14/Aircraft D...	alpha, rad	
✓ sldemo_f14/Pilot	Stick	
✓ sldemo_f14/Pilot G-for...	NzPilot, g	
xout		
yout		
Run 2: sldemo_f14		
Run 3: sldemo_f14		

Line Style

Solid line

Dashed line

Dotted line

Dash-Dot line

Preview —

R 0.0 G 0.0 B 0.0

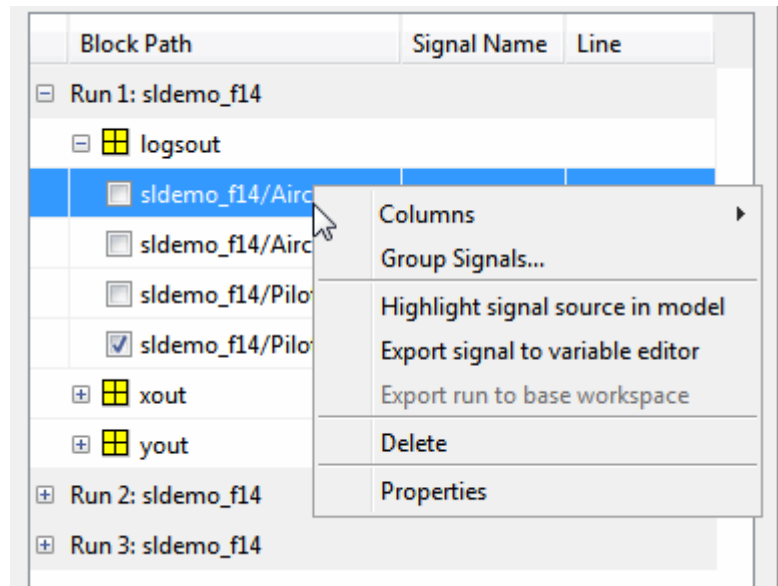
OK Cancel

2 Specify the color and the **Line Style** for the signal.

3 Click **OK**.

### Select a Run or Signal Option in the Signal Browser Table

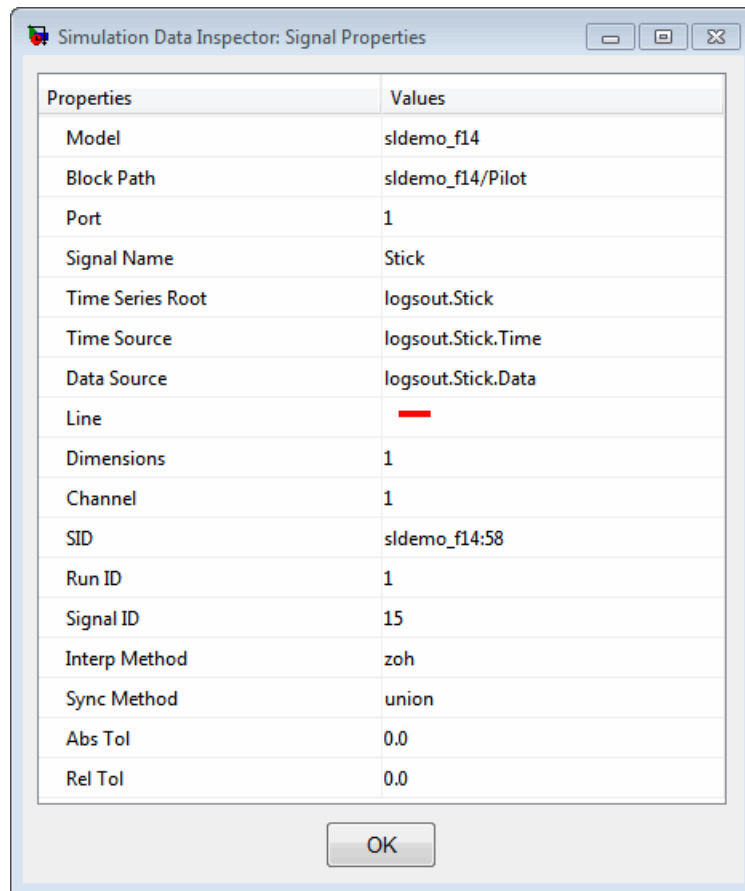
In the Signal Browser table, right-click a run or signal for a menu list of options.



To...	Select...
Display the list of Column options. See Column Options for the Inspect Signals and Compare Signals Tabs on page 15-71	<b>Columns</b>
Group signal data by the specified options: <b>Run</b> , <b>Block Path</b> , <b>Data Source</b> , <b>Model</b> , and <b>Signal Name</b> (this option does not appear in the <b>Compare Runs</b> tab)	<b>Group By</b>
Highlight the source of the selected signal in the model diagram	<b>Highlight signal source in model</b>
Open the Variable Editor and display the selected signal data	<b>Export signal to variable editor</b>
Save signal data in the run to the base workspace	<b>Export run to base workspace</b>

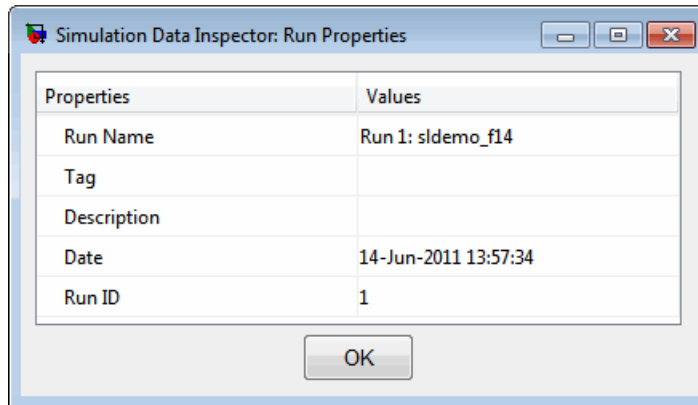
To...	Select...
Delete the highlighted signal in the Signal Browser table (this option does not appear in the <b>Compare Runs</b> tab)	<b>Delete</b>
Display the signal properties of the selected signal	<b>Properties</b>

The Signal Properties dialog box displays the following signal information.




## Display Run Properties

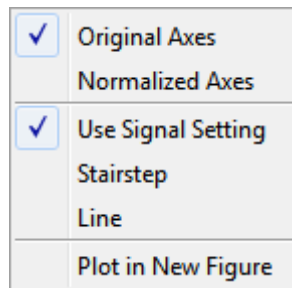
In the Signal Browser table, right-click a run name to view a list of options. To open the Run Properties dialog box, from the options list, select **Properties**.




## Modify a Plot in the Simulation Data Inspector Tool

To modify a plot, you can:

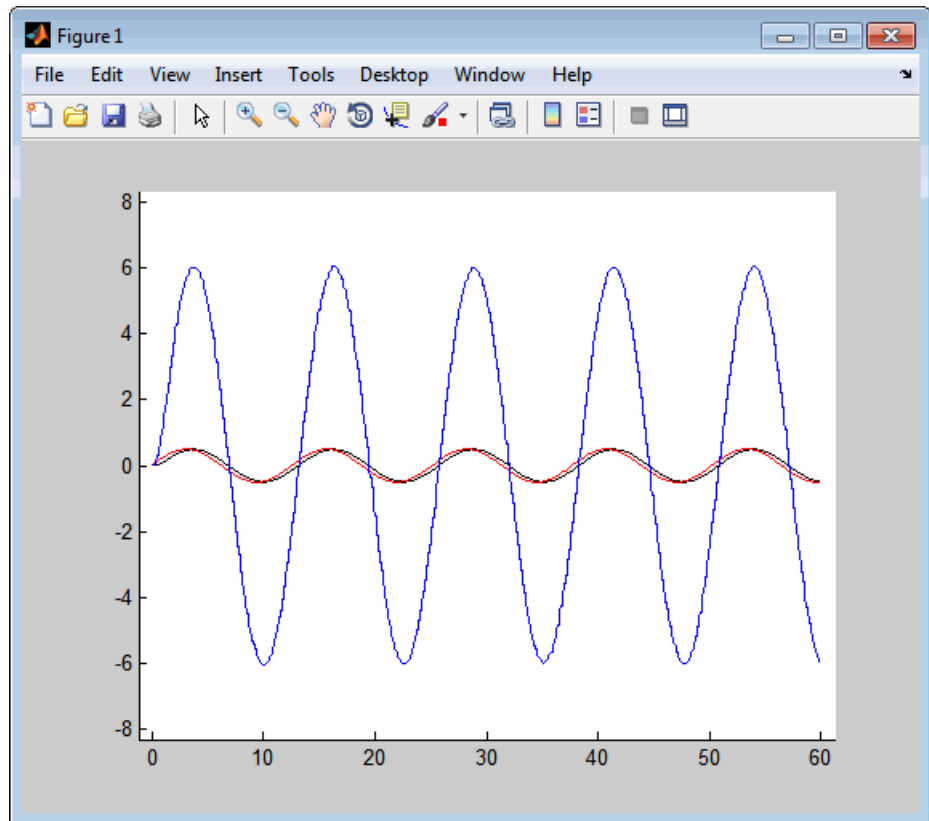
- **Toolbar:** Select icons to zoom into data, move the plot, or add a data point to the plot. For more information on these icons, see the “Toolbar” on page 15-81 section.
- **Plot options:** Click  on the plot to select alternatives for plotting the data.



To...	Simulation Data Inspector...
<b>Original Axes</b>	Plots the data according to the maximum and minimum values of the data points. (default)
<b>Normalized Axes</b>	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.
<b>Stairstep</b>	Plots the data as a stairstep plot. (default)
<b>Line</b>	Interpolates the data points and produces a linear plot.
<b>Plot in New Figure</b>	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 the *MATLAB Graphics* documentation.

To view an example, see “Create, Save, and Print a Figure”, in the *Simulink Getting Started Guide*.

### **Toolbar**

The toolbar contains the following command buttons.

<b>To...</b>	<b>Click...</b>
Clear the Simulation Data Inspector of all data.	<b>New</b> 
Open a MAT-file previously saved from the Simulation Data Inspector.	<b>Open</b> 
Save data in Simulation Data Inspector to a MAT-file.	<b>Save</b> 
Launches the Data Import tool.	<b>Import Data</b> 
Enable recording of data from a simulation. After you click the button, simulate your model and the logged data automatically populates the Simulation Data Inspector.	<b>Record</b> 
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.	<b>Zoom in T</b> 
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.	<b>Zoom in Y</b> 
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.	<b>Zoom in T and Y</b> 
Zoom out from the graph. After selecting the icon, click the graph to incrementally zoom out.	<b>Zoom Out</b> 

<b>To...</b>	<b>Click...</b>
Fit the plot to the graph. After selecting the icon, click the graph to enlarge the plot to fill the graph.	<b>Fit to View</b> 
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.	<b>Pan</b> 
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.	<b>Data Cursor</b> 

### **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	<code>Simulink.sdi.view</code>
Compare the data of two signals	<code>Simulink.sdi.compareSignals</code>
Compare the output of two simulation runs	<code>Simulink.sdi.compareRuns</code>

### 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	<code>Simulink.sdi.getRunCount</code>
Get the run ID from the list of simulation runs in the Simulation Data Inspector	<code>Simulink.sdi.getRunIDByIndex</code>
Determine if a run ID corresponds to a run currently in the Simulation Data Inspector	<code>Simulink.sdi.isValidRunID</code>
Add more data to a run currently in the Simulation Data Inspector	<code>Simulink.sdi.addToRun</code>
Make a copy of a run currently in the Simulation Data Inspector	<code>Simulink.sdi.copyRun</code>

To...	Use...
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	<code>Simulink.sdi.save</code>
Load previously saved Simulation Data Inspector session	<code>Simulink.sdi.load</code>
Clear all data from the Simulation Data Inspector	<code>Simulink.sdi.clear</code>

## 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();
```



# Analyzing Simulation Results

---

- “Viewing Output Trajectories” on page 16-2
- “Linearizing Models” on page 16-5
- “Finding Steady-State Points” on page 16-11

## Viewing Output Trajectories

### In this section...

“Viewing and Exporting Simulation Data” on page 16-2

“Using the Scope Block” on page 16-2

“Using Return Variables” on page 16-3

“Using the To Workspace Block” on page 16-3

“Using the Simulation Data Inspector Tool” on page 16-4

### 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 Chapter 29, “Importing and Exporting Simulation Data” and “Approaches for Exporting Signal Data” on page 29-4.

### Using the Scope Block

You can display output trajectories on a Scope block during simulation as illustrated by the following model.

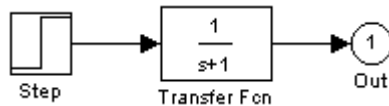


The display on the Scope shows the output trajectory. The Scope block enables you to zoom in on an area of interest or save the data to the workspace.

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.



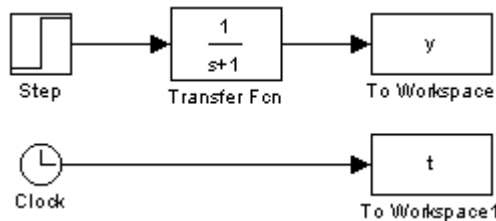
The block labeled Out is an Outport block from the Ports & Subsystems library. The output trajectory, `yout`, is returned by the integration solver. For more information, see “Data Import/Export Pane”.

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

The screenshot shows the Configuration Parameters dialog box for the Simulation Data Inspector tool. It is divided into two main sections: "Time, State, Output" and "Signals".

**Time, State, Output section:**

- Time: tout (text field) Format: Structure with time (dropdown menu)
- States: xout (text field)  Limit data points to last: 1000 (text field)
- Output: yout (text field) Decimation: 1 (text field)
- Final states: xFinal (text field)  Save complete SimState in final state

**Signals section:**

- Signal logging: log sout (text field) Signal logging format: ModelDataLogs (dropdown menu)
- Configure Signals to Log... (button)

Select the following parameters:

- **Time**
- **States**
- **Output**
- **Signal logging**
- “Format”: specify Structure with time
- “Signal logging format”: specify ModelDataLogs or Dataset

For more information on the Simulation Data Inspector tool, see “Inspecting and Comparing Logged Signal Data” on page 15-33.



## Linearizing Models

### In this section...

“About Linearizing Models” on page 16-5

“Linearization with Referenced Models” on page 16-7

“Linearization Using the ‘v5’ Algorithm” on page 16-9

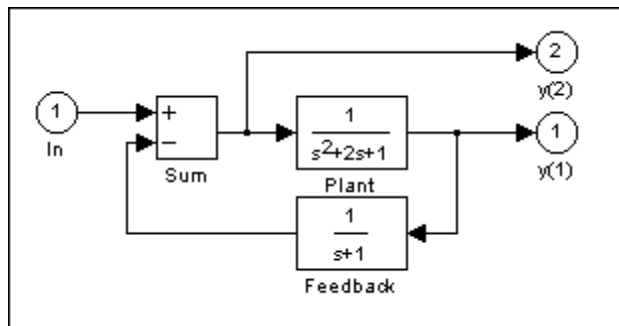
### About Linearizing Models

The Simulink product provides the `linmod`, `linmod2`, and `dlinmod` functions to extract linear models in the form of the state-space matrices  $A$ ,  $B$ ,  $C$ , and  $D$ . State-space matrices describe the linear input-output relationship as

$$\dot{x} = Ax + Bu$$

$$y = Cx + Du,$$

where  $x$ ,  $u$ , and  $y$  are state, input, and output vectors, respectively. For example, the following model is called `lmod`.



To extract the linear model of this system, enter this command.

```
[A,B,C,D] = linmod('lmod')
```

```
A =  
  -2   -1   -1  
   1    0    0  
   0    1   -1  
B =  
   1  
   0  
   0  
C =  
   0    1    0  
   0    0   -1  
D =  
   0  
   1
```

Inputs and outputs must be defined using Inport and Outport blocks from the Ports & Subsystems library. Source and sink blocks do not act as inputs and outputs. Inport blocks can be used in conjunction with source blocks, using a Sum block. Once the data is in the state-space form or converted to an LTI object, you can apply functions in the Control System Toolbox product for further analysis:

- Conversion to an LTI object

```
sys = ss(A,B,C,D);
```

- Bode phase and magnitude frequency plot

```
bode(A,B,C,D) or bode(sys)
```

- Linearized time response

```
step(A,B,C,D) or step(sys)  
impulse(A,B,C,D) or impulse(sys)  
lsim(A,B,C,D,u,t) or lsim(sys,u,t)
```

You can use other functions in the Control System Toolbox and the Robust Control Toolbox™ products for linear control system design.

When the model is nonlinear, an operating point can be chosen at which to extract the linearized model. Extra arguments to `linmod` specify the operating point.

```
[A,B,C,D] = linmod('sys', x, u)
```

For discrete systems or mixed continuous and discrete systems, use the function `dlinmod` for linearization. This function has the same calling syntax as `linmod` except that the second right-hand argument must contain a sample time at which to perform the linearization.

## Linearization with Referenced Models

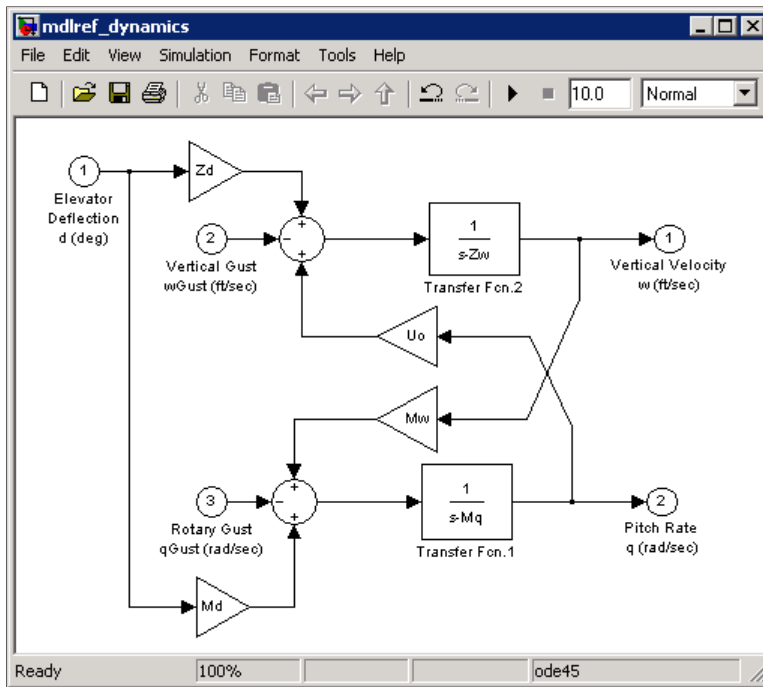
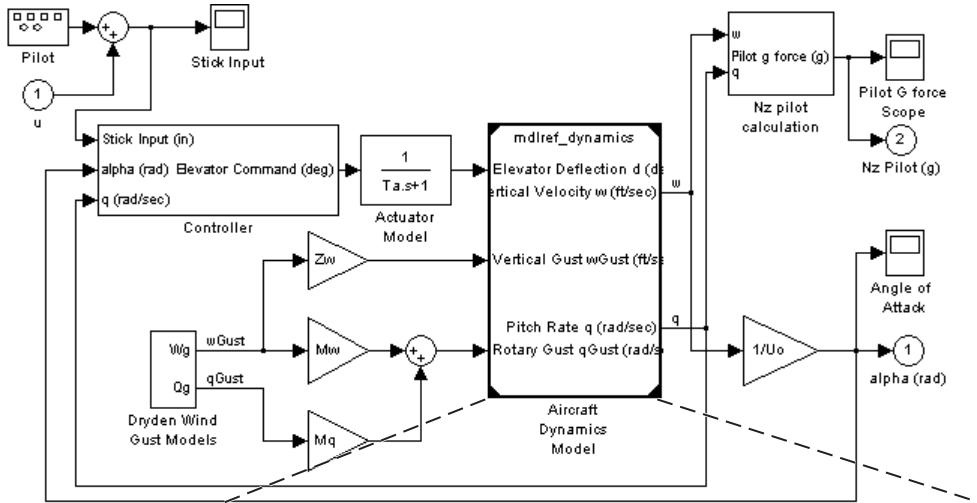
You can use `linmod` to extract a linear model from a Simulink environment that contains Model blocks.

---

**Note** In Normal mode, the `linmod` command applies the block-by-block linearization algorithm on blocks inside the referenced model. If the Model block is in Accelerator mode, the `linmod` command uses numerical perturbation to linearize the referenced model. Due to limitations on linearizing multirate Model blocks in Accelerator mode, you should use Normal mode simulation for all models referenced by Model blocks when linearizing with referenced models. See the Simulink Control Design™ documentation for an explanation of the block-by-block linearization algorithm.

---

For example, consider the f14 model `mdlref_f14.mdl`. The Aircraft Dynamics Model block refers to the model `mdlref_dynamics.mdl`.



To linearize the md1ref\_f14 model, call the `linmod` command on the top md1ref\_f14 model as follows.

```
[A,B,C,D] = linmod('mdlref_f14')
```

The resulting state-space model corresponds to the complete f14 model, including the referenced model.

You can call `linmod` with a state and input operating point for models that contain Model blocks. When using operating points, the state vector `x` refers to the total state vector for the top model and any referenced models. You must enter the state vector using the structure format. To get the complete state vector, call

```
x = Simulink.BlockDiagram.getInitialState(topModelName)
```

## Linearization Using the 'v5' Algorithm

Calling the `linmod` command with the 'v5' argument invokes the perturbation algorithm created prior to MATLAB software version 5.3. This algorithm also allows you to specify the perturbation values used to perform the perturbation of all the states and inputs of the model.

```
[A,B,C,D]=linmod('sys',x,u,para,xpert,upert,'v5')
```

Using `linmod` with the 'v5' option to linearize a model that contains Derivative or Transport Delay blocks can be troublesome. Before linearizing, replace these blocks with specially designed blocks that avoid the problems. These blocks are in the Simulink Extras library in the Linearization sublibrary.

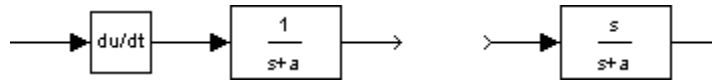
You access the Extras library by opening the Blocksets & Toolboxes icon:

- For the Derivative block, use the Switched derivative for linearization.
- For the Transport Delay block, use the Switched transport delay for linearization. (Using this block requires that you have the Control System Toolbox product.)

When using a Derivative block, you can also try to incorporate the derivative term in other blocks. For example, if you have a Derivative block in series with a Transfer Fcn block, it is better implemented (although this is not always possible) with a single Transfer Fcn block of the form

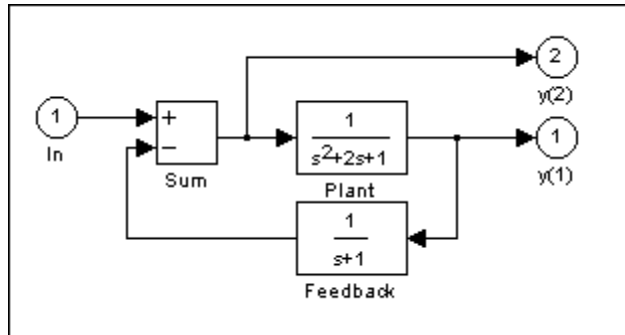
$$\frac{s}{s+a}$$

In this example, the blocks on the left of this figure can be replaced by the block on the right.



## Finding Steady-State Points

The Simulink `trim` function uses a model to determine steady-state points of a dynamic system that satisfy input, output, and state conditions that you specify. Consider, for example, this model, called `lmod`.



You can use the `trim` function to find the values of the input and the states that set both outputs to 1. First, make initial guesses for the state variables ( $x$ ) and input values ( $u$ ), then set the desired value for the output ( $y$ ).

```
x = [0; 0; 0];
u = 0;
y = [1; 1];
```

Use index variables to indicate which variables are fixed and which can vary.

```
ix = [];      % Don't fix any of the states
iu = [];      % Don't fix the input
iy = [1;2];   % Fix both output 1 and output 2
```

Invoking `trim` returns the solution. Your results might differ because of roundoff error.

```
[x,u,y,dx] = trim('lmod',x,u,y,ix,iu,iy)
```

```
x =  
    0.0000  
    1.0000  
    1.0000  
u =  
     2  
y =  
    1.0000  
    1.0000  
dx =  
    1.0e-015 *  
    -0.2220  
    -0.0227  
     0.3331
```

Note that there might be no solution to equilibrium point problems. If that is the case, `trim` returns a solution that minimizes the maximum deviation from the desired result after first trying to set the derivatives to zero. For a description of the `trim` syntax, see `trim` in the *Simulink Reference*.



# Improving Simulation Performance and Accuracy

---

- “About Improving Performance and Accuracy” on page 17-2
- “Speeding Up the Simulation” on page 17-3
- “Comparing Performance” on page 17-5
- “Improving Acceleration Mode Performance” on page 17-9
- “Improving Simulation Accuracy” on page 17-11

### **About Improving Performance and Accuracy**

Simulation performance and accuracy can be affected by many things, including the model design and choice of configuration parameters.

The solvers handle most model simulations accurately and efficiently with their default parameter values. However, some models yield better results if you adjust solver parameters. Also, if you know information about your model's behavior, your simulation results can be improved if you provide this information to the solver.

## Speeding Up the Simulation

Slow simulation speed can have many causes. Here are a few:

- Your model includes 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 2-40.
- Your model feeds a Random Number block into an Integrator block. For continuous systems, use the Band-Limited White Noise block in the Sources library.

- Your model contains a scope viewer that displays a large number of data points. Try adjusting the viewer parameter settings that can affect performance. For more information, see “How Scope Signal Viewer Parameter Settings Can Affect Performance” on page 15-21.

## Comparing Performance

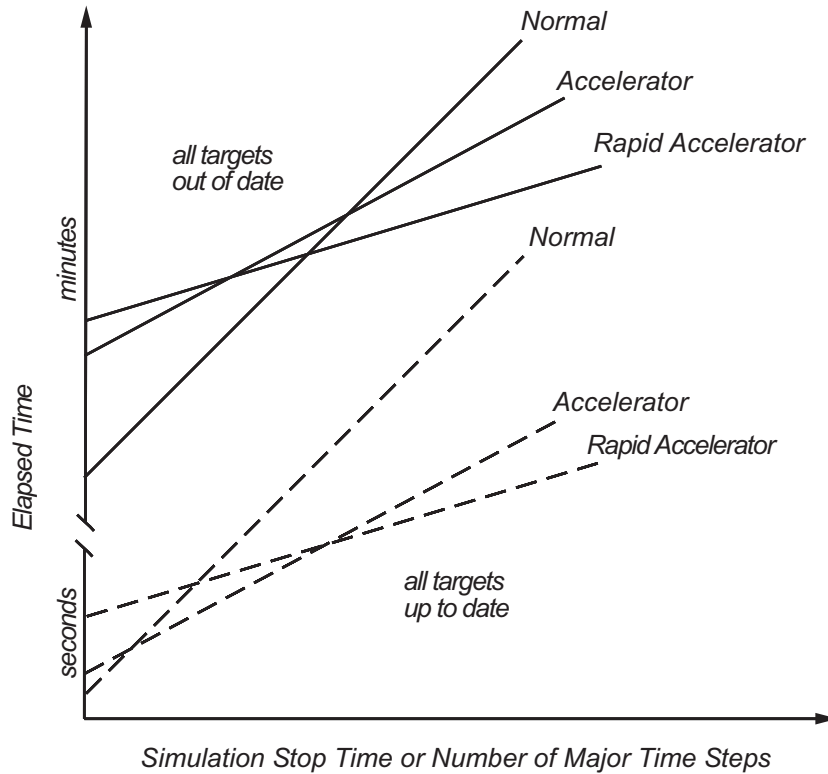
In this section...
“Performance of the Simulation Modes” on page 17-5
“Measuring Performance” on page 17-7

### 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 “Selecting Blocks for Accelerator Mode” on page 19-15) 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.

### **Measuring Performance**

You can use the `tic`, `toc`, and `sim` commands to compare Accelerator mode or Rapid Accelerator mode execution times to Normal mode.

**1** Use `load_system` to load your model into memory without opening a window.

**2** From the **Simulation** menu, select **Normal**.

**3** Use the `tic`, `toc`, and `sim` commands at the command line prompt to measure how long the model takes to simulate in Normal mode:

```
tic,[t,x,y]=sim('myModel',10000);toc
```

`tic` and `toc` work together to record and return the elapsed time and display a message such as the following:

```
Elapsed time is 17.789364 seconds.
```

**4** Select either **Accelerator** or **Rapid Accelerator** from the **Simulation** menu, and build an executable for the model by clicking the **Start** button. The acceleration modes use this executable in subsequent simulations as long as the model remains structurally unchanged. “Code Regeneration in Accelerated Models” on page 19-7 discusses the things that cause your model to rebuild.

**5** Rerun the compiled model at the command prompt:

```
tic,[t,x,y]=sim('myModel',10000);toc
```

**6** The elapsed time displayed shows the run time for the accelerated model. For example:

```
Elapsed time is 12.419914 seconds.
```

The difference in elapsed times (5.369450 seconds in this example) shows the improvement obtained by accelerating your model.



## Improving Acceleration Mode Performance

### In this section...

“Techniques” on page 17-9

“C Compilers” on page 17-10

### 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 “Controlling S-Function Execution” on page 19-16 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 “Customizing the Build Process” on page 19-21 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/](http://www.mathworks.com/support/compilers/current_release/)

---

## Improving Simulation Accuracy

To check your simulation accuracy, run the simulation over a reasonable time span. Then, either reduce the relative tolerance to 1e-4 (the default is 1e-3) or reduce the absolute tolerance and run it again. Compare the results of both simulations. If the results are not significantly different, you can feel confident that the solution has converged.

If the simulation misses significant behavior at its start, reduce the initial step size to ensure that the simulation does not step over the significant behavior.

If the simulation results become unstable over time,

- Your system might be unstable.
- If you are using `ode15s`, you might need to restrict the maximum order to 2 (the maximum order for which the solver is A-stable) or try using the `ode23s` solver.

If the simulation results do not appear to be accurate,

- For a model that has states whose values approach zero, if the absolute tolerance parameter is too large, the simulation takes too few steps around areas of near-zero state values. Reduce this parameter value or adjust it for individual states in the Integrator dialog box.
- If reducing the absolute tolerances does not sufficiently improve the accuracy, reduce the size of the relative tolerance parameter to reduce the acceptable error and force smaller step sizes and more steps.

Certain modeling constructs can also produce unexpected or inaccurate simulation results.

- A Source block that inherits its sample time can produce different simulation results if, for example, the sample times of the downstream blocks are modified (see “How Propagation Affects Inherited Sample Times” on page 4-29).
- A Derivative block found in an algebraic loop can result in a loss in solver accuracy.



# Simulink Debugger

---

- “Introduction to the Debugger” on page 18-2
- “Using the Debugger’s Graphical User Interface” on page 18-3
- “Using the Debugger’s Command-Line Interface” on page 18-11
- “Getting Online Help” on page 18-13
- “Starting the Simulink Debugger” on page 18-14
- “Starting a Simulation” on page 18-16
- “Running a Simulation Step by Step” on page 18-20
- “Setting Breakpoints” on page 18-28
- “Displaying Information About the Simulation” on page 18-34
- “Displaying Information About the Model” on page 18-40

## Introduction to the Debugger

With the debugger, you run your simulation method by method. You can stop after each method to examine the execution results. In this way, you can pinpoint problems in your model to specific blocks, parameters, or interconnections.

---

**Note** Methods are functions that the Simulink software uses to solve a model at each time step during the simulation. Blocks are made up of multiple methods. “Block execution” in this documentation is shorthand for “block methods execution.” Block diagram execution is a multi-step operation that requires execution of the different block methods in all the blocks in a diagram at various points during the process of solving a model at each time step during simulation, as specified by the simulation loop.

---

The debugger has both a graphical and a command-line user interface. The graphical interface allows you to access the most commonly used features of the debugger. The command-line interface gives you access to all of the capabilities in the debugger. If you can use either to perform a task, the documentation shows you first how to use the graphical interface, then the command-line interface.

## Using the Debugger's Graphical User Interface

### In this section...

“Displaying the Graphical Interface” on page 18-3

“Toolbar” on page 18-4

“Breakpoints Pane” on page 18-6

“Simulation Loop Pane” on page 18-7

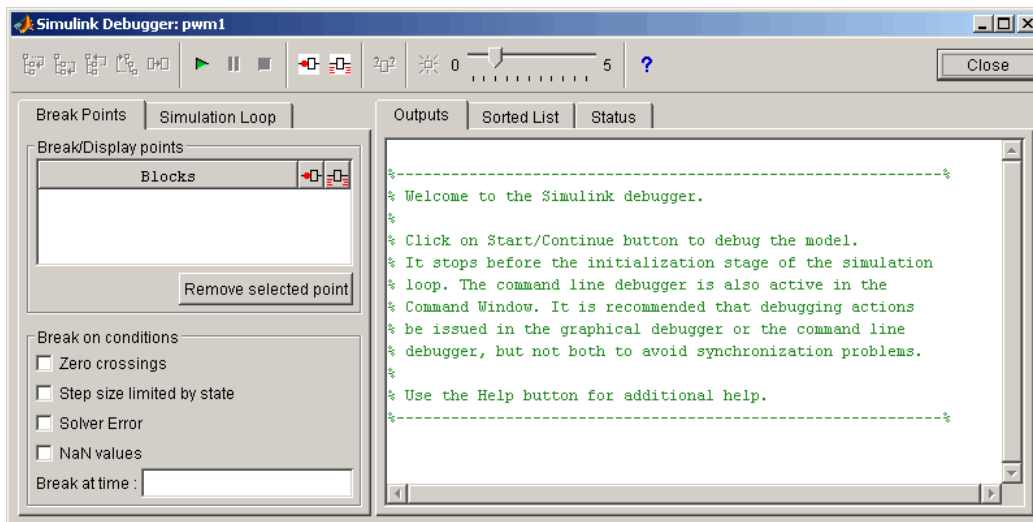
“Outputs Pane” on page 18-8

“Sorted List Pane” on page 18-9

“Status Pane” on page 18-10

### Displaying the Graphical Interface

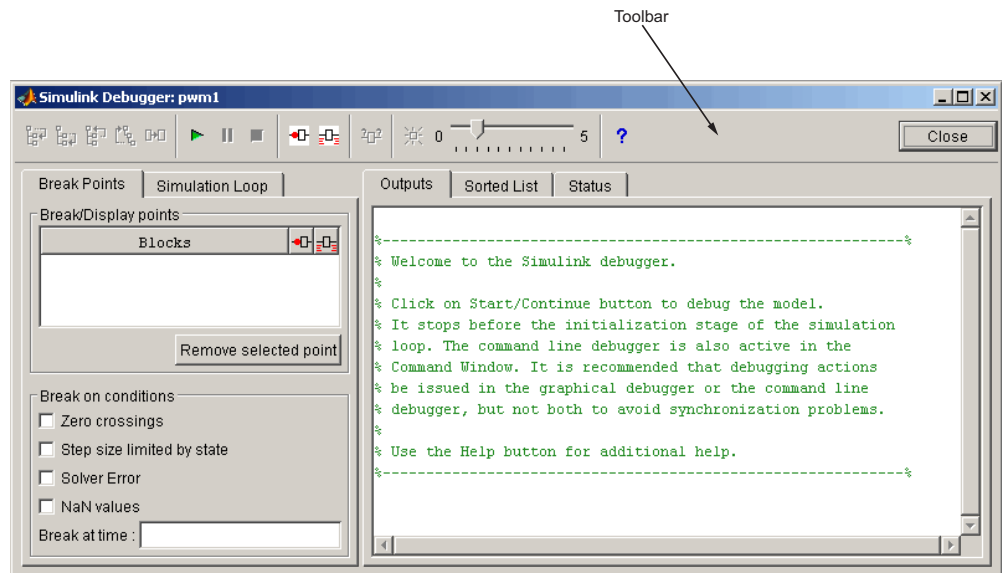
Select **Simulink Debugger** from a model window's **Tools** menu to display the debugger graphical interface.





**Note** The debugger graphical user interface does not display state or solver information. The command line interface does provide this information. See “Displaying System States” on page 18-38 and “Displaying Solver Information” on page 18-39.

## Toolbar












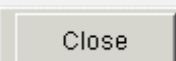
The debugger toolbar appears at the top of the debugger window.



From left to right, the toolbar contains the following command buttons:

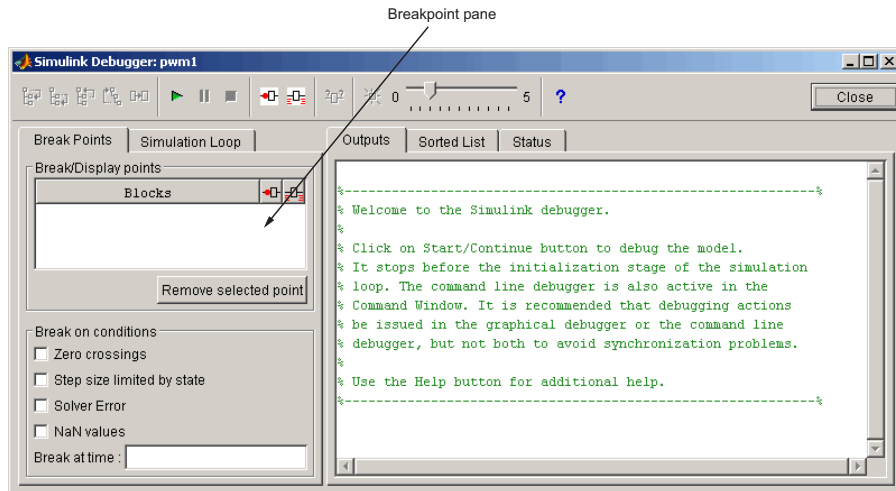
Button	Purpose
	Step into the next method (see “Stepping Commands” on page 18-22 for more information on this command, and the following stepping commands).
	Step over the next method.



Button	Purpose
	Step out of the current method.
	Step to the first method at the start of next time step.
	Step to the next block method.
	Start or continue the simulation.
	Pause the simulation.
	Stop the simulation.
	Break before the selected block.
	Display inputs and outputs of the selected block when executed (same as trace gcb).
	Display the current inputs and outputs of selected block (same as probe gcb).
	Toggle animation mode on or off (see “Animation Mode” on page 18-24). The slider next to this button controls the animation rate.
	Display help for the debugger.
	Close the debugger.

## Breakpoints Pane

To display the **Breakpoints** pane, select the **Break Points** tab on the debugger window.



The **Breakpoints** pane allows you to specify block methods or conditions at which to stop a simulation. See “Setting Breakpoints” on page 18-28 for more information.

---

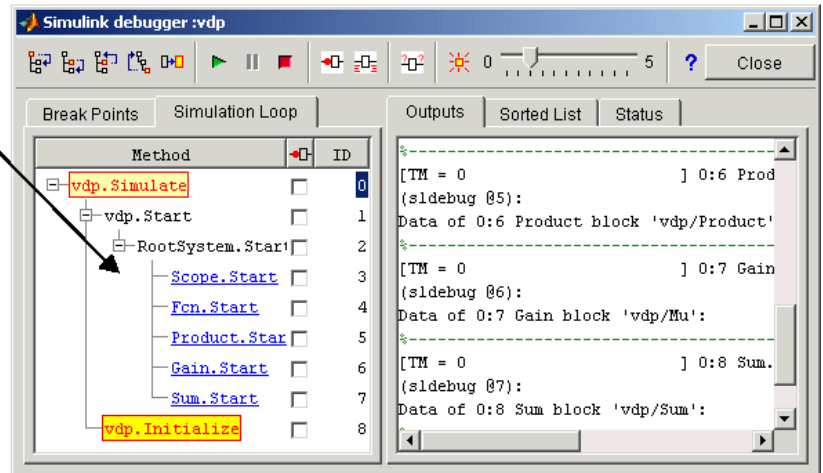
**Note** The debugger grays out and disables the **Breakpoints** pane when you select animation mode (see “Animation Mode” on page 18-24). This prevents you from setting breakpoints and indicates that animation mode ignores existing breakpoints.

---

## Simulation Loop Pane

To display the **Simulation Loop** pane, select the **Simulation Loop** tab on the debugger window.

Simulation Loop pane



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 18-30 for more information.

---

**Note** This column is disabled when its animation mode is selected (see “Animation Mode” on page 18-24), because in animation mode you can’t set breakpoints.

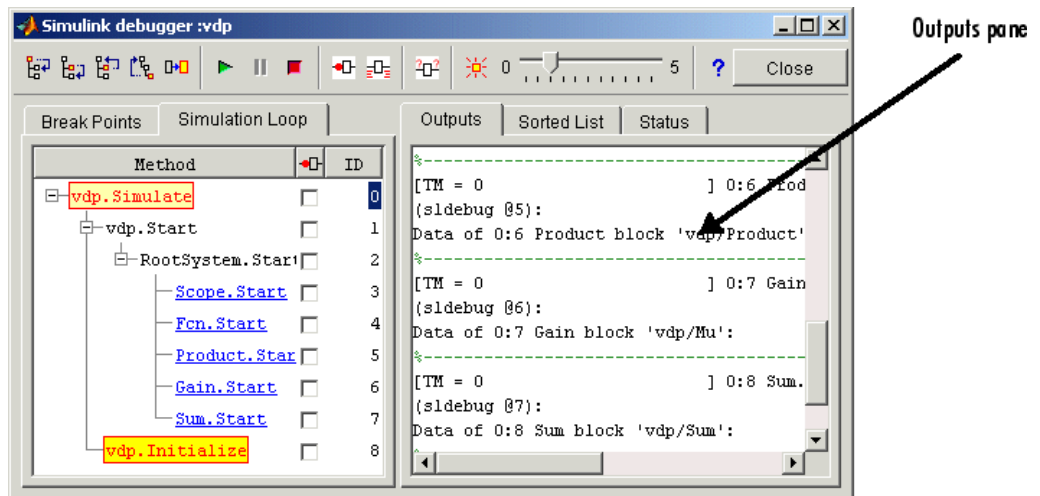
---

## ID Column

The ID column lists the IDs of the methods listed in the **Methods** column. See “Method ID” on page 18-11 for more information.

## Outputs Pane

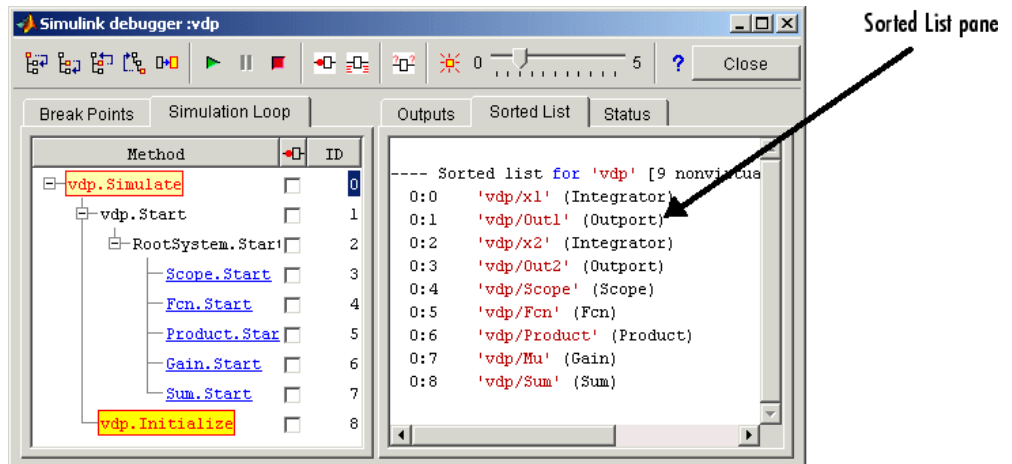
To display the **Outputs** pane, select the **Outputs** tab on the debugger window.



The Outputs pane displays the same debugger output that would appear in the MATLAB command window if the debugger were running in command-line mode. The output includes the debugger command prompt and the inputs, outputs, and states of the block at whose method the simulation is currently paused (see “Block Data Output” on page 18-21). The command prompt displays current simulation time and the name and index of the method in which the debugger is currently stopped (see “Block ID” on page 18-11).

## Sorted List Pane

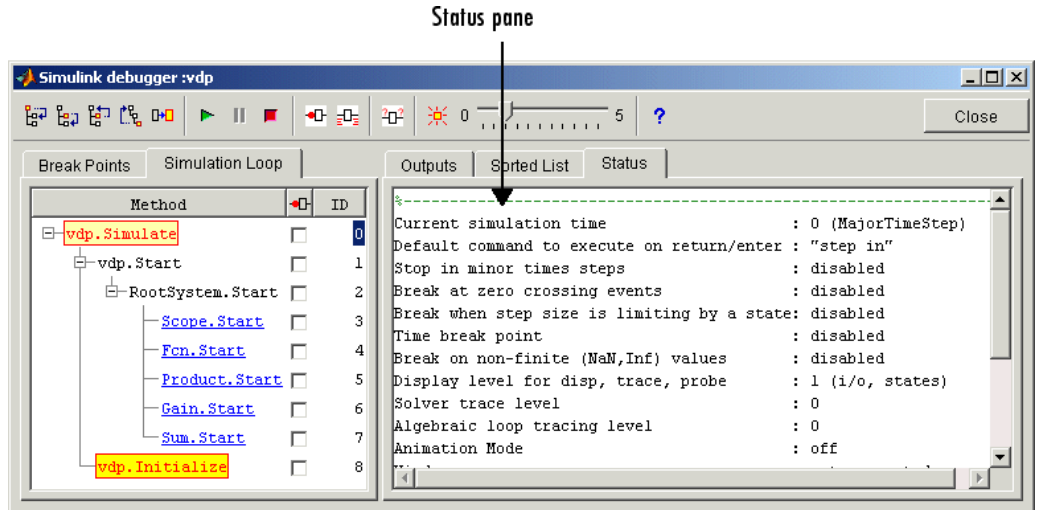
To display the **Sorted List** pane, select the **Sorted List** tab on the debugger window.



The **Sorted List** pane displays the sorted lists for the model being debugged. See “Displaying a Models Sorted Lists” on page 18-40 for more information.

## Status Pane

To display the **Status** pane, select the **Status** tab on the debugger window.



The **Status** pane displays the values of various debugger options and other status information.

## Using the Debugger's Command-Line Interface

### In this section...

“Controlling the Debugger” on page 18-11

“Method ID” on page 18-11

“Block ID” on page 18-11

“Accessing the MATLAB Workspace” on page 18-12

### Controlling the Debugger

In command-line mode, you control the debugger by entering commands at the debugger command line in the MATLAB Command Window. The debugger accepts abbreviations for debugger commands. See “Simulink Debugger Commands” for a list of command abbreviations and repeatable commands.

---

**Note** You can repeat some commands by entering an empty command (i.e., by pressing the **Enter** key) at the command line.

---

### Method ID

Some of the Simulink software commands and messages use method IDs to refer to methods. A method ID is an integer assigned to a method the first time the method is invoked. The debugger assigns method indexes sequentially, starting with 0.

### Block ID

Some of the debugger commands and messages use block IDs to refer to blocks. Block IDs are assigned to blocks while generating the model's sorted lists during the compilation phase of the simulation. A block ID has the form `sysIdx:blkIdx`, where `sysIdx` is an integer identifying the system that contains the block (either the root system or a nonvirtual subsystem) and `blkIdx` is the position of the block in the system's sorted list. For example, the block ID `0:1` refers to the first block in the model's root system. The `slist` command shows the block ID for each debugged block in the model.

## Accessing the MATLAB Workspace

You can enter any MATLAB expression at the `sldebug` prompt. For example, suppose you are at a breakpoint and you are logging time and output of your model as `tout` and `yout`. The following command creates a plot.

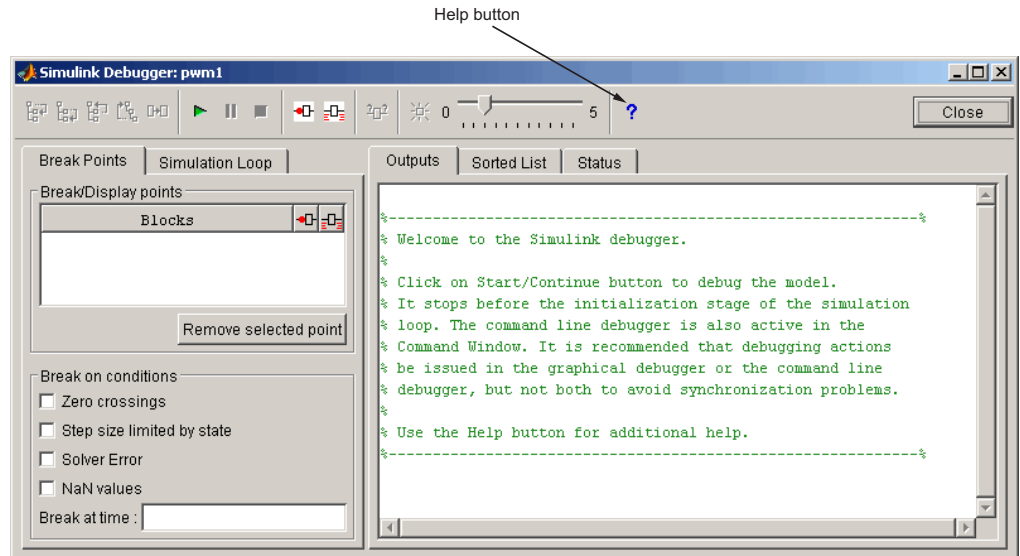
```
(sldebug ...) plot(tout, yout)
```

You cannot display the value of a workspace variable whose name is partially or entirely the same as that of a debugger command by entering it at the debugger command prompt. You can, however, use the `eval` command to work around this problem. For example, use `eval('s')` to determine the value of `s` rather than `s(tep)` the simulation.



## Getting Online Help

You can get online help on using the debugger by clicking the **Help** button on the debugger toolbar. Clicking the **Help** button displays help for the debugger in the MATLAB product Help browser.



In command-line mode, you can get a brief description of the debugger commands by typing `help` at the debug prompt.

## Starting the Simulink Debugger

You can start the debugger from either a Simulink model window or from the MATLAB Command Window.

### In this section...

“Starting from a Model Window” on page 18-14

“Starting from the Command Window” on page 18-14

### Starting from a Model Window

- 1 In a model window, select **Tools > Simulink Debugger**.

The debugger graphical user interface opens. See “Using the Debugger’s Graphical User Interface” on page 18-3.

- 2 Continue selecting toolbar buttons.

---

**Note** When running the debugger in graphical user interface (GUI) mode, you must explicitly start the simulation. For more information, see “Starting a Simulation” on page 18-16.

---

### Starting from the Command Window

- 1 In the MATLAB Command Window, enter either
  - the `sim` command. For example, enter

```
sim('vdp', 'StopTime', '10', 'debug', 'on')
```
  - or the `sldebug` command. For example, enter

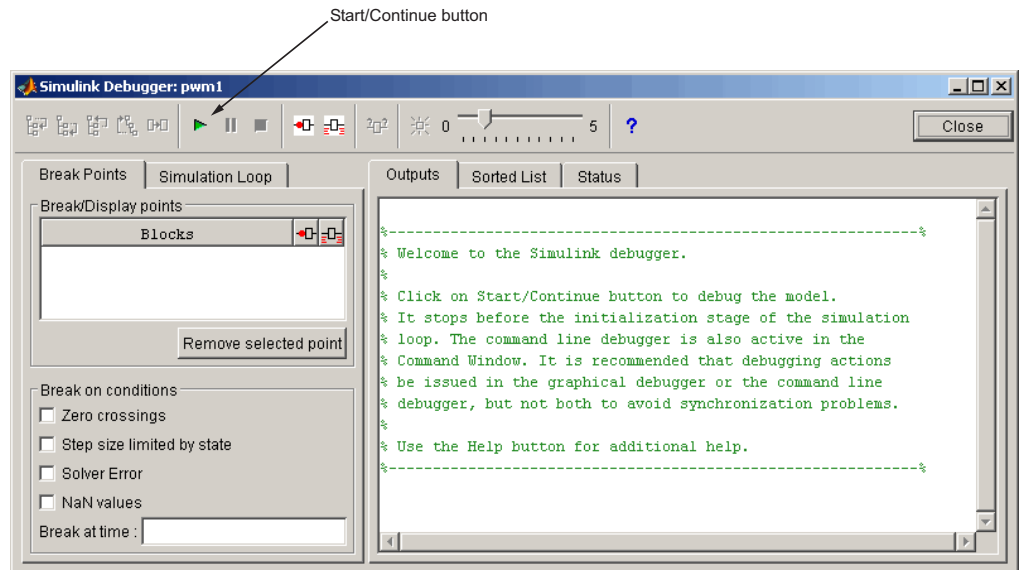
```
sldebug 'vdp'
```

In both cases, the demo model `vdp` loads into memory, starts the simulation, and stops the simulation at the first block in the model execution list.

**2** Continue entering debugger commands.

## Starting a Simulation

To start the simulation, click the **Start/Continue** button on the debugger toolbar.

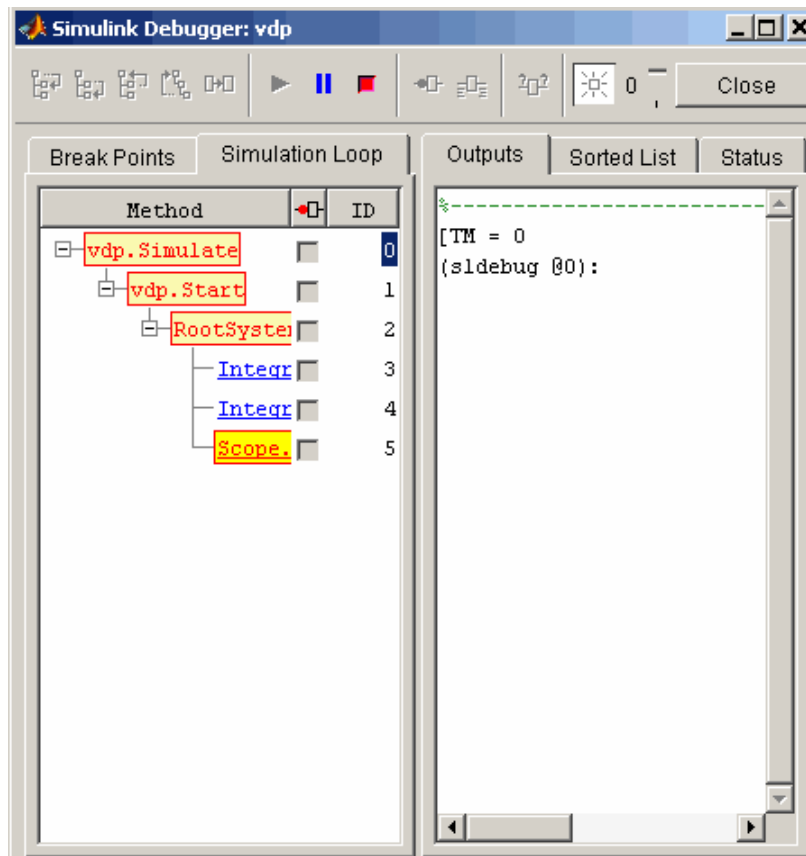


The simulation starts and stops at the first simulation method that is to be executed. It displays the name of the method in its **Simulation Loop** pane and in the debug pointer on the block diagram. The debug pointer indicates on the block diagram which block method is being executed at each step. At this point, you can

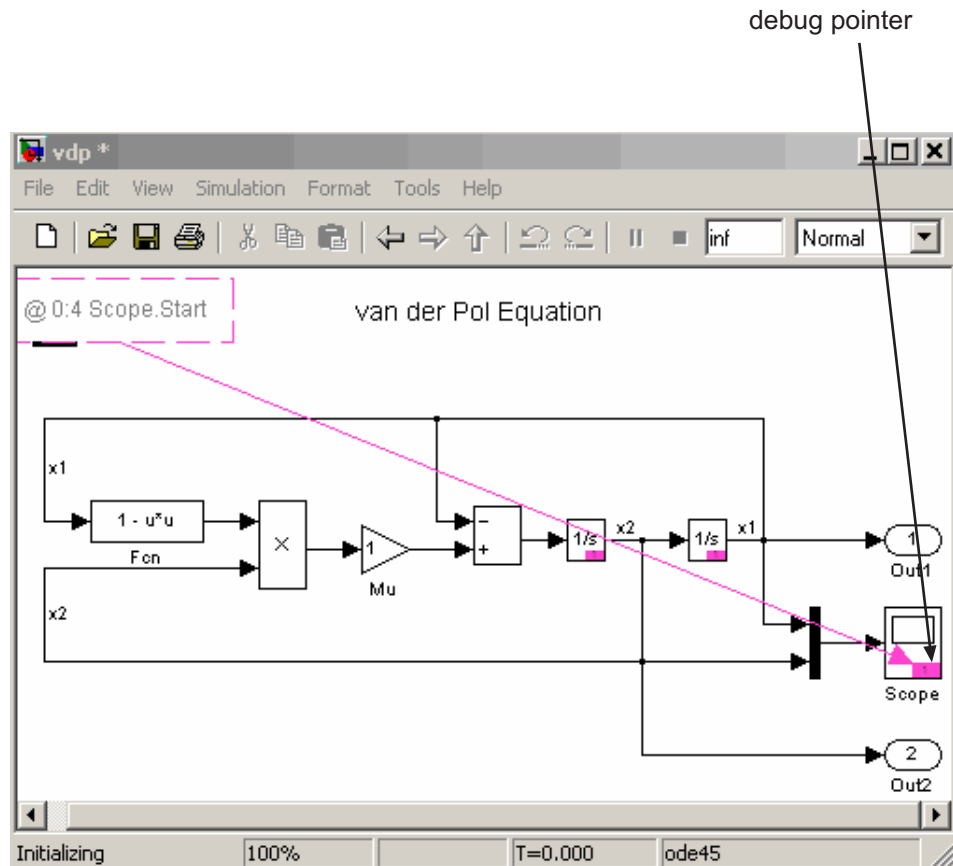
- Set breakpoints.
- Run the simulation step by step.
- Continue the simulation to the next breakpoint or end.
- Examine data.
- Perform other debugging tasks.

As the simulation progresses, the block diagram updates with debug pointers.

The debugger displays the name of the method in the Simulation Loop pane, as shown in the following figure:



The debugger also displays a graphical debug pointer (see “Debug Pointer” on page 18-26) in the block diagram of the model that you are debugging. The debug pointer points to the first block method to be executed.



The following sections explain how to use the debugger controls to perform these debugging tasks.

---

**Note** When you start the debugger in GUI mode, the debugger command-line interface is also active in the MATLAB Command Window. However, to prevent synchronization errors between the graphical and command-line interfaces, you should avoid using the command-line interface.

---

## Running a Simulation Step by Step

### In this section...

“Introduction” on page 18-20  
“Block Data Output” on page 18-21  
“Stepping Commands” on page 18-22  
“Continuing a Simulation” on page 18-23  
“Running a Simulation Nonstop” on page 18-25  
“Debug Pointer” on page 18-26

### Introduction

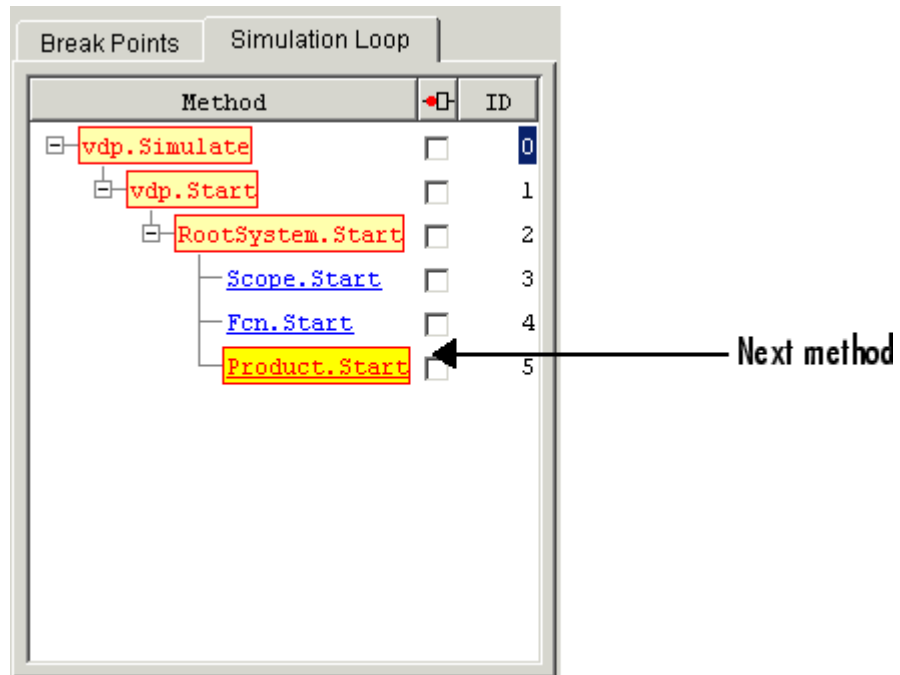
The debugger provides various commands that let you advance a simulation from the method where it is currently suspended (the next method) by various increments (see “Stepping Commands” on page 18-22). For example, you can advance the simulation

- Into or over the next method
- Out of the current method
- To the top of the simulation loop.

After each advance, the debugger displays information that enables you to determine the point to which the simulation has advanced and the results of advancing the simulation to that point.

For example, in GUI mode, after each step command, the debugger highlights the current method call stack in the **Simulation Loop** pane. The call stack comprises the next method and the methods that invoked the next method either directly or indirectly. The debugger highlights the call stack by highlighting the names of the methods that make up the call stack in the **Simulation Loop** pane.





In command-line mode, you can use the `where` command to display the method call stack. If the next method is a block method, the debugger points the debug pointer at the block corresponding to the method (see “Debug Pointer” on page 18-26 for more information). If the block of the next method to be executed resides in a subsystem, the debugger opens the subsystem and points to the block in the subsystem block diagram.

## Block Data Output

After executing a block method, the debugger prints any or all of the following block data in the debugger **Output** panel (in GUI mode) or, if in command line mode, the MATLAB Command Window:

- $U_n = v$   
where  $v$  is the current value of the block’s  $n$ th input.
- $Y_n = v$

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.

```

          Current time      Next method
          ↙                ↘
%-----%
[Tm = 2.009509145207664e-005 ] 0:2 Integrator.Outputs 'vdp/x2'
(sldebug @44):
Data of 0:2 Integrator block 'vdp/x2':
U1      = [-2]
Y1      = [-4.0190182904153282e-005]
CSTATE  = [-4.0190182904153282e-005]
%-----%
[Tm = 2.009509145207664e-005 ] 0:3 Outputport.Outputs 'vdp/Out2'

```

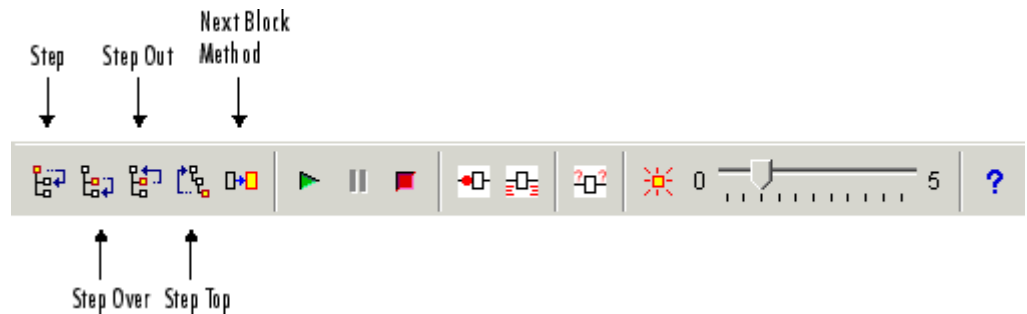
## Stepping Commands

Command-line mode provides the following commands for advancing a simulation incrementally:

This command...	Advances the simulation...
step [in into]	Into the next method, stopping at the first method in the next method or, if the next method does not contain any methods, at the end of the next method
step over	To the method that follows the next method, executing all methods invoked directly or indirectly by the next method

This command...	Advances the simulation...
<code>step out</code>	To the end of the current method, executing any remaining methods invoked by the current method
<code>step top</code>	To the first method of the next time step (i.e., the top of the simulation loop)
<code>step blockmth</code>	To the next block method to be executed, executing all intervening model- and system-level methods
<code>next</code>	Same as <code>step over</code>

Buttons in the debugger toolbar allow you to access these commands in GUI mode.



Clicking a button has the same effect as entering the corresponding command at the debugger command line.

## Continuing a Simulation

In GUI mode, the **Stop** button turns red when the debugger suspends the simulation for any reason. To continue the simulation, click the **Start/Continue** button. In command-line mode, enter `continue` to continue the simulation. By default, the debugger runs the simulation to the next breakpoint (see “Setting Breakpoints” on page 18-28) or to the end of the simulation, whichever comes first.

## Animation Mode

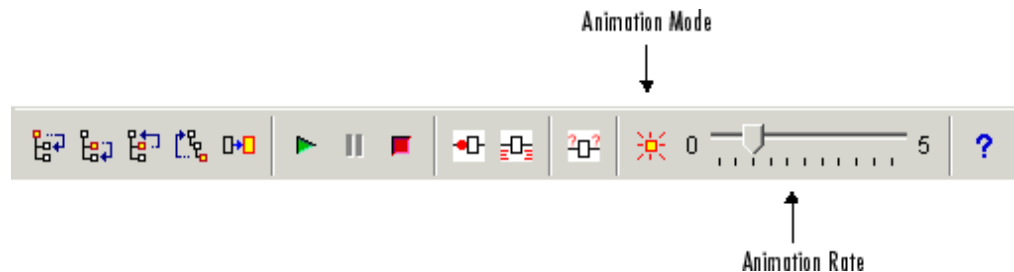
In *animation mode*, the **Start/Continue** button or the `continue` command advances the simulation method by method, pausing after each method, to the first method of the next major time step. While running the simulation in animation mode, the debugger uses its debug pointer (see “Debug Pointer” on page 18-26) to indicate on the block diagram which block method is being executed at each step. The moving pointer shows the simulation progress.

---

**Note** In animation mode, the debugger does not allow you to set breakpoints and ignores any breakpoints that you set when animating the simulation.

---

To enable animation when running the debugger in GUI mode, click the **Animation Mode** button on the debugger toolbar.



Use the slider on the debugger toolbar to increase or decrease the delay between method invocations, and so slow down or speed up the animation rate. To disable animation mode when running the debugger in GUI mode, toggle the **Animation Mode** button on the toolbar.

To enable animation when running the debugger in command-line mode, enter the `animate` command at the command line. The `animate` command has an optional delay parameter for you to specify the length of the pause between method invocations (1 second by default), and thereby accelerate or slow down the animation. For example, the command

```
animate 0.5
```

causes the animation to run at twice its default rate. To disable animation mode when running the debugger in command-line mode, at the command line enter:

```
animate stop
```

## Running a Simulation Nonstop

The run command lets you run a simulation to the end of the simulation, skipping any intervening breakpoints. At the end of the simulation, the debugger returns you to the command line. To continue debugging a model, you must restart the debugger.

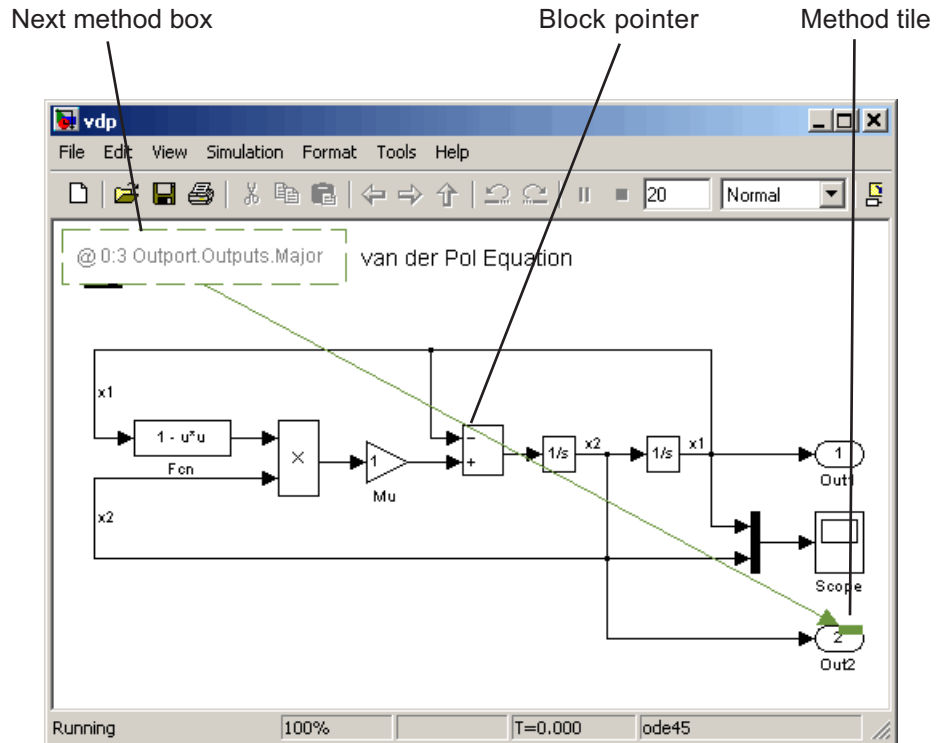
---

**Note** The GUI mode does not provide a graphical version of the run command. To run the simulation to the end, you must first clear all breakpoints and then click the **Start/Continue** button.

---

## Debug Pointer

The debugger displays a debug pointer on the block diagram whenever it stops the simulation at a method.



The debug pointer is an annotation that indicates the next method to be executed when simulation resumes. It consists of the following elements:

- Next method box
- Block pointer
- Method tile

## Next Method Box

The next method box appears in the upper-left corner of the block diagram. It specifies the name and ID of the next method to be executed.

## Block Pointer

The block pointer appears when the next method is a block method. It indicates the block on which the next method operates.

## Method Tile

The method tile is a rectangular patch of color that appears when the next method is a block method. The tile overlays a portion of the block on which the next method executes. The color and position of the tile on the block indicate the type of the next block method as follows.

Update (red)	Outputs Major Time Step (dark green)
Derivatives (orange)	Outputs Minor Time Step (green)
Zero Crossings (light blue)	Start (magenta) Initialize (blue) etc.

In animation mode, the tiles persist for the length of the current major time step and a number appears in each tile. The number specifies the number of times that the corresponding method has been invoked for the block thus far in the time step.

## Setting Breakpoints

### In this section...

“About Breakpoints” on page 18-28

“Setting Unconditional Breakpoints” on page 18-28

“Setting Conditional Breakpoints” on page 18-31

### 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

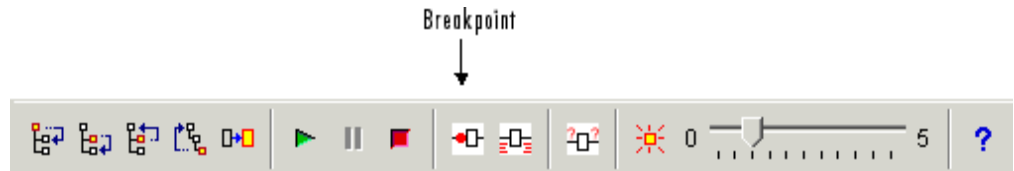
You can set unconditional breakpoints from the:

- Debugger toolbar
- **Simulation Loop** pane
- MATLAB product Command Window (command-line mode only)

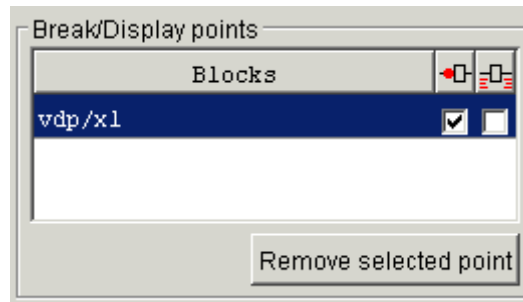
### Setting Breakpoints from the Debugger Toolbar

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.

---

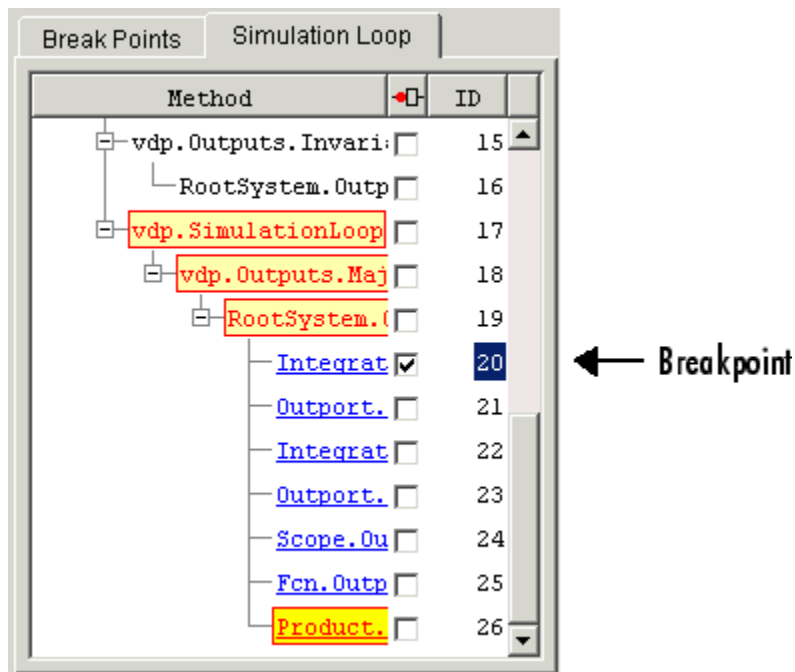
You can temporarily disable the breakpoints on a block by deselecting the check box in the breakpoints column of the panel. To clear the breakpoints on a block and remove its entry from the panel,

- 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 18-42).

### Setting Breakpoints from the Simulation Loop Pane

To set a breakpoint at a particular invocation of a method displayed in the Simulation Loop pane, select the check box next to the method's name in the breakpoint column of the pane.



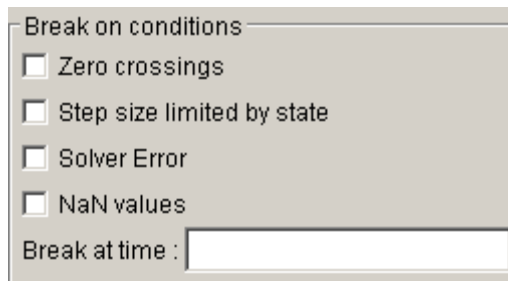
To clear the breakpoint, deselect the check box.

## Setting Breakpoints from the Command Window

In command-line mode, use the `break` and `bafter` commands to set breakpoints before or after a specified method, respectively. Use the `clear` command to clear breakpoints.

## Setting Conditional Breakpoints

You can use either the **Break on conditions** controls group on the debugger **Breakpoints** pane



or the following commands (in command-line mode) to set conditional breakpoints.

This command...	Causes the Simulation to Stop...
<code>tbreak [t]</code>	At a simulation time step
<code>ebreak</code>	At a recoverable error in the model
<code>nanbreak</code>	At the occurrence of an underflow or overflow (NaN) or infinite (Inf) value
<code>xbreak</code>	When the simulation reaches the state that determines the simulation step size
<code>zcbreak</code>	When a zero crossing occurs between simulation time steps

## Setting Breakpoints at Time Steps

To set a breakpoint at a time step, enter a time in the debugger **Break at time** field (GUI mode) or enter the time using the `tbreak` command. This causes the debugger to stop the simulation at the `Outputs.Major` method of the model at the first time step that follows the specified time. For example, starting `vdp` in debug mode and entering the commands

```
tbreak 2
continue
```

causes the debugger to halt the simulation at the `vdp.Outputs.Major` method of time step 2.078 as indicated by the output of the `continue` command.

```
%-----
%
[TM = 2.078784598291364      ] vdp.Outputs.Major
(sdebug @18):
```

## Breaking on Nonfinite Values

Selecting the debugger **NaN values** option or entering the `nanbreak` command causes the simulation to stop when a computed value is infinite or outside the range of values that is supported by the machine running the simulation. This option is useful for pinpointing computational errors in a model.

## Breaking on Step-Size Limiting Steps

Selecting the **Step size limited by state** option or entering the `xbreak` command causes the debugger to stop the simulation when the model uses a variable-step solver and the solver encounters a state that limits the size of the steps that it can take. This command is useful in debugging models that appear to require an excessive number of simulation time steps to solve.

## Breaking at Zero Crossings

Selecting the **Zero crossings** option or entering the `zcbreak` command causes the simulation to halt when a nonsampled zero crossing is detected in a model that includes blocks where zero crossings can arise. After halting, the ID, type, and name of the block in which the zero crossing was detected is

displayed. The block ID (s:b:p) consists of a system index s, block index b, and port index p separated by colons (see “Block ID” on page 18-11).

For example, setting a zero-crossing break at the start of execution of the `zeroxing` demo model,

```
>> sldebug zeroxing
%-----
%
[TM = 0                               ] zeroxing.Simulate
(sldebug @0): >> zcbreak
Break at zero crossing events          : enabled
```

and continuing the simulation

```
(sldebug @0): >> continue
```

results in a zero-crossing break at

```
2 Zero crossings detected at the following locations
 6 0:5:1 Saturate 'zeroxing/Saturation'
 7 0:5:2 Saturate 'zeroxing/Saturation'
ZeroCrossing Events detected. Interrupting model execution
%-----%
[tm = 0.4                               ] zeroxing.zc.SearchLoop
(sldebug @55): >>
```

If a model does not include blocks capable of producing nonsampled zero crossings, the command prints a message advising you of this fact.

## Breaking on Solver Errors

Selecting the debugger **Solver Errors** option or entering the `ebreak` command causes the simulation to stop if the solver detects a recoverable error in the model. If you do not set or disable this breakpoint, the solver recovers from the error and proceeds with the simulation without notifying you.

## Displaying Information About the Simulation

### In this section...

“Displaying Block I/O” on page 18-34

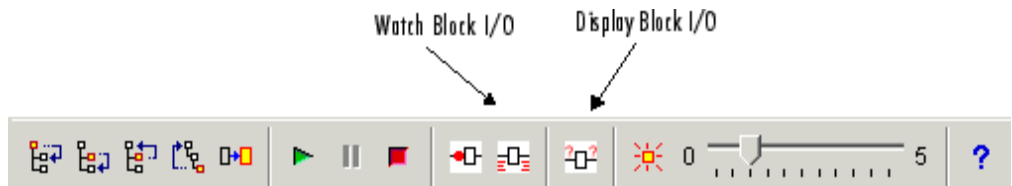
“Displaying Algebraic Loop Information” on page 18-36

“Displaying System States” on page 18-38

“Displaying Solver Information” on page 18-39

### Displaying Block I/O

The debugger allows you to display block I/O by clicking the appropriate buttons on the debugger toolbar





or by entering the appropriate debugger command.

This command...	Displays a Blocks I/O...
probe	Immediately
disp	At every breakpoint any time execution stops
trace	Whenever the block executes

**Note** The two debugger toolbar buttons, Watch Block I/O (☐←) and Display Block I/O (☐→) correspond, respectively, to `trace gcb` and `probe gcb`. The `probe` and `disp` commands do not have a one-to-one correspondence with the debugger toolbar buttons.

## Displaying I/O of a Selected Block

To display the I/O of a block, select the block and click  in GUI mode or enter the probe command in command-line mode. In the following table, the probe gcb command has a corresponding toolbar button. The other commands do not.

Command	Description
probe	Enter or exit probe mode. In probe mode, the debugger displays the current inputs and outputs of any block that you select in the model's block diagram. Typing any command causes the debugger to exit probe mode.
probe gcb	Display I/O of selected block. Same as  .
probe s:b	Print the I/O of the block specified by system number s and block number b.

The debugger prints the current inputs, outputs, and states of the selected block in the debugger **Outputs** pane (GUI mode) or the Command Window of the MATLAB product.

The probe command is useful when you need to examine the I/O of a block whose I/O is not otherwise displayed. For example, suppose you are using the step command to run a model method by method. Each time you step the simulation, the debugger displays the inputs and outputs of the current block. The probe command lets you examine the I/O of other blocks as well.

## Displaying Block I/O Automatically at Breakpoints

The disp command causes the debugger to display a specified block's inputs and outputs whenever it halts the simulation. You can specify a block either by entering its block index or by selecting it in the block diagram and entering gcb as the disp command argument. You can remove any block from the debugger list of display points, using the undisp command. For example, to remove block 0:0, either select the block in the model diagram and enter undisp gcb or simply enter undisp 0:0.



---

**Note** Automatic display of block I/O at breakpoints is not available in the debugger GUI mode.

---

The `disp` command is useful when you need to monitor the I/O of a specific block or set of blocks as you step through a simulation. Using the `disp` command, you can specify the blocks you want to monitor and the debugger will then redisplay the I/O of those blocks on every step. Note that the debugger always displays the I/O of the current block when you step through a model block by block, using the `step` command. You do not need to use the `disp` command if you are interested in watching only the I/O of the current block.

### Watching Block I/O

To watch a block, select the block and click  in the debugger toolbar or enter the trace command. In GUI mode, if a breakpoint exists on the block, you can set a watch on it as well by selecting the check box for the block in the watch column  of the **Break/Display points** pane. In command-line mode, you can also specify the block by specifying its block index in the `trace` command. You can remove a block from the debugger list of trace points using the `untrace` command.

The debugger displays a watched block's I/O whenever the block executes. Watching a block allows you obtain a complete record of the block's I/O without having to stop the simulation.

### Displaying Algebraic Loop Information

The `atrace` command causes the debugger to display information about a model's algebraic loops (see “Algebraic Loops” on page 2-40) each time they are solved. The command takes a single argument that specifies the amount of information to display.



<b>This command...</b>	<b>Displays for each algebraic loop...</b>
atrace 0	No information
atrace 1	The loop variable solution, the number of iterations required to solve the loop, and the estimated solution error
atrace 2	Same as level 1
atrace 3	Level 2 plus the Jacobian matrix used to solve the loop
atrace 4	Level 3 plus intermediate solutions of the loop variable

## Displaying System States

The states debug command lists the current values of the system states in the MATLAB Command Window. For example, the following sequence of commands shows the states of the bouncing ball demo (sldemo\_bounce) after its first, second, and third time steps. However, before entering the debugger, 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                               ] sldemo_bounce.Simulate
(sldebug @0): >> step top
%------%
[TM = 0                               ] sldemo_bounce.Outputs.Major
(sldebug @16): >> next
%------%
[TM = 0                               ] sldemo_bounce.Update
(sldebug @23): >> states

Continuous States:
Idx Value                               (system:block:element Name 'BlockName')
  0  10                                (0:4:0 CSTATE 'sldemo_bounce/Second-Order Integrator')
  1. 15                                (0:4:1)

(sldebug @23): >> next
%------%
[TM = 0                               ] sldemo_bounce.Solver
(sldebug @26): >> states

Continuous States:
Idx Value                               (system:block:element Name 'BlockName')
  0  10                                (0:4:0 CSTATE 'sldemo_bounce/Second-Order Integrator')
  1. 15                                (0:4:1)

(sldebug @26): >> next
%------%
[TM = 0.01                             ] sldemo_bounce.Outputs.Major
(sldebug @16): >> states

Continuous States:
Idx Value                               (system:block:element Name 'BlockName')
  0  10.1495095                        (0:4:0 CSTATE 'sldemo_bounce/Second-Order Integrator')
  1. 14.9019                            (0:4:1)

```

## Displaying Solver Information

The `strace` command allows you to pinpoint problems in solving a model's differential equations that can slow down simulation performance. Executing this command causes the debugger to display solver-related information at the command line of the MATLAB product when you run or step through a simulation. The information includes the sizes of the steps taken by the solver, the estimated integration error resulting from the step size, whether a step size succeeded (i.e., met the accuracy requirements that the model specifies), the times at which solver resets occur, etc. If you are concerned about the time required to simulate your model, this information can help you to decide whether the solver you have chosen is the culprit and hence whether choosing another solver might shorten the time required to solve the model.

## Displaying Information About the Model

### In this section...

“Displaying a Models Sorted Lists” on page 18-40

“Displaying a Block” on page 18-41

### Displaying a Models Sorted Lists

In GUI mode, the debugger **Sorted List** pane displays lists of blocks for a models root system and each nonvirtual subsystem. Each list lists the blocks that the subsystems contains sorted according to their computational dependencies, alphabetical order, and other block sorting rules. In command-line mode, you can use the `slist` command to display a model's sorted lists.

```
---- Sorted list for 'vdp' [12 blocks, 9 nonvirtual blocks,
directFeed=0]
 0:0   'vdp/Integrator1' (Integrator)
 0:1   'vdp/Out1' (Outport)
 0:2   'vdp/Integrator2' (Integrator)
 0:3   'vdp/Out2' (Outport)
 0:4   'vdp/Fcn' (Fcn)
 0:5   'vdp/Product' (Product)
 0:6   'vdp/Mu' (Gain)
 0:7   'vdp/Scope' (Scope)
 0:8   'vdp/Sum' (Sum)
```

These displays include the block index for each command. You can use them to determine the block IDs of the models blocks. Some debugger commands accept block IDs as arguments.

### Identifying Blocks in Algebraic Loops

If a block belongs to an algebraic list, the `slist` command displays an algebraic loop identifier in the entry for the block in the sorted list. The identifier has the form

```
algId=s#n
```

where *s* is the index of the subsystem containing the algebraic loop and *n* is the index of the algebraic loop in the subsystem. For example, the following entry for an Integrator block indicates that it participates in the first algebraic loop at the root level of the model.

```
0:1 'test/ss/I1' (Integrator, tid=0) [algId=0#1, discontinuity]
```

You can use the debugger `ashow` command to highlight the blocks and lines that make up an algebraic loop. See “Displaying Algebraic Loops” on page 18-43 for more information.

## Displaying a Block

To determine the block in a models diagram that corresponds to a particular index, enter `bshow s:b` at the command prompt, where *s:b* is the block index. The `bshow` command opens the system containing the block (if necessary) and selects the block in the systems window.

## Displaying a Models Nonvirtual Systems

The `systems` command displays a list of the nonvirtual systems in the model that you are debugging. For example, the clutch demo (`clutch`) contains the following systems:

```
sdebug clutch
[tm=0 ] **Start** of system 'clutch' outputs
(sdebug @0:0 'clutch/Clutch Pedal'): systems
0 'clutch'
1 'clutch/Locked'
2 'clutch/Unlocked'
```

---

**Note** The `systems` command does not list subsystems that are purely graphical. That is, subsystems that the model diagram represents as Subsystem blocks but that are solved as part of a parent system. are not listed. In Simulink models, the root system and triggered or enabled subsystems are true systems. All other subsystems are virtual (that is, graphical) and do not appear in the listing from the `systems` command.

---

## Displaying a Model's Nonvirtual Blocks

The `slist` command displays a list of the nonvirtual blocks in a model. The listing groups the blocks by system. For example, the following sequence of commands produces a list of the nonvirtual blocks in the Van der Pol (vdp) demo model.

```
sldebug vdp
[Tm=0                ] **Start** of system 'vdp' outputs
(sldebug @0:0 'vdp/Integrator1'): slist
---- Sorted list for 'vdp' [12 blocks, 9 nonvirtual blocks,
directFeed=0]
  0:0  'vdp/Integrator1' (Integrator)
  0:1  'vdp/Out1' (Output)
  0:2  'vdp/Integrator2' (Integrator)
  0:3  'vdp/Out2' (Output)
  0:4  'vdp/Fcn' (Fcn)
  0:5  'vdp/Product' (Product)
  0:6  'vdp/Mu' (Gain)
  0:7  'vdp/Scope' (Scope)
  0:8  'vdp/Sum' (Sum)
```

---

**Note** The `slist` command does not list blocks that are purely graphical. That is, blocks that indicate relationships between or groupings among computational blocks.

---

## Displaying Blocks with Potential Zero Crossings

The `zclist` command displays a list of blocks in which nonsampled zero crossings can occur during a simulation. For example, `zclist` displays the following list for the clutch sample model:

```
(sldebug @0:0 'clutch/Clutch Pedal'): zclist
  2:3  'clutch/Unlocked/Sign' (Signum)
  0:4  'clutch/Lockup Detection/Velocities Match' (HitCross)
  0:10  'clutch/Lockup Detection/Required Friction
        for Lockup/Abs' (Abs)
  0:11  'clutch/Lockup Detection/Required Friction for
        Lockup/ Relational Operator' (RelationalOperator)
```

```

0:18 'clutch/Break Apart Detection/Abs' (Abs)
0:20 'clutch/Break Apart Detection/Relational Operator'
      (RelationalOperator)
0:24 'clutch/Unlocked' (SubSystem)
0:27 'clutch/Locked' (SubSystem)

```

## Displaying Algebraic Loops

The `ashow` command highlights a specified algebraic loop or the algebraic loop that contains a specified block. To highlight a specified algebraic loop, enter `ashow s#n`, where `s` is the index of the system (see “Identifying Blocks in Algebraic Loops” on page 18-40) that contains the loop and `n` is the index of the loop in the system. To display the loop that contains the currently selected block, enter `ashow gcb`. To show a loop that contains a specified block, enter `ashow s:b`, where `s:b` is the block’s index. To clear algebraic-loop highlighting from the model diagram, enter `ashow clear`.

## Displaying Debugger Status

In GUI mode, the debugger displays the settings of various debug options, such as conditional breakpoints, in its **Status** panel. In command-line mode, the `status` command displays debugger settings. For example, the following sequence of commands displays the initial debug settings for the `vdp` model:

```

sim('vdp', 'StopTime', '10', 'debug', 'on')
[Tm=0 ] **Start** of system 'vdp' outputs
(sldebug @0:0 'vdp/Integrator1'): status
  Current simulation time: 0 (MajorTimeStep)
  Last command: ""
  Stop in minor times steps is disabled.
  Break at zero crossing events is disabled.
  Break when step size is limiting by a state is disabled.
  Break on non-finite (NaN,Inf) values is disabled.
  Display of integration information is disabled.
  Algebraic loop tracing level is at 0.

```





# Accelerating Models

---

- “What Is Acceleration?” on page 19-2
- “How the Acceleration Modes Work” on page 19-3
- “Code Regeneration in Accelerated Models” on page 19-7
- “Choosing a Simulation Mode” on page 19-10
- “Designing Your Model for Effective Acceleration” on page 19-15
- “Performing Acceleration” on page 19-21
- “Interacting with the Acceleration Modes Programmatically” on page 19-25
- “Using the Accelerator Mode with the Simulink Debugger” on page 19-28
- “Capturing Performance Data” on page 19-30

## 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 “Using the Accelerator Mode with the Simulink Debugger” on page 19-28 and “Capturing Performance Data” on page 19-30.

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 17-5.

## How the Acceleration Modes Work

In this section...
“Overview” on page 19-3
“Normal Mode” on page 19-3
“Accelerator Mode” on page 19-4
“Rapid Accelerator Mode” on page 19-5

### 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.

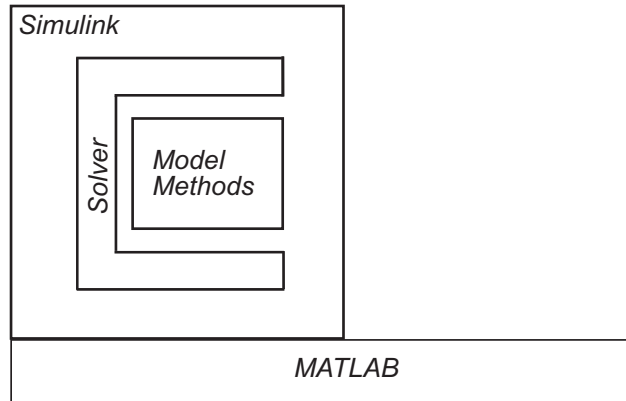
---

**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.



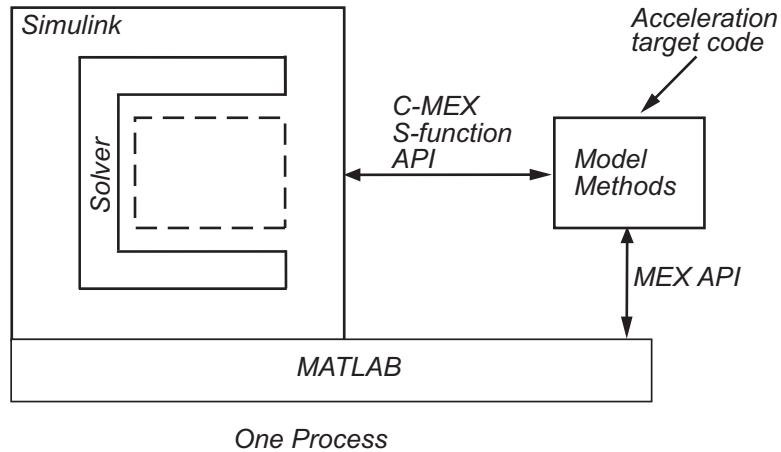
One Process

## 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.

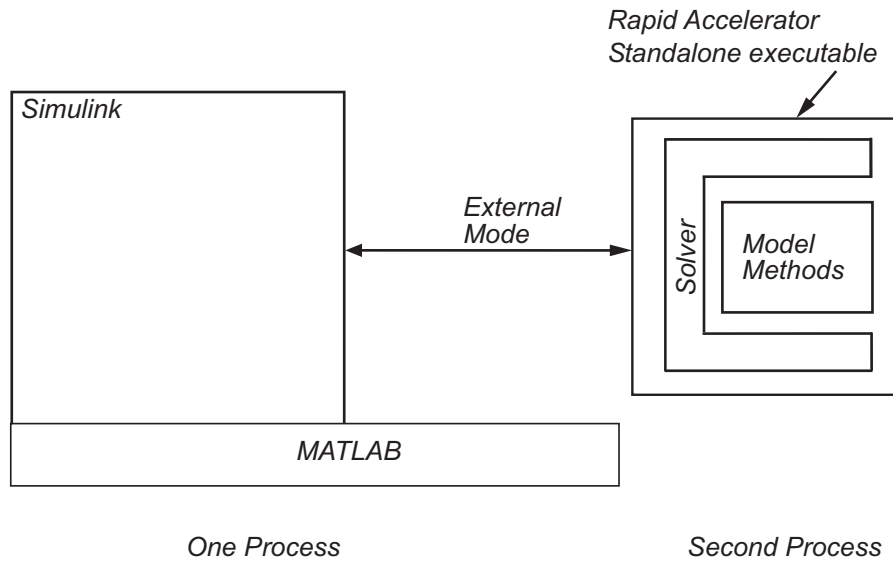
Simulink checks that the acceleration target code is up to date before reusing it. As explained in “Code Regeneration in Accelerated Models” on page 19-7, the target code regenerates if it is not up to date.

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” on page 19-7
“Determining If the Simulation Will Rebuild” on page 19-7

### Structural Changes That Cause Rebuilds

Changing the structure of your model causes the Rapid Accelerator mode to regenerate the standalone executable, and for the Accelerator mode to regenerate the target code and update (overwrite) the existing MEX-file.

Examples of model structure changes that result in a rebuild include:

- Changing the solver type, for example from `Variable-step` to `Fixed-step`
- Adding or deleting blocks or connections between blocks
- Changing the values of nontunable block parameters, for example, the **Seed** parameter of the Random Number block
- Changing the number of inputs or outputs of blocks, even if the connectivity is vectorized
- Changing the number of states in the model
- Selecting a different function in the Trigonometric Function block
- Changing signs used in a Sum block
- Adding a Target Language Compiler (TLC) file to inline an S-function
- Changing the `sim` command output argument when using the Rapid Accelerator mode
- Changing solver parameters such as `stop time` or `rel tol` when using the Rapid Accelerator mode

### Determining If the Simulation Will Rebuild

The Accelerator and Rapid Accelerator modes use a checksum to determine if the model has changed, indicating that the code should be regenerated. The

checksum is an array of four integers computed using an MD5 checksum algorithm based on attributes of the model and the blocks it contains.

Use the `Simulink.BlockDiagram.getChecksum` command to obtain the checksum for your model. For example:

```
cs1 = Simulink.BlockDiagram.getChecksum('myModel');
```

Obtain a second checksum after you have altered your model. The code regenerates if the new checksum does not match the previous checksum. You can use the information in the checksum to determine why the simulation target rebuilt. For a detailed explanation of this procedure, see the demo model `slAccelDemoWhyRebuild`.

### Parameter Handling in Rapid Accelerator Mode

In terms of model rebuilds, Block Diagram and Run-time parameters are handled differently than other parameters in rapid accelerator mode.

Some Block Diagram parameters can be changed during simulation without causing a rebuild. These Block Diagram parameters include the following:

<b>BLOCK DIAGRAM PARAMETERS THAT DO NOT REQUIRE RAPID ACCELERATOR REBUILD</b>	
<b>Solver Parameters</b>	<b>Loading and Logging Parameters</b>
AbsTol	Decimation
ConsecutiveZCsStepRelTol	FinalStateName
ExtrapolationOrder	InitialState
InitialStep	LimitDataPoints
MaxConsecutiveMinStep	LoadExternalInput
MaxConsecutiveZCs	LoadInitialState
MaxNumMinSteps	MaxDataPoints
MaxOrder	OutputOption
MaxStep	OutputSaveName



<b>BLOCK DIAGRAM PARAMETERS THAT DO NOT REQUIRE RAPID ACCELERATOR REBUILD</b>	
MinStep	SaveFinalState
NumberNwtonIterations	SaveFormat
OutputTimes	SaveOutput
Refine	SaveState
RelTol	SaveTime
SolverName	SignalLogging
StartTime	SignalLoggingName
StopTime	StateSaveName
ZCDetectionTol	TimeSaveName

Run-time parameters are collected within an *rtp* structure either by user specification via a *simset* option or through automatic collection during the compile phase. Changes to the Run-time parameters are supported if they are passed directly to *sim*. However, if they are passed graphically via the block diagram or programmatically via the *set\_param* command, then a rebuild may be necessary. All other parameter changes may necessitate a rebuild.

<b>Parameter Changes:</b>	<b>Passed Directly to <i>sim</i> command</b>	<b>Passed Graphically via Block Diagram or via <i>set_param</i> command</b>
Run-time	Rebuild <i>Not</i> Required	Rebuild May Be Required
Block Diagram (Solver and Logging Parameters)	Rebuild <i>Not</i> Required	Rebuild <i>Not</i> Required
Other	Rebuild May Be Required	Rebuild May Be Required

## Choosing a Simulation Mode

### In this section...

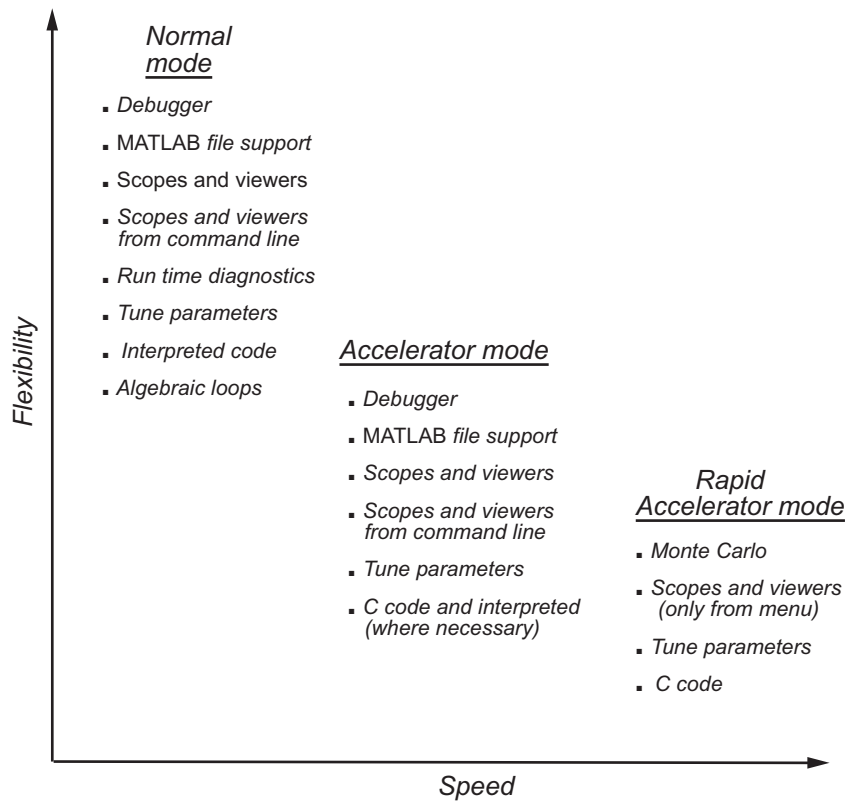
“Simulation Mode Tradeoffs” on page 19-10

“Comparing Modes” on page 19-11

“Decision Tree” on page 19-13

### 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 mdl; % executes in less than one second in Normal mode
end
```

For this set of conditions, you will typically obtain the best performance by simulating the model in Normal mode.

---

---

**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 5-21.

---

## 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
<b>Performance</b>			
Run your model in a separate address space			✓
Efficiently run batch and Monte Carlo simulations			✓
<b>Model Adjustment</b>			
Change model parameters such as solver type, stop time without rebuilding	✓	✓	
Change block tunable parameters such as gain	✓	✓	✓
<b>Model Requirement</b>			
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	✓	✓	
<b>Data Display</b>			
Use scopes and signal viewers	✓	✓	See “Behavior of Scopes and Viewers with Rapid Accelerator Mode” on page 19-17
Use scopes and signal viewers when running your model from the command line	✓	✓	

---

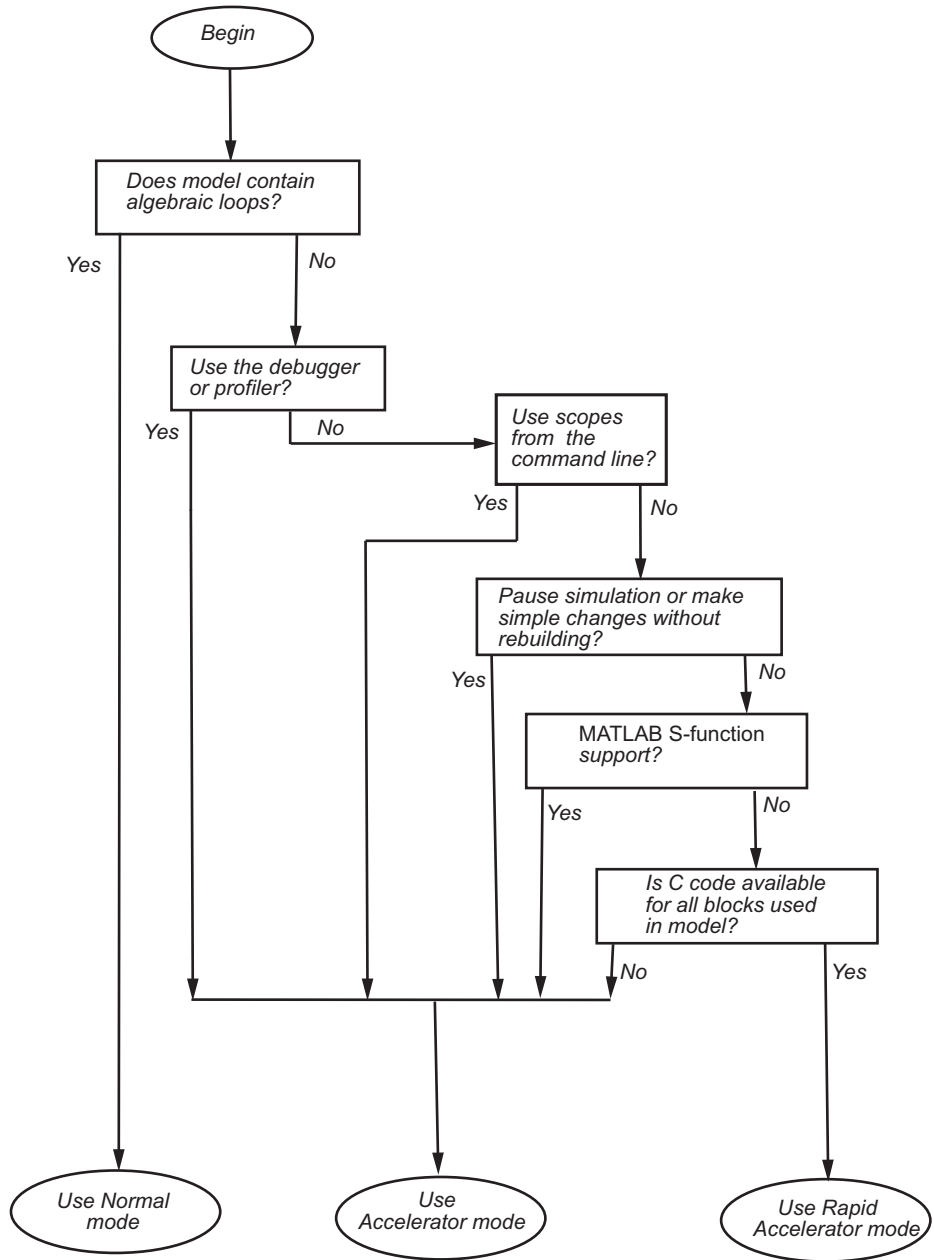
**Note** Scopes and viewers do not update if you run your model from the command line in Rapid Accelerator mode.

---

## **Decision Tree**

The following decision tree can help you select between Normal mode, Accelerator mode, or Rapid Accelerator mode.

See “Comparing Performance” on page 17-5 to understand how effective the accelerator modes will be in improving the performance of your model.



## Designing Your Model for Effective Acceleration

### In this section...

“Selecting Blocks for Accelerator Mode” on page 19-15

“Selecting Blocks for Rapid Accelerator Mode” on page 19-16

“Controlling S-Function Execution” on page 19-16

“Accelerator and Rapid Accelerator Mode Data Type Considerations” on page 19-17

“Behavior of Scopes and Viewers with Rapid Accelerator Mode” on page 19-17

“Factors Inhibiting Acceleration” on page 19-18

### Selecting Blocks for Accelerator Mode

The Accelerator simulation mode runs the following blocks as if you were running Normal mode because these blocks do not generate code for the accelerator build. Consequently, if your model contains a high percentage of these blocks, the Accelerator mode may not increase performance significantly. All of these Simulink blocks use interpreted code.

- Display
- 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.

---

## Selecting Blocks for Rapid Accelerator Mode

Blocks that do not support code generation (such as SimEvents®) or blocks that generate code only for a specific target (such as vxWorks), cannot be simulated in Rapid Accelerator mode.

Additionally, Rapid Accelerator mode does not work if your model contains any of the following blocks:

- 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.

---

## Controlling S-Function Execution

Inlining S-functions using the Target Language Compiler increases performance with the Accelerator mode by eliminating unnecessary calls to the Simulink application program interface (API). By default, however, the Accelerator mode ignores an inlining TLC file for an S-function, even though the file exists. The Rapid Accelerator mode always uses the TLC file if one is available.

A device driver S-Function block written to access specific hardware registers on an I/O board is one example of why this behavior was chosen as the default. Because the Simulink software runs on the host system rather than



the target, it cannot access the targets I/O registers and so would fail when attempting to do so.

To direct the Accelerator mode to use the TLC file instead of the S-function MEX-file, specify `SS_OPTION_USE_TLC_WITH_ACCELERATOR` in the `mdlInitializeSizes` function of the S-function, as in this example:

```
static void mdlInitializeSizes(SimStruct *S)
{
    /* Code deleted */
    ssSetOptions(S, SS_OPTION_USE_TLC_WITH_ACCELERATOR);
}
```

## Accelerator and Rapid Accelerator Mode Data Type Considerations

- Accelerator mode supports fixed-point signals and vectors up to 128 bits.
- Rapid Accelerator mode does not support fixed-point signals or vectors greater than 32 bits.
- Rapid Accelerator mode supports fixed-point parameters up to 128 bits.
- Rapid Accelerator mode supports fixed-point root inputs up to 32 bits
- Rapid Accelerator mode supports root inputs of Enumerated data type
- Rapid Accelerator mode does not support fixed-point data for the From Workspace block.
- Rapid Accelerator mode supports bus objects as parameters.
- The Accelerator mode and Rapid Accelerator mode store integers as compactly as possible.
- Simulink Fixed Point does not collect min, max, or overflow data in the Accelerator or Rapid Accelerator modes.

## 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	<ul style="list-style-type: none"> <li>• Logging is supported</li> <li>• Scope window is not updated</li> </ul>
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. “Running Acceleration Mode from the User Interface” on page 19-22 shows how to run Rapid Accelerator mode from the menu. “Interacting with the Acceleration Modes Programmatically” on page 19-25 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 “Configuring Generated Identifiers”. Additional keywords that apply only to the Accelerator and Rapid accelerator modes are:

<code>muDoubleScalarAbs</code>	<code>muDoubleScalarCos</code>	<code>muDoubleScalarMod</code>
<code>muDoubleScalarAcos</code>	<code>muDoubleScalarCosh</code>	<code>muDoubleScalarPower</code>
<code>muDoubleScalarAcosh</code>	<code>muDoubleScalarExp</code>	<code>muDoubleScalarRound</code>
<code>muDoubleScalarAsin</code>	<code>muDoubleScalarFloor</code>	<code>muDoubleScalarSign</code>
<code>muDoubleScalarAsinh</code>	<code>muDoubleScalarHypot</code>	<code>muDoubleScalarSin</code>
<code>muDoubleScalarAtan</code> ,	<code>muDoubleScalarLog</code>	<code>muDoubleScalarSinh</code>
<code>muDoubleScalarAtan2</code>	<code>muDoubleScalarLog10</code>	<code>muDoubleScalarSqrt</code>

muDoubleScalarAtanh

muDoubleScalarMax

muDoubleScalarTan

muDoubleScalarCeil

muDoubleScalarMin

muDoubleScalarTanh

## Performing Acceleration

### In this section...

“Customizing the Build Process” on page 19-21

“Running Acceleration Mode from the User Interface” on page 19-22

“Making Run-Time Changes” on page 19-24

### Customizing 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 **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.

#### Accelerating simulations

Compiler optimization level: Optimizations on (faster runs) ▼

Verbose accelerator builds

### 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 `s1prj/accel/modelname` (for example, `s1prj/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 > 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**.

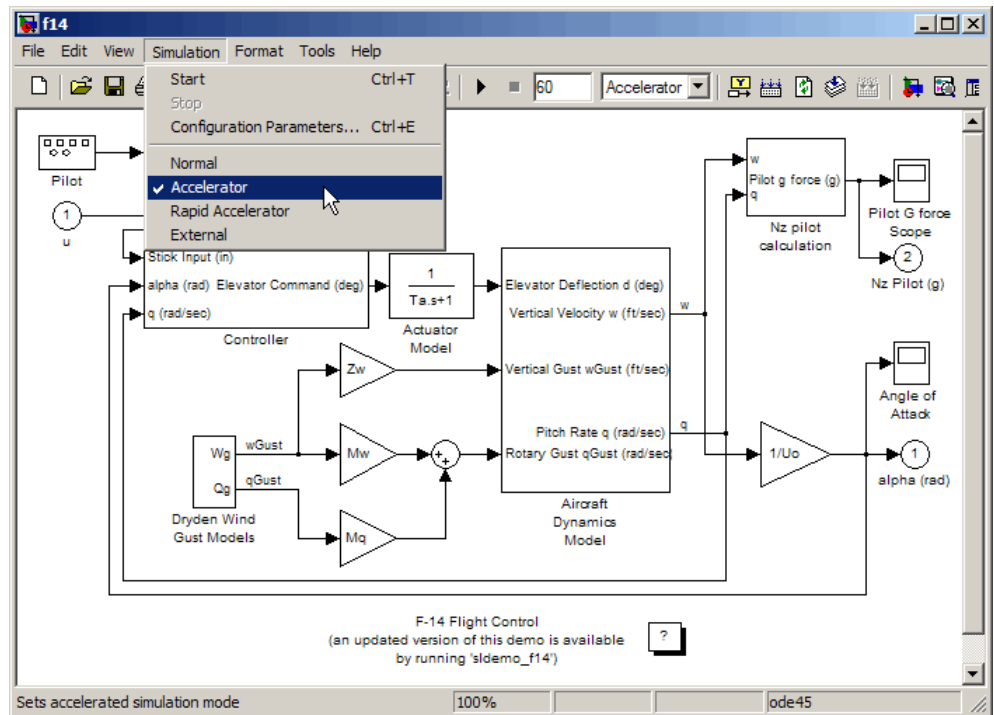
### **Running Acceleration Mode from the User Interface**

To accelerate a model, first open it, and then from the **Simulation** menu, select either **Accelerator** or **Rapid Accelerator**. Then start the simulation.

The following example shows how to accelerate the already opened f14 model using the Accelerator mode:

- 1 From the **Simulation** menu, select **Accelerator**.

Alternatively, you can select Accelerator from the model editor's toolbar.



**2** From the **Simulation** menu, select **Start**.

The Accelerator and Rapid Accelerator modes first check to see if code was previously compiled for your model. If code was created previously, the Accelerator or Rapid Accelerator mode runs the model. If code was not previously built, they first generate and compile the C code, and then run the model.

For an explanation of why these modes rebuild your model, see “Code Regeneration in Accelerated Models” on page 19-7.

The Accelerator mode places the generated code in a subfolder of the working folder called `s\prj\accel\modelname` (for example, `s\prj\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 19-21.

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.



# Interacting with the Acceleration Modes Programmatically

## In this section...

“Why Interact Programmatically?” on page 19-25

“Building Accelerator Mode MEX-files” on page 19-25

“Controlling Simulation” on page 19-25

“Simulating Your Model” on page 19-26

“Customizing the Acceleration Build Process” on page 19-27

## Why Interact Programmatically?

You can build an accelerated model, select the simulation mode, and run the simulation from the command prompt or from MATLAB script. With this flexibility, you can create Accelerator mode MEX-files in batch mode, allowing you to build the C code and executable before running the simulations. When you use the Accelerator mode interactively at a later time, it will not be necessary to generate or compile MEX-files at the start of the accelerated simulations.

## Building Accelerator Mode MEX-files

With the `accelbuild` command, you can build the Accelerator mode MEX-file without actually simulating the model. For example, to build an Accelerator mode simulation of `myModel`:

```
accelbuild myModel
```

## Controlling Simulation

You can control the simulation mode from the command line prompt by using the `set_param` command:

```
set_param('modelName', 'SimulationMode', 'mode')
```

The simulation mode can be `normal`, `accelerator`, `rapid`, or `external`.

For example, to simulate your model with the Accelerator mode, you would use:

```
set_param('myModel','SimulationMode','accelerator')
```

However, a preferable method is to specify the simulation mode within the `sim` command:

```
simOut = sim('myModel', 'SimulationMode', 'accelerator');
```

You can use `gcs` (“get current system”) to set parameters for the currently active model (that is, the active model window) rather than *modelName* if you do not wish to explicitly specify the model name.

For example, to simulate the currently opened system in the Rapid Accelerator mode, you would use:

```
simOut = sim(gcs,'SimulationMode','rapid');
```

## Simulating Your Model

You can use `set_param` to configure the model parameters (such as the simulation mode and the stop time), and use the `sim` command to start the simulation:

```
sim('modelName', 'ReturnWorkspaceOutputs', 'on');
```

However, the preferred method is to configure model parameters directly using the `sim` command, as shown in the previous section.

You can substitute `gcs` for *modelName* if you do not want to explicitly specify the model name.

Unless target code has already been generated, the `sim` command first builds the executable and then runs the simulation. However, if the target code has already been generated and no significant changes have been made to the model (see “Code Regeneration in Accelerated Models” on page 19-7 for a description), the `sim` command executes the generated code without regenerating the code. This process lets you run your model after making simple changes without having to wait for the model to rebuild.

## Simulation Example

The following sequence shows how to programmatically simulate `myModel` in Rapid Accelerator mode for 10,000 seconds.

First open `myModel`, and then type the following in the Command Window:

```
simOut = sim('myModel', 'SimulationMode', 'rapid' ...  
'StopTime', '10000');
```

Use the `sim` command again to resimulate after making a change to your model. If the change is minor (adjusting the gain of a gain block, for instance), the simulation runs without regenerating code.

## Customizing the Acceleration Build Process

You can programmatically control the Accelerator mode and Rapid Accelerator mode build process and the amount of information displayed during the build process. See “Customizing the Build Process” on page 19-21 for details on why doing so might be advantageous.

### Controlling the Build Process

Use the `SimCompilerOptimization` parameter to control the acceleration build process. The permitted values are `on` or `off`. The default is `off`.

Enter the following at the command prompt to turn on compiler optimization:

```
set_param('myModel', 'SimCompilerOptimization', 'on')
```

### Controlling Verbosity During Code Generation

Use the `AccelVerboseBuild` parameter to display progress information during code generation. The permitted values are `on` or `off`. The default is `off`.

Enter the following at the command prompt to turn on verbose build:

```
set_param('myModel', 'AccelVerboseBuild', 'on')
```

## Using the Accelerator Mode with the Simulink Debugger

### In this section...

“Advantages of Using Accelerator Mode with the Debugger” on page 19-28

“How to Run the Debugger” on page 19-28

“When to Switch Back to Normal Mode” on page 19-29

### Advantages of Using Accelerator Mode with the Debugger

The Accelerator mode can shorten the length of your debugging sessions if you have large and complex models. For example, you can use the Accelerator mode to simulate a large model and quickly reach a distant break point.

For more information on the debugger, see Chapter 18, “Simulink Debugger”.

---

**Note** You cannot use the Rapid Accelerator mode with the debugger.

---

### How to Run the Debugger

To run your model in the Accelerator mode with the debugger:

**1** From the **Simulation** menu, select **Accelerator**.

**2** At the command prompt, enter:

```
sldebug modelName
```

**3** At the debugger prompt, set a time break:

```
tbreak 10000  
continue
```

**4** Once you reach the breakpoint, use the debugger command `emode` (execution mode) to toggle between Accelerator and Normal mode.

## **When to Switch Back to Normal Mode**

You must switch to Normal mode to step through the simulation by blocks, and when you want to use the following debug commands:

- trace
- break
- zcbreak
- nanbreak

## Capturing Performance Data

### In this section...

“What Is the Profiler?” on page 19-30

“How the Profiler Works” on page 19-30

“Enabling the Profiler” on page 19-32

“How to Save Simulink Profiler Results” on page 19-35

### What Is the Profiler?

The profiler captures data while your model runs and identifies the parts of your model requiring the most time to simulate. You use this information to decide where to focus your model optimization efforts.

---

**Note** You cannot use the Rapid Accelerator mode with the Profiler.

---

Performance data showing the time spent executing each function in your model is placed in a report called the *simulation profile*.

### How the Profiler Works

The following pseudocode summarizes the execution model on which the Profiler is based.

```
Sim()
  ModelInitialize().
  ModelExecute()
  for t = tStart to tEnd
    Output()
    Update()
    Integrate()
    Compute states from derivs by repeatedly calling:
      MinorOutput()
      MinorDeriv()
    Locate any zero crossings by repeatedly calling:
      MinorOutput()
```

```

    MinorZeroCrossings()
  EndIntegrate
  Set time t = tNew.
EndModelExecute
ModelTerminate
EndSim

```

According to this conceptual model, your model is executed by invoking the following functions zero, one, or more times, depending on the function and the model.

Function	Purpose	Level
sim	Simulate the model. This top-level function invokes the other functions required to simulate the model. The time spent in this function is the total time required to simulate the model.	System
ModelInitialize	Set up the model for simulation.	System
ModelExecute	Execute the model by invoking the output, update, integrate, etc., functions for each block at each time step from the start to the end of simulation.	System
Output	Compute the outputs of a block at the current time step.	Block
Update	Update a block's state at the current time step.	Block
Integrate	Compute a block's continuous states by integrating the state derivatives at the current time step.	Block
MinorOutput	Compute a block's output at a minor time step.	Block

Function	Purpose	Level
MinorDeriv	Compute a block's state derivatives at a minor time step.	Block
MinorZeroCrossings	Compute a block's zero-crossing values at a minor time step.	Block
ModelTerminate	Free memory and perform any other end-of-simulation cleanup.	System
Nonvirtual Subsystem	Compute the output of a nonvirtual subsystem at the current time step by invoking the output, update, integrate, etc., functions for each block that it contains. The time spent in this function is the time required to execute the nonvirtual subsystem.	Block

The Profiler measures the time required to execute each invocation of these functions and generates a report at the end of the model that describes how much time was spent in each function.

## Enabling the Profiler

To profile a model, open the model and select **Profiler** from the **Tools** menu. Then start the simulation. When the simulation finishes, the Simulink code generates and displays the simulation profile for the model in the Help browser.



**Simulink Profiler Report**

File Edit View Go Debug Desktop Window Help

Summary | [Function Details](#) | [Simulink Profiler Help](#) | [Clear Highlighted Blocks](#)

## Simulink Profile Report: Summary

Report generated 12-Jan-2009 12:24:50

Total recorded time: 0.06 s  
 Number of Block Methods: 13  
 Number of Internal Methods: 9  
 Number of Nonvirtual Subsystem Methods: 4  
 Clock precision: 0.00000004 s  
 Clock Speed: 2400 MHz

To write this data as vdpProfileData in the base workspace [click here](#)

### Function List

Name	Time		Calls	Time/call	Self time		Location (must use MATLAB Web Browser to view)
<a href="#">sim</a>	0.06250000	100.0%	1	0.06250000000	0.00000000	0.0%	<a href="#">vdp</a>
<a href="#">ModelExecute</a>	0.03125000	50.0%	1	0.03125000000	0.01562500	25.0%	<a href="#">vdp</a>
<a href="#">ModelInitialize</a>	0.03125000	50.0%	1	0.03125000000	0.03125000	50.0%	<a href="#">vdp</a>
<a href="#">vdp (MinorDeriv)</a>	0.01562500	25.0%	331	0.00004720544	0.01562500	25.0%	<a href="#">vdp</a>
<a href="#">MinorDeriv</a>	0.01562500	25.0%	331	0.00004720544	0.00000000	0.0%	<a href="#">vdp</a>
<a href="#">Integrate</a>	0.01562500	25.0%	55	0.00028409091	0.00000000	0.0%	<a href="#">vdp</a>
<a href="#">ModelTerminate</a>	0.00000000	0.0%	1	0.00000000000	0.00000000	0.0%	<a href="#">vdp</a>
<a href="#">vdp (MinorOutput)</a>	0.00000000	0.0%	330	0.00000000000	0.00000000	0.0%	<a href="#">vdp</a>
<a href="#">MinorOutputs</a>	0.00000000	0.0%	330	0.00000000000	0.00000000	0.0%	<a href="#">vdp</a>

## Summary Section

The summary file displays the following performance totals.

Item	Description
<b>Total Recorded Time</b>	Total time required to simulate the model
<b>Number of Block Methods</b>	Total number of invocations of block-level functions (e.g., <code>Output()</code> )
<b>Number of Internal Methods</b>	Total number of invocations of system-level functions (e.g., <code>ModelExecute</code> )
<b>Number of Nonvirtual Subsystem Methods</b>	Total number of invocations of nonvirtual subsystem functions
<b>Clock Precision</b>	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
<b>Name</b>	Name of function. This item is a hyperlink. Clicking it displays a detailed profile of this function.
<b>Time</b>	Total time spent executing all invocations of this function as an absolute value and as a percentage of the total simulation time
<b>Calls</b>	Number of times this function was invoked
<b>Time/Call</b>	Average time required for each invocation of this function, including the time spent in functions invoked by this function

Item	Description
Self Time	Average time required to execute this function, excluding time spent in functions called by this function
Location	Specifies the block or model executed for which this function is invoked. This item is a hyperlink. Clicking it highlights the corresponding icon in the model diagram. The link works only if you are viewing the profile in the Help browser.

### Detailed Profile Section

This section contains detailed profiles for each function invoked to simulate the model. Each detailed profile contains all the information shown in the summary profile for the function. In addition, the detailed profile displays the function (parent function) that invoked the profiled function and the functions (child functions) invoked by the profiled function. Clicking the name of the parent or a child function takes you to the detailed profile for that function.

---

**Note** Enabling the Profiler on a parent model does not enable profiling for referenced models. You must enable profiling separately for each submodel. Profiling occurs only if the submodel executes in Normal mode. See Chapter 5, “Referencing a Model” for more information.

---

### How to Save Simulink Profiler Results

You can save the Profiler report to a variable in the MATLAB workspace, and subsequently, to a `mat` file. At a later time, you can regenerate and review the report.

To save the Profiler report for a model `vdp` to the variable `profile1` and to the data file `report1.mat`, complete the following steps:

- 1** In the **Simulink Profiler Report** window, click **click here**. Simulink saves the report data to the variable `vdpProfileData`.
- 2** Navigate to the MATLAB command window.

**3** To review the report, at the command line enter:

```
siprofreport(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  
siprofreport(profile1);
```

# Managing Blocks

---

- Chapter 20, “Working with Blocks”
- Chapter 21, “Working with Block Parameters”
- Chapter 22, “Working with Lookup Tables”
- Chapter 23, “Working with Block Masks”
- Chapter 24, “Creating Custom Blocks”
- Chapter 25, “Working with Block Libraries”
- Chapter 26, “Using the MATLAB Function Block”



# Working with Blocks

---

- “About Blocks” on page 20-2
- “Adding Blocks” on page 20-4
- “Editing Blocks” on page 20-9
- “Block Properties Dialog Box” on page 20-15
- “Changing a Block’s Appearance” on page 20-22
- “Displaying Port Values” on page 20-29
- “Controlling and Displaying the Sorted Order” on page 20-35
- “Accessing Block Data During Simulation” on page 20-53
- “Configuration a Block for Code Generation” on page 20-57

## About Blocks

In this section...
“What Are Blocks?” on page 20-2
“Block Data Tips” on page 20-2
“Virtual Blocks” on page 20-2

### What Are Blocks?

Blocks are the elements from which the Simulink software builds models. You can model virtually any dynamic system by creating and interconnecting blocks in appropriate ways. This section discusses how to use blocks to build models of dynamic systems. Most blocks contain fields called *block parameters* that you can use to enter values that customize the behavior of the block. Be careful not to confuse block parameters with Simulink parameters, which are objects of type `simulink.parameter` that exist in the base workspace. See Chapter 21, “Working with Block Parameters” for information about setting and changing block parameters.

### Block Data Tips

Information about a block is displayed in a pop-up window when you allow the pointer to hover over the block in the diagram view. To disable this feature or control what information a data tip includes, select **Block data tips options** from the Simulink **View** menu.

### Virtual Blocks

When creating models, you need to be aware that Simulink blocks fall into two basic categories: nonvirtual blocks and virtual blocks. Nonvirtual blocks play an active role in the simulation of a system. If you add or remove a nonvirtual block, you change the model’s behavior. Virtual blocks, by contrast, play no active role in the simulation; they help organize a model graphically. Some Simulink blocks are virtual in some circumstances and nonvirtual in others. Such blocks are called conditionally virtual blocks. The following table lists Simulink virtual and conditionally virtual blocks.



<b>Block Name</b>	<b>Condition Under Which Block Is Virtual</b>
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 Output block.
From	Always virtual.
Goto	Always virtual.
Goto Tag Visibility	Always virtual.
Ground	Always virtual.
Inport	Virtual <i>unless</i> the block resides in a conditionally executed or atomic subsystem <i>and</i> has a direct connection to an Output block.
Mux	Always virtual.
Output	Virtual when the block resides within any subsystem block (conditional or not), and does <i>not</i> reside in the root (top-level) Simulink window.
Selector	Virtual only when <b>Number of input dimensions</b> specifies 1 and <b>Index Option</b> specifies Select all, Index vector (dialog), or Starting index (dialog).
Signal Specification	Always virtual.
Subsystem	Virtual unless the block is conditionally executed or the <b>Treat as atomic unit</b> check box is selected.  You can check if a block is virtual with the <code>IsSubsystemVirtual</code> block property. See “Block-Specific Parameters” in the <i>Simulink Reference</i> .
Terminator	Always virtual.
Trigger	Virtual when the output port is <i>not</i> present.

## Adding Blocks

In this section...
“Ways to Add Blocks” on page 20-4
“Adding Blocks by Browsing or Searching with the Library Browser” on page 20-5
“Copying Blocks from a Model” on page 20-5
“Adding Frequently Used Blocks” on page 20-6
“Adding Blocks Programmatically” on page 20-8

### 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	<ul style="list-style-type: none"> <li>You are not sure which block to add.</li> <li>You do not have a familiar model from which to copy blocks.</li> </ul>
Copy blocks from a model	<ul style="list-style-type: none"> <li>You know where in a model a block is that you want to copy.</li> <li>You want to replicate many of the parameter settings of an existing block.</li> </ul>

Method	When to Use
Use the Most Frequently Used Blocks pane or context menu	<ul style="list-style-type: none"> <li>• You want to add a block that you have used frequently and recently.</li> <li>• You are working on multiple models that share several of the same blocks.</li> <li>• You do not have a familiar model from which to copy similar blocks.</li> </ul>
Add blocks programmatically with the <code>add_block</code> function	<ul style="list-style-type: none"> <li>• You want to replicate most of the parameter settings of a block.</li> <li>• You are working on multiple models that share several of the same blocks.</li> </ul>

## Adding Blocks by Browsing or Searching with the Library Browser

To browse or search for a block from a block library installed on your system, use the Library Browser. You can browse a list of block libraries or search for blocks whose names include the search string you specify.

When you find the block you want, select that block in the Library Browser and drag the block into your model. See “Populating a Model” on page 3-4 for more information.

## Copying Blocks from a Model

To copy a block from a model in the Model Editor:

- 1 Select the block you want to copy.
- 2 Choose **Edit > Copy**.
- 3 If you have multiple model windows open, make the target model window the active window.
- 4 Choose **Edit > Paste**.

When you copy a block, the parameters use default values.

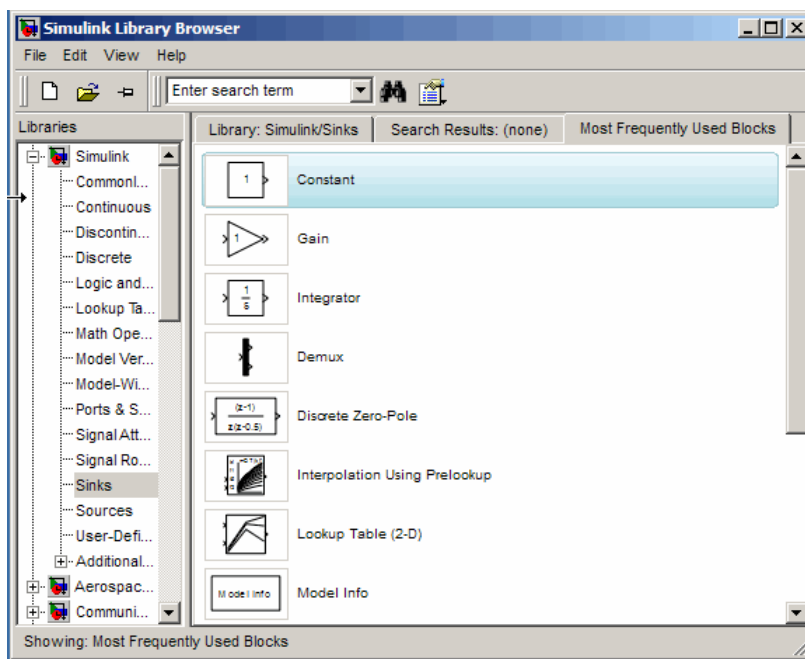
See “Copying and Moving Blocks from One Window to Another” on page 20-9 for details.

## Adding Frequently Used Blocks

When using the same block repeatedly, you can save time by using the **Most Frequently Used Blocks** feature in the Library Browser or Model Editor.

### Selecting Your Most Frequently Used Blocks From the Library Browser

Open the **Most Frequently Used Blocks** pane with the third tab in the Library Browser.



To add a block to a model, select the block from the list and do either one of the following:

- Drag the block into your model.
- Select **Add to <model\_name>** at the top of the context menu for the block.

## Selecting Your Most Frequently Used Blocks from the Model Editor

In the Model Editor, you can view a list of your most frequently used blocks. Right-click anywhere in the model except with the cursor directly on a block or signal. In the context menu, select **Most Frequently Used Blocks**.

### What Blocks Appear in the Most Frequently Used Blocks Lists

The Most Frequently Used Blocks pane lists blocks that you have added most often, with the most frequently used block at the top. The list reflects your ongoing modeling activity. For example, if you add several Gain blocks, the Gain block appears in the list if the list:

- Does not already include the Gain block
- Has less than 25 blocks
- Has 25 blocks, but you added more Gain blocks than the number of instances of the least frequently used block in the list

The list displays blocks that you rename as instances of the library block. For example, if you rename several Gain blocks to be MyGain1, MyGain2, and so on, those blocks count as Gain blocks.

When you close and reopen the Library Browser, the list reflects the blocks that you added up through the previous session. The list updates only when the Library Browser is open.

The list does *not* reflect blocks that you:

- Add programmatically
- Include in subsystems (In other words, if you add a subsystem that uses a specific type of block repeatedly, the list does not reflect that activity.)

The list in the Model Editor is the same as the Library Browser list, except that the Model Editor list includes only five blocks.

## **Adding Blocks Programmatically**

To add a block programmatically, use the `add_block` function.

The `add_block` function copies the parameter values of the source block to the new block. You can use `add_block` to specify values for parameters of the new block.

## Editing Blocks

### In this section...

“Copying and Moving Blocks from One Window to Another” on page 20-9

“Moving Blocks in a Model” on page 20-10

“Copying Blocks in a Model” on page 20-13

“Deleting Blocks” on page 20-14

## Copying and Moving Blocks from One Window to Another

As you build your model, you often copy blocks from Simulink block libraries or other libraries or models into your model window. To do this:

- 1 Open the appropriate block library or model window.
- 2 Drag the block to copy into the target model window. To drag a block, position the cursor over the block, then press and hold down the mouse button. Move the cursor into the target window, then release the mouse button.

You can also drag blocks from the Simulink Library Browser into a model window. See “Browsing Block Libraries” on page 3-5 for more information.

---

**Note** The names of Sum, Mux, Demux, Bus Creator, and Bus Selector blocks are hidden when you copy them from the Simulink block library to a model. This is done to avoid unnecessarily cluttering the model diagram. (The shapes of these blocks clearly indicate their respective functions.)

---

You can also copy blocks by using the **Copy** and **Paste** commands from the **Edit** menu:

- 1 Select the block you want to copy.
- 2 Choose **Copy** from the **Edit** menu.

**3** Make the target model window the active window.

**4** Choose **Paste** from the **Edit** menu.

Simulink assigns a name to each copied block. If it is the first block of its type in the model, its name is the same as its name in the source window. For example, if you copy the Gain block from the Math library into your model window, the name of the new block is Gain. If your model already contains a block named Gain, Simulink adds a sequence number to the block name (for example, Gain1, Gain2). You can rename blocks; see “Manipulating Block Names” on page 20-26.

When you copy a block, the new block inherits all the original block’s parameter values.

For more ways to add blocks, see “Adding Blocks” on page 20-4.

add blocks

## **Moving Blocks in a Model**

To move a single block from one place to another in a model window, drag the block to a new location. Simulink automatically repositions lines connected to the moved block.

To move more than one block, including connecting lines:

**1** Select the blocks and lines. If you need information about how to select more than one block, see “Selecting Multiple Objects” on page 3-7.

**2** Drag the objects to their new location and release the mouse button.

To move a block, disconnecting lines:

**1** Select the block.

**2** Press the **Shift** key, then drag the block to its new location and release the mouse button.

You can also move a block by selecting the block and pressing the arrow keys.



Moving blocks from one window to another is similar to copying blocks, except that you hold down the **Shift** key while you select the blocks.

You can use the **Undo** command from the **Edit** menu to remove an added block.

## Aligning Blocks

You can use tools to manually align blocks. These tools include a grid snap feature and smart guides that indicate when a block center or port aligns with the center or port of another block. You can also use commands that align a group of blocks automatically (see “Aligning, Distributing, and Resizing Groups of Blocks Automatically” on page 3-24 for details).

**Grid Snap.** Simulink uses an invisible five-pixel grid to simplify the alignment of blocks. When you move a block to a new location, the block snaps to the nearest line on the grid. You can display the grid and change its spacing.

To display the grid, enter the following command at the MATLAB command prompt.

```
set_param('<model name>', 'showgrid', 'on')
```

The default width of the grid is 20 pixels. To change the grid spacing, enter

```
set_param('<model name>', 'gridspacing', <number of pixels>)
```

For example, to change the grid spacing to 25 pixels, enter

```
set_param('<model name>', 'gridspacing', 25)
```

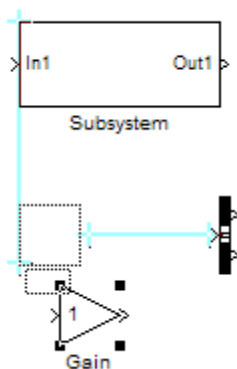
---

**Note** The new spacing must be a multiple of five pixels to ensure that the displayed grid aligns with the invisible snap grid.

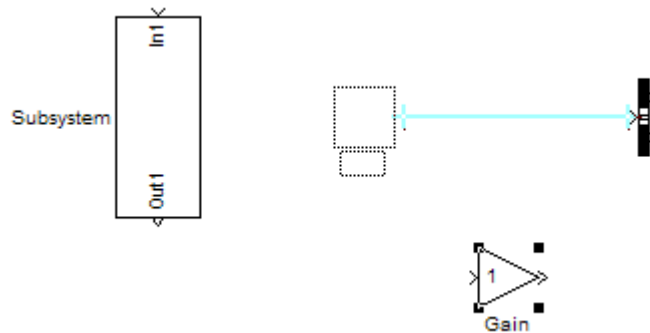
---

For either of the above commands, you can also select the model, then enter `gcs` instead of `<model name>`.

**Smart Guides.** When you move a block, smart guides appear by default to indicate when the block ports, center, or edges are aligned with the ports, centers, and edges of other blocks in the same diagram. For example, the following figure shows a snapshot of a Gain block that you drag from one position in a diagram to another. The dotted outline indicates the position to which the Gain block has been dragged. The blue smart guides indicate that if you drop the Gain block at this position, its left edge will be aligned with the left edge of the Subsystem block and its output port will be aligned with the input port of the Mux block.



When you drag a block, one of its alignment features, for example, a port, may match more than one alignment feature of another block. In this case, Simulink displays a line for one of the features, using the following precedence order: ports, centers, edges. For example, in the following drag-and-drop snapshot, the Gain block's center aligns with the Subsystem's center and the Gain block's output port aligns with the Mux block's input port. However, because ports take precedence over centers, Simulink draws a guide only for the ports.



You can turn smart guides off or on (the default) by selecting **Format > Smart Guides**.

### Positioning Blocks Programmatically

You can position (and resize) a block programmatically, using its `Position` parameter. For example, the following command

```
set_param(gcb, 'Position', [5 5 20 20]);
```

moves the currently selected block to a location 5 points down and 5 points to the right of the top left corner of the block diagram and sets the block's height and width to 15 points, respectively.

---

**Note** The maximum size of a block diagram's height and width is 32767 points. An error message appears if you try to move or resize a block to a position that exceeds the diagram's boundaries.

---

### Copying Blocks in a Model

You can copy blocks in a model as follows. While holding down the **Ctrl** key, select the block with the left mouse button, then drag it to a new location. You can also do this by dragging the block using the right mouse button. Duplicated blocks have the same parameter values as the original blocks. Sequence numbers are added to the new block names.

---

**Note** The model editor sorts block names alphabetically when generating names for copies pasted into a model. This action can cause the names of pasted blocks to be out of order. For example, suppose you copy a row of 16 gain blocks named Gain, Gain1, Gain2...Gain15 and paste them into the model. The names of the pasted blocks occur in the following order: Gain16, Gain17, Gain24...Gain23.

---

## **Deleting Blocks**

To delete one or more blocks, select the blocks to be deleted and press the **Delete** or **Backspace** key. You can also choose **Clear** or **Cut** from the **Edit** menu. The **Cut** command writes the blocks into the clipboard, which enables you to paste them into a model. Using the **Delete** or **Backspace** key or the **Clear** command does not enable you to paste the block later.

You can use the **Undo** command from the **Edit** menu to replace a deleted block.

## Block Properties Dialog Box

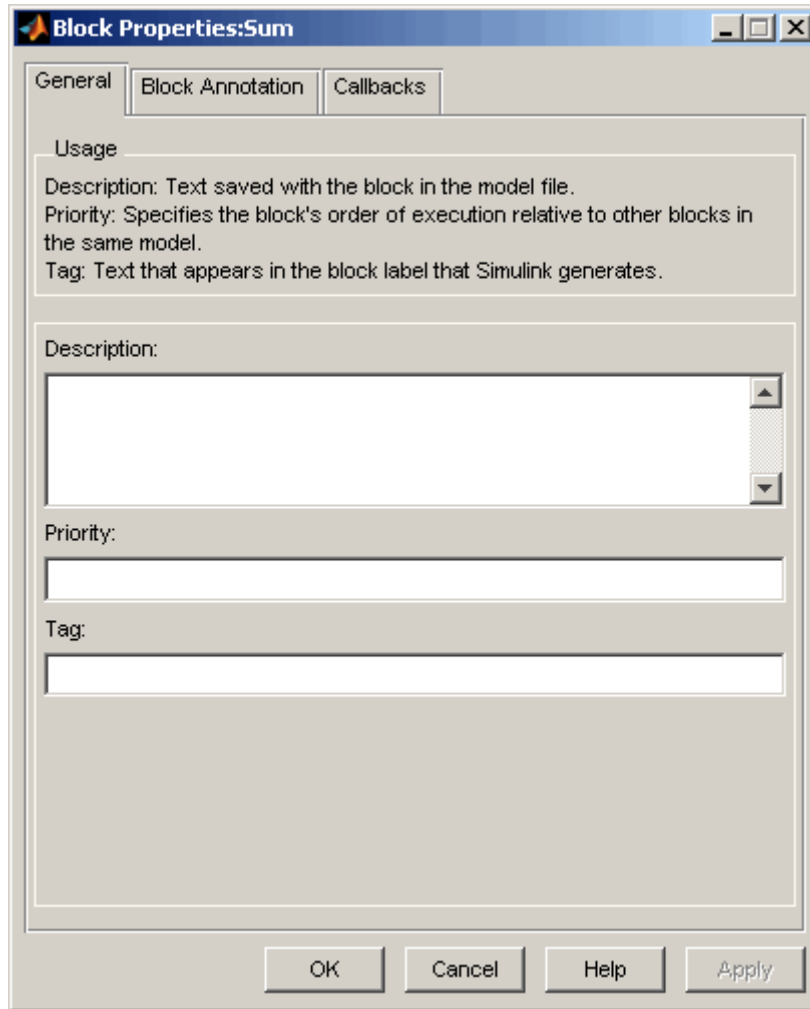
The Block Properties dialog box lets you set a block's properties. To display this dialog, select the block in the model window and then select **Block Properties** from the **Edit** menu.

The dialog box contains the following tabbed panes:

- “General Pane” on page 20-15
- “Block Annotation Pane” on page 20-17
- “Callbacks Pane” on page 20-19

### General Pane

This pane allows you to set the following properties.



**Description**

Brief description of the block’s purpose.

**Priority**

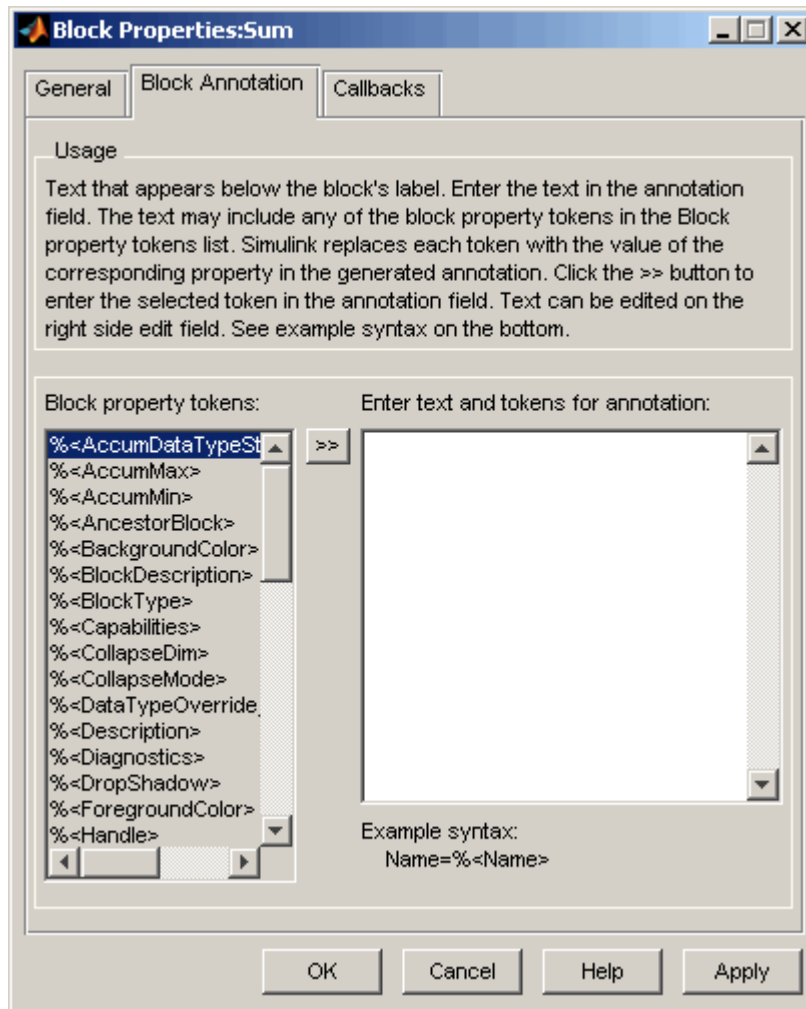
Execution priority of this block relative to other blocks in the model. See “Assigning Block Priorities” on page 20-48 for more information.

**Tag**

Text that is assigned to the block's Tag parameter and saved with the block in the model. You can use the tag to create your own block-specific label for a block.

**Block Annotation Pane**

The block annotation pane allows you to display the values of selected block parameters in an annotation that appears beneath the block's icon.

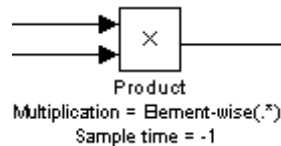


Enter the text of the annotation in the text field that appears on the right side of the pane. The text can include any of the block property tokens that appear in the list on the left side of the pane. A block property token is simply the name of a block parameter preceded by %< and followed by >. When displaying the annotation, the Simulink software replaces the tokens with the values of the corresponding block parameters. For example, suppose that you enter the following text and tokens for a Product block:



```
Multiplication = %<Multiplication>  
Sample time = %<SampleTime>
```

In the model editor window, the annotation appears as follows:

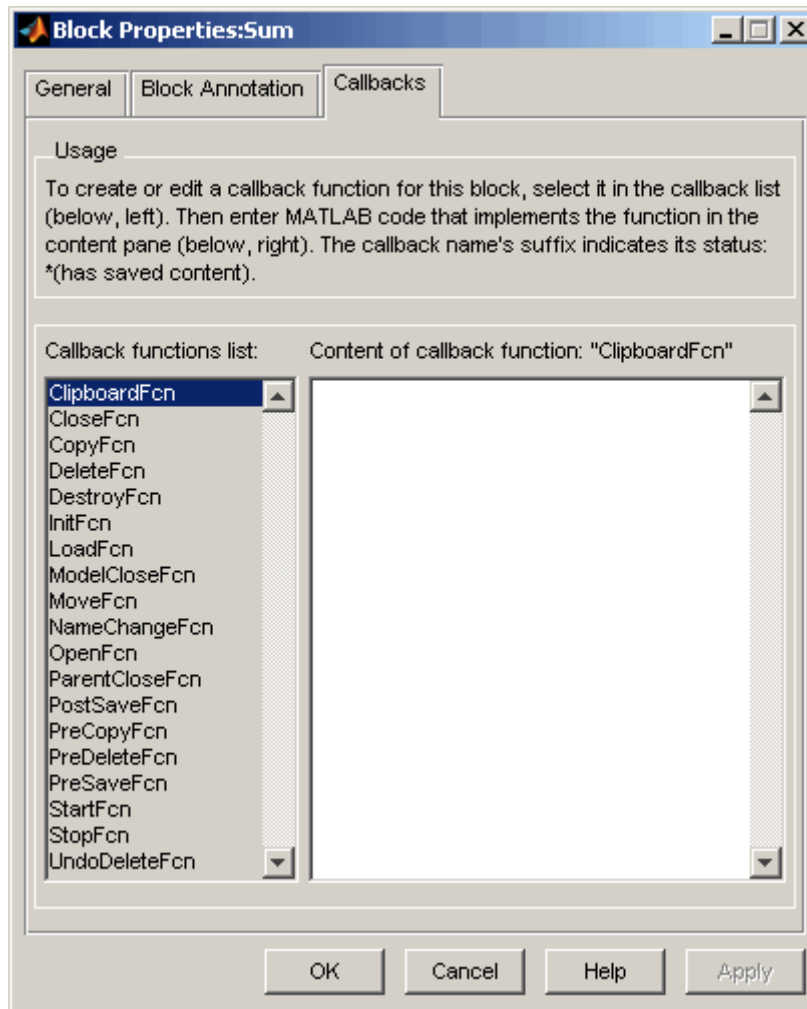


The block property token list on the left side of the pane lists all the parameters that are valid for the currently selected block (see “Model and Block Parameters” in the *Simulink Reference*). To add one of the listed tokens to the text field on the right side of the pane, select the token and then click the button between the list and the text field.

You can also create block annotations programmatically. See “Creating Block Annotations Programmatically” on page 20-21.

## Callbacks Pane

The **Callbacks Pane** allows you to specify implementations for a block’s callbacks (see “Using Callback Functions” on page 3-54).



To specify an implementation for a callback, select the callback in the callback list on the left side of the pane. Then enter MATLAB commands that implement the callback in the right-hand field. Click **OK** or **Apply** to save the change. Simulink appends an asterisk to the name of the saved callback to indicate that it has been implemented.

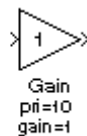
## Creating Block Annotations Programmatically

You can use a block's `AttributesFormatString` parameter to display selected block parameters beneath the block as an “attributes format string,” i.e., a string that specifies values of the block's attributes (parameters). “Model and Block Parameters” in *Simulink Reference* describes the parameters that a block can have. Use the Simulink `set_param` function to set this parameter to the desired attributes format string.

The attributes format string can be any text string that has embedded parameter names. An embedded parameter name is a parameter name preceded by `%<` and followed by `>`, for example, `%<priority>`. Simulink displays the attributes format string beneath the block's icon, replacing each parameter name with the corresponding parameter value. You can use line-feed characters (`\n`) to display each parameter on a separate line. For example, specifying the attributes format string

```
pri=%<priority>\ngain=%<Gain>
```

for a Gain block displays



If a parameter's value is not a string or an integer, Simulink displays N/S (not supported) for the parameter's value. If the parameter name is invalid, Simulink displays ??? as the parameter value.

## Changing a Block's Appearance

### In this section...

“Changing a Block's Orientation” on page 20-22

“Resizing a Block” on page 20-25

“Displaying Parameters Beneath a Block” on page 20-26

“Using Drop Shadows” on page 20-26

“Manipulating Block Names” on page 20-26

“Specifying a Block's Color” on page 20-28

### Changing a Block's Orientation

By default, a block is oriented so that its input ports are on the left, and its output ports are on the right. You can change the orientation of a block by rotating it 90 degrees around its center or flipping it 180 degrees around its horizontal or vertical axis.

- “How to Rotate a Block” on page 20-22
- “How to Flip a Block” on page 20-24

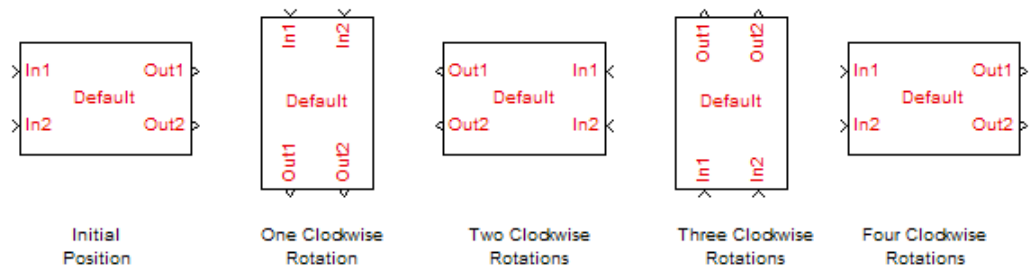
#### How to Rotate a Block

You can rotate a block 90 degrees by selecting one of these commands from the **Format** menu:

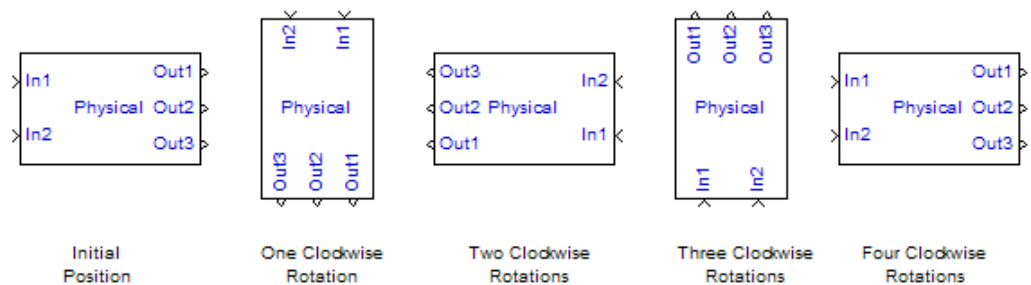
- **Rotate Block > Clockwise (Ctrl+R)**
- **Rotate Block > Counterclockwise**

A rotation command effectively moves a block's ports from its sides to its top and bottom or from its top and bottom to its size, depending on the initial orientation of the block. The final positions of the block's ports depend on the block's *port rotation type*.

**Port Rotation Type.** After rotating a block clockwise, Simulink may, depending on the block, reposition the block's ports to maintain a left-to-right port numbering order for ports along the top and bottom of the block and a top-to-bottom port numbering order for ports along the left and right sides of the block. A block whose ports are reordered after a clockwise rotation is said to have a *default port rotation type*. This policy helps to maintain the left-right and top-down block diagram orientation convention used in control system modeling applications. All nonmasked blocks and all masked blocks by default have the default rotation policy. The following figure shows the effect of using the **Rotate Block > Clockwise** command on a block with the default rotation policy.



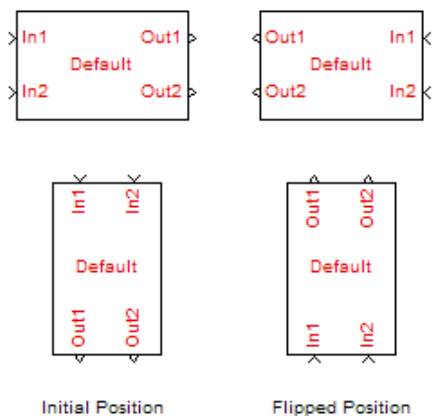
A masked block can optionally specify that its ports not be reordered after a clockwise rotation (see “Port Rotation”). Such a block is said to have a *physical port rotation type*. This policy facilitates layout of diagrams in mechanical and hydraulic systems modeling and other applications where diagrams do not have a preferred orientation. The following figure shows the effect of clockwise rotation on a block with a physical port rotation type



## How to Flip a Block

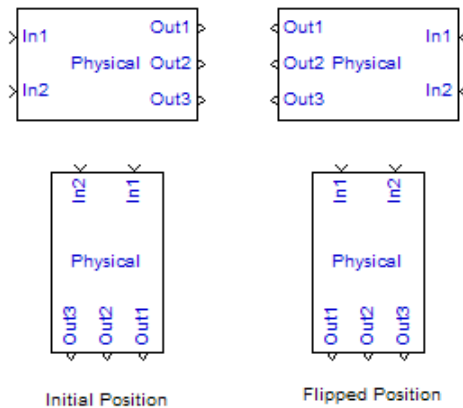
Simulink provides a set of commands that allow you to flip a block 180 degrees about its horizontal or vertical axis. The commands effectively move a block's input and output ports to opposite sides of the block or reverse the ordering of the ports, depending on the block's port rotation type.

A block with the default rotation type has one flip command: **Format > Flip Block (Ctrl+I)**. This command effectively moves the block's input and output ports to the side of the block opposite to the side on which they are initially located, i.e., from the left to the right side or from the top to the bottom side.



A block with a physical rotation type has two flip commands: **Format > Flip Block > Left-Right** or **Format > Flip Block > Up-Down**. The effect of these commands depends on the initial position of the ports.

**Left-Right Flip.** If the block's ports initially reside on the left and right sides of the block, the **Left-Right** command reverses the sides on which the input and ports are located. If the ports are located on the top and bottom of the block, the command reverses the order of the ports without changing their sides.

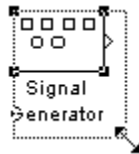


## Resizing a Block

To change the size of a block, select it, then drag any of its selection handles. While you hold down the mouse button, a dotted rectangle shows the new block size. When you release the mouse button, the block is resized.

For example, the following figure below shows a Signal Generator block being resized. The lower-right handle was selected and dragged to the cursor position. When the mouse button is released, the block takes its new size.

This figure shows a block being resized:




---

**Tip** Use the model editor's resize blocks commands to make one block the same size as another (see “Aligning, Distributing, and Resizing Groups of Blocks Automatically” on page 3-24).

---

## Displaying Parameters Beneath a Block

You can cause Simulink to display one or more of a block's parameters beneath the block. You specify the parameters to be displayed in the following ways:

- By entering an attributes format string in the **Attributes format string** field of the block's **Block Properties** dialog box (see “Block Properties Dialog Box” on page 20-15)
- By setting the value of the block's `AttributesFormatString` property to the format string, using `set_param`

## Using Drop Shadows

You can add a drop shadow to a block by selecting the block, then choosing **Show Drop Shadow** from the **Format** menu. When you select a block with a drop shadow, the menu item changes to **Hide Drop Shadow**. The following figure shows a Subsystem block with a drop shadow:



## Manipulating Block Names

All block names in a model must be unique and must contain at least one character. By default, block names appear below blocks whose ports are on the sides, and to the left of blocks whose ports are on the top and bottom, as the following figure shows:




---

**Note** Simulink commands interpret a forward slash, i.e., /, as a block path delimiter. For example, the path `vdv/Mu` designates a block named `Mu` in the model named `vdv`. Therefore, avoid using forward slashes (/) in block names to avoid causing Simulink to interpret the names as paths.

---



## Changing Block Names

You can edit a block name in one of these ways:

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

When you click the pointer anywhere else in the model or take any other action, the name is accepted or rejected. If you try to change the name of a block to a name that already exists, Simulink displays an error message.

You can modify the font used in a block name by selecting the block, then choosing the **Font** menu item from the **Format** menu. Select a font from the **Set Font** dialog box. This procedure also changes the font of any text that appears inside the block.

You can cancel edits to a block name by choosing **Undo** from the **Edit** menu.

---

**Note** If you change the name of a library block, all links to that block become unresolved.

---

## Changing the Location of a Block Name

You can change the location of the name of a selected block in two ways:

- By dragging the block name to the opposite side of the block.
- By choosing the **Flip Name** command from the **Format** menu. This command changes the location of the block name to the opposite side of the block.

For more information about block orientation, see “How to Rotate a Block” on page 20-22.

### **Changing Whether a Block Name Appears**

To change whether the name of a selected block is displayed, choose a menu item from the **Format** menu:

- The **Hide Name** menu item hides a visible block name. When you select **Hide Name**, it changes to **Show Name** when that block is selected.
- The **Show Name** menu item shows a hidden block name.

### **Specifying a Block's Color**

See “Specifying Block Diagram Colors” on page 3-9 for information on how to set the color of a block.

## Displaying Port Values

### In this section...

“Port Value Data Tips” on page 20-29

“Setting Port Value Data Tip Options” on page 20-30

“Enabling Port Value Display” on page 20-31

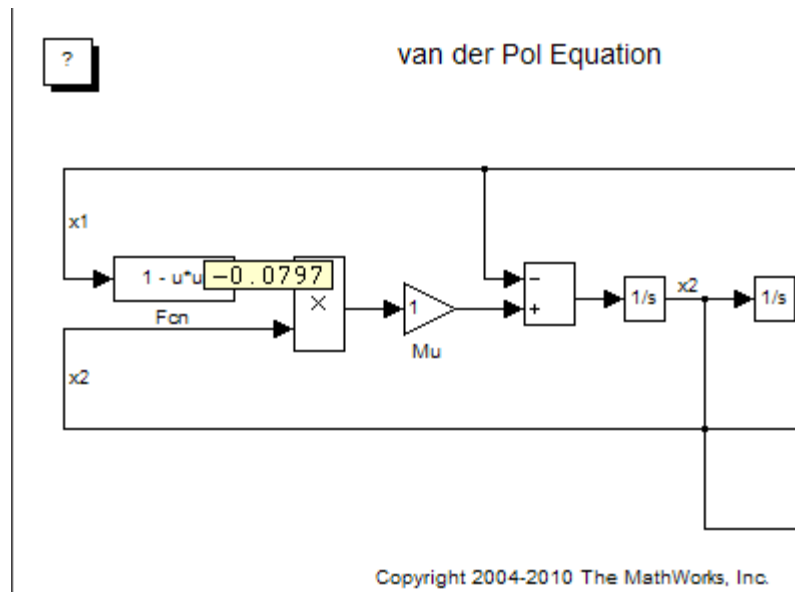
“Controlling the Port Value Display” on page 20-31

“Displayed Value When No Data Is Available” on page 20-32

“Port Value Display Limitations” on page 20-33

### 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 `-0.0797`.



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:

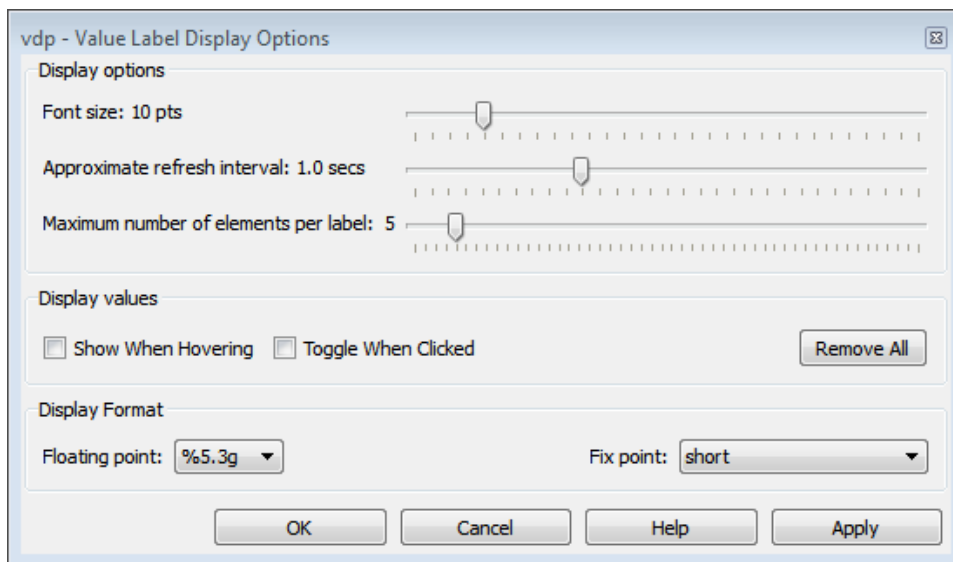
- Accelerated modes
- Signal storage reuse
- Signals with some complex data types, such as bus signals

See “Port Value Display Limitations” on page 20-33.

---

## Setting Port Value Data Tip Options

You can set data tip options by selecting **Port Value Labels > Options** from the Model Editor **View** menu and using the Value Label Display Options dialog box.



## Enabling Port Value Display

To turn port value display on or off, in the **Display values** section of the dialog box, select one of these options:

- **Show When Hovering**

Displays output port values for the block under the mouse cursor.

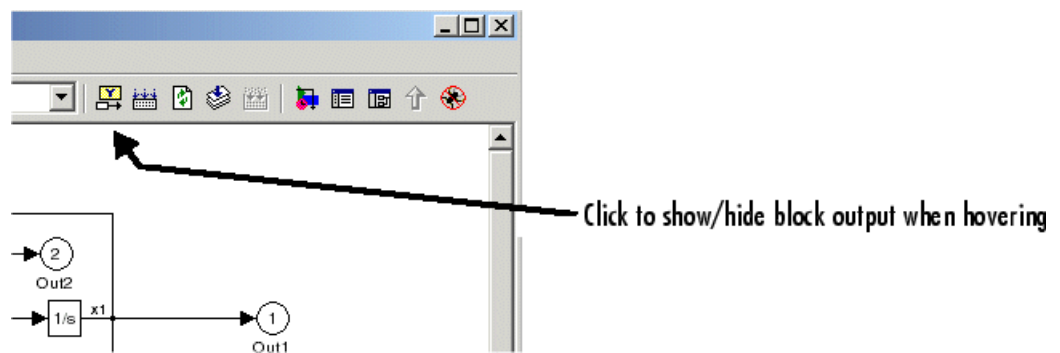
- **Toggle When Clicked**

Displays output port values when you select a block. Reselecting that block turns off the display. 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 turn off all port value displays, select **Remove All**.

- **Remove All**

Turns off port value display.

Simulink on Microsoft Windows platforms also has a Model Editor output display button to enable or disable port value display when hovering.



## Controlling the Port Value Display

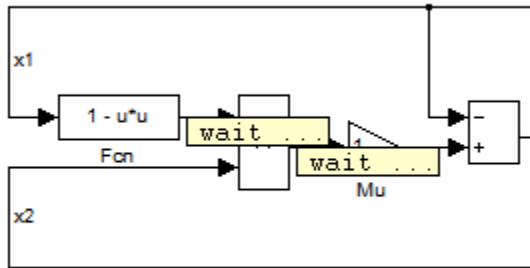
You can specify port value display formatting and how frequently the display updates.

<b>Port Value Data Tip Display Characteristic</b>	<b>What You Specify</b>
Text size	To increase the size of the output display text, move the <b>Font size</b> slider to the right.
Floating point data format	Choose a floating point format from the <b>Floating point</b> list.
Fixed-point data format	Choose a fixed-point format from the <b>Fix point</b> 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 <b>Approximate refresh interval: 1.0</b> 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 <b>Maximum number of elements per label: 3</b> 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.

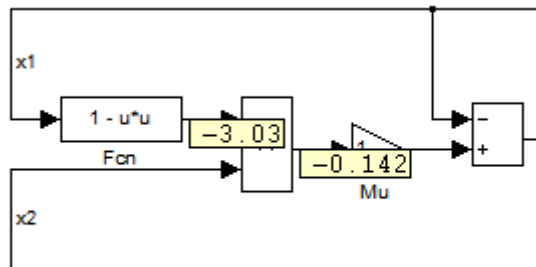
## Displayed Value When No Data Is Available

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. This is the port value display of the optimized component with the wait string:



This is the port value of the optimized component after the port value is updated;



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 20-29.
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

If you select **Show When Hovering** or **Toggle When Clicked** for a model with the **Signal storage reuse** parameter enabled, invoking the port value displays the text optimized if the software cannot determine the signal value.

To enable the port value display, open the Configuration Parameters dialog box and clear the **Signal storage reuse** check box on the **Optimization > Signals and Parameters** pane. Disabling signal storage reuse increases the amount of memory used during simulation.

## Signal Data Types

The port value displays for ports connected to most kinds of signals, including signals with built-in data types (such as `double`, `int32`, or `Boolean`), `DYNAMICALLY_TYPED`, and several other data types. However, no data displays for signals with some complex data types, such as bus signals.



## Controlling and Displaying the Sorted Order

### In this section...

- “What Is Sorted Order?” on page 20-35
- “Displaying the Sorted Order” on page 20-35
- “Sorted Order Notation” on page 20-36
- “How Simulink Determines the Sorted Order” on page 20-46
- “Assigning Block Priorities” on page 20-48
- “Rules for Block Priorities” on page 20-49
- “Block Priority Violations” on page 20-52

### What Is Sorted Order?

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

You cannot set this order, but you can assign priorities to nonvirtual blocks to indicate to Simulink their execution order relative to other blocks. Simulink always honors block priority settings, unless there is a conflict with data dependencies. To confirm the results of priorities that you have set, or to debug your model, display and review the sorted order of your nonvirtual blocks and subsystems.

---

**Note** For more information about block methods and execution, see:

- “Block Methods” on page 2-16
  - “Conditional Execution Behavior” on page 6-28
- 

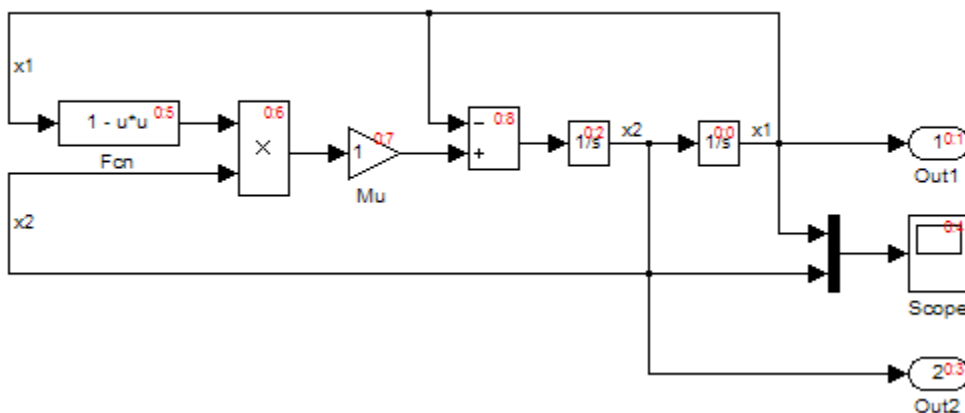
### Displaying the Sorted Order

To display the sorted order of the vdp demo model:

1 Open the van der Pol equation demo model:

vdp

2 In the model window, select **Format > Block Displays > Sorted Order**.



Simulink displays a notation in the top-right corner of each nonvirtual block and each nonvirtual subsystem. These numbers indicate the order in which the blocks execute. The first block to execute has a sorted order of 0.

For example, in the van der Pol equation model, the Integrator block with the sorted order 0:0 executes first. The Out1 block, with the sorted order 0:1, executes second. Similarly, the remaining blocks execute in numeric order from 0:2 to 0:8.

You can save the sorted order setting with your model. To display the sorted order when you reopen the model, select **Edit > Update diagram**.

## Sorted Order Notation

The sorted order notation varies depending on the type of block. The following table summarizes the different formats of sorted order notation. Each format is described in detail in the sections that follows the table.

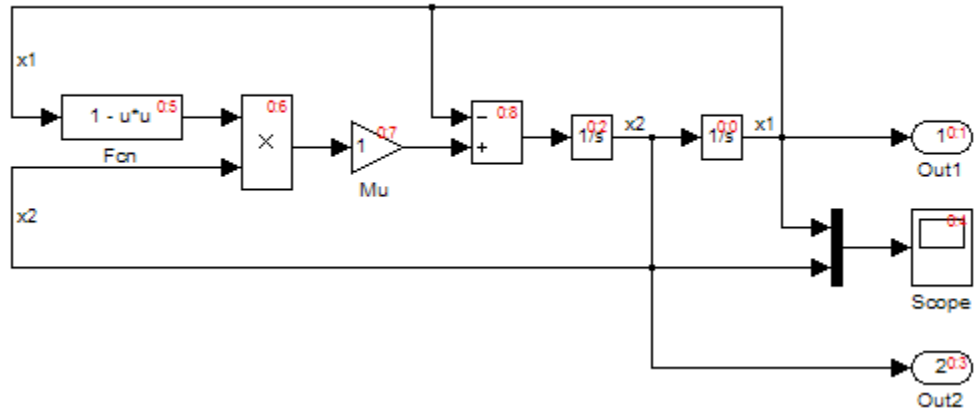
Block Type	Sorted Order Notation	Description
“Nonvirtual Blocks” on page 20-38	$s:b$	<ul style="list-style-type: none"> <li>• <math>s</math> is the system index of the model or subsystem. For root-level models, <math>s</math> is always 0.</li> <li>• <math>b</math> specifies the block position within the sorted order for the designated execution context.</li> </ul>
“Nonvirtual Subsystems” on page 20-39	$s:b\{s_i\}$	<ul style="list-style-type: none"> <li>• <math>s</math> is the system index of the model or subsystem.</li> <li>• <math>b</math> specifies the block position within the sorted order for the designated execution context.</li> <li>• <math>s_i</math> is the subsystem index.</li> </ul>
“Virtual Blocks and Subsystems” on page 20-41	Not applicable	Virtual blocks do not execute.
“Function-Call Subsystems” on page 20-42	One initiator: $s:F\{s_i\}$	<ul style="list-style-type: none"> <li>• <math>s</math> is the system index of the model or subsystem.</li> <li>• <math>F</math> indicates a function-call subsystem.</li> <li>• <math>s_i</math> is the subsystem index.</li> </ul>
	Two or more initiators: <ul style="list-style-type: none"> <li>• <math>s:F\{s_i\}</math> when the initiators all execute at the same level of the model hierarchy</li> <li>• <math>M:F\{s_i\}</math>, when the initiators execute at different levels of the model hierarchy</li> </ul>	<ul style="list-style-type: none"> <li>• <math>s</math> is the system index of the initiators.</li> <li>• <math>F</math> indicates a function-call subsystem.</li> <li>• <math>s_i</math> is the subsystem index.</li> <li>• <math>M</math> indicates that the initiators execute at different levels of the model hierarchy.</li> </ul>

<b>Block Type</b>	<b>Sorted Order Notation</b>	<b>Description</b>
“Function-Call Split Blocks” on page 20-44	$s : Bb$	<ul style="list-style-type: none"> <li>• <math>s</math> is a system index of the model or subsystem.</li> <li>• <math>B</math> indicates a branch of the function-call signal.</li> <li>• <math>b</math> specifies the index of each subsystem connected to each branch of the given function-call signal.</li> </ul>
“Bus-Capable Blocks” on page 20-45	$s : B$	<ul style="list-style-type: none"> <li>• <math>s</math> is a system index of the model or subsystem.</li> <li>• <math>B</math> indicates a bus-capable block.</li> </ul>

- “Nonvirtual Blocks” on page 20-38
- “Nonvirtual Subsystems” on page 20-39
- “Virtual Blocks and Subsystems” on page 20-41
- “Function-Call Subsystems” on page 20-42
- “Function-Call Split Blocks” on page 20-44
- “Bus-Capable Blocks” on page 20-45

### **Nonvirtual Blocks**

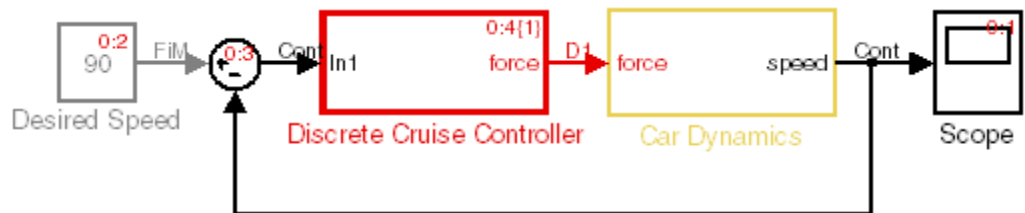
In the van der Pol equation model, all the nonvirtual blocks in the model have a sorted order. The system index for the top-level model is 0, and the block execution order ranges from 0 to 8.



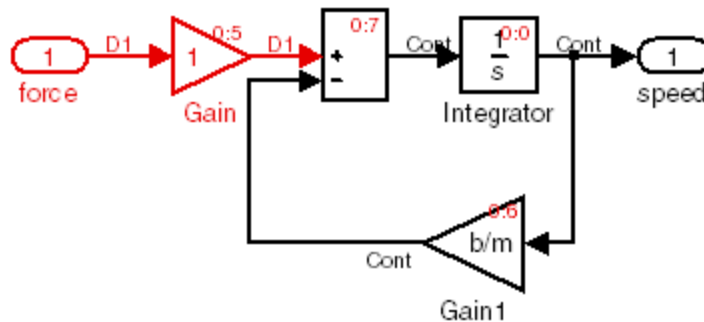
## Nonvirtual Subsystems

The following model contains an atomic, nonvirtual subsystem named Discrete Cruise Controller.

When you enable the sorted order display for the root-level system, Simulink displays the sorted order of the blocks.



The Scope block in this model has the lowest sorted order, but its input depends on the output of the Car Dynamics subsystem. The Car Dynamics subsystem is virtual, so it does not have a sorted order and does not execute as an atomic unit. However, the blocks within the subsystem execute at the root level, so the Integrator block in the Car Dynamics subsystem executes first. The Integrator block sends its output to the Scope block in the root-level model, which executes second.

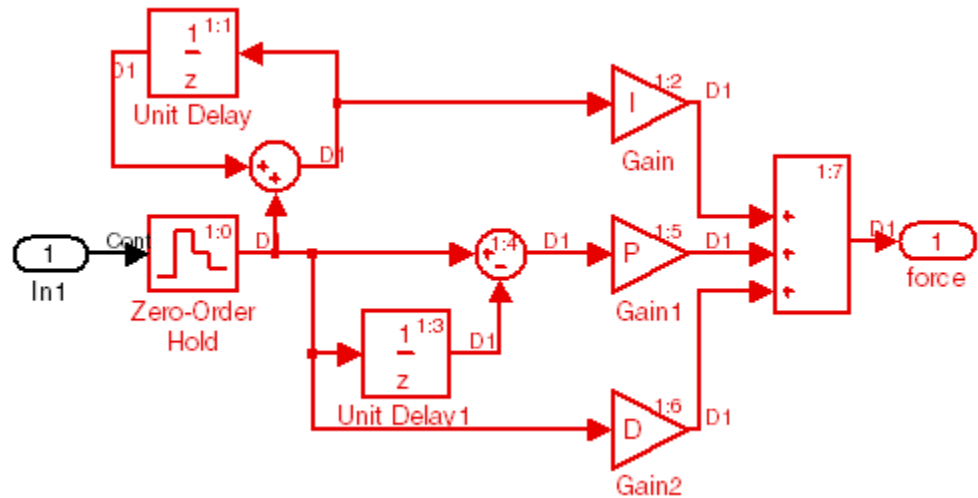


The Discrete Cruise Controller subsystem has a sorted order of  $0:4\{1\}$ :

- 0 indicates that this atomic subsystem is part of the root level of the hierarchal system comprised of the primary system and the two subsystems.
- 4 indicates that the atomic subsystem is the fifth block that Simulink executes relative to the blocks within the root level.
- $\{1\}$  represents the subsystem index. This index does *not* indicate the relative order in which the atomic subsystem runs.

The sorted order of each block inside the Discrete Cruise Controller subsystem has the form  $1:b$ , where:

- 1 is the system index for that subsystem.
- $b$  is the block position in the execution order. In the Discrete Cruise Controller subsystem, the sorted order ranges from 0 to 7.

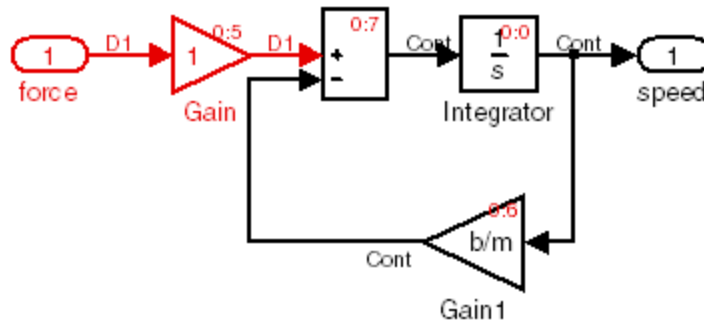


## Virtual Blocks and Subsystems

Virtual blocks, such as the Mux block, exist only graphically and do not execute. Consequently, they are not part of the sorted order and do not display any sorted order notation.

Virtual subsystems do not execute as a unit, and like a virtual block, are not part of the sorted order. The blocks inside the virtual subsystem are part of the root-level system sorted order, and therefore share the system index.

In the model in “Nonvirtual Subsystems” on page 20-39, 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.



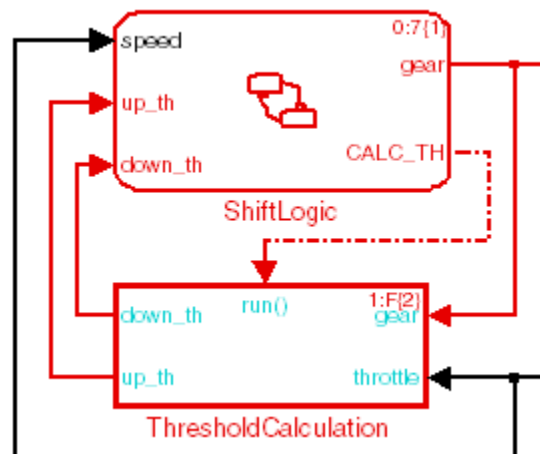
## Function-Call Subsystems

**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.



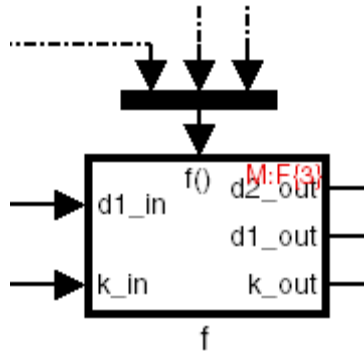


**Multiple Initiators.** For a function-call subsystem that connects to more than one initiator, the sorted order notation depends on the execution context of the initiators:

- 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 `s1_subsystem_fcncal16` demo model. The `f` subsystem has three initiators, two from the Stateflow chart, `Chart1`, and one from the Stateflow chart, `Chart`.

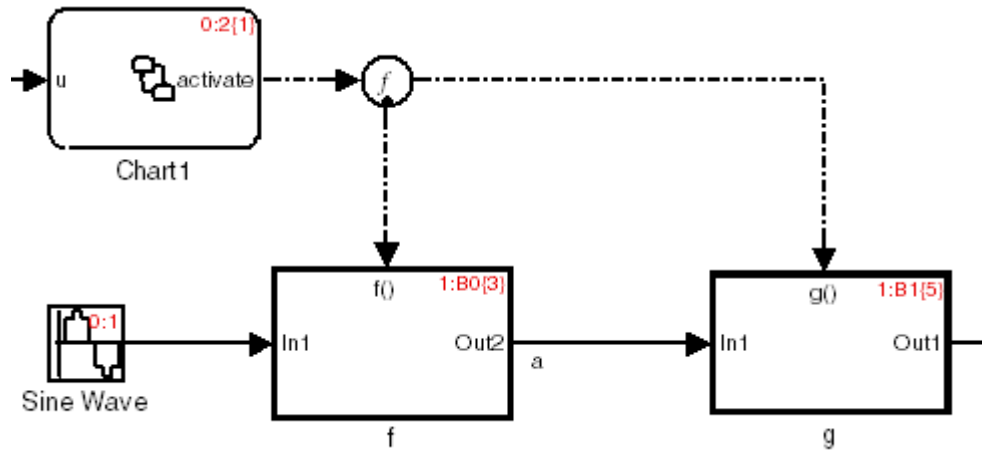
Because `Chart1` has a system index of 2 and `Chart` has a system index of 1, the initiators execute at different levels in the model hierarchy. The Function-Call Subsystem `f` has a sorted order notation of  $M:F\{3\}$ .



### Function-Call Split Blocks

When a function-call signal is branched using a Function-Call Split block, Simulink displays the order in which subsystems (or models) that connect to the branches execute when the initiator invokes the function call. Simulink uses the notation  $s:Bb$  to indicate this order, where  $B$  stands for branch. The block position  $b$  ranges from 0 to one less than the total number of subsystems (or models) that connect to branches ( $B0$ ,  $B1$ , etc.). When the function-call is invoked, the subsystems execute in ascending order based on this number.

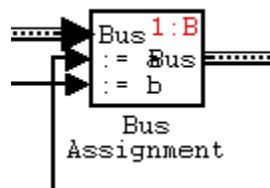
For example, open the `s1_subsys_fncall111` demo model and display the sorted order. The sorted order indicates that the subsystem  $f$  ( $B0$ ) executes before the subsystem  $g$  ( $B1$ ).



### Bus-Capable Blocks

A bus-capable block does not execute as a unit and therefore does not have a unique sorted order. Such a block displays its sorted order as  $s:B$  where  $B$  stands for bus.

For example, open the `sldemo_bus_arrays` demo model and display the sorted order. Open the For Each Subsystem to see that the sorted order for the Bus Assignment block appears as  $1:B$ .



For more information, see “Bus-Capable Blocks” on page 32-14.

## 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.

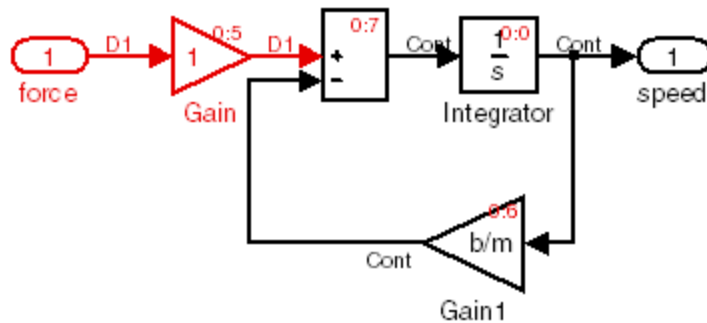
Placing all blocks that do not have direct-feedthrough ports at the beginning of the sorted order satisfies this rule. This arrangement allows Simulink to ignore these blocks during the sorting process.

Applying these rules results in the sorted order. Blocks without direct-feedthrough ports appear at the beginning of the list in no particular

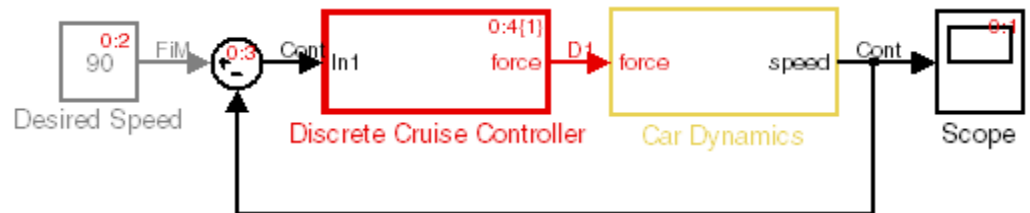
order. These blocks are followed by blocks with direct-feedthrough ports arranged such that they can supply valid inputs to the blocks which they drive.

The following model, from “Nonvirtual Subsystems” on page 20-39, 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:

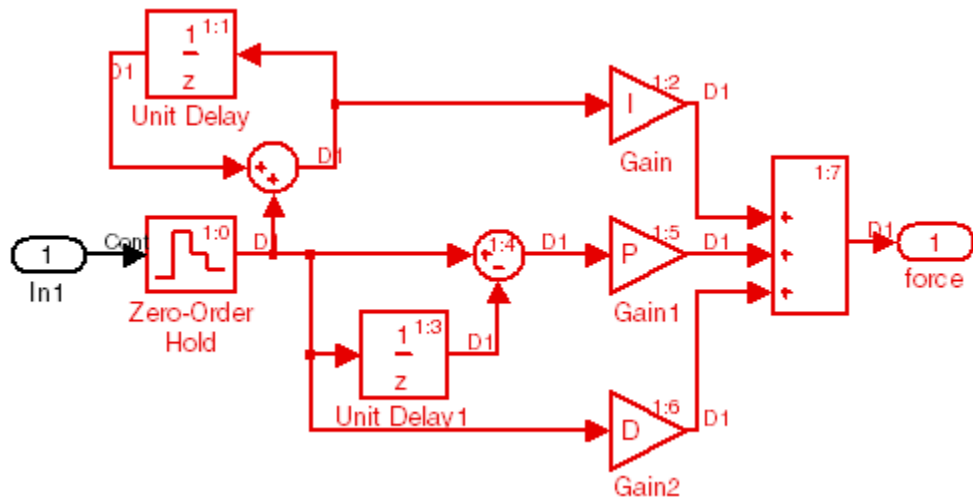
- Integrator block in the Car Dynamics virtual subsystem



- 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.



## Assigning Block Priorities

You can assign a priority to a nonvirtual block or to an entire subsystem. Higher priority blocks appear before lower priority blocks in the sorted order. The lower the number, the higher the priority.

- “Assigning Block Priorities Programmatically” on page 20-48
- “Assigning Block Priorities Interactively” on page 20-48

### 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 **Block Properties**.
- 2 On the **General** tab, in the **Priority** field, enter the priority.

## Rules for Block Priorities

Simulink honors the block priorities that you specify unless they violate data dependencies. (“Block Priority Violations” on page 20-52 describes situations that cause block property violations.)

In assessing priority assignments, Simulink attempts to create a sorted order such that the priorities for the individual blocks within the root-level system or within a nonvirtual subsystem are honored relative to one another.

Three rules pertain to priorities:

- “Priorities Are Relative” on page 20-49
- “Priorities Are Hierarchical” on page 20-50
- “Lack of Priority May Not Result in Low Priority” on page 20-51

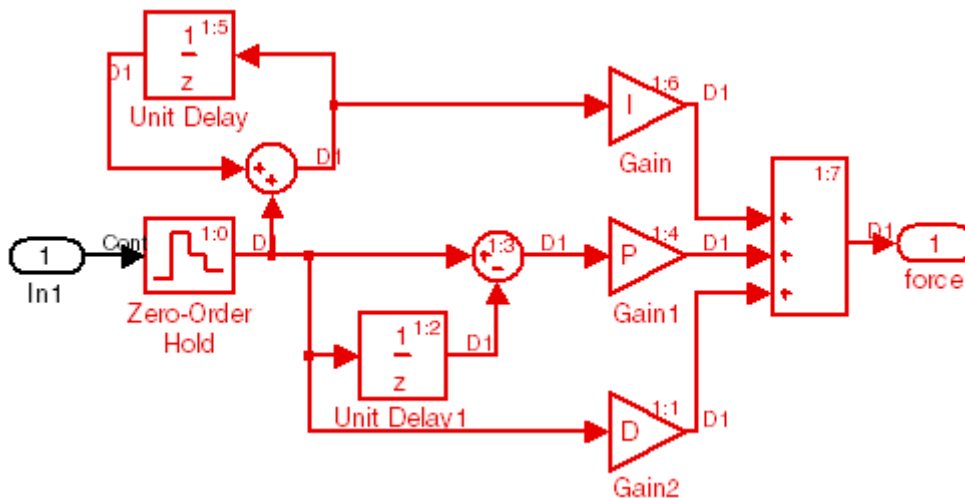
### Priorities Are Relative

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 20-39.

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.

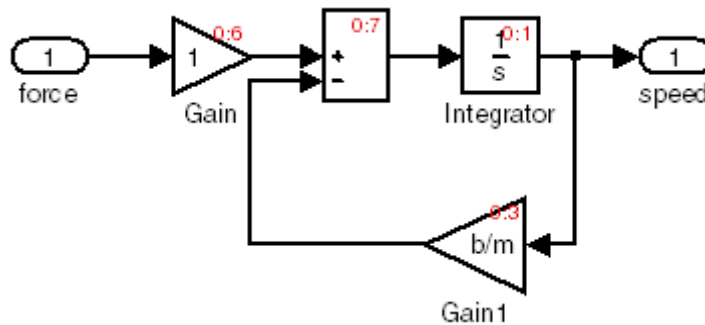
### Priorities Are Hierarchical

In the Car Dynamics virtual subsystem, suppose you set the priorities of the Gain blocks as follows.

Block	Priority
Gain	2
Gain1	1

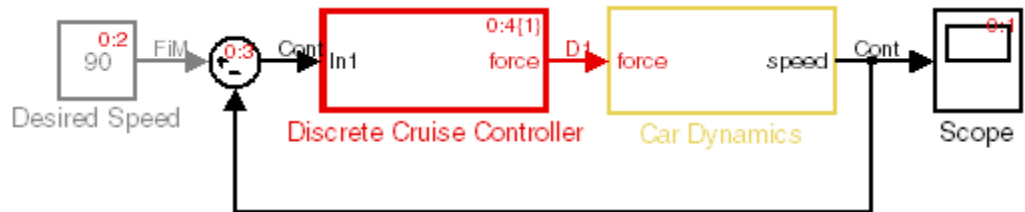
After updating the diagram, the sorted order for the Gain blocks is as illustrated. With these priorities, Gain1 always executes before Gain.





You can set a priority of 1 to one block in each of the two subsystems because of the hierarchical nature of the subsystems within a model. Simulink never compares the priorities of the blocks in one subsystem to the priorities of blocks in any other subsystem.

For example, consider this model again.



The blocks within the Car Dynamics virtual subsystem are part of the root-level system hierarchy and are part of the root-level sorted order. The Discrete Cruise Controller subsystem has an independent sorted order with the blocks arranged consecutively from 1:0 to 1:7.

### Lack of Priority May Not Result in Low Priority

A lack of priority does not necessarily result in a low priority (higher sorting order) for a given block. Blocks that do not have direct-feedthrough ports execute before blocks that have direct-feedthrough ports, regardless of their priority.

If a model has two atomic subsystems, A and B, you can assign priorities of 1 and 2 respectively to A and B. This priority causes all the blocks in A to

execute before any of the blocks in B. The blocks within an atomic subsystem execute as a single unit, so the subsystem has its own system index and its own sorted order.

## Block Priority Violations

Simulink software honors the block priorities that you specify unless they violate data dependencies. If Simulink is unable to honor a block priority, it displays a Block Priority Violation diagnostic message.

As an example:

- 1 Open the `sldemo_bounce` demo model.

Notice that the output of the Memory block provides the input to the Coefficient of Restitution Gain block.

- 2 Set the priority of the Coefficient of Restitution block to 1, and set the priority of the Memory block to 2.

Setting these priorities specifies that the Coefficient of Restitution block 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 **Edit > Update Diagram**.

The block priority violation warning appears in the MATLAB Command Window. The warning includes the priority for the respective blocks:

```
Warning: Unable to honor user-specified priorities.  
'sldemo_bounce/Memory' (pri=[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.

## Accessing Block Data During Simulation

### In this section...

“About Block Run-Time Objects” on page 20-53

“Accessing a Run-Time Object” on page 20-53

“Listening for Method Execution Events” on page 20-54

“Synchronizing Run-Time Objects and Simulink Execution” on page 20-55

### About Block Run-Time Objects

Simulink provides an application programming interface, called the block run-time interface, that enables programmatic access to block data, such as block inputs and outputs, parameters, states, and work vectors, while a simulation is running. You can use this interface to access block run-time data from the MATLAB command line, the Simulink Debugger, and from Level-2 MATLAB S-functions (see “Writing S-Functions in MATLAB” in the online Simulink documentation).

---

**Note** You can use this interface even when the model is paused or is running or paused in the debugger.

---

The block run-time interface consists of a set of Simulink data object classes (see “Working with Data Objects” on page 27-37) whose instances provide data about the blocks in a running model. In particular, the interface associates an instance of `Simulink.RunTimeBlock`, called the block’s run-time object, with each nonvirtual block in the running model. A run-time object’s methods and properties provide access to run-time data about the block’s I/O ports, parameters, sample times, and states.

### Accessing a Run-Time Object

Every nonvirtual block in a running model has a `RuntimeObject` parameter whose value, while the simulation is running, is a handle for the blocks’ run-time object. This allows you to use `get_param` to obtain a block’s run-time object. For example, the following statement

```
rto = get_param(gcb, 'RuntimeObject');
```

returns the run-time object of the currently selected block.

---

**Note** Virtual blocks (see “Virtual Blocks” on page 20-2) do not have run-time objects. Blocks eliminated during model compilation as an optimization also do not have run-time objects (see “Block reduction”). A run-time object exists only while the model containing the block is running or paused. If the model is stopped, `get_param` returns an empty handle. When you stop or pause a model, all existing handles for run-time objects become empty.

---

## Listening for Method Execution Events

One application for the block run-time API is to collect diagnostic data at key points during simulation, such as the value of block states before or after blocks compute their outputs or derivatives. The block run-time API provides an event-listener mechanism that facilitates such applications. For more information, see the *Simulink Reference* for the `add_exec_event_listener` command. For an example of using method execution events, enter

```
sldemo_msfcn_lms
```

at the MATLAB command line. This Simulink model contains the S-function `adapt_lms.m`, which performs a system identification to determine the coefficients of an FIR filter. The S-function’s `PostPropagationSetup` method initializes the block run-time object’s `DWork` vector such that the second vector stores the filter coefficients calculated at each time step.

In the Simulink model, double-clicking on the annotation below the S-function block executes its `OpenFcn`. This function first opens a figure for plotting the FIR filter coefficients. It then executes the function `add_adapt_coef_plot.m` to add a `PostOutputs` method execution event to the S-function’s block run-time object using the following lines of code.

```
% Get the full path to the S-function block
blk = 'sldemo_msfcn_lms/LMS Adaptive';

% Attach the event-listener function to the S-function
h = add_exec_event_listener(blk, ...
```

```
'PostOutputs', @plot_adapt_coefs);
```

The function `plot_adapt_coefs.m` is registered as an event listener that is executed after every call to the S-function's `Outputs` method. The function accesses the block run-time object's `DWork` vector and plots the filter coefficients calculated in the `Outputs` method. The calling syntax used in `plot_adapt_coefs.m` follows the standard needed for any listener. The first input argument is the S-function's block run-time object, and the second argument is a structure of event data, as shown below.

```
function plot_adapt_coefs(block, eventData)

% The figure's handle is stored in the block's UserData
hFig = get_param(block.BlockHandle, 'UserData');
tAxis = findobj(hFig, 'Type', 'axes');

tAxis = tAxis(2);
tLines = findobj(tAxis, 'Type', 'Line');

% The filter coefficients are stored in the block run-time
% object's second DWork vector.
est = block.Dwork(2).Data;

set(tLines(3), 'YData', est);
```

## Synchronizing Run-Time Objects and Simulink Execution

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(gcf, '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”).

## Configuration 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 User’s Guide* for more information.





# Working with Block Parameters

---

- “About Block Parameters” on page 21-2
- “Setting Block Parameters” on page 21-4
- “Specifying Parameter Values” on page 21-6
- “Checking Parameter Values” on page 21-9
- “Using Tunable Parameters” on page 21-13
- “Inlining Parameters” on page 21-14
- “Using Structure Parameters” on page 21-16

## 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 “Resolving Symbols” on page 3-76. Do not confuse Simulink block parameters with Simulink parameter objects. See “Block Parameters” on page 2-9 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 “Configuration Parameters Dialog Box” for more information.

You can separately define each MATLAB variable intended for use in block parameter expressions. However, this technique has several disadvantages, such as cluttering the base workspace and providing no convenient way to group related parameters. To avoid these disadvantages, you can combine numeric base workspace variables into a MATLAB structure, then:

- Dereference the structure fields to provide values used in block parameter expressions
- Pass a whole structure as an argument to a masked subsystem or a referenced model
- Set the structure to be tunable or nontunable as you could a separately defined variable

A structure used for any of these purposes can contain only numeric data. See “Using Structure Parameters” on page 21-16 for more information.

## Setting Block Parameters

You can use the Simulink `set_param` command to set the value of any Simulink block parameter. In addition, you can set many block parameters via Simulink dialog boxes and menus. These include:

- **Format** menu

The Model Editor's **Format** menu allows you to specify attributes of the currently selected block that are visible on the model's block diagram, such as the block's name and color (see "Changing a Block's Appearance" on page 20-22 for more information).

- **Block Properties** dialog box

Specifies various attributes that are common to all blocks (see "Block Properties Dialog Box" on page 20-15 for more information).

- **Block Parameter** dialog box

Every block has a dialog box that allows you to specify values for attributes that are specific to that type of block. See "Displaying a Block Parameter Dialog Box" on page 21-4 for information on displaying a block's parameter dialog box. For information on the parameter dialog of a specific block, see "Blocks — Alphabetical List" in the online Simulink reference.

- Model Explorer

The Model Explorer allows you to quickly find one or more blocks and set their properties, thus facilitating global changes to a model, for example, changing the gain of all of a model's Gain blocks. See "The Model Explorer: Overview" on page 8-2 for more information.

### Displaying a Block Parameter Dialog Box

To display a block's parameter dialog box, double-click the block in the model or library window. You can also display a block's parameter dialog box by selecting the block in the model's block diagram and choosing **BLOCK Parameters** from the model window's **Edit** menu or from the block's context (right-click) menu, where **BLOCK** is the name of the block you selected, for example, **Constant Parameters**.

---

**Note** Double-clicking a block to display its parameter dialog box works for all blocks with parameter dialog boxes except for Subsystem blocks and the Model block. You must use the Model Editor's **Edit** menu or the block's context menu to display a Subsystem or Model block's parameter dialog box.

---

## Specifying Parameter Values

### In this section...

“About Parameter Values” on page 21-6

“Using Workspace Variables in Parameter Expressions” on page 21-6

“Resolving Variable References in Block Parameter Expressions” on page 21-7

“Using Parameter Objects to Specify Parameter Values” on page 21-7

“Determining Parameter Data Types” on page 21-8

### About Parameter Values

Many block parameters, including mathematical parameters, accept MATLAB expression strings as values. When Simulink compiles a model, for example, at the start of a simulation or when you update the model, Simulink sets the compiled values of the parameters to the result of evaluating the expressions.

### Using Workspace Variables in Parameter Expressions

Block parameter expressions can include variables defined in the model’s mask and model workspaces and in the MATLAB workspace. Using a workspace variable facilitates updating a model that sets multiple block parameters to the same value, i.e., it allows you to update multiple parameters by setting the value of a single workspace variable. For more information, see “Resolving Symbols” on page 3-76 and “Specifying Numeric Values with Symbols” on page 3-78.

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 “Using Tunable Parameters” on page 21-13.

---

**Note** If you plan to generate code from a model, you can use workspace variables to specify the name, data type, scope, volatility, tunability, and other attributes of variables used to represent the parameter in the generated code. For more information, see “Parameters” in the Simulink Coder documentation.

---

## Resolving Variable References in Block Parameter Expressions

When evaluating a block parameter expression that contains a variable, Simulink by default searches the workspace hierarchy. If the variable is not defined in any workspace, Simulink halts compilation of the model and displays an error message. See “Resolving Symbols” on page 3-76 and “Specifying Numeric Values with Symbols” on page 3-78 for more information.

## Using Parameter Objects to Specify Parameter Values

You can use `Simulink.Parameter` objects in parameter expressions to specify parameter values. For example, `K` and `2*K` are both valid parameter expressions where `K` is a workspace variable that references a `Simulink.Parameter` object. In both cases, Simulink uses the parameter object’s `Value` property as the value of `K`. See “Resolving Symbols” on page 3-76 and “Specifying Numeric Values with Symbols” on page 3-78 for 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 21-15 and “Parameterizing Model References” on page 5-52 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.

---

## Determining Parameter Data Types

When Simulink compiles a model, each of the model's blocks determines a data type for storing the values of its parameters whose values are specified by MATLAB parameter expressions.

Most blocks use internal rules to determine the data type assigned to a specific parameter. Exceptions include the Gain block, whose parameter dialog box allows you to specify the data type assigned to the compiled value of its Gain parameter. You can configure your model to check whether the data type assigned to a parameter can accommodate the parameter value specified by the model (see “Data Validity Diagnostics Overview”).

## Obtaining Parameter Information

You can use `get_param` to find the system and block parameter values for your model. See “Model and Block Parameters” for a list of arguments `get_param` accepts.

The model's signal attributes and parameter expressions must be evaluated before some parameters are properly reported. This evaluation occurs during the simulation compilation phase. Alternatively, you can compile your model without first running it, and then obtain parameter information. For instance, to access the port width, data types, and dimensions of the blocks in your model, enter the following at the command prompt:

```
modelName([],[],[], 'compile')
q=get_param(gcf, 'PortHandles');
get_param(q.Inport, 'CompiledPortDataType')
get_param(q.Inport, 'CompiledPortWidth')
get_param(q.Inport, 'CompiledPortDimensions')
modelName([],[],[], 'term')
```



## Checking Parameter Values

In this section...
“About Value Checking” on page 21-9
“Blocks That Perform Parameter Range Checking” on page 21-9
“Specifying Ranges for Parameters” on page 21-10
“Performing Parameter Range Checking” on page 21-11

### 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

## Specifying Ranges for Parameters

In general, use the **Output minimum** and **Output maximum** parameters that appear on a block parameter dialog box to specify a range of valid values for the block parameters. The following exceptions apply:

- For the Gain block, use the **Parameter minimum** and **Parameter maximum** fields to specify a range for the **Gain** parameter.
- For the Data Store Memory block, use the **Minimum** and **Maximum** fields to specify a range for the **Initial value** parameter.

When specifying minimum and maximum values that constitute a range, enter only expressions that evaluate to a 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 31-38).

---

**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  $(\text{sqrt}(a^2+b^2))$ .

## Performing Parameter Range Checking

You can initiate parameter range checking in the following ways:

- When you click the **OK** or **Apply** button on a block parameter dialog box, the block performs range checking for its parameters. However, the block checks only the parameters that it can readily evaluate. For example, the block does not check parameters that use an undefined workspace variable.
- When you start a simulation or select **Update Diagram** from the Simulink **Edit** menu, Simulink performs parameter range checking for all blocks in that model.

Simulink performs parameter range checking by comparing the values of applicable block parameters with both the specified range (see “Specifying Ranges for Parameters” on page 21-10) and the block data type. That is, Simulink performs the following check:

$$\text{DataTypeMin} \quad \text{MinValue} \quad \text{VALUE} \quad \text{MaxValue} \quad \text{DataTypeMax}$$

where

- `DataTypeMin` is the minimum value representable by the block data type.
- `MinValue` is the minimum value the block should output, specified by, e.g., **Output minimum**.
- `VALUE` is the numeric value of a block parameter.
- `MaxValue` is the maximum value the block should output, specified by, e.g., **Output maximum**.
- `DataTypeMax` is the maximum value representable by the block data type.

When Simulink detects a parameter value that violates the check, it displays an error message. For example, consider a model that contains a Constant block whose

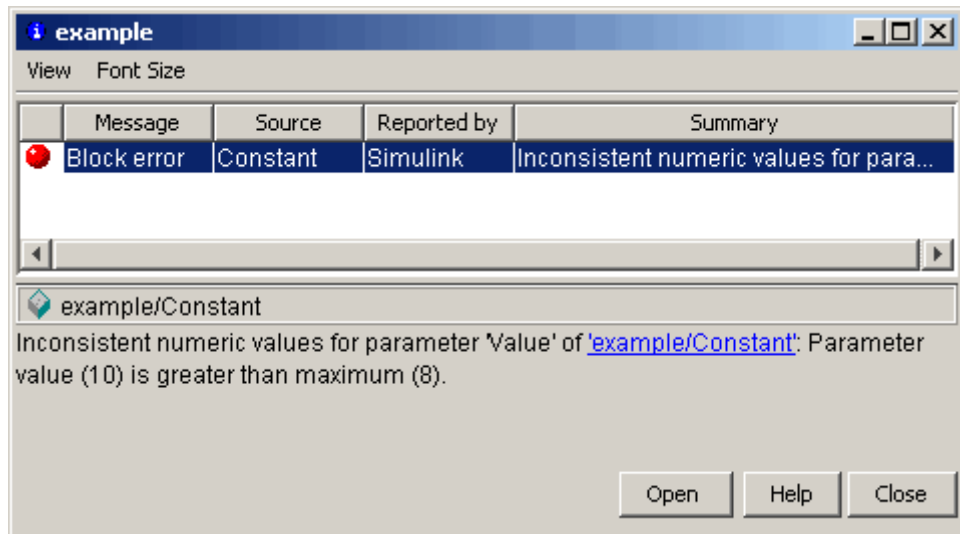
- **Constant value** parameter specifies the variable `const`, which you have yet to define in a workspace.
- **Output minimum** and **Output maximum** parameters are set to 2 and 8, respectively.

- **Output data type** parameter is set to uint8.

In this situation, Simulink does not perform parameter range checking when you click the **OK** button on the Constant block dialog box because the variable `const` is undefined. But suppose you define its value by entering

```
const = 10
```

at the MATLAB prompt, and then you update the diagram (see “Updating a Block Diagram” on page 1-32). Simulink displays the following error message:



## Using Tunable Parameters

In this section...
“About Tunable Parameters” on page 21-13
“Tuning a Block Parameter” on page 21-13

### About Tunable Parameters

Simulink lets you change the values of many block parameters during simulation. Such parameters are called *tunable parameters*. In general, only parameters that represent mathematical variables, such as the Gain parameter of the Gain block, are tunable. Parameters that specify the appearance or structure of a block, e.g., the number of inputs of a Sum block, or when it is evaluated, e.g., a block’s sample time or priority, are not tunable.

You can tell whether a particular parameter is tunable by examining its edit control in the block’s dialog box or Model Explorer during simulation. If the control is disabled, the parameter is nontunable. You cannot tune inline parameters. See “Inlining Parameters” on page 21-14 for more information.

### Tuning a Block Parameter

You can use a block’s dialog box or the Model Explorer to modify the tunable parameters of any block. To use the block’s parameter dialog box, open the block’s parameter dialog box, change the value displayed in the dialog box, and click the dialog box’s **OK** or **Apply** button.

You can also tune a parameter at the MATLAB command line, using either the `set_param` command or by assigning a new value to the MATLAB workspace variable that specifies the parameter’s value. In either case, you must update the model’s block diagram for the change to take effect (see “Updating a Block Diagram” on page 1-32).

## Inlining Parameters

### In this section...

“About Inlined Parameters” on page 21-14

“Specifying Some Parameters as Noninline” on page 21-14

### 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.

### Specifying Some Parameters as Noninline

Suppose that you want to take advantage of the **Inline parameters** optimization while retaining the ability to tune some of your model parameters. You can do this by declaring some parameters as *noninline*, using either the “Model Parameter Configuration Dialog Box” or a `Simulink.Parameter` object. In either case, you must use a workspace variable to specify the value of the parameter.

When compiling a model with the inline parameters option on, Simulink checks to ensure that the data types of the workspace variables used to specify the model’s noninline parameters are compatible with code generation. If not, Simulink halts the compilation and displays an error. See “Tunable Workspace Parameter Data Type Considerations” for more information.

---

**Note** The documentation for the 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 "Using Parameter Objects to Specify Parameter Values" on page 21-7), 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.

---

## Using Structure Parameters

### In this section...

“About Structure Parameters” on page 21-16

“Defining Structure Parameters” on page 21-17

“Referencing Structure Parameters” on page 21-17

“Structure Parameter Arguments” on page 21-18

“Tunable Structure Parameters” on page 21-19

“Parameter Structure Limitations” on page 21-20

### About Structure Parameters

Separately defining all base workspace variables used in block parameter expressions can clutter the base workspace and result in very long lists of arguments to subsystems and referenced models. The technique provides no way to conveniently group related base workspace variables, or to configure generated code to reflect the variables' relationships.

To minimize the disadvantages of separately defining workspace variables used by block parameters, you can group numeric variables by specifying their names and values as the fields of a MATLAB structure in the base workspace. A MATLAB structure that Simulink uses in block parameter expressions is called a *structure parameter*. You can use structure parameters to:

- Simplify and modularize the base workspace by using multiple structures to group related variables and to prevent name conflicts
- Dereference the structure in block parameter expressions to provide values from structure fields rather than separate variables
- Pass all the fields in a structure to a subsystem or referenced model with a single argument.
- Improve generated code to use structures rather multiple separate variables

For information about creating and using MATLAB structures, see Structures in the MATLAB documentation. You can use all the techniques described



there to manipulate structure parameters. This section assumes that you know those techniques, and provides only information that is specific to Simulink.

For information on structure parameters in the context of generated code for a model, see “Structure Parameters and Generated Code”. For an example of how to convert a model that uses unstructured workspace variables to a model that uses structure parameters, see `sldemo_applyVarStruct`.

## Defining Structure Parameters

Defining a structure parameter is syntactically the same as defining any MATLAB structure, as described in Structures. Every field in a MATLAB structure that functions as a structure parameter must have a numeric data type, even if Simulink never uses the field. Different fields can have different numeric types.

In structure parameters, numeric types include enumerated types, by virtue of their underlying integers. The value of a structure parameter field, can be a real or complex scalar, vector, or multidimensional array. However, a structure that contains any multidimensional array cannot be tuned. See “Tunable Structure Parameters” on page 21-19.

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

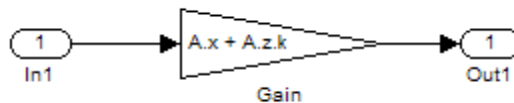
You can use MATLAB syntax, as described in Structures, to dereference a structure parameter field anywhere in a block parameter expression that a MATLAB variable can appear. You cannot specify a structure name in a mathematical block parameter expression, because that would pass a structure rather than 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 2-11, Chapter 23, “Working with Block Masks”, and “Using Model Arguments” on page 5-53 more information about passing and using arguments.

## Tunable Structure Parameters

You can declare a structure parameter to be tunable using the same techniques that you use to make an ordinary base workspace parameter tunable:

- Clear **Configuration Parameters > Optimization > Signals and Parameters > Inline parameters**. See “Inline parameters” for more information.
- Set **Inline parameters**, then specify the parameter structure as tunable in the Model Parameter Configuration Dialog Box.
- Associate a `Simulink.Parameter` object with the structure parameter, and specify the object’s storage class as anything other than `auto`.

A tunable structure parameter can contain a nontunable numeric field (like a multidimensional array) without affecting the tunability of the rest of the structure. You cannot define individual substructures or fields within a structure parameter to be tunable. Only the name of the root level of the structure appears in the Model Configuration Parameter dialog box, and only the root can have a `Simulink.Parameter` object assigned to it.

For more information about tunability, see “Inlining Parameters” on page 21-14 and “Using Tunable Parameters” on page 21-13. 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.

# Working with Lookup Tables

---

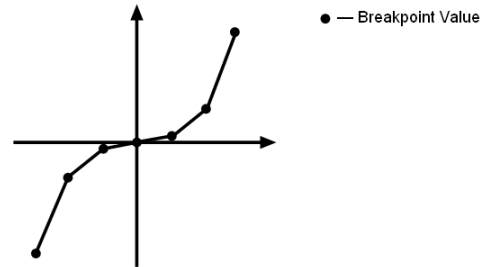
- “About Lookup Table Blocks” on page 22-2
- “Anatomy of a Lookup Table” on page 22-4
- “Lookup Tables Block Library” on page 22-5
- “Guidelines for Choosing a Lookup Table” on page 22-7
- “Entering Breakpoints and Table Data” on page 22-11
- “Characteristics of Lookup Table Data” on page 22-18
- “Methods for Estimating Missing Points” on page 22-23
- “Lookup Table Editor” on page 22-28
- “Example of a Logarithm Lookup Table” on page 22-63
- “Examples for Prelookup and Interpolation Blocks” on page 22-66
- “Tips to Optimize Generated Code for Lookup Table Blocks” on page 22-67
- “Updating Your Model to Use Current Lookup Table Blocks” on page 22-71
- “Lookup Table Glossary” on page 22-77

## 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.

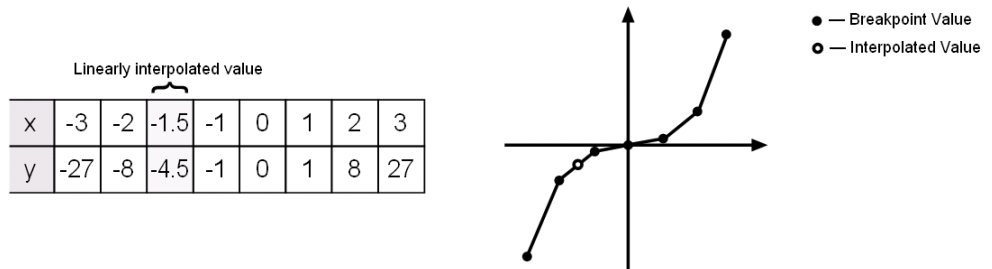
The following example illustrates a one-dimensional lookup table that approximates the function  $y = x^3$ . The lookup table defines its output ( $y$ ) data discretely over the input ( $x$ ) range  $[-3, 3]$ . The following table and graph illustrate the input/output relationship:

x	-3	-2	-1	0	1	2	3
y	-27	-8	-1	0	1	8	27

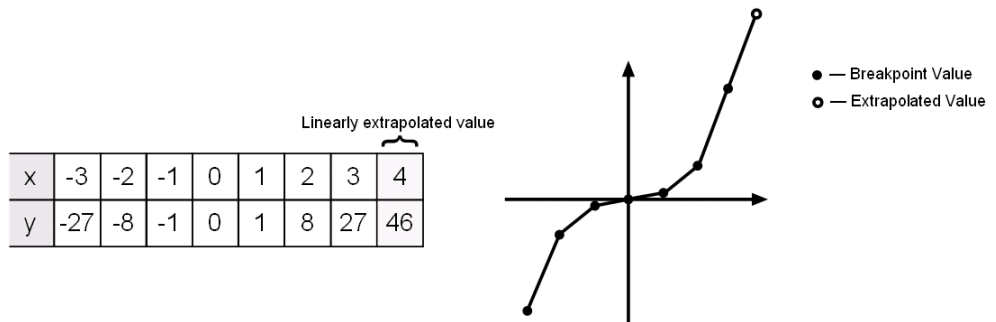


An input of -2 enables the table to look up and retrieve the corresponding output value (-8). Likewise, the lookup table outputs 27 in response to an input of 3.

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.



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.



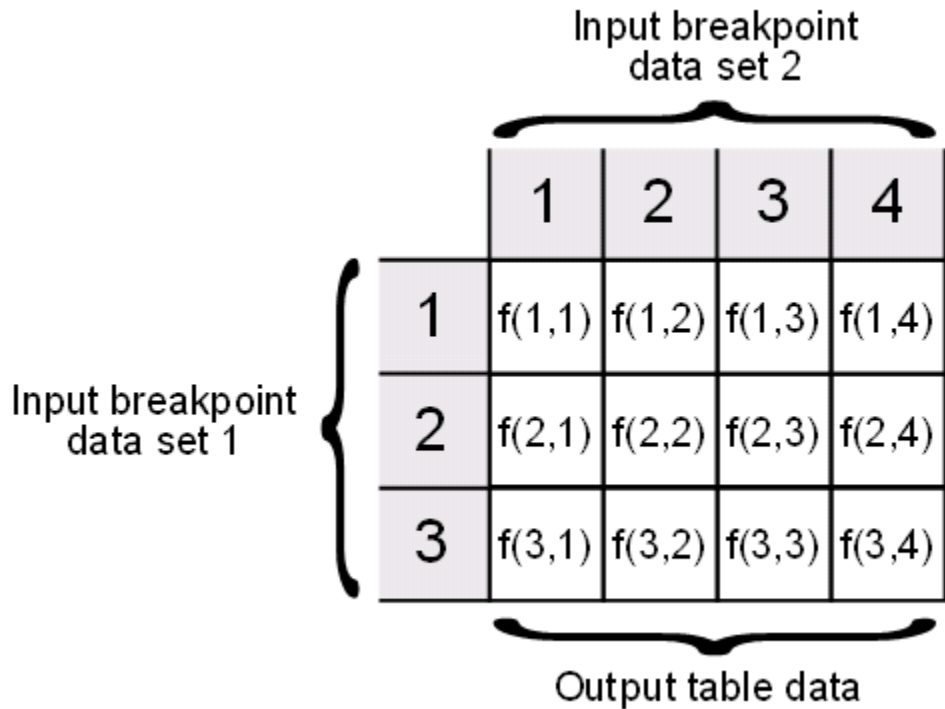
Since table lookups and simple estimations can be faster than mathematical function evaluations, using lookup table blocks might result in speed gains when simulating a model. Consider using lookup tables in lieu of mathematical function evaluations when:

- 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.

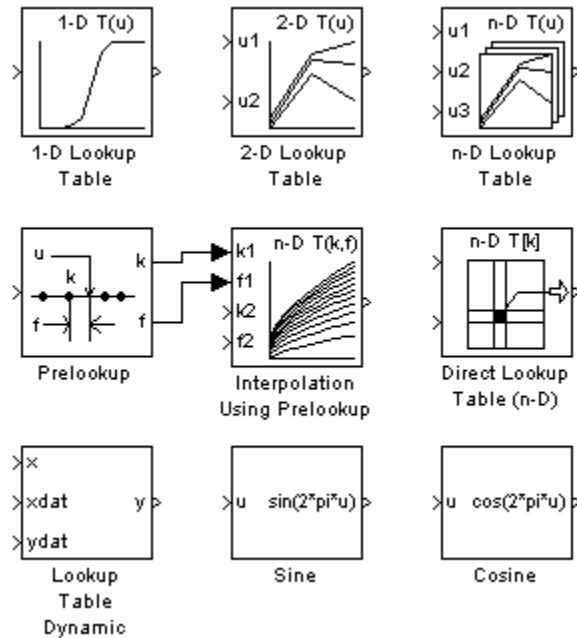


Each breakpoint data set is an index of input values for a particular dimension of the lookup table. The array of table data serves as a sampled representation of a function evaluated at the breakpoint values. Lookup table blocks use breakpoint data sets to relate a table's input values to the output 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.

<b>Block Name</b>	<b>Description</b>
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” on page 22-7
- “Data Set Numeric and Data Types” on page 22-7
- “Data Accuracy and Smoothness” on page 22-8
- “Dynamics of Table Inputs” on page 22-8
- “Efficiency of Performance” on page 22-8
- “Summary of Lookup Table Block Features” on page 22-10

### 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
<b>Interpolation Methods</b>							
Flat	•	•	•	•	•	•	•
Linear	•	•	•	•		•	•
Cubic spline	•	•		•			
<b>Extrapolation Methods</b>							
Clip	•	•	•	•	•	•	•
Linear	•	•	•	•		•	•
Cubic spline	•	•		•			
<b>Numeric &amp; Data Type Support</b>							
Complex	•	•		•	•		
Double, Single	•	•	•	•	•	•	•
Integer	•	•	•	•	•	•	•
Fixed point	•	•	•	•	•	•	•
<b>Index Search Methods</b>							
Binary	•	•	•	•		•	
Linear	•	•		•		•	
Evenly spaced points	•	•		•	•	•	
Start at previous index	•	•		•		•	
<b>Miscellaneous</b>							
Sub-table selection					•		•
Dynamic breakpoint data						•	
Dynamic table data			•		•		•
Input range checking	•	•		•	•	•	•

## Entering Breakpoints and Table Data

### In this section...

“Entering Data in a Block Parameter Dialog Box” on page 22-11

“Entering Data in the Lookup Table Editor” on page 22-13

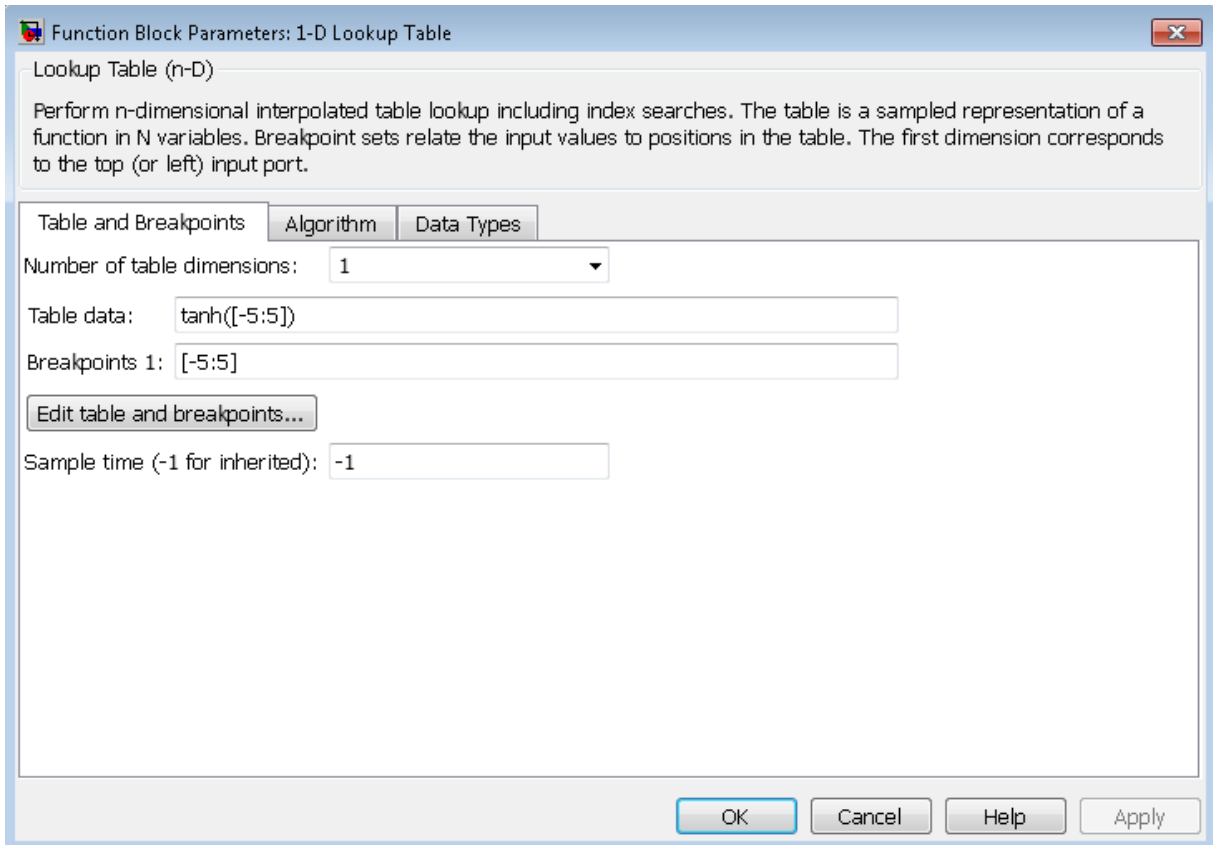
“Entering Data Using Inports of the Lookup Table Dynamic Block” on page 22-16

### 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.

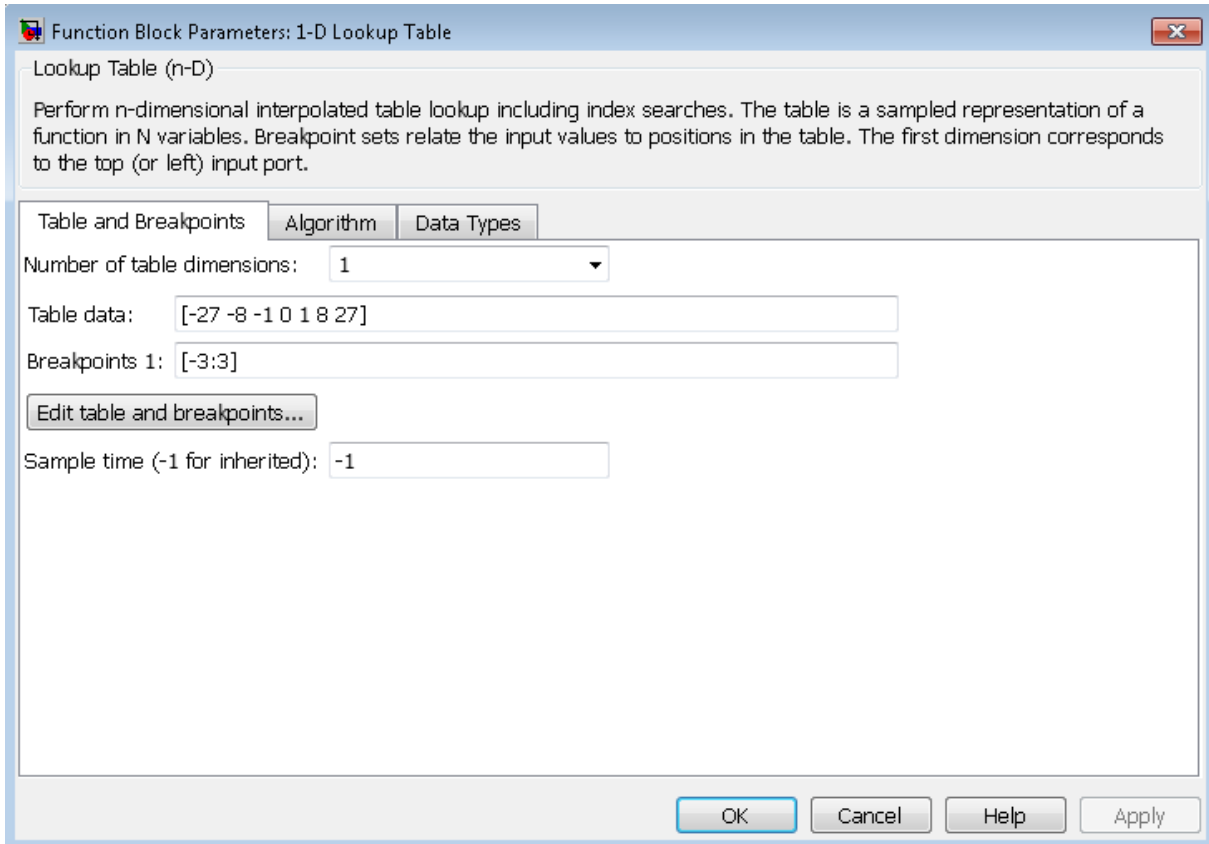


The dialog box displays the default values for the block.

- 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.

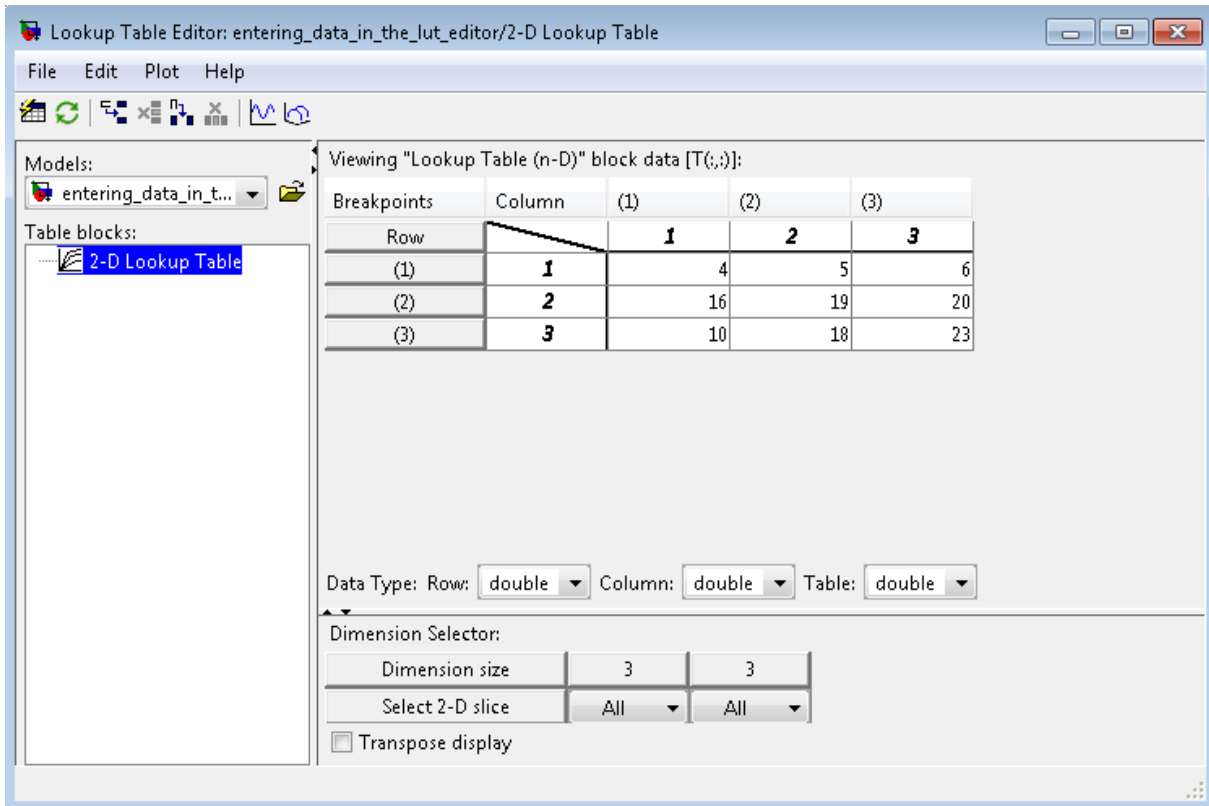
## Entering Data in the Lookup Table Editor

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 **Tools** menu or by clicking **Edit table and breakpoints** on the dialog box of the 2-D Lookup Table block.

The Lookup Table Editor appears.

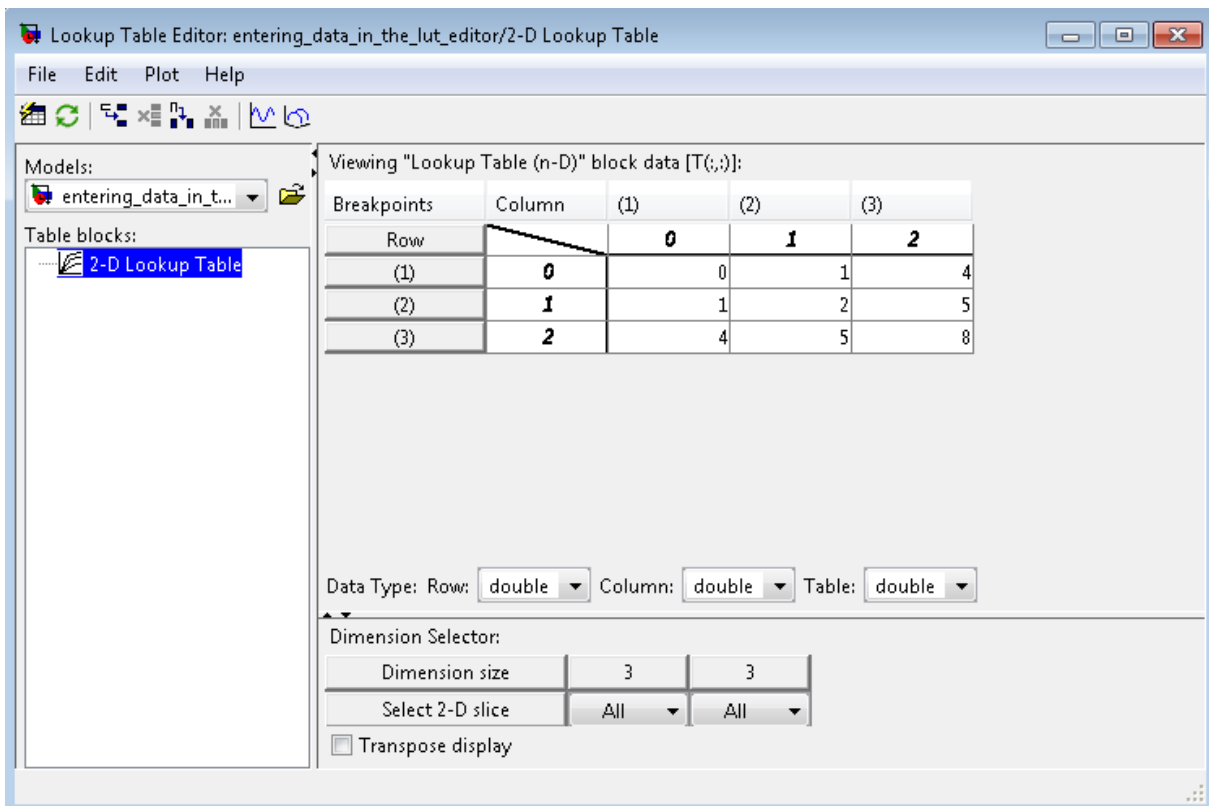


It displays the default data for the 2-D Lookup Table block.

- 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

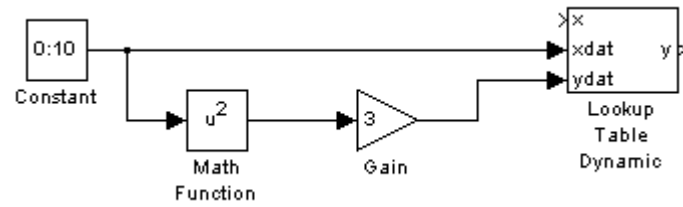
Use the following procedure to populate a Lookup Table Dynamic block using that block's inports. In this example, the lookup table approximates the function  $y = 3x^2$  over the range  $[0, 10]$ .

- 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 output 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” on page 22-18

“Monotonicity of Breakpoint Data Sets” on page 22-19

“Representation of Discontinuities in Lookup Tables” on page 22-20

“Formulation of Evenly Spaced Breakpoints” on page 22-22

### Sizes of Breakpoint Data Sets and Table Data

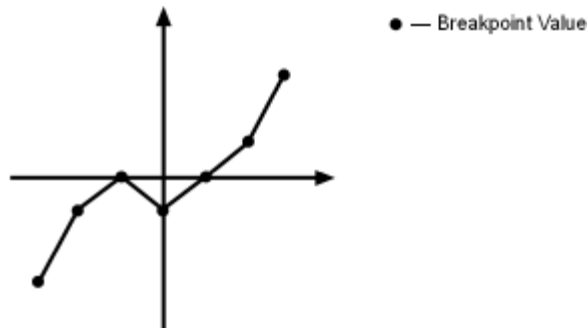
The following constraints apply to the sizes of breakpoint data sets and table data associated with lookup table blocks:

- 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

$$A = [0 \quad 0.5 \quad 1 \quad 1.9 \quad 2 \quad 2 \quad 2 \quad 2.1 \quad 3]$$

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

$$B = [0 \quad 0.5 \quad 1 \quad 1.9 \quad 2 \quad 2.1 \quad 2.17 \quad 3]$$

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.

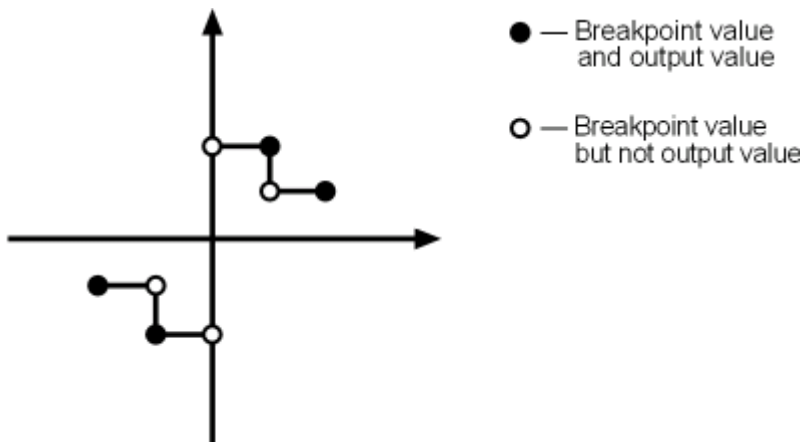
---

### 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:

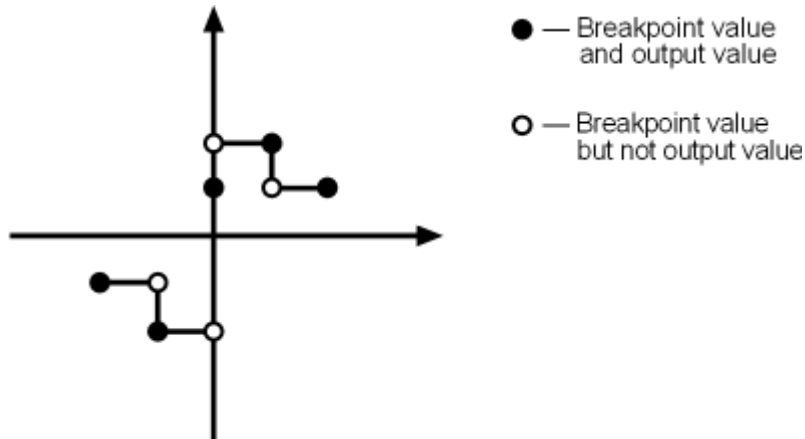


- If the input signal is less than zero, the block returns the output value associated with the last occurrence of the input value in the breakpoint data set. In this example, if the input is  $-1$ ,  $y$  is  $-2$ , marked with a solid circle.
- If the input signal is greater than zero, the block returns 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
<code>[first_value:spacing:last_value]</code>	<code>[10:10:200]</code>	The lookup table does <i>not</i> use double or single.
<code>first_value + spacing * [0:(last_value-first_value)/spacing]</code>	<code>1 + (0.02 * [0:450])</code>	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 22-10.

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” on page 22-23

“Interpolation Methods” on page 22-23

“Extrapolation Methods” on page 22-24

“Rounding Methods” on page 22-25

“Example Output for Lookup Methods” on page 22-26

### 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 22-25.
- **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.

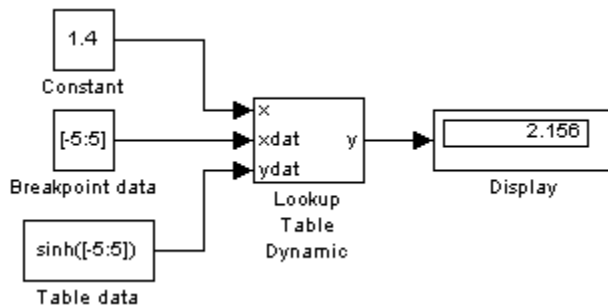
## Rounding Methods

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.

<b>Lookup Method</b>	<b>Input</b>	<b>Output</b>	<b>Comment</b>
Interpolation- Extrapolation	1.4	2.156	N/A
	5.2	83.59	N/A
Interpolation- Use End Values	1.4	2.156	N/A
	5.2	74.2	The block uses the value for $\sinh(5.0)$ .
Use Input Above	1.4	3.627	The block uses the value for $\sinh(2.0)$ .
	5.2	74.2	The block uses the value for $\sinh(5.0)$ .
Use Input Below	1.4	1.175	The block uses the value for $\sinh(1.0)$ .
	-5.2	-74.2	The block uses the value for $\sinh(-5.0)$ .
Use Input Nearest	1.4	1.175	The block uses the value for $\sinh(1.0)$ .

## Lookup Table Editor

### In this section...

“When to Use the Lookup Table Editor” on page 22-28

“Layout of the Lookup Table Editor” on page 22-28

“Browsing Lookup Table Blocks” on page 22-29

“Editing Table Values” on page 22-30

“Working with Table Data of Standard Format” on page 22-32

“Working with Table Data of Nonstandard Format” on page 22-36

“Importing Data from an Excel Spreadsheet” on page 22-53

“Adding and Removing Rows and Columns in a Table” on page 22-55

“Displaying N-Dimensional Tables in the Editor” on page 22-56

“Plotting Lookup Tables” on page 22-57

“Editing Custom Lookup Table Blocks” on page 22-61

### 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 22-61). 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 **Tools** menu. The editor appears.



Models: sldemo\_fuelsys

Table blocks:

- Throttle Command
- fuel\_rate\_control
- airflow\_calc
- Pumping Constant**
- Ramp Rate Ki
- control\_logic

Viewing "Lookup Table (n-D)" block data [T(:,,:)]:

Breakpoints	Column	(1)	(2)	(3)	(4)	(5)
Row		<b>0.05</b>	<b>0.1</b>	<b>0.15</b>	<b>0.2</b>	<b>0.25</b>
(1)	<b>50</b>	-0.0556348	0.0185328	0.0419484	0.052676	0.056348
(2)	<b>75</b>	-0.00228280...	0.0465088	0.061465733...	0.067964	0.07228280...
(3)	<b>100</b>	0.0256932	0.0617968	0.0725244	0.076908	0.0817968
(4)	<b>125</b>	0.0435188	0.0720096	0.0801996	0.0833144	0.08435188
(5)	<b>150</b>	0.0562692	0.0796848	0.086183066...	0.088452	0.08962692
(6)	<b>175</b>	0.066119485...	0.085909942...	0.091199828...	0.092864571...	0.093079
(7)	<b>200</b>	0.0741572	0.0912288	0.0956124	0.096824	0.09741572
(8)	<b>250</b>	0.08697	0.1002352	0.10335	0.1039272	0.10397

Data Type: Row: double Column: double Table: double

Dimension Selector:

Dimension size	18	19
Select 2-D slice	All	All

Transpose display

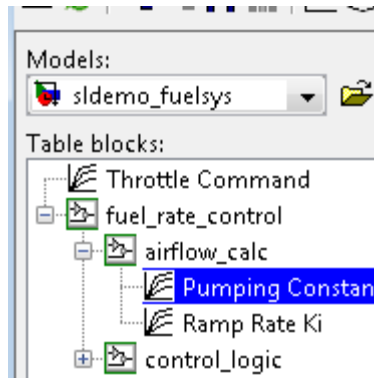
The editor contains two panes and a toolbar.

- Use the left pane to browse and select lookup table blocks in any open model (see “Browsing Lookup Table Blocks” on page 22-29).
- Use the right pane to edit the lookup table of the selected block (see “Editing Table Values” on page 22-30).
- 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 22-30).

---

**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		<b>0.05</b>	<b>0.1</b>	<b>0.15</b>
(1)	<b>50</b>	-0.0556348	0.0185328	0.0419484
(2)	<b>75</b>	-0.00228280...	0.0465088	0.061465733..
(3)	<b>100</b>	0.0256932	0.0617968	0.0725244
(4)	<b>125</b>	0.0435188	0.0720096	0.0801996
(5)	<b>150</b>	0.0562692	0.0796848	0.086183066..
(6)	<b>175</b>	0.066119485...	0.085909942...	0.091199828..

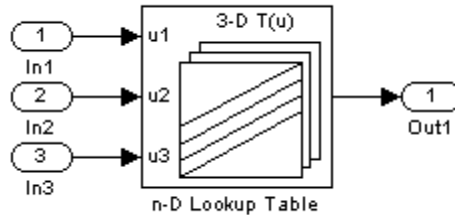
The table view displays the entire table if it is one- or two-dimensional or a two-dimensional slice of the table if the table has more than two dimensions (see “Displaying N-Dimensional Tables in the Editor” on page 22-56). To change any value that appears, double-click the value. The Lookup Table Editor 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.

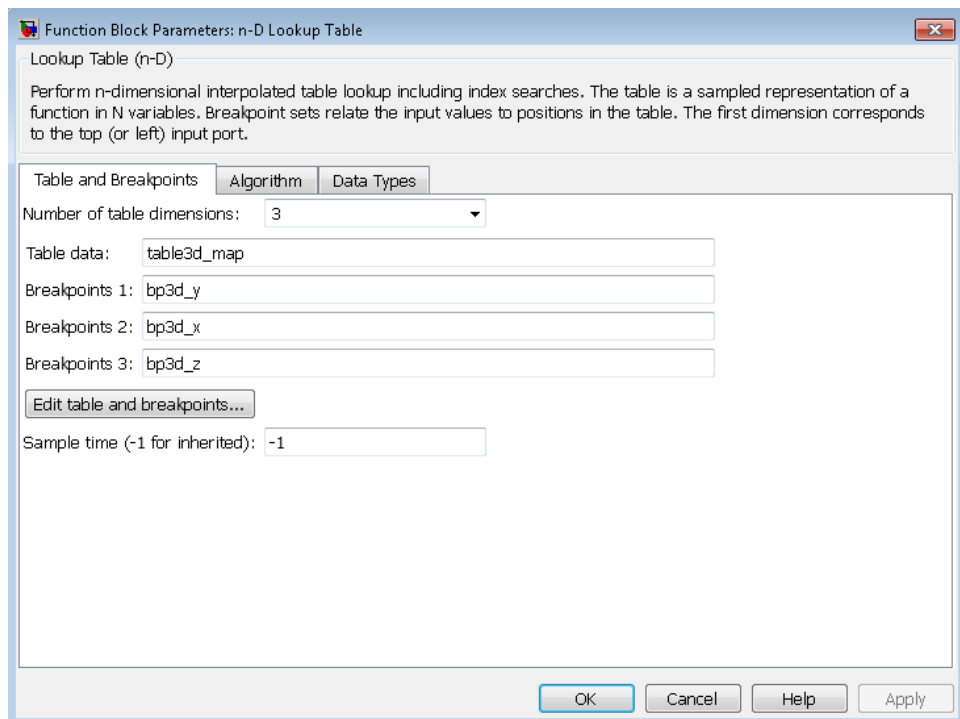
The Lookup Table Editor records your changes by maintaining a copy of the table. To update the copy that the lookup table block maintains, select **File > Update Block Data** in the Lookup Table Editor. To restore the Lookup Table Editor’s copy to the values stored in the block, select **File > Reload 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
-----	------

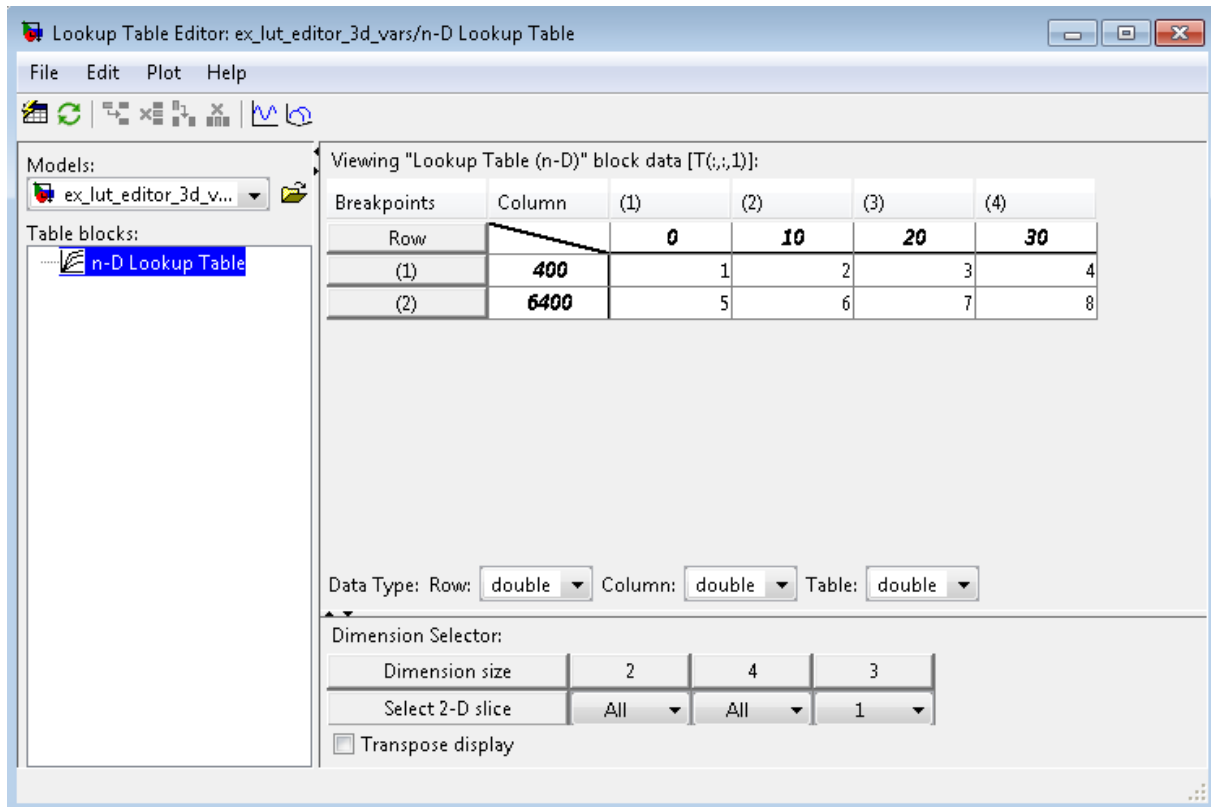
```
bp3d_x =
```

0	10	20	30
---	----	----	----

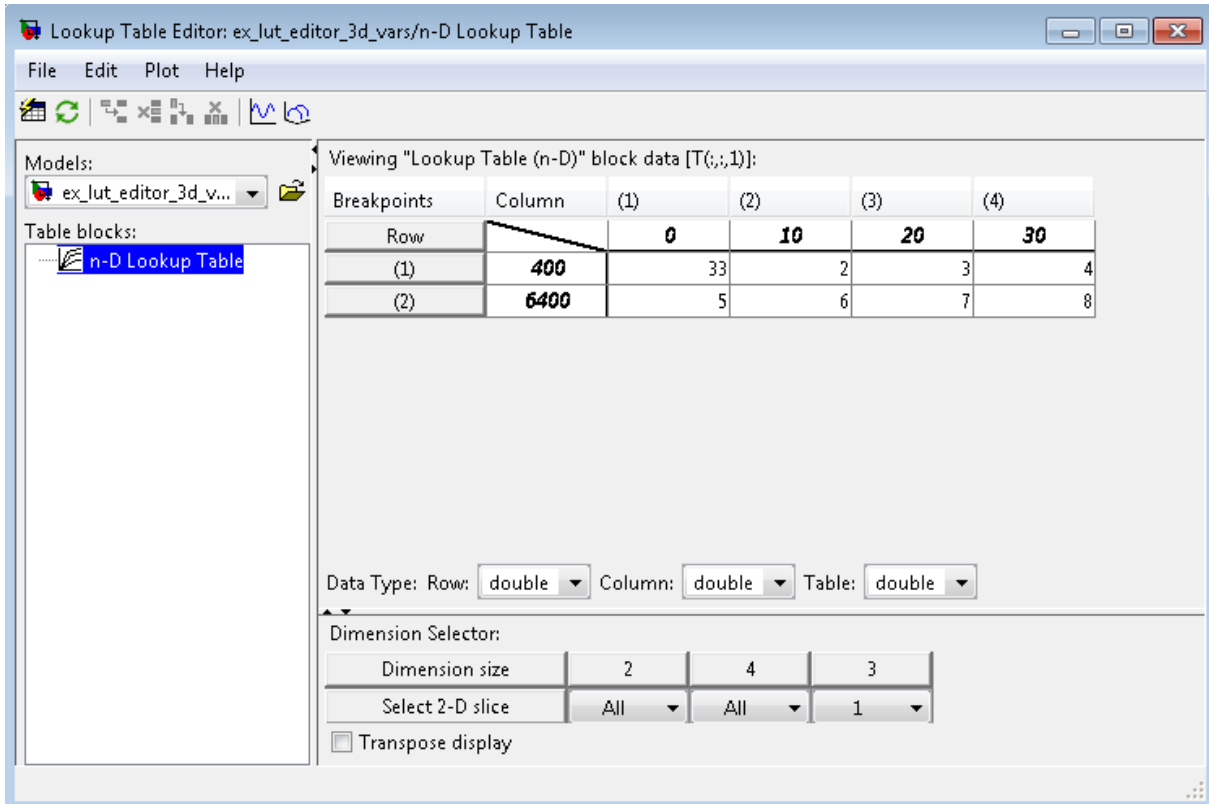
```
bp3d_z =
```

0	10	20
---	----	----

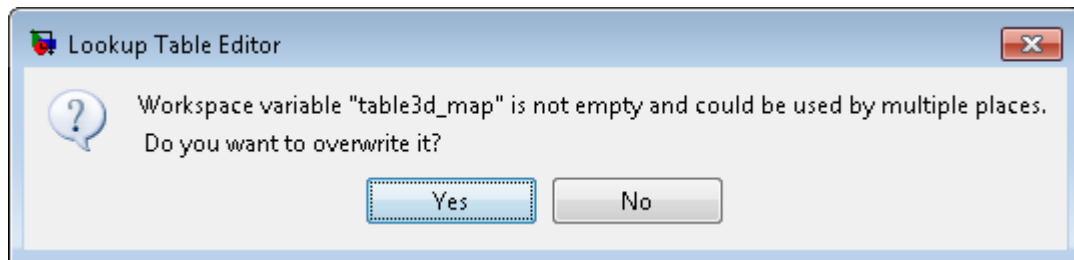
When you click **Edit table and breakpoints** to open the Lookup Table Editor, you see:



Suppose that you change a value in the Lookup Table Editor as follows:

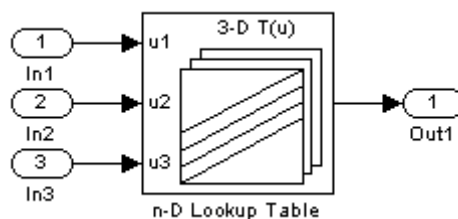


When you select **File > Update Block Data**, you can propagate the change to `table3d_map`, the workspace variable that contains the table data for the n-D Lookup Table block. To propagate the change, click **Yes** in the pop-up window that asks if you want to overwrite the workspace variable:



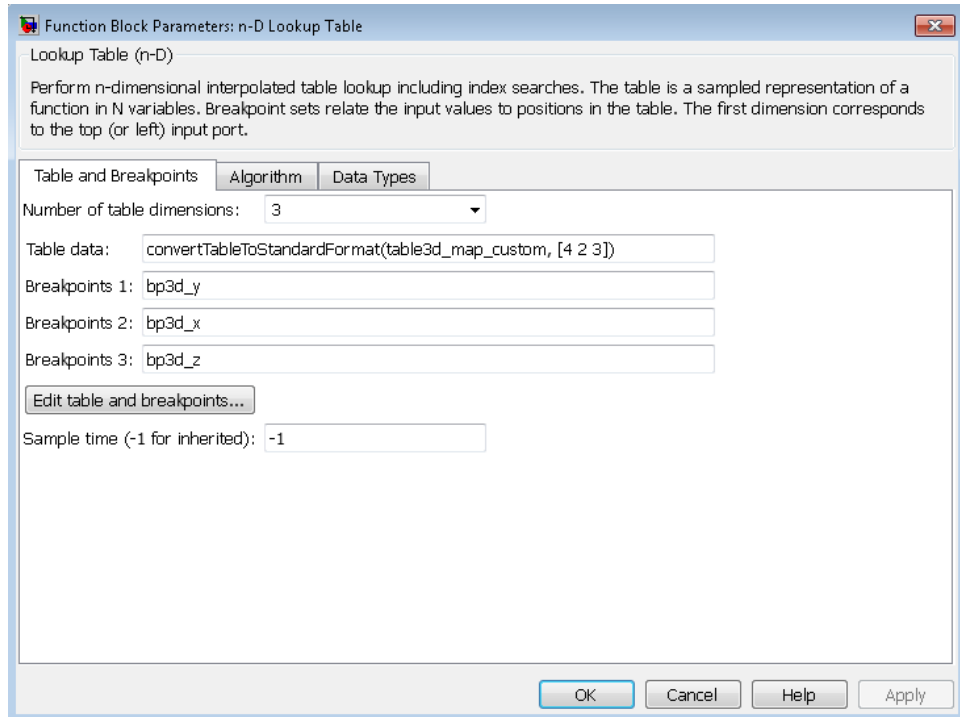
### Working with Table Data of Nonstandard Format

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:

The screenshot shows the 'Lookup Table Editor' window for a file named 'ex\_lut\_editor\_3d\_vars\_custom/n-D Lookup Table'. The window has a menu bar (File, Edit, Plot, Help) and a toolbar with icons for file operations and plotting. On the left, there is a 'Models' pane with a dropdown menu showing 'ex\_lut\_editor\_3d\_v...' and a 'Table blocks' pane with a single entry 'n-D Lookup Table'. The main area displays the title 'Viewing "Lookup Table (n-D)" block data [T(:,:),1]:' above a table. Below the table are 'Data Type' dropdowns for Row, Column, and Table, all set to 'double'. At the bottom, there is a 'Dimension Selector' section with a table for dimension sizes and 2-D slices, and a 'Transpose display' checkbox.

Breakpoints	Column	(1)	(2)	(3)	(4)
Row		<b>0</b>	<b>10</b>	<b>20</b>	<b>30</b>
(1)	<b>400</b>	1	2	3	4
(2)	<b>6400</b>	5	6	7	8

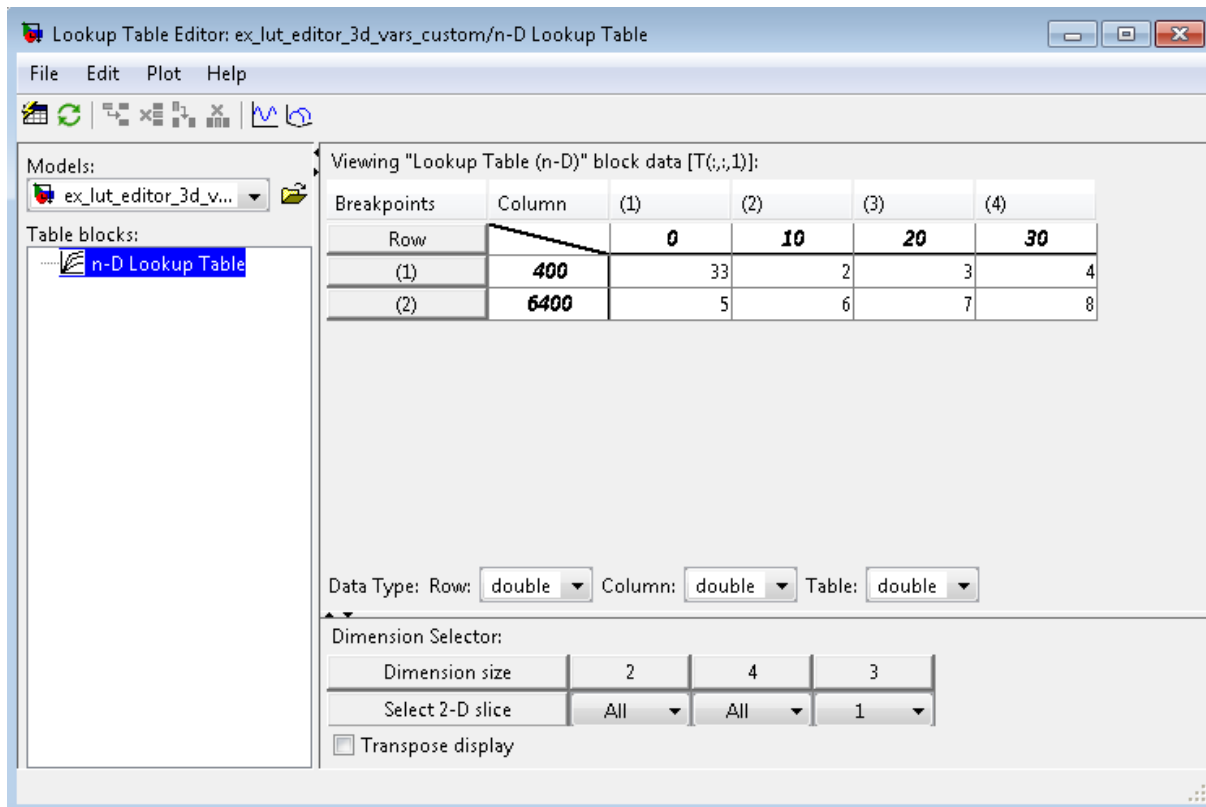
Data Type: Row:  Column:  Table:

Dimension Selector:

Dimension size	2	4	3
Select 2-D slice	All	All	1

Transpose display

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 22-45.

## 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 22-41
2	Select the appropriate responses when prompted in the Lookup Table Editor.	“How to Respond to Prompts in the Lookup Table Editor” on page 22-45

## 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 <code>allowTableConvertLocal</code> 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 `s1_customization.m` with the following contents:

```
function s1_customization(cm)

cm.LookupTableEditorCustomizer.getTableConvertToCustomInfoFcnHandle{end+1} = ...
@myGetTableConvertInfoFcn;

end
```

In this file:

- The `s1_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 `s1_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
```

```

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);
    numRows = 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

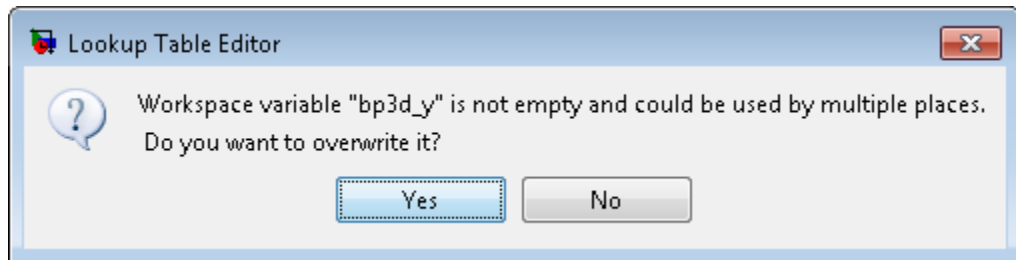
end

end
```

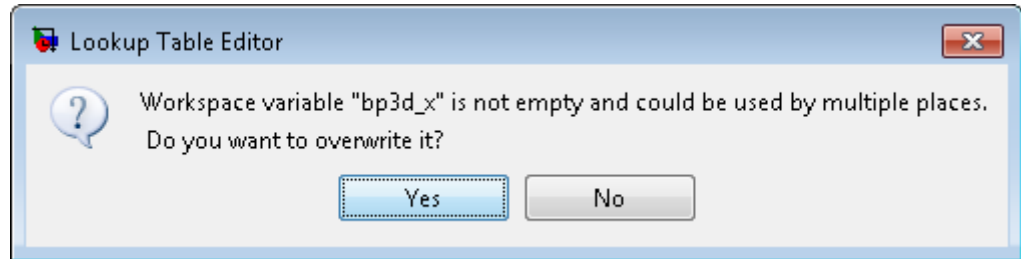
- 5 Put `sl_customization.m` on the MATLAB search path.
- 6 At the MATLAB prompt, enter the following command to refresh all Simulink customizations.

```
sl_refresh_customizations
```

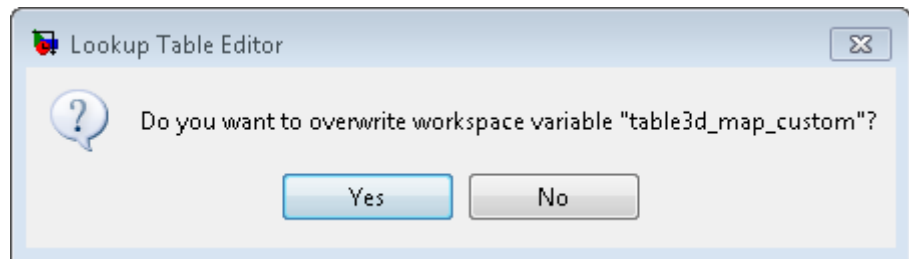
- 7 In the Lookup Table Editor, select **File > Update Block Data**. Several pop-up windows appear:
  - a Click **Yes** to overwrite the workspace variable `bp3d_y`.



- b Click **Yes** to overwrite the workspace variable `bp3d_x`.



- c Click **Yes** to overwrite the workspace variable `table3d_map_custom`.



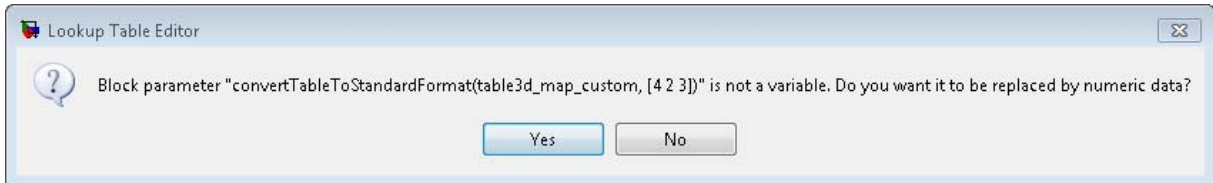
- 8 If you check the value of `table3d_map_custom` in the base workspace, you now see:

`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...
<p><b>Yes</b></p>	<p>The block dialog box replaces the expression in the <b>Table data</b> field with numeric data.</p>
<p><b>No</b></p>	<p>Your Lookup Table Editor changes for the table data do not appear in the block dialog box.</p>



## 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)

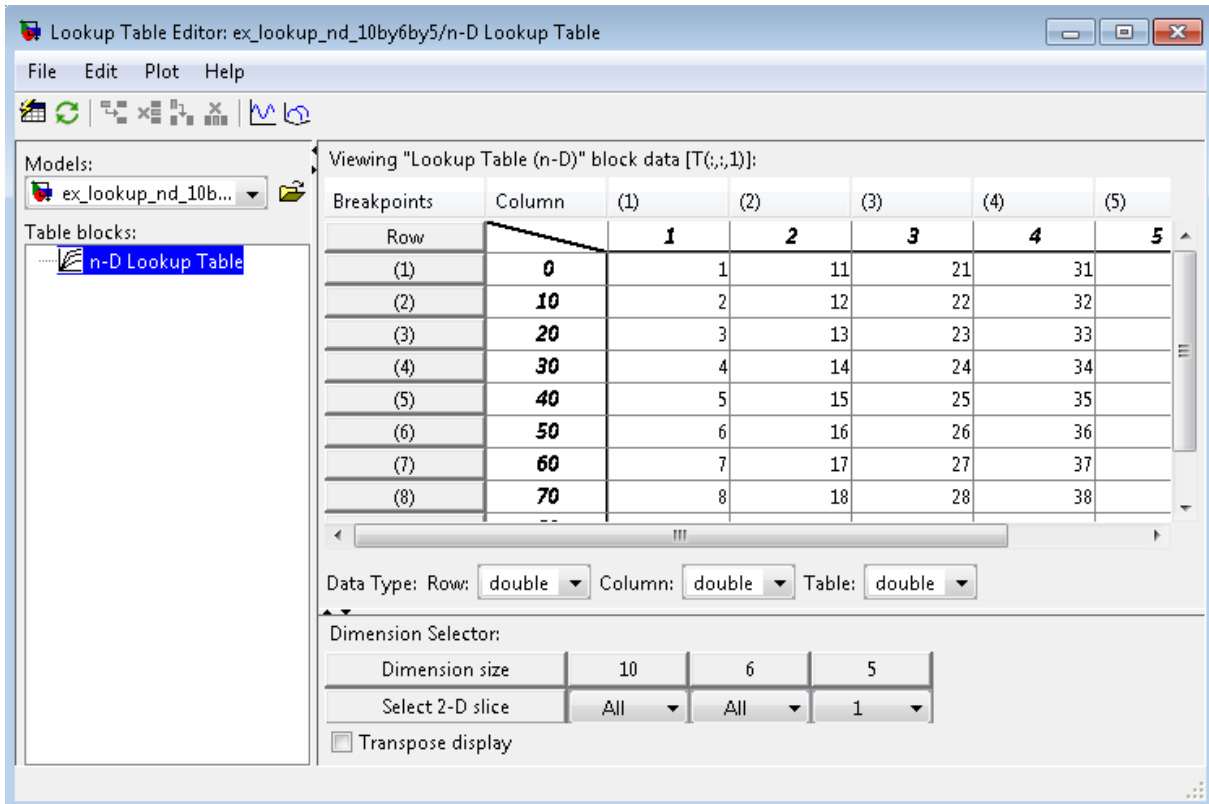
In those cases, follow these instructions to add or remove columns of a table in the Lookup Table Editor.

To perform this action:	Use one of these methods:
Add a row or column to a table that appears in the table view	<ul style="list-style-type: none"> <li>• Select <b>Edit &gt; Add Row</b> or <b>Edit &gt; Add Column</b> in the editor.</li> <li>• Click the Add Row button  or the Add Column button  in the toolbar.</li> </ul>
Remove a row or column from the table that appears in the table view	<ul style="list-style-type: none"> <li>• Highlight the row or column to remove and then select <b>Edit &gt; Remove Row(s)</b> or <b>Edit &gt; Remove Column(s)</b> in the editor.</li> <li>• Highlight the row or column to remove and then click the Remove Row button  or the Remove Column button  in the toolbar.</li> </ul>

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.

Dimension Selector:

Dimension size	10	6	5
Select 2-D slice	All ▼	All ▼	1 ▼

Transpose display

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:

Lookup Table Editor: sldemo\_fuelsys/fuel\_rate\_control/airflow\_calc/Ramp Rate Ki

File Edit Plot Help

Models: sldemo\_fuelsys

Table blocks: Throttle Command, fuel\_rate\_control, airflow\_calc, Pumping Constant, Ramp Rate Ki, control\_logic

Viewing "Lookup Table (n-D)" block data [T(:,,:)]:

Breakpoints	Column	(1)	(2)	(3)	(4)	(5)
Row		<b>0</b>	<b>0.2</b>	<b>0.4</b>	<b>0.6</b>	<b>0.8</b>
(1)	<b>100</b>	0.012	0.024	0.036000000...	0.048	0.060
(2)	<b>200</b>	0.024	0.048	0.072000000...	0.096	0.120
(3)	<b>300</b>	0.036000000...	0.072000000...	0.108	0.144000000...	0.180
(4)	<b>400</b>	0.048	0.096	0.144000000...	0.192	0.240
(5)	<b>500</b>	0.060	0.120	0.180	0.240	0.300
(6)	<b>600</b>	0.072000000...	0.144000000...	0.216	0.288000000...	0.360

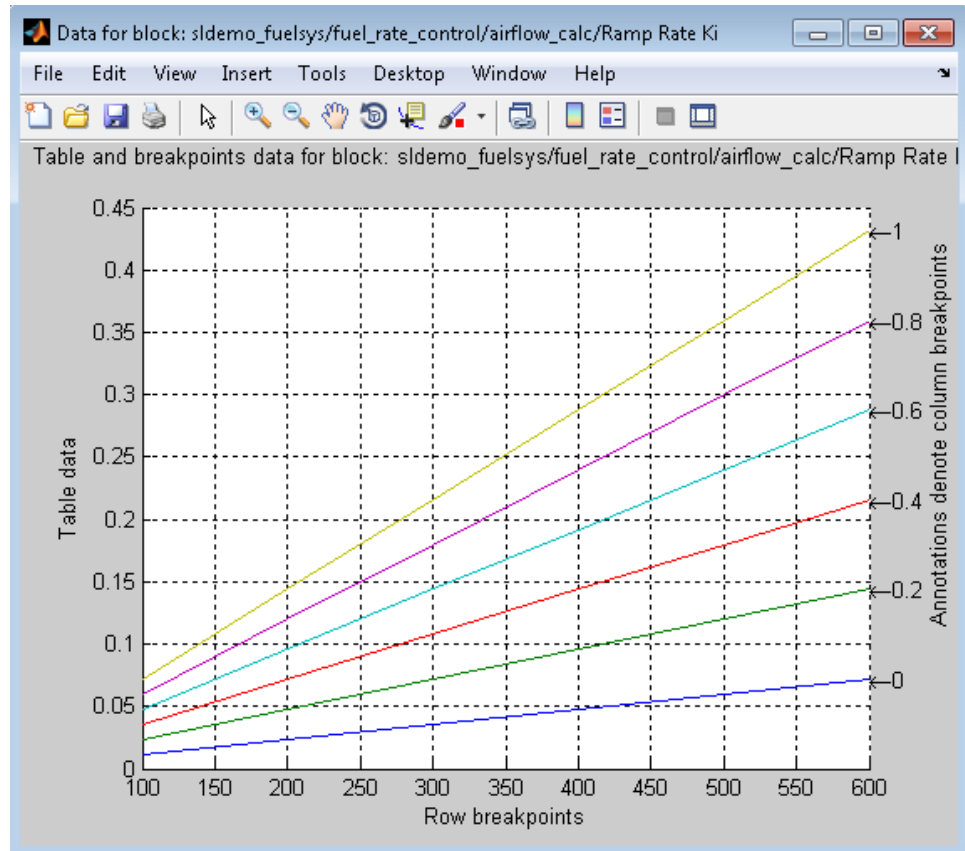
Data Type: Row: double Column: double Table: double

Dimension Selector:

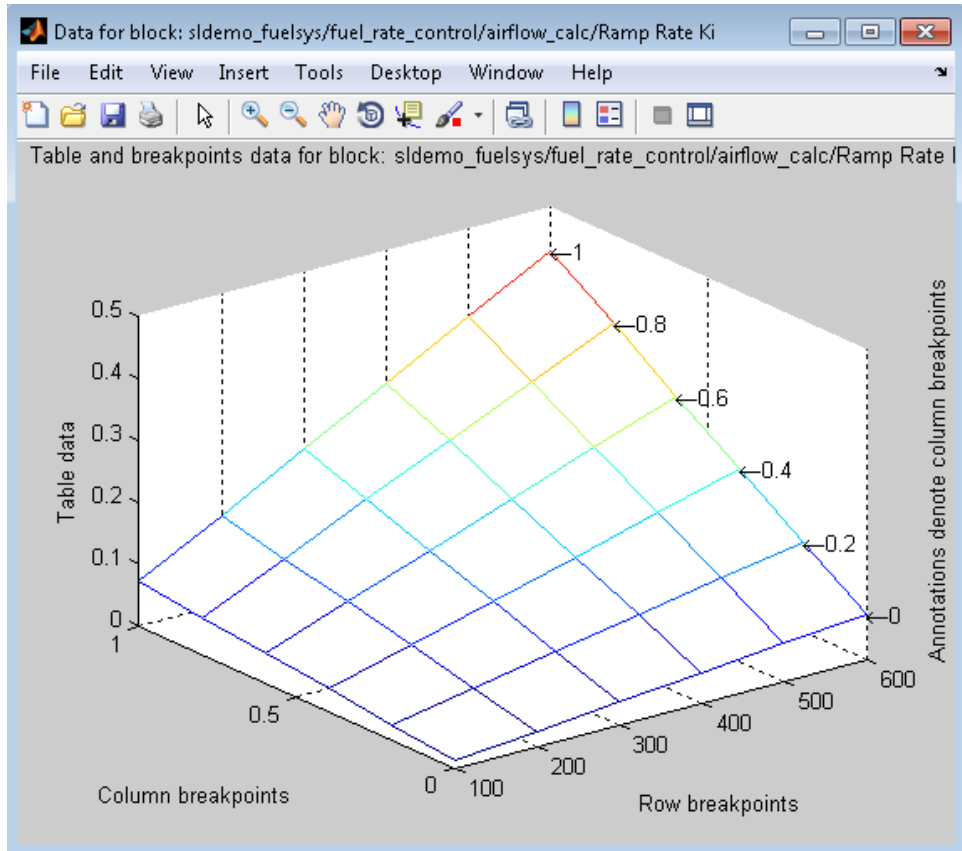
Dimension size	6	6
Select 2-D slice	All	All

Transpose display

A linear plot of the table looks something like this:



A mesh plot of the table looks something like this:

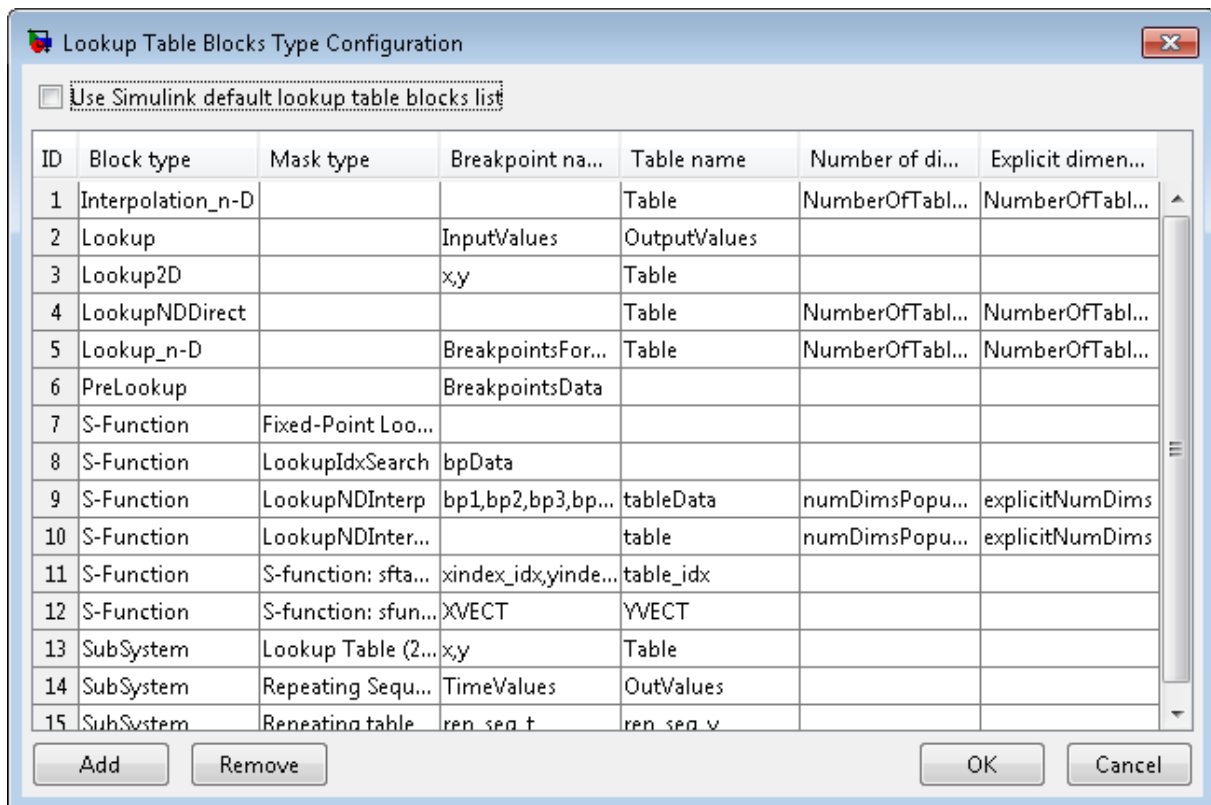




## Editing Custom Lookup Table Blocks

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.

<b>Field Name</b>	<b>Description</b>
Block type	Block type of the custom block. The block type is the value of the block's <code>BlockType</code> parameter.
Mask type	Mask type of the custom block. The mask type is the value of the block's <code>MaskType</code> parameter.
Breakpoint name	Names of the block parameters that store the breakpoints.
Table name	Name of the block parameter that stores the table data.
Number of dimensions	Leave empty.
Explicit dimensions	Leave empty.

- 3 Click **OK**.

### **Removing Custom Lookup Table Block Types**

To remove a custom lookup table block type from the list that the Lookup Table Editor recognizes, select the custom entry in the table of the Lookup Table Blocks Type Configuration dialog box. Then click **Remove**.

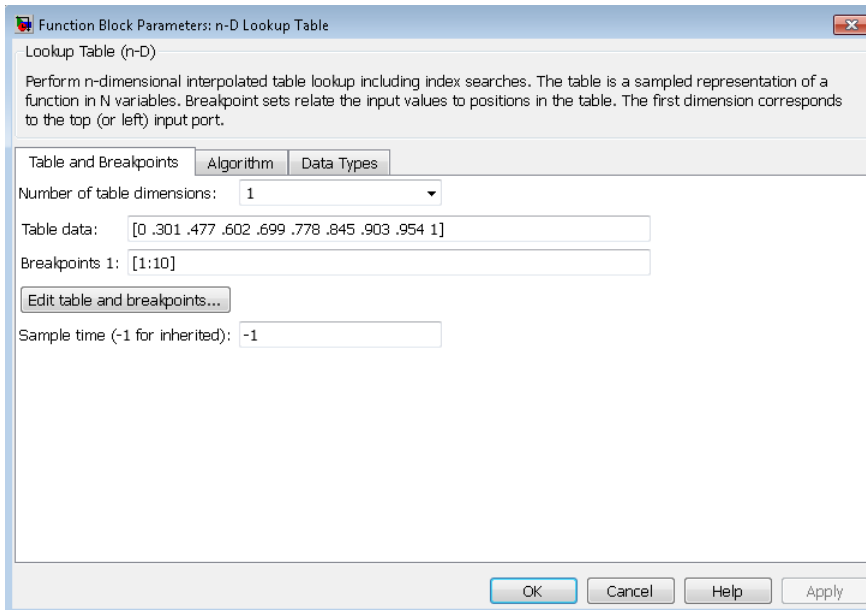
To remove all custom lookup table block types, select the **Use Simulink default lookup table blocks list** check box at the top of the dialog box.

## Example of a Logarithm Lookup Table

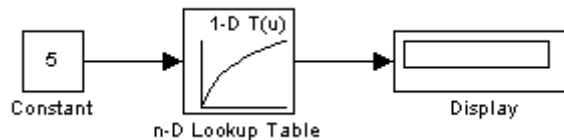
Suppose you want to approximate the common logarithm (base 10) over the input range [1, 10] without performing an expensive computation. You can perform this approximation using a lookup table block as described in the following procedure.

- 1** Copy the following blocks to a Simulink model:
  - 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.

## Examples for Prelookup and Interpolation Blocks

The following examples show the benefits of using Prelookup and Interpolation Using Prelookup blocks.

Action	Benefit	Example
Use an index search to relate inputs to table data, followed by an interpolation and extrapolation stage that computes outputs	Enables reuse of index search results to look up data in multiple tables, which reduces simulation time	To open the model, type <code>sldemo_bpcheck</code> at the command prompt.
Set breakpoint and table data types explicitly	Lowers memory required to store: <ul style="list-style-type: none"> <li>• Breakpoint data that uses a smaller type than the input signal</li> <li>• Table data that uses a smaller type than the output signal</li> </ul>	To open the model, type <code>sldemo_interp_memory</code> at the command prompt.
	Provides easier sharing of: <ul style="list-style-type: none"> <li>• Breakpoint data among Prelookup blocks</li> <li>• Table data among Interpolation Using Prelookup blocks</li> </ul>	To open the model, type <code>fxpdemo_lookup_shared_param</code> at the command prompt.
	Enables reuse of utility functions in the generated code	To open the model, type <code>fxpdemo_prelookup_utilfcn</code> 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 <code>fxpdemo_interp_precision</code> at the command prompt.

## Tips to Optimize Generated Code for Lookup Table Blocks

### In this section...

“Remove Code That Checks for Out-of-Range Inputs” on page 22-67

“Optimize Breakpoint Spacing in Lookup Tables” on page 22-69

### 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	<b>Remove protection against out-of-range input in generated code</b>
2-D Lookup Table	
n-D Lookup Table	
Prelookup	
Interpolation Using Prelookup	<b>Remove protection against out-of-range index in generated code</b>

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.

<b>Model Advisor Check</b>	<b>When to Run the Check</b>
<b>By Product &gt; Embedded Coder &gt; Identify lookup table blocks that generate expensive out-of-range checking code</b>	For code efficiency
<b>By Product &gt; Simulink Verification and Validation &gt; Modeling Standards &gt; DO-178B Checks &gt; Check usage of lookup table blocks</b>	For safety-critical applications

For more information about the Model Advisor, see “Consulting the Model Advisor” on page 3-81 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 “Consulting the Model Advisor” on page 3-81 in the Simulink documentation.

## Updating Your Model to Use Current Lookup Table Blocks

### In this section...

“Comparison of Blocks with Current Versions” on page 22-71

“Compatibility of Models with Older Versions of Lookup Table Blocks” on page 22-72

“How to Update Your Model” on page 22-73

“What to Expect from the Model Advisor Check” on page 22-74

### 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	<ul style="list-style-type: none"> <li>Block renamed as 1-D Lookup Table</li> <li>Icon changed</li> </ul>	<ul style="list-style-type: none"> <li>Default integer rounding mode changed from Floor to Simplest</li> <li>Support for the following features:           <ul style="list-style-type: none"> <li>Specification of parameter data types different from input or output signal types</li> <li>Reduced memory use and faster code execution for nontunable breakpoints with even spacing</li> <li>Cubic-spline interpolation and extrapolation</li> <li>Table data with complex values</li> <li>Fixed-point data types with word lengths up to 128 bits</li> <li>Specification of data types for fraction and intermediate results</li> <li>Specification of index search method</li> <li>Specification of diagnostic for out-of-range inputs</li> </ul> </li> </ul>

Block	Changes	Enhancements
Lookup Table (2-D)	<ul style="list-style-type: none"> <li>• Block renamed as 2-D Lookup Table</li> <li>• Icon changed</li> </ul>	<ul style="list-style-type: none"> <li>• Default integer rounding mode changed from Floor to Simplest</li> <li>• Support for the following features:               <ul style="list-style-type: none"> <li>▪ Specification of parameter data types different from input or output signal types</li> <li>▪ Reduced memory use and faster code execution for nontunable breakpoints with even spacing</li> <li>▪ Cubic-spline interpolation and extrapolation</li> <li>▪ Table data with complex values</li> <li>▪ Fixed-point data types with word lengths up to 128 bits</li> <li>▪ Specification of data types for fraction and intermediate results</li> <li>▪ Specification of index search method</li> <li>▪ Specification of diagnostic for out-of-range inputs</li> </ul> </li> <li>• Check box for <b>Require all inputs to have the same data type</b> now selected by default</li> </ul>
Lookup Table (n-D)	<ul style="list-style-type: none"> <li>• Block renamed as n-D Lookup Table</li> <li>• Icon changed</li> </ul>	<ul style="list-style-type: none"> <li>• Default integer rounding mode changed from Floor to Simplest</li> </ul>

### 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: <b>By Product &gt; Simulink &gt; Check model, local libraries, and referenced models for known upgrade issues requiring compile time information.</b>	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: <ul style="list-style-type: none"> <li>Decide how to address each warning.</li> <li>Adjust block parameters as needed.</li> </ul>	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 <code>slookup</code> 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 “Consulting the Model Advisor” on page 3-81 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
<p>The <b>Lookup Method</b> is Use Input Nearest or Use Input Above. The replacement block does not support these lookup methods.</p>	<p>Change the lookup method to one of the following options:</p> <ul style="list-style-type: none"> <li>• Interpolation - Extrapolation</li> <li>• Interpolation - Use End Values</li> <li>• Use Input Below</li> </ul>	<p>The <b>Lookup Method</b> changes to Interpolation - Use End Values.</p> <p>In the replacement block, this setting corresponds to:</p> <ul style="list-style-type: none"> <li>• <b>Interpolation</b> set to Linear</li> <li>• <b>Extrapolation</b> set to Clip</li> </ul>
<p>The <b>Lookup Method</b> 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.</p>	<p>Change the extrapolation method or the port data types of the block.</p>	<p>You also see a message that explains possible numerical differences.</p>
<p>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.</p>	<p>None</p>	<p>You see a message that explains possible numerical differences.</p>

### **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.

<b>Term</b>	<b>Meaning</b>
rounding	A process for approximating a value by altering its digits according to a known rule.
strictly monotonically increasing	The elements of a set are ordered such that each successive element is greater than its preceding element.
table data	An array that serves as a sampled representation of a function evaluated at a lookup table's breakpoint values. A lookup table uses breakpoint data sets to index the table data, ultimately returning an output value.

# Working with Block Masks

---

- “What Are Masks?” on page 23-2
- “Why Use a Mask?” on page 23-3
- “Masked Subsystem Example” on page 23-5
- “Roadmap for Masking Blocks” on page 23-8
- “Mask Terminology” on page 23-10
- “Creating a Block Mask” on page 23-11
- “Masking a Model Block” on page 23-32
- “Masks on Blocks in User Libraries” on page 23-34
- “Masking Blocks and Promoting Parameters” on page 23-36
- “Operating on Existing Masks” on page 23-50
- “Roadmap for Dynamic Masks” on page 23-53
- “Calculating Values Used Under the Mask” on page 23-54
- “Controlling Masks Programmatically” on page 23-57
- “Creating Dynamic Mask Dialog Boxes” on page 23-63
- “Creating Dynamic Masked Subsystems” on page 23-68
- “Understanding Mask Code Execution” on page 23-72
- “Debugging Masks That Use MATLAB Code” on page 23-75

## What Are Masks?

A mask is a custom user interface for a Simulink block. The mask hides the native user interface of the underlying block, substituting an icon and a parameters dialog box defined by the mask. You can apply a mask to any Subsystem block, Model block, or S-Function block. The block can optionally reside in a user-defined library. You can also mask built-in blocks.

Masking a block changes only the user interface of the block, not its underlying characteristics. For example, masking a nonatomic subsystem does not make it act as an atomic subsystem, and masking a virtual block does not convert it to a nonvirtual block. You cannot save a mask separately from the block that it masks, or create a freestanding mask definition and apply it to more than one block.

The icon and parameters dialog boxes for a mask can provide any capability that a native block icon and dialog box can provide. When you set mask parameter values, the mask can use the values to dynamically change the mask icon and dialog box, and to calculate values to be used under the mask. A mask on a subsystem can dynamically change the subsystem to reflect mask parameter values.

## Why Use a Mask?

Masks can provide interface customization, logic encapsulation, and data hiding. For example, although defining a subsystem simplifies the graphical appearance of a model, the simplification does not provide a user interface that is specific to the subsystem. The lack of a subsystem-specific interface has several possible disadvantages, including:

- The subsystem icon is generic: it does not indicate the meaning of the subsystem, and cannot change to provide information about parameter settings in the subsystem.
- The subsystem parameters that need to be changed to control behavior may be distributed among many subsystem blocks, making the parameters hard to find.
- The parameter names in the blocks comprising the subsystem reflect only the generic purpose of each block, rather than the parameter's purpose in the context of the model.
- Making any change to the subsystem requires exposing its complete contents in an editor, which makes the subsystem vulnerable to unintended changes.
- Because the subsystem has no separate parameters dialog box, no Block Help information is available for the subsystem, as it would be for a built-in block.

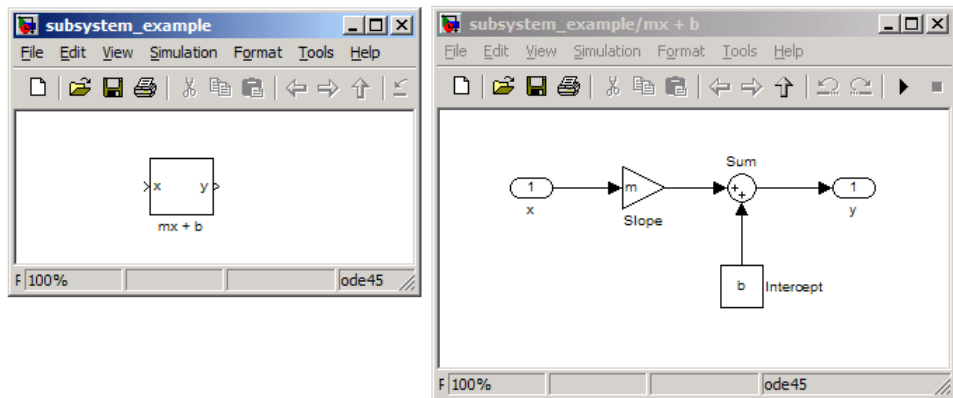
Masking a subsystem can address all of these problems. A subsystem mask can:

- Display a meaningful icon that updates dynamically and reflects values within the subsystem.
- Define customized user-settable parameters whose names reflect the purpose of the subsystem.
- Provide a parameters dialog box that gives access only to parameters that should be exposed.
- Shows customized Block Help and Online Help information that is specific to the subsystem.

The mask thereby encapsulates the subsystem under an interface that reflects the subsystem as the user sees it, as distinct from the subsystem's architecture, and provides the look and feel of a built-in Simulink block. Similar advantages apply to masks on Model blocks, S-Function blocks, and built-in blocks.

## Masked Subsystem Example

The next figure shows a Subsystem block that models the equation for a line,  $y = mx + b$ . The techniques for creating such a subsystem appear in “Creating Subsystems” on page 3-37. The subsystem is not atomic, so the Subsystem block is just a graphical abbreviation for the underlying blocks:



Double-clicking an unmasked Subsystem block opens a separate window that displays the contents of the subsystem, as shown in the above figure. This subsystem contains a Gain block, named **Slope**, whose **Gain** parameter is specified as  $m$ , and a Constant block, named **Intercept**, whose **Constant value** parameter is specified as  $b$ . These parameters represent the slope and intercept of a line. To examine this model, click `subsystem_example` or execute:

```
run([docroot ' /toolbox/simulink/ug/examples/masking/subsystem_example.mdl' ])
```

The organization of this model has several disadvantages:

- Although the block gives some indication of its purpose by showing the calculation that it performs, the icon adds no specific information.
- Only the values of the **Gain** and **Constant value** parameters are relevant outside the subsystem, but editing the subsystem displays its entire contents.

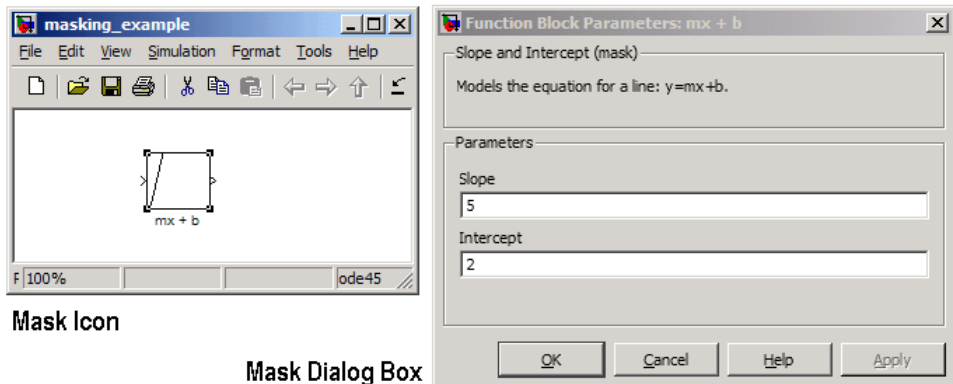
- The names of the block parameters within the subsystem relate to Simulink architecture rather than to the purpose of the subsystem.

You can overcome these problems by applying a mask to the Subsystem block. This mask can:

- Provide an icon that reflects the purpose of the subsystem
- Show only the parameters that are used outside the subsystem
- Give those parameters names that relate to the subsystem's purpose

The next figure shows the above model with a mask applied to the Subsystem block. To examine this model, click `masking_example` or execute:

```
run([docroot ' /toolbox/simulink/ug/examples/masking/masking_example.mdl'])
```



Mask Icon

Mask Dialog Box

Masking the subsystem has created a self-contained functional unit. A customized mask icon replaces the default Subsystem block icon. Double-clicking the mask icon opens a customized Mask Parameters dialog box, which replaces the Subsystem block dialog box. The Mask Parameters dialog box shows two parameters: **Slope**, which provides the value of  $m$  in the subsystem Gain block, and **Intercept**, which provides the value of  $b$  in the subsystem Constant block.

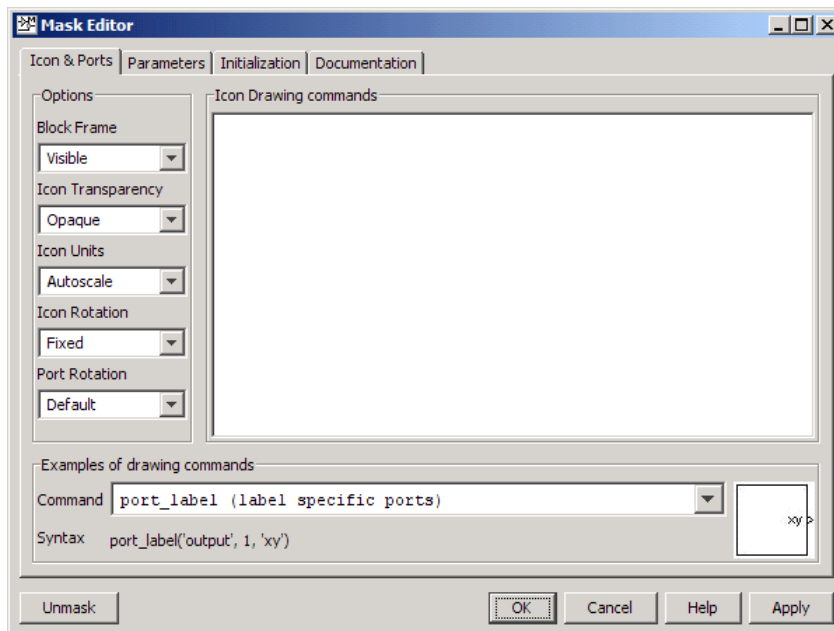
These parameters are the only constructs within the subsystem that are of interest outside the subsystem, so the mask has been designed to hide everything else. The mask parameters are currently set to 5 and 2,



respectively. These values are not part of the mask itself, but were entered just as if they were the values of ordinary block parameters. The parameter values are available to all the blocks in the underlying subsystem. The mask icon displays a line that reflects the current value of the **Slope** parameter.

## Roadmap for Masking Blocks

The Mask Editor provides the capabilities necessary for creating, changing, and removing a Subsystem, Model, or S-Function block mask. When you first open the Mask Editor, it looks like this:



The Mask Editor provides four tabbed panes, which you can use to perform any masking operation:

- “Icon & Ports Pane” — Specifies code that draws and controls the icon representing the masked block.
- “Parameters Pane” — Specifies mask parameters and code that executes when a parameter value changes.
- “Initialization Pane” — Specifies code that executes as needed to initialize the mask and underlying block.
- “Documentation Pane” — Specifies documentation that describes the block in its dialog box and in Online Help.

Use the preceding links as needed to access the Mask Editor reference. Definitions and instructions for masking a block appear in “Creating a Block Mask” on page 23-11:

If the block to be masked resides in a user-defined library, you will also need the information in “Masks on Blocks in User Libraries” on page 23-34:

After you have defined a block mask, you can perform various operations on it, as described in “Operating on Existing Masks” on page 23-50.

If you want to define a mask that can use mask parameter values to dynamically change the mask icon and dialog box, or calculate values to be used under the mask, first read the sections listed above as needed, then read: “Roadmap for Dynamic Masks” on page 23-53

All dynamic masking techniques require MATLAB programming, which is described in *MATLAB Programming Fundamentals*.

## Mask Terminology

The rest of this chapter assumes that you know the following definitions:

**Mask Icon** — An icon that replaces the standard icon for a masked block when the masked block appears in a model. You can accept a default icon or provide drawing code that defines the icon.

**Mask Parameters** — Optional parameters that link to block parameters that exist under the mask. Setting a mask parameter sets the associated block parameter.

**Mask Initialization Code** — Optional MATLAB code that runs when needed to initialize the masked subsystem. You can use initialization code to modify a masked subsystem to reflect current parameter values.

**Mask Callback Code** — Optional MATLAB code that runs whenever a mask parameter value changes. You can use callback code to modify a mask dialog box to reflect current parameter values.

**Mask Documentation** — Optional information that names and briefly describes the masked block, and provides Help information about how to use it.

**Mask Dialog Box** — A dialog box that replaces the masked block's standard parameters dialog box. The mask dialog box displays a block description, contains controls that enable a user to set mask parameter values, and provides Help information.

**Mask Workspace** — If the mask uses mask parameters or initialization code, it has a mask workspace that holds parameter and temporary values used by the mask.

## Creating a Block Mask

### In this section...

“Introduction” on page 23-11  
“Opening the Mask Editor” on page 23-12  
“Defining a Mask Icon” on page 23-13  
“Defining Mask Initialization” on page 23-16  
“Understanding Mask Parameters” on page 23-19  
“Defining Mask Parameters” on page 23-21  
“Defining Mask Documentation” on page 23-26  
“Using a Block Mask” on page 23-29

### Introduction

This section describes techniques for masking any type of block. The techniques are the same whether you mask a Subsystem block, Model block, or S-Function block. The masked block can optionally be included in a user-defined library, as described in “Masks on Blocks in User Libraries” on page 23-34. When you mask a Model block, one special consideration applies, as described in “Masking a Model Block” on page 23-32. Masking an S-Function block requires no special provisions. Masking built-in blocks requires some additional steps described in “Masking Blocks and Promoting Parameters” on page 23-36.

In practice, most masks are subsystem masks, because Model blocks and S-Function blocks already provide a high degree of encapsulation. For simplicity, the instructions and examples in this section refer specifically to a subsystem, and the mask does not dynamically change its dialog box or the subsystem under the mask. Instructions for masks that make dynamic changes begin in “Roadmap for Dynamic Masks” on page 23-53, which assumes that you understand everything in this section.

This section demonstrates only some of the capabilities of the Mask Editor. See “Simulink Mask Editor” for complete reference information. The section assumes that you know the definitions in “Mask Terminology” on page 23-10 and are familiar with the “Masked Subsystem Example” on page 23-5.

This section illustrates the described operations by constructing the mask described in “Masked Subsystem Example” on page 23-5. You can read the section and apply the operations to your own model, or you can use the section as a tutorial, as follows:

- 1** Open the unmasked source model by clicking `subsystem_example` or executing:

```
run([docroot ' /toolbox/simulink/ug/examples/masking/subsystem_example.mdl'])
```

- 2** Save the model in a writable working folder.

- 3** Optionally open the completed example by clicking `masking_example` or executing:

```
run([docroot ' /toolbox/simulink/ug/examples/masking/masking_example.mdl'])
```

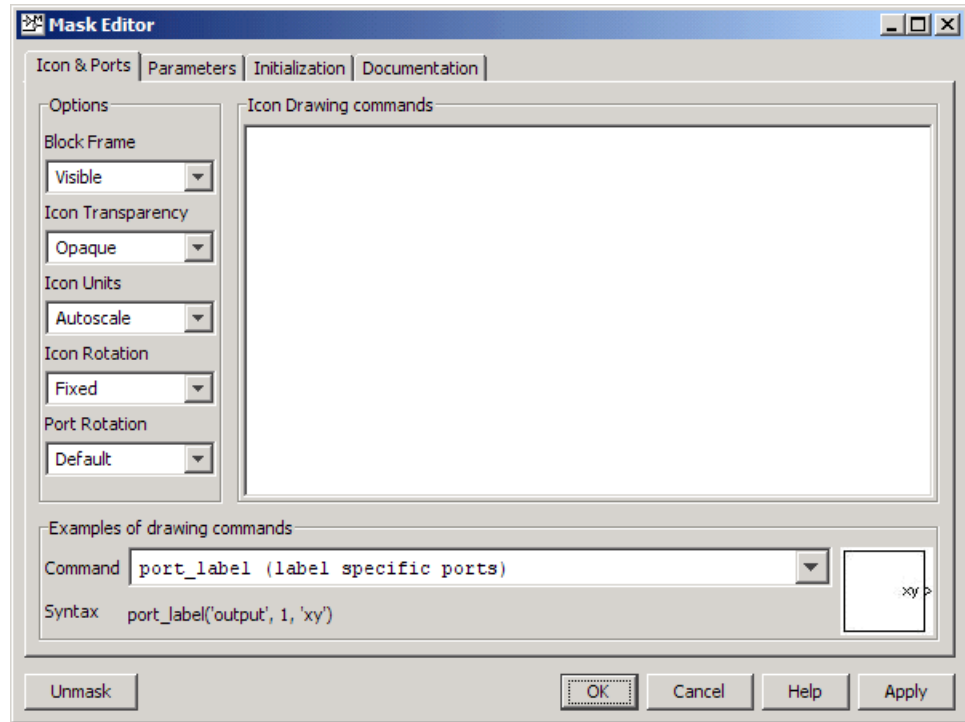
- 4** Execute the instructions in this section on the copy you made of `subsystem_example` to implement the capabilities in `masking_example`.

## Opening the Mask Editor

The Simulink Mask Editor provides all of the capabilities necessary for masking a block. To invoke the editor on an unmasked block:

- Select the Subsystem block.
- From the **Edit** menu or the context menu of the block, choose **Mask Subsystem**.

The Mask Editor opens:



You can define mask components in any order, as long as the final result is correct. You can also open the Mask Editor on a block that is already masked, as described in “Changing a Block Mask” on page 23-50.

## Applying Changes

Click **Apply** to make changes within the model, or **OK** to make changes within the model and close the editor. Save the model to permanently save the changes. If you close the model without saving it, all unsaved Mask Editor changes are lost.

## Defining a Mask Icon

A mask icon replaces the standard icon for a masked block when the masked block appears in a model. Mask icons can contain descriptive text, graphics,

images, state equations, one or more plots, or a transfer function. Simulink uses the commands and variables that you supply to draw the mask icon.

Use the Mask Editor **Icon & Ports** pane to specify the icon for a masked block. This pane is always selected by default when you open the Mask Editor. See the “Icon & Ports Pane” reference for information about all **Icon & Ports** pane capabilities. This section gives an example of their use.

To define a mask icon, enter:

- Any variables necessary for drawing the icon
- Commands to draw the icon

### **Variables**

For model efficiency, use the **Icon & Ports** pane to run MATLAB code and to define variables used by the mask icon drawing commands. Simulink executes the MATLAB code in the **Icon & Ports** pane only when the block icon needs to be drawn. If you include variables used by mask icon drawing commands in the **Initialization** pane, Simulink evaluates the variables as part of simulation and code generation. For details, see “Understanding Mask Code Execution” on page 23-72.

### **Drawing Commands**

To draw an icon, enter one or more of the commands described in “Mask Icon Drawing Commands” in the **Icon Drawing commands** text box. Use only these commands to draw a mask icon. To see examples of drawing command syntax, use the pull-down list in the **Examples of drawing commands** pane.

The drawing commands can access all variables defined in the mask workspace.

You can include MATLAB comments at the end of a drawing command or on their own line, as in the following examples:

```
image(imread('engine.jpg')) % Use engine icon for subsystem
```

```
% Use engine icon for subsystem  
image(imread('engine.jpg'))
```



If any drawing command cannot successfully execute, the icon displays three question marks.

### Example of Defining a Mask Icon

This example illustrates how to define a mask icon that is accurate, regardless of the shape of the block.

The mask icon in `masking_example` displays a line that reflects the slope of the line modeled in the masked subsystem. To define this icon in your copy of `subsystem_example.mdl`:

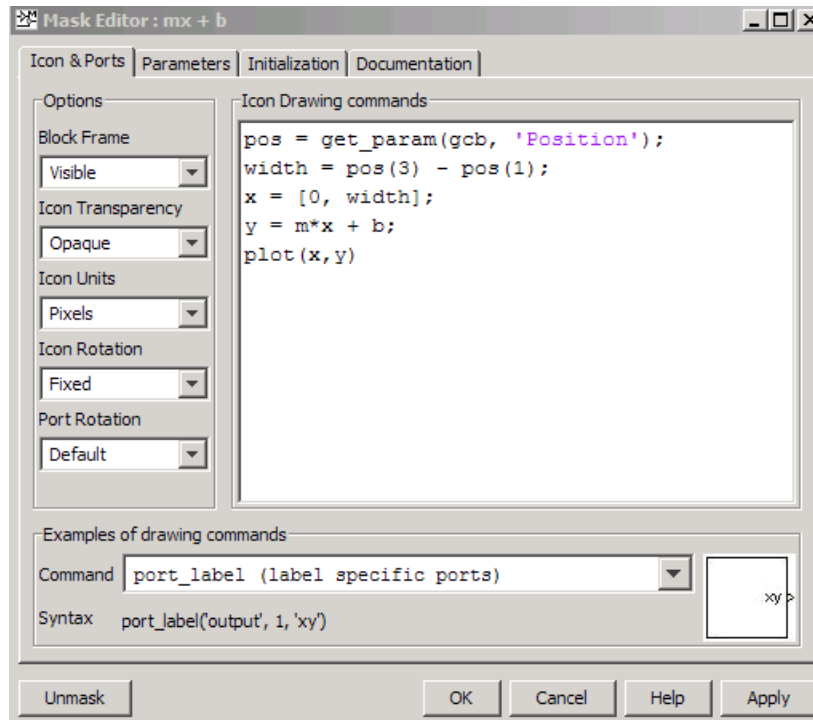
- 1 Type the following command into the **Icon Drawing commands** pane:

```
pos = get_param(gcb, 'Position');
width = pos(3) - pos(1);
x = [0, width];
y = m*x + b;
plot(x,y)
```

- 2 Under **Options**, set **Icon Units** to **Pixels**.

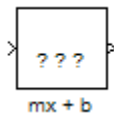
The pull-down lists under **Options** allow you to specify the icon frame visibility, icon transparency, drawing context, icon rotation, and port rotation.

The **Icon & Ports** pane now looks like this:



### 3 Click **Apply**.

If Simulink cannot evaluate all commands in the **Icon Drawing commands** pane to obtain a displayable result, the content of the icon is three question marks. In `masking_example`, three question marks appear at this point because the variable `m` has not yet been defined:



## Defining Mask Initialization

The initialization code is MATLAB code that you specify and that Simulink runs to initialize the masked subsystem at critical times, such as model

loading and the start of a simulation run (see “Initialization Command Execution” on page 23-73). 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.

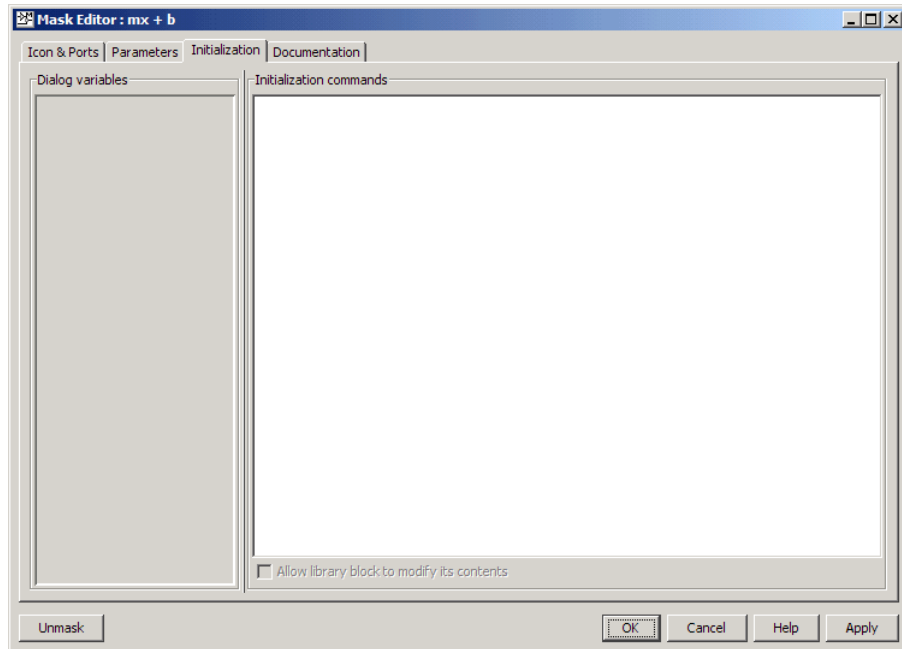
When you reference the block within, or copy the block into, a model, the Mask Parameters dialog box displays the specified default values. You cannot use mask initialization code to change mask parameter default values in a library block or any other block.

### **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 23-19 and “Debugging Masks That Use MATLAB Code” on page 23-75.

## Initialization Command Limitations

Mask initialization commands must observe the following rules:

- Do not use initialization code to create dynamic mask dialog boxes (that is, dialog boxes whose appearance or control settings change depending on changes made to other control settings). Instead, use the mask callbacks that are specifically for this purpose. For more information, see “Creating Dynamic Mask Dialog Boxes” on page 23-63.
- Avoid using `set_param` commands on blocks residing in another masked subsystem that you are initializing. Trying to set parameters of blocks in lower-level masked subsystems can trigger unresolvable symbol errors if lower-level masked subsystems reference symbols defined by higher-level masked subsystems. Suppose, for example, a masked subsystem A contains masked subsystem B, which contains Gain block C, whose Gain parameter references a variable defined by B. Suppose also that subsystem A has initialization code that contains the following command:

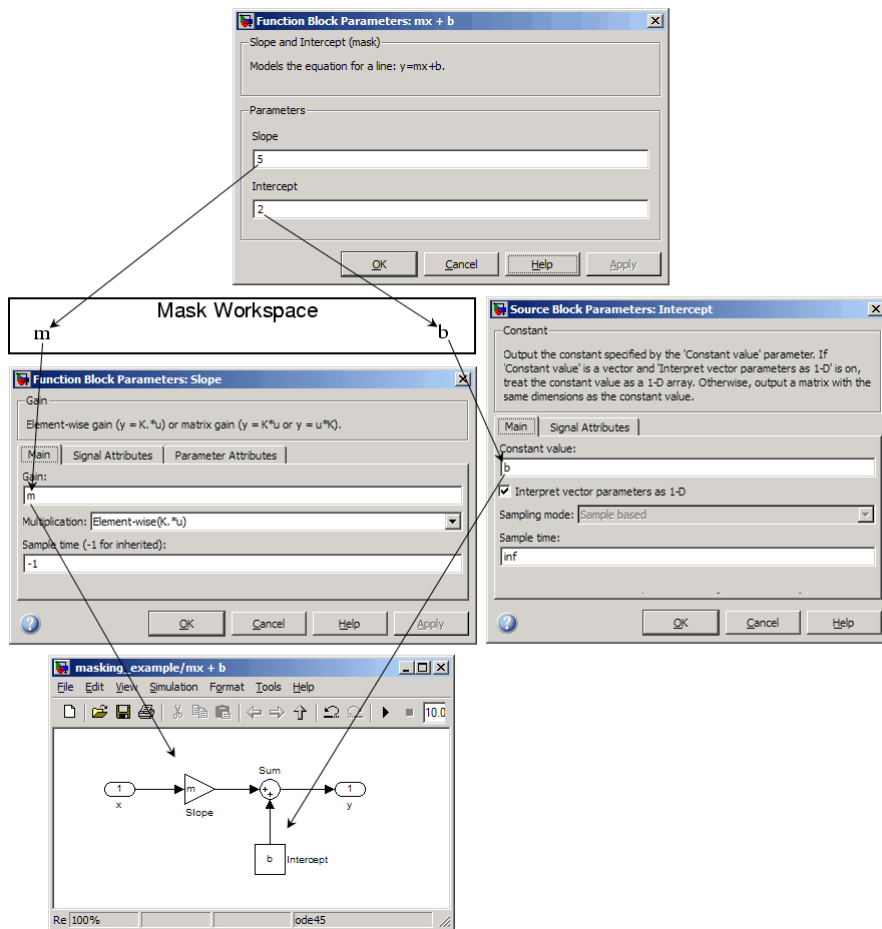
```
set_param([gcb '/B/C'], 'SampleTime', '-1');
```

Simulating or updating a model containing A causes an unresolvable symbol error.

## Understanding Mask Parameters

Mask parameters provide the connection between the Mask Parameters dialog box and the underlying block. Each mask parameter appears in the Mask Parameters dialog box as a control, such as an edit box, a pop-up control, a check box, or a data type control. Setting the value of this control sets the value of an associated mask parameter that is defined in the mask workspace. The underlying block specifies that parameter as the value of

one or more block parameters, and accesses the value of the corresponding control in the Mask Parameters dialog box. The next figure illustrates this relationship for the `masking_example`.



In this figure, the Mask Parameters dialog box (top) contains edit-box controls for two parameters: **Slope**, which is associated with the mask workspace variable `m`, and **Intercept**, which is associated with the mask workspace variable `b`. In the subsystem (bottom), the Gain block named `Slope` specifies its **Gain** parameter as `m`, and the Constant block named `Intercept` specifies

its **Constant value** parameter as **b**, as shown in the two Block Parameters dialog boxes (middle).

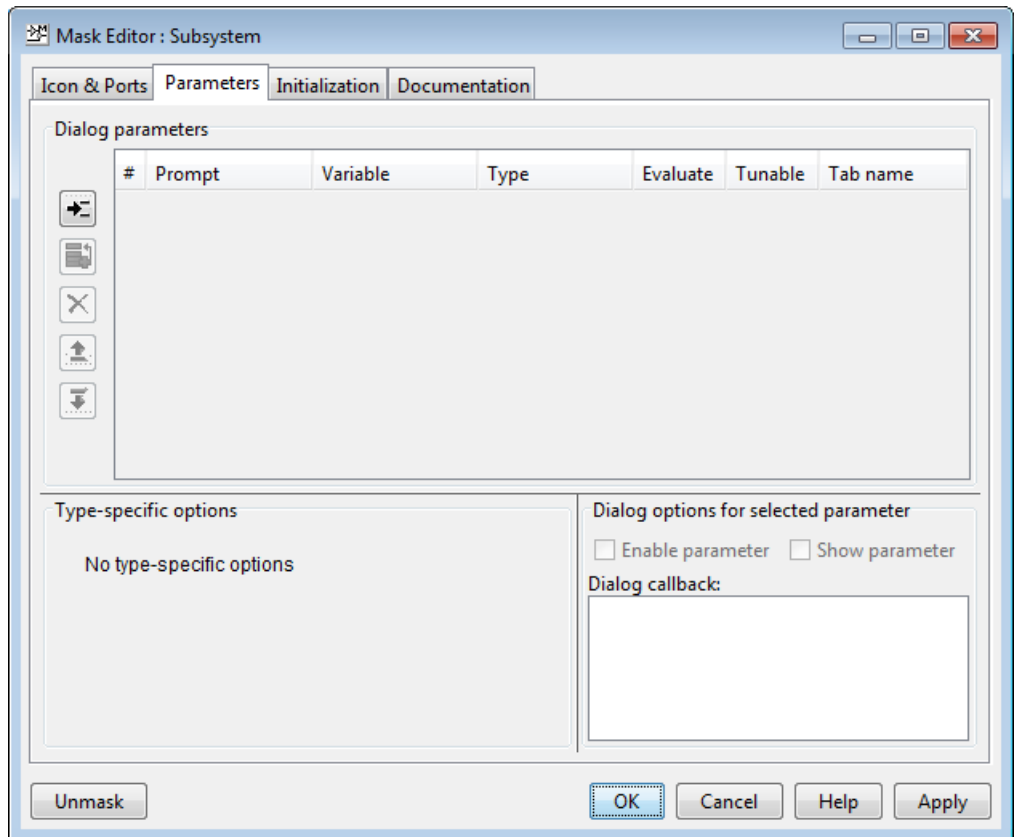
When the user of the masked block sets the values of **Slope** and **Intercept** in the Mask Parameters dialog box, Simulink automatically assigns the mask parameter values to the corresponding mask workspace variables, **m** and **b**, respectively. For example, as shown in the diagram above, when the masked block user sets the **Slope** parameter in the Mask Parameters dialog box to 5, Simulink sets the **m** variable in the mask workspace to 5. The Gain block uses 5 as its **Gain** parameter value, because the **Gain** parameter in the Gain block has a value of **m**.

Before simulation begins, Simulink tries to resolve the Gain block's **Gain** parameter **m** and the Constant block's **Constant Value** parameter **b** to numeric values by searching up the workspace hierarchy, as described in "Resolving Symbols" on page 3-76. Because a mask exists, Simulink searches the mask workspace first. There it finds **m** and **b** defined, so it successfully resolves the two block parameters. For example, the **Slope** parameter in the Mask Parameters dialog box is defined in the Mask Editor to be **m**, and the **Gain** parameter in the Gain block is also defined to be **m**.

If no mask exists (and therefore, no mask workspace), but the subsystem itself does not change, Simulink performs the same hierarchical search seeking a value for **m** and **b**, and the search for each value must succeed before simulation can begin. Therefore, the existence of a mask affects hierarchical search only by providing a mask workspace that Simulink searches first.


## Defining Mask Parameters

Be sure you have read "Understanding Mask Parameters" on page 23-19 before reading this section. Use the Mask Editor **Parameters** pane to specify block mask parameters.



For reference information about all **Parameters** pane capabilities, see the “Parameters Pane”. This section gives an example of their use.

Parameters appear in the Mask Parameters dialog box in the same order that you define the corresponding parameter definitions in the **Dialog parameters** table. To define the mask parameters used in the `masking_example`:

- 1 Click the **Add** button  at the upper left of the **Parameters** pane to create a new parameter:



#	Prompt	Variable	Type	Evaluate	Tunable	Tab name
1			edit	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	

**Tip** To promote underlying block parameters to the mask, use the Promote buttons. See “Masking Blocks and Promoting Parameters” on page 23-36.

- 2 Edit the **Prompt** field to specify Slope and the **Variable** field to specify m:

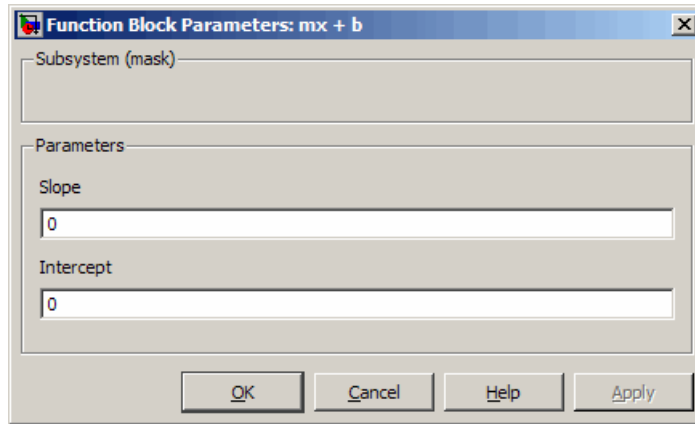
#	Prompt	Variable	Type	Evaluate	Tunable	Tab name
1	Slope	m	edit	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	

- 3 Click **Add** to create a second parameter, and specify its **Prompt** as Intercept and its **Variable** as b.

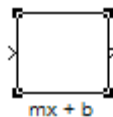
#	Prompt	Variable	Type	Evaluate	Tunable	Tab name
1	Slope	m	edit	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
2	Intercept	b	edit	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	

- 4 Click **Apply** to save the parameter definitions.

Double-click the masked subsystem to see the current Mask Parameters dialog box:



The variables  $m$  and  $b$  now exist in the mask workspace. The GUI parameters in the Mask Parameters dialog box are mapped to the corresponding workspace variables. By default, these variables are of type `double` and have a default value of 0. The mask icon now shows an initial **Slope** of 0:



The Mask Editor parameters pane defines both the individual mask parameters and the organization of the Mask Parameters dialog box. For each mask parameter, a row exists in the **Dialog parameters** table on the **Parameters** pane. The fields in this row are:

- **Prompt** — A prompt that represents the parameter in the Mask Parameters dialog box
- **Variable** — A variable in the mask workspace that corresponds to the mask parameter
- **Type** — The type of control that represents the mask parameter in the Mask Parameters dialog box
- **Evaluate** — Whether Simulink uses the value of the mask parameter literally, or evaluates it

- **Tunable** — Whether the parameter is editable (tunable) while simulation is running
- **Tab name** — The name of the tab, if any, on which the control appears in the mask dialog box

See the “Parameters Pane” reference for information about all **Parameters** pane capabilities.

### Mask Parameters Dialog Box Callback Code

Enter the MATLAB code that you want the Simulink software to execute when a user applies a change to the selected parameter (selects the **Apply** or **OK** button on the Mask Parameters dialog box). You can use such callbacks to create dynamic dialog boxes, which are dialog boxes whose appearance changes, depending on changes to control settings made by the user (for example, enabling an edit field when a user checks a check box). For more information, see “Creating Dynamic Mask Dialog Boxes” on page 23-63.

---

**Note** Callbacks are not intended to be used to alter the contents of a masked subsystem. Altering a masked subsystem’s contents in a callback, for example, by adding or deleting blocks or changing block parameter values, can trigger errors during model update or simulation. If you need to modify the contents of a masked subsystem, use the mask’s initialization code to perform the modifications (see “Initialization Pane”).

---

The callback can create and reference variables only in the base workspace of the block. If the callback needs the value of a mask parameter, it can use `get_param` to obtain the value. For example:

```
if str2num(get_param(gcf, 'g'))<0
    error('Gain is negative.')
end
```

For information on debugging dialog box callbacks, see “Debugging Masks That Use MATLAB Code” on page 23-75.

## Defining Mask Documentation

A block mask can display three types of documentation. They are all optional, but in practice essentially all masks provide them.

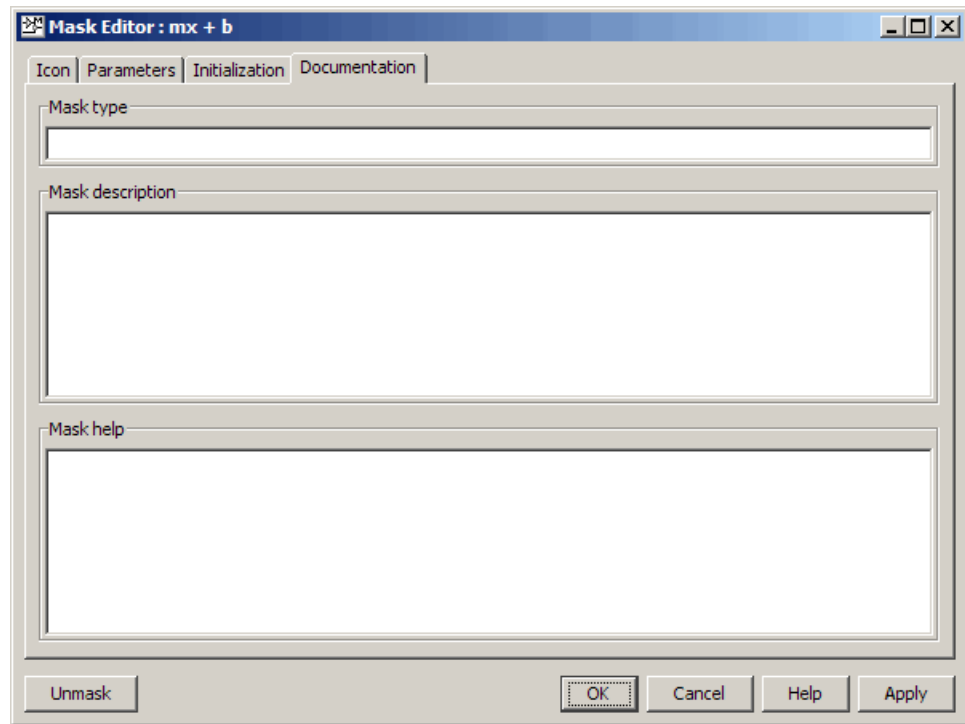
**Mask type** — A name that appears at the top of the Mask Parameters dialog box. When Simulink displays the Mask Parameters dialog box, it adds (mask) to the mask type. You cannot use newlines in the text.

**Mask description** — Summary text that describe the purpose of the masked block. The description appears in the Mask Parameters dialog box under the mask type. You can use newlines and multiple blanks for formatting.

**Mask help** — Provides additional information that appears when the user clicks the **Help** button on the Mask Parameters dialog box. The text can be:

- Plain text. Use newlines and multiple blanks for formatting.
- HTML text and graphics. Any standard HTML tag can appear.
- A URL that points to information, which can be text or HTML.
- A `web` or `eval` command that returns text or HTML to display.

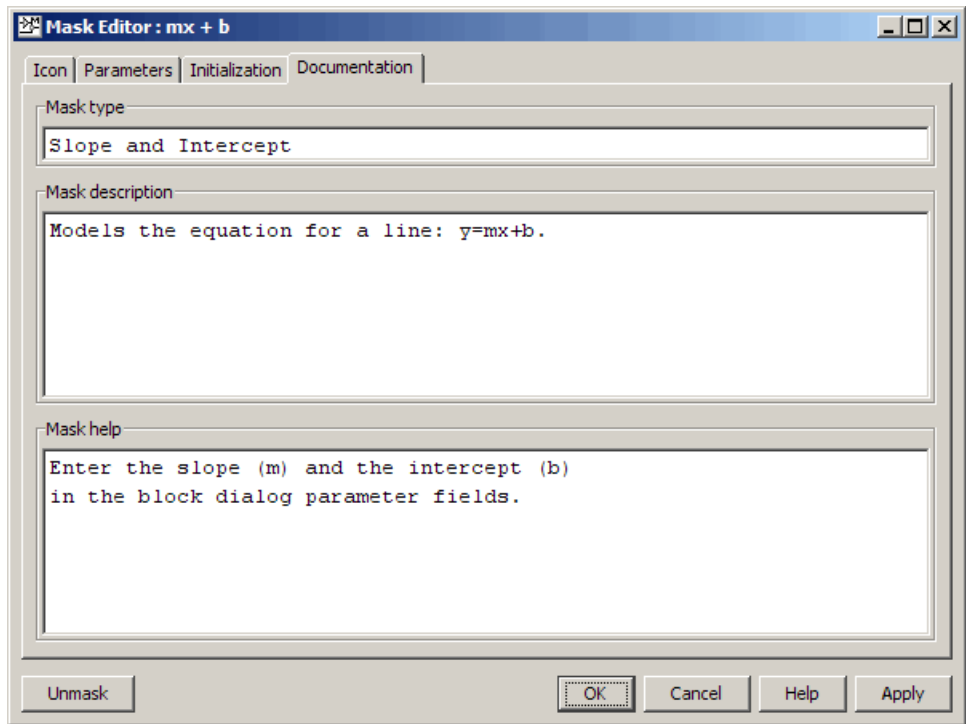
Use the Mask Editor **Documentation** pane to specify the **Mask type**, **Mask description**, and **Mask Help** for a masked block:



For information about all **Documentation** pane capabilities, see the “Documentation Pane” reference.

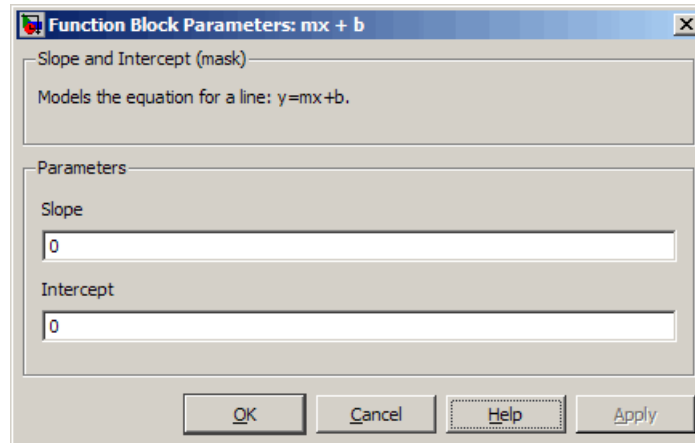
To specify mask documentation, enter text in the three fields of the **Documentation** pane. To define the `masking_example` documentation:

- 1 Enter the text shown below in the **Mask type**, **Mask description**, and **Mask help** fields:

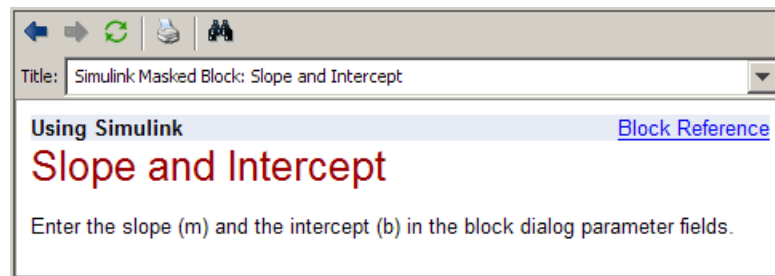


### 2 Click **Apply**.

The Mask Parameters dialog box closes if it is open. Double-click the masked subsystem to open the dialog box:



In the Mask Parameters dialog box, the mask type and description now show the text that you entered in the **Documentation** pane. Simulink adds (mask) to the Mask type to indicate that the dialog box shows a mask rather than a native block dialog box. To see the mask help, click the **Help** button. The help text appears in the MATLAB Help browser:



You can use the full capabilities of the MATLAB Help browser for the help that you access from a Mask Parameters dialog box.

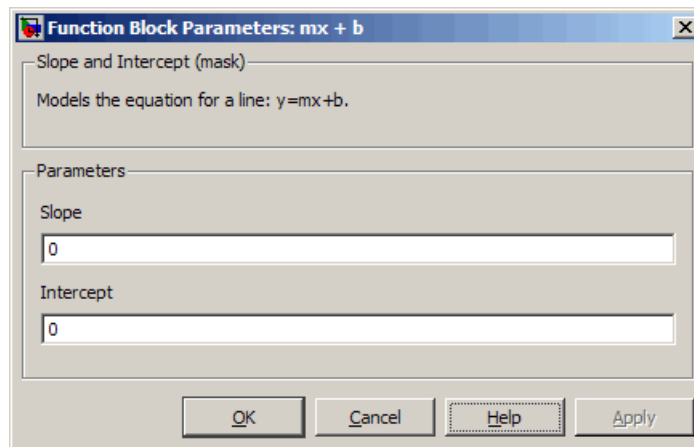
## Using a Block Mask

Once you have completed the operations described above, click **OK** to apply any final changes to the mask and close the Mask Editor. If you want to save the mask for later examination, save the model. If you close a model without saving it, all unsaved Mask Editor changes are lost.

You can now use the masked Subsystem block  $mx + b$  exactly as you could if it were an instance of a built-in block whose capabilities are those of the subsystem and whose interface is that of the mask:

- 1 Double-click the masked block  $mx + b$ .

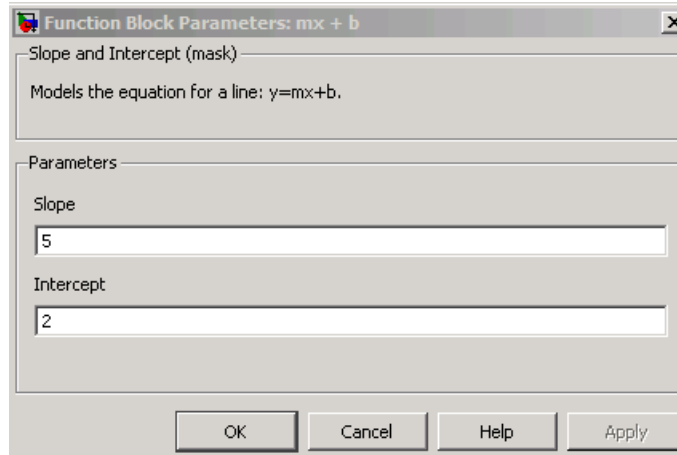
The Mask Parameters dialog box opens:



- 2 Change the parameter values so that **Slope** = 5 and **Intercept** = 2.
- 3 Click **Apply**.

The Mask Parameters dialog box and the mask icon now look like this:





When you click **Apply**, Simulink assigns the value of **Slope** to the mask workspace parameter **m**, and the value of **Intercept** to the mask workspace parameter **b**, as described in “Understanding Mask Parameters” on page 23-19. The blocks in the subsystem that reference **m** and **b** will use those values during simulation. The mask icon now reflects **Slope = 5** via the drawing command `plot(x,y)`, as described in “Defining a Mask Icon” on page 23-13. The mask documentation is as defined in “Defining Mask Documentation” on page 23-26.

## Masking a Model Block

### In this section...

“Special Considerations for Masking a Model Block” on page 23-32

“Specifying the Model Name” on page 23-32

“Workspace for Variables” on page 23-33

### Special Considerations for Masking a Model Block

You can use all techniques described in “Creating Dynamic Masked Subsystems” on page 23-68 to mask a Model block, except for how you specify the model name and what workspace you use for variables.

### Specifying the Model Name

If a mask specifies the name of the model referenced by a Model block, or by any Model block in a masked subsystem, the name of the referenced model must be given literally, rather than obtained by evaluating a workspace variable. This requirement exists because Simulink updates model reference targets before evaluating block parameters. To enforce the requirement, use one of these approaches, depending on which user interaction you prefer for the Mask Parameters dialog box:

- To restrict the user to specifying one of a predefined set of models, use a pop-up control to specify the name of the referenced model. Clear the **Evaluate** parameter for the pop-up control. Clearing the **Evaluate** parameter causes the control to provide a textual rather than a numeric value.
- To allow the user to specify any model as the referenced model, use an edit control to specify the name of the referenced model. Clear the **Evaluate** parameter for the edit control. Clearing the **Evaluate** parameter causes the name that the user provides to be interpreted literally.

See “Defining Mask Parameters” on page 23-21 for information about defining Pop-Up and Edit controls.

## **Workspace for Variables**

The mask workspace of a Model block is not visible to the model that it references. Any variables used by the referenced model must resolve to workspaces that the referenced model defines, or to the MATLAB base workspace.

## Masks on Blocks in User Libraries

### In this section...

“About Masks and User-Defined Libraries” on page 23-34

“Masking a Block for Inclusion in a User Library” on page 23-34

“Masking a Block that Resides in a User Library” on page 23-34

“Masking a Block Copied from a User Library” on page 23-35

### About Masks and User-Defined Libraries

You can mask a block that will be included in a user library or already resides in a user library, or you can mask an instance of a user library block that you have copied into a model. For example, a user library block might provide the capabilities that a model needs, but its native interface might be inappropriate or unhelpful in the context of the particular model. Masking the block could give it a more appropriate user interface.

### Masking a Block for Inclusion in a User Library

You can create a custom block by encapsulating a block diagram that defines the block’s behavior in a masked subsystem and then placing the masked subsystem in a library. You can also apply a mask to any other type of block that supports masking, then include the block in a library.

Masking a block that will later be included in a library requires no special provisions. Create the block and its mask as described in this chapter, and include the block in the library as described in “Creating Block Libraries” on page 25-21.

### 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. Complete information about user libraries appears in Chapter 25, "Working with Block Libraries". Additional information relating to masked library blocks appears in "Creating Block Libraries" on page 25-21.

## **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.

## Masking Blocks and Promoting Parameters

### In this section...

“Masking Built-In Blocks Directly and Within Subsystems” on page 23-36

“Promoting Block Parameters to the Mask” on page 23-36

“Creating a Simplified Custom Interface for a Built-In Block” on page 23-40

“Creating a Simplified Custom Interface for Multiple Parameters in a Subsystem” on page 23-44

“Rules for Promoting Parameters” on page 23-47

### Masking 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.

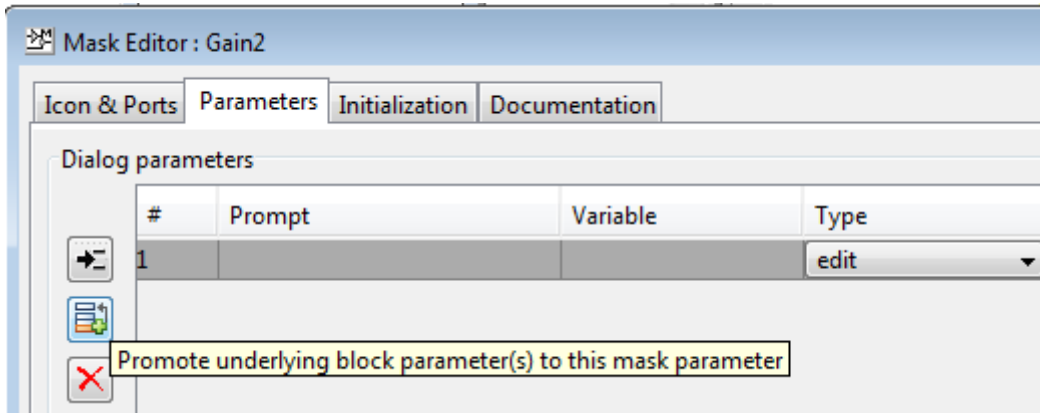
You can use masking in the following use cases:

- 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.

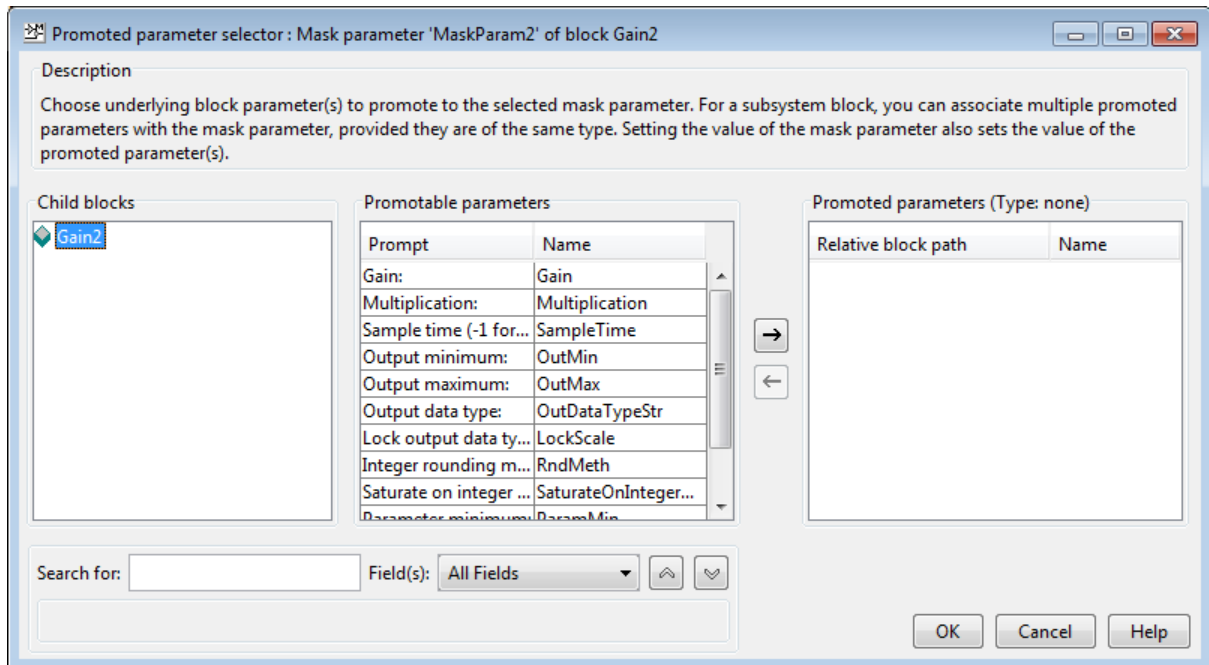
### Promoting Block Parameters to the Mask

- 1 Right-click your block or subsystem and select **Create Mask**.
- 2 In the Mask Editor, select the **Parameters** pane.

- 3 To choose one or more parameters for promotion:
  - a Create a new mask parameter by clicking **Add Parameter**.
  - b Click the **Promote** button, just beneath the **Add Parameter** 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**.

---

- If you are masking a subsystem, you can use the **Child blocks** list or the **Search** box to find the underlying block parameters that you want to promote.
- (Optional) If you are 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

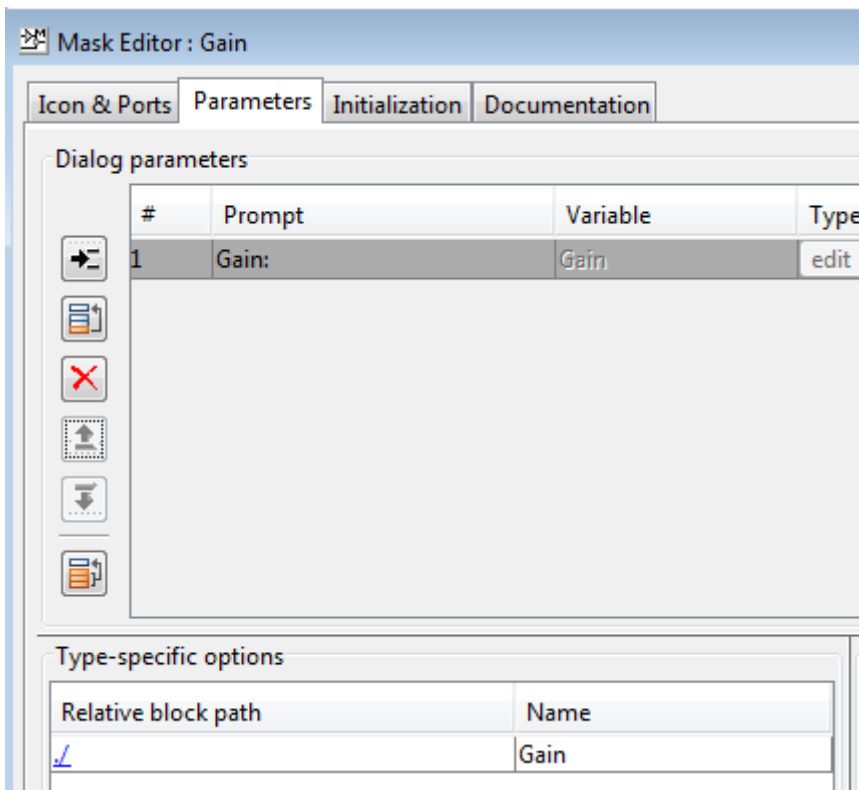


multiple Gain parameters in a subsystem to a single prompt on your mask.

**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”). You can 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 23-47.
- 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**  to save time.

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.

## **Creating a Simplified Custom Interface for a Built-In Block**

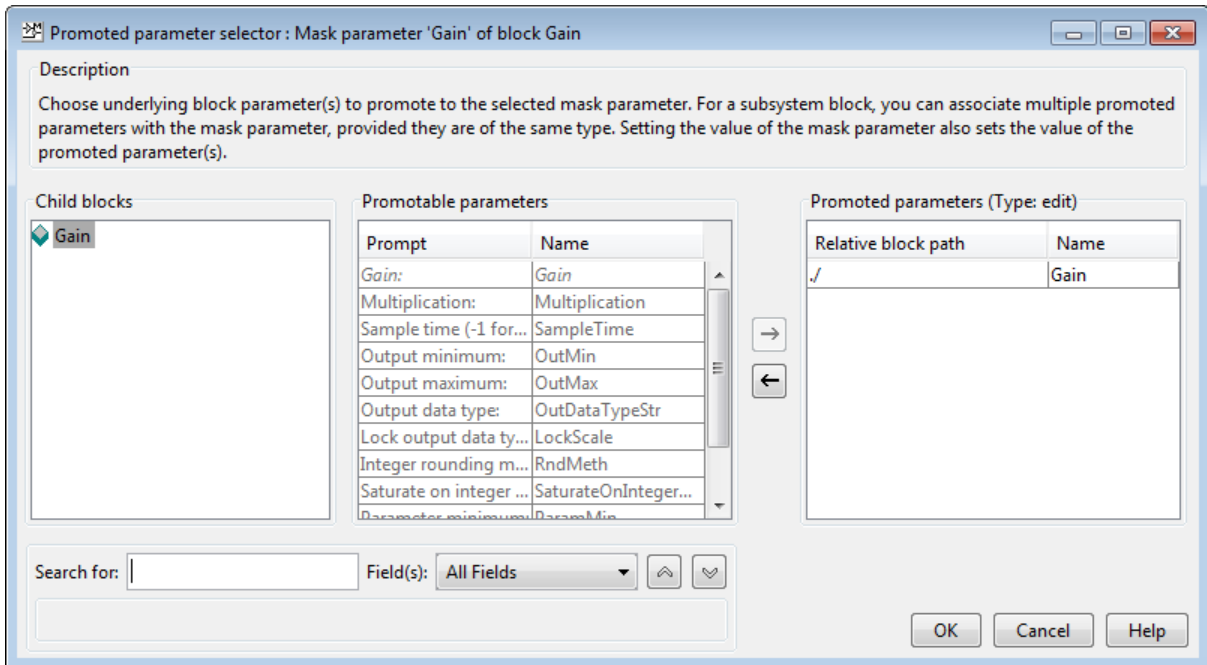
You can directly mask a built-in block to simplify the interface and add custom parameters. The following example demonstrates how to mask the Gain block and promote only the Gain parameter to the mask, while hiding the other options and adding custom parameters.

- 1 Right-click your Gain block and select **Create Mask**.
- 2 In the Mask Editor, select the **Parameters** pane.
- 3 Create a new mask parameter by clicking **Add Parameter**.

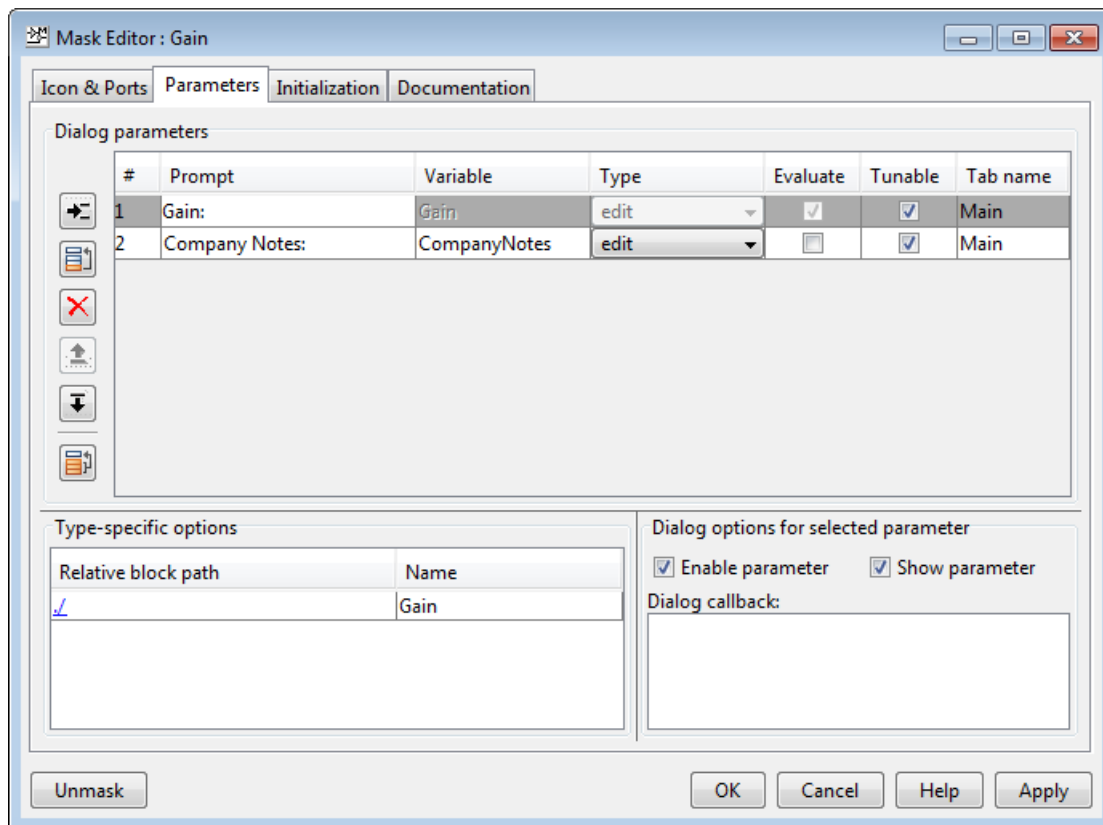
- 4 Click the **Promote** button, just beneath the **Add Parameter** button. .

The Promoted parameter selector dialog box opens.

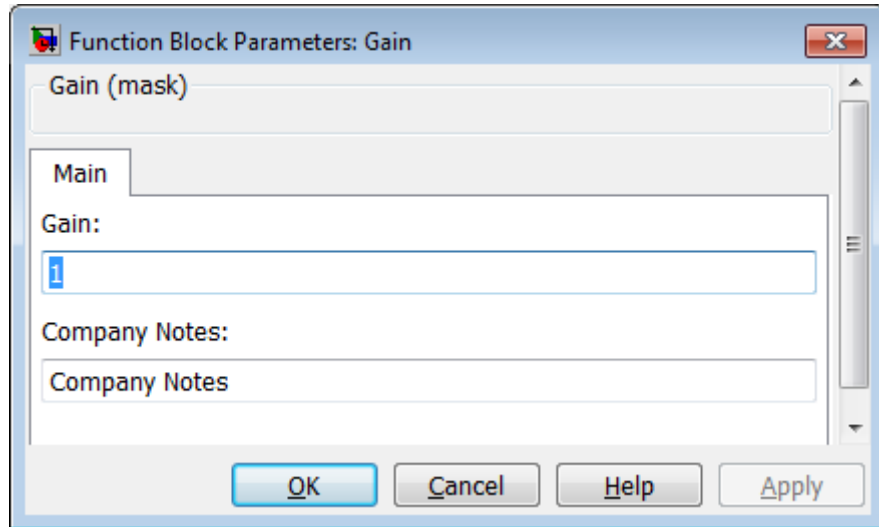
- 5 Select the Gain parameter in the **Promotable parameters** table and click the right-arrow button to add to the **Promoted parameters** list.



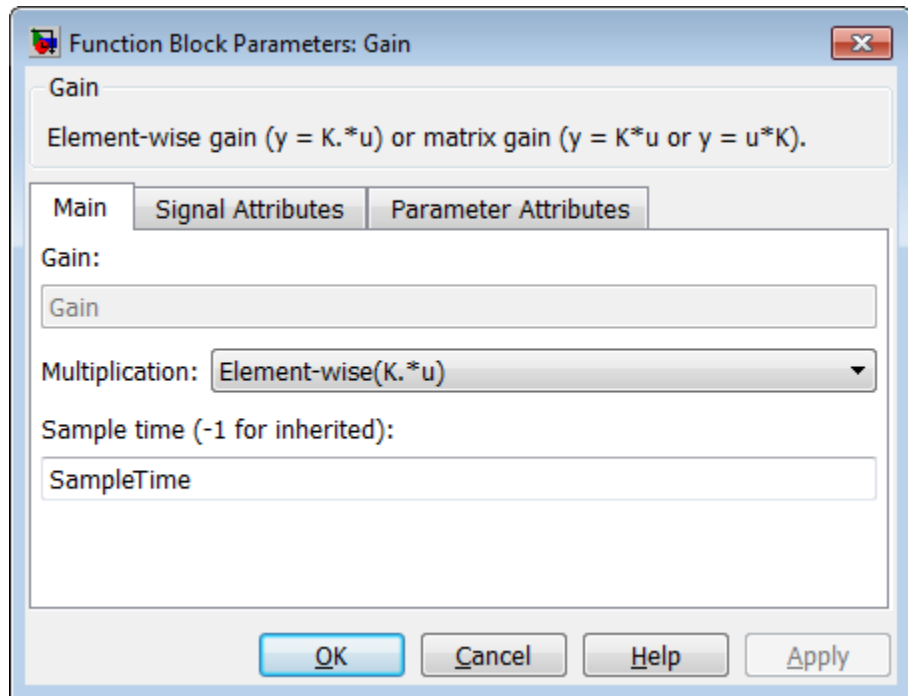
- 6 Click **OK** to return to the Mask Editor.
- 7 Observe that fields such as **Variable** and **Type** are now disabled because you have promoted a built-in parameter to this mask parameter, and the **Relative block path** table shows you the location of the underlying original block (where “./” means “self”). You can 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**. The example shown next adds an edit box for 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.

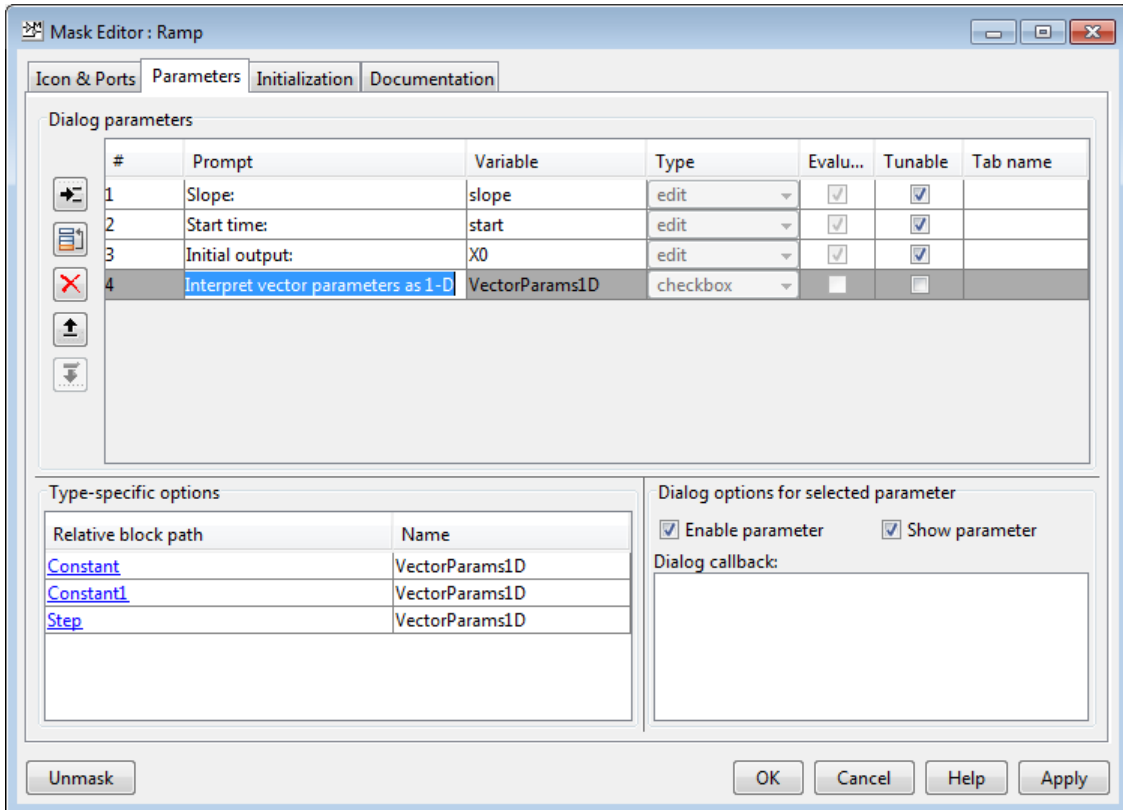


## Creating a Simplified Custom Interface for Multiple Parameters in a Subsystem

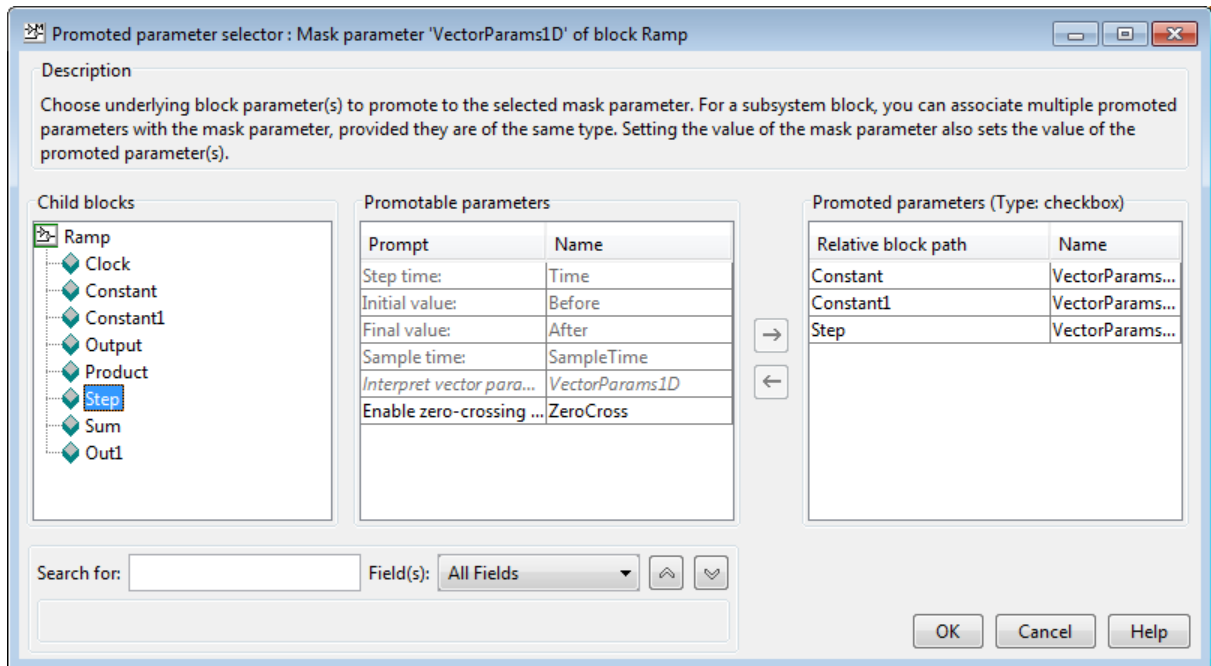
You can promote multiple parameters from child blocks to a single mask parameter for a subsystem block. This enables you to use a simplified single setting in the mask to set multiple child block parameters (of the same type) in the subsystem.

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.

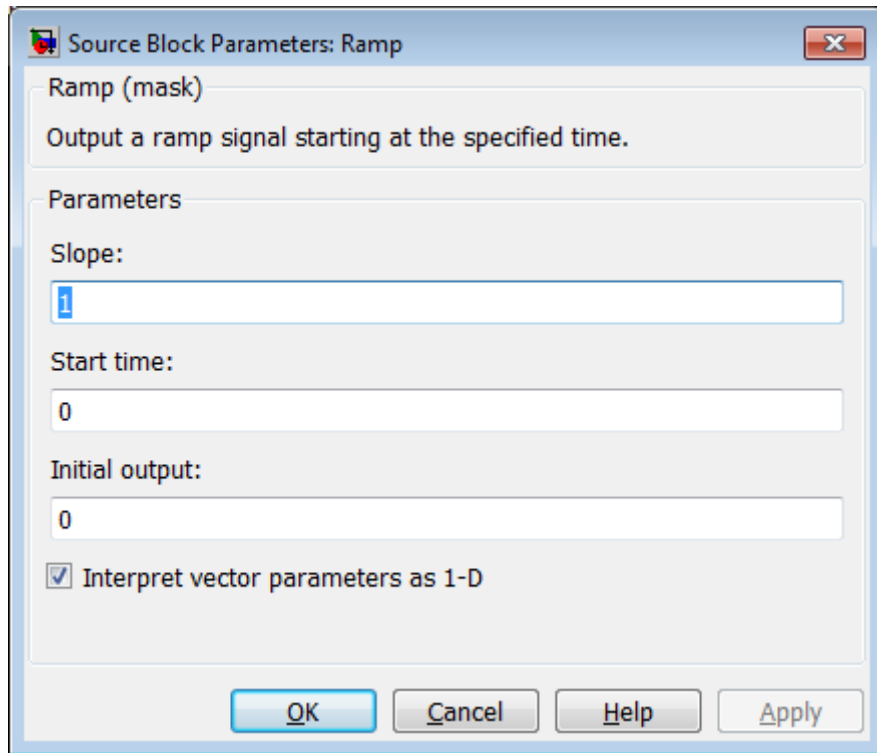


The Promoted parameter selector dialog shown next demonstrates how to specify this setup. Three parameters of the same type, from different child blocks, are added to the **Promoted parameters** list to promote to the currently selected mask parameter.



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.

## Rules for Promoting Parameters

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 you see an error message.
- After you promote a parameter to the mask:

- 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, you see an error message.
- You cannot promote the same parameter again to a different 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.

When promoting parameters from a directly masked built-in 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.

Promoting parameters 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.

## Operating on Existing Masks

### In this section...

- “Changing a Block Mask” on page 23-50
- “Viewing Mask Parameters” on page 23-50
- “Looking Under a Block Mask” on page 23-50
- “Removing and Caching a Mask” on page 23-51
- “Restoring a Cached Mask” on page 23-52
- “Permanently Deleting a Mask” on page 23-52

### Changing a Block Mask

You can change an existing mask by reopening the Mask Editor and using the same techniques that you used to create the mask:

- 1** Select the masked block.
- 2** Choose **Edit Mask** from the **Edit** menu or the block’s context menu.

The Mask Editor reopens, showing the existing mask definition. Change the mask as needed. After you change a mask, be sure to save the model before closing it, or the changes will be lost.

### Viewing Mask Parameters

To display a masked block’s Mask Parameters dialog box, either double-click the block or select it and choose **Mask Parameters** from the **Edit** menu or the block’s context menu.

To display the Block Parameters dialog box that double-clicking would display if no mask existed, select the masked block and choose **BlockType Parameters** from the **Edit** menu or the context menu for the block.

### Looking Under a Block Mask

To see the block diagram under a masked Subsystem block, built-in block, or the model referenced by a masked Model block, select the block and choose

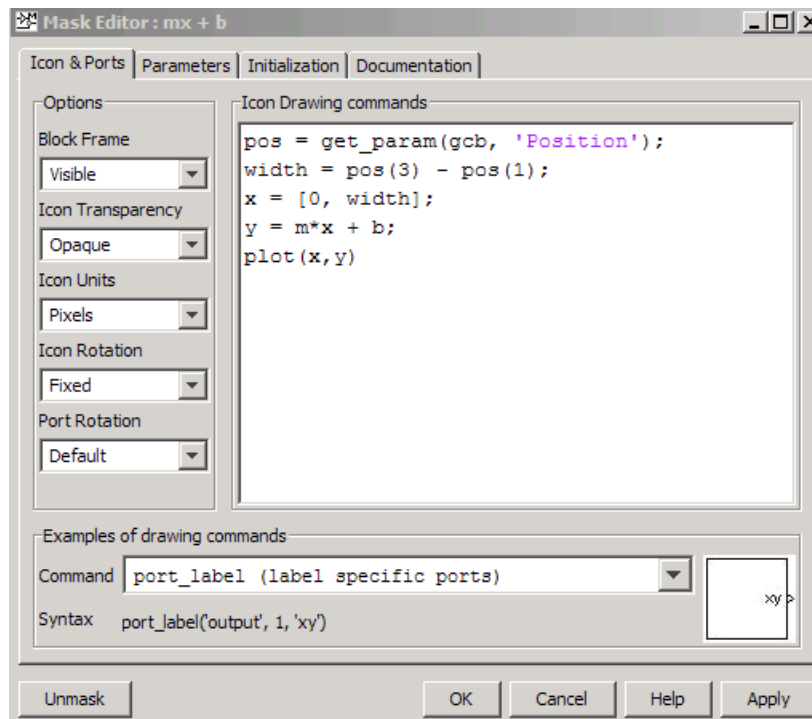
**Look Under Mask** from the **Edit** menu or the block's context menu. The block diagram or referenced model opens in a separate window.

## Removing and Caching a Mask

To remove a mask from a block and cache it for possible restoration later:

- 1 Select the block.
- 2 Choose **Edit Mask** from the **Edit** menu or the context menu of the block.

The Mask Editor opens and displays the existing mask, for example:



- 3 Click **Unmask** in the lower left corner of the Mask Editor.

The Mask Editor removes the mask from the block, saves the mask in a cache for possible restoration, then closes. The editor caches masks separately for

each block, so removing a mask from one block has no effect on a mask cached for any other block. Closing the Mask Editor has no effect on cached masks.

When you have removed and cached a mask, you can later restore it, as described in “Restoring a Cached Mask” on page 23-52, or delete it, as described in “Permanently Deleting a Mask” on page 23-52. The removed cached mask has no further effect unless you restore it.

## Restoring a Cached Mask

As long as a model remains open, you can restore a mask that you removed as described in “Removing and Caching a Mask” on page 23-51.

- 1 Select the block.
- 2 Choose **Create Mask** from the **Edit** menu or the block’s context menu.

The Mask Editor reopens, showing the cached masked definition.

- 3 Modify the definition if needed, using the techniques in “Roadmap for Masking Blocks” on page 23-8.
- 4 Click **Apply** or **OK** to restore the mask, including any changes that you made.

If you made any changes, be sure to save the model before closing it, or the changes will be lost.

## Permanently Deleting a Mask

To delete a mask permanently, first remove it as described in “Removing and Caching a Mask” on page 23-51, then save and close the model. You do not need to close the model immediately after removing a mask that you intend to delete. The removed mask remains in the cache and has no further effect unless you restore it.

## Roadmap for Dynamic Masks

You can use the Mask Editor to perform all of the mask operations referenced in “Roadmap for Masking Blocks” on page 23-8 without writing MATLAB code. You can also use MATLAB code to perform the following dynamic mask operations:

- Calculate values assigned under the mask rather than using the values that the user specified
- Change a Mask Parameters dialog box to reflect parameter values specified by the user
- Change the architecture of a masked subsystem to reflect parameter values set by the user

To perform any of these operations, you will need to understand all topics listed in “Roadmap for Masking Blocks” on page 23-8 that relate to your situation, and in particular the `masking_example` shown in “Example of Defining a Mask Icon” on page 23-15 and constructed in “Creating a Block Mask” on page 23-11. You can then read the following sections as needed:

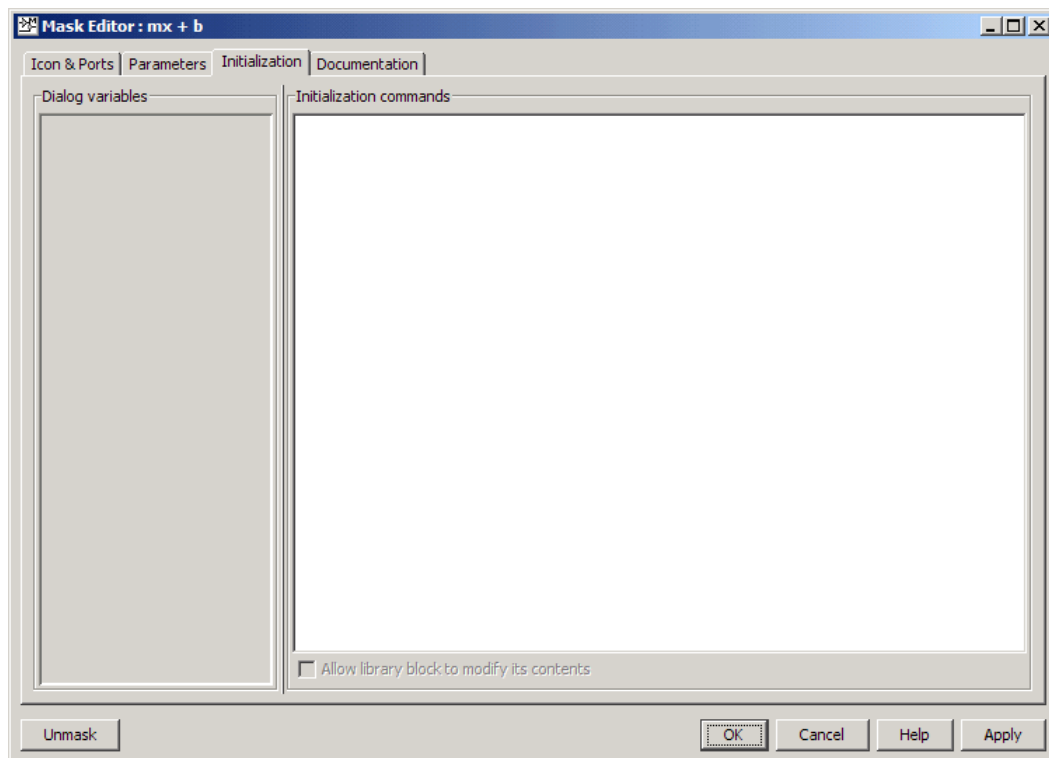
- “Calculating Values Used Under the Mask” on page 23-54
- “Creating Dynamic Mask Dialog Boxes” on page 23-63
- “Creating Dynamic Masked Subsystems” on page 23-68

These operations require using the “Parameters Pane” and the “Initialization Pane” to specify MATLAB code. For information about MATLAB programming, see *MATLAB Programming Fundamentals*.

## Calculating Values Used Under the Mask

The `masking_example` assigns the values input using the Mask Parameters dialog box directly to block parameters underneath the mask, as described in “Understanding Mask Parameters” on page 23-19. The assignment occurs because the block parameter and the mask parameter have the same name, so the search that always occurs when a block parameter needs a value finds the mask parameter value automatically, as described in “Resolving Symbols” on page 3-76.

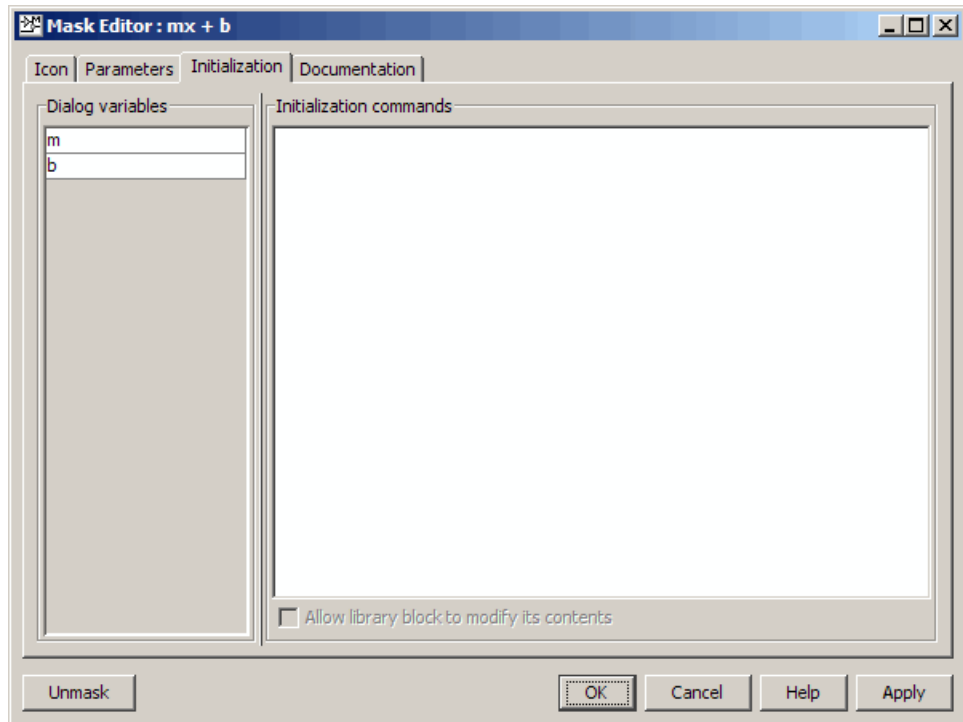
You can use the Mask Editor to insert any desired calculation between a value in the Mask Parameters dialog box and an underlying block parameter:





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.

---

## Controlling Masks Programmatically

### In this section...

“Using the `get_param` and `set_param` Commands” on page 23-57

“Predefined Masked Dialog Box Parameters” on page 23-58

“Notes on Mask Parameter Storage” on page 23-61

### Using the `get_param` and `set_param` Commands

The Simulink software defines a set of masked block parameters that define the current state of the masked block dialog box. You can use the Mask Editor to inspect and set many of these parameters. The `get_param` and `set_param` commands also let you inspect and set mask dialog box parameters. The `set_param` command allows you to set parameters that change the appearance of a dialog box while the dialog box is open. This ability to change the appearance of the dialog box while the dialog box is open allows you to create dynamic masked dialog box.

For example, you can use the `set_param` command in mask callback functions to be invoked when a user changes the values of user-defined parameters. The callback functions, in turn, can use `set_param` commands to change the values of predefined parameters of the masked block dialog box, and hence its state. For example, the callback function can hide, show, enable, or disable a user-defined parameter control.

Use the 'mask' option of the `open_system` command to open the Mask Parameters dialog box for a block at the MATLAB command line or in a MATLAB program.

You can use `get_param` and `set_param` to access this mask parameter.

You can customize every feature of the Mask Parameters dialog box, including which parameters appear on the dialog box, the order in which they appear, parameter prompts, the controls used to edit the parameters, and the parameter callbacks (code used to process parameter values entered by the user).

However, changing the mask parameter value with `set_param` does *not* change the value of the underlying block variable. You cannot use `get_param` or `set_param` to access the value of the underlying variable, because it is hidden by the mask.

The `set_param` and `get_param` commands are insensitive to case differences in mask variable names. For example, suppose a model named `MyModel` contains a masked subsystem named `A` that defines a mask variable named `Volume`. Then, the following line of code returns the value of the `Volume` parameter.

```
get_param('MyModel/A', 'voLUME')
```

However, case does matter when using a mask variable as the value of a block parameter inside the masked subsystem. For example, suppose a Gain block inside the masked subsystem `A` specifies `VOLUME` as the value of its Gain parameter. This variable name does not resolve in the masked subsystem's workspace, as it contains a mask variable named `Volume`. If the base workspace does not contain a variable named `VOLUME`, simulating `MyModel` produces an error.

## Predefined Masked Dialog Box Parameters

The following predefined parameters are associated with masked dialog boxes.

### MaskCallbacks

The value of this parameter is a cell array of strings that specify callback expressions for the user-defined parameter controls for the dialog box. The first cell defines the callback for the first parameter control, the second for the second parameter control, etc. The callbacks can be any valid MATLAB expressions, including expressions that invoke MATLAB commands. This capability means that you can implement complex callbacks as MATLAB program files.

You can use either the Mask Editor or the MATLAB command line to specify mask callbacks. To use the Mask Editor to enter a callback for a parameter, enter the callback in the **Callback** field for the parameter.

The easiest way to set callbacks for a mask dialog box at the MATLAB command is to first select the corresponding masked dialog box in a model

or library window and then to issue a `set_param` command at the MATLAB command line. For example, the following code

```
set_param(gcf, '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(gcf, '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(gcf, '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.

---



## Creating Dynamic Mask Dialog Boxes

### In this section...

“About Dynamic Masked Dialog Boxes” on page 23-63

“Show parameter” on page 23-64

“Enable parameter” on page 23-64

“Setting Masked Block Dialog Box Parameters” on page 23-64

“Setting Nested Masked Block Parameters” on page 23-66

### About Dynamic Masked Dialog Boxes

You can create dialogs for masked blocks whose appearance changes in response to user input. Features of masked dialog boxes that can change in this way include

- Visibility of parameter controls

Changing a parameter can cause the control for another parameter to appear or disappear. The dialog expands or shrinks when a control appears or disappears, respectively.

- Enabled state of parameter controls

Changing a parameter can cause the control for another parameter to be enabled or disabled for input. A disabled control is grayed to indicate visually that it is disabled.

- Parameter values

Changing a mask dialog box parameter can cause related mask dialog box parameters to be set to appropriate values.

Creating a dynamic masked dialog box entails using the Mask Editor in combination with the `set_param` command. Specifically, you use the Mask Editor to define parameters of the dialog box, both static and dynamic. For each dynamic parameter, you enter a callback function that defines how the dialog box responds to changes to that parameter (see “Mask Parameters Dialog Box Callback Code” on page 23-25). 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 23-64). Finally, you save the model or library containing the masked subsystem to complete the creation of the dynamic masked dialog box.

### **Show parameter**

The selected parameter appears on the Mask Parameters dialog box only if this option is checked (the default).

### **Enable parameter**

Clearing this option grays the prompt of the selected parameter and disables the edit control of the prompt.

## **Setting Masked Block Dialog Box Parameters**

The following example creates a mask dialog box with two parameters. The first parameter is a pop-up menu that selects one of three gain values: 2, 5, or User-defined. The selection in this pop-up menu determines the visibility of an edit field for specifying the gain.

- 1** Mask a subsystem: from the **Edit** menu or the context menu of the block, choose **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(gcf,'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(gcf,'MaskVisibilities',{'on';'on'}),

else

    % Turn off the visibility of the Value field
    % when User-defined is not selected.

    set_param(gcf,'MaskVisibilities',{'on';'off'}),

    % Set the string in the Values field equal to the
    % string selected in the Gain pop-up menu.

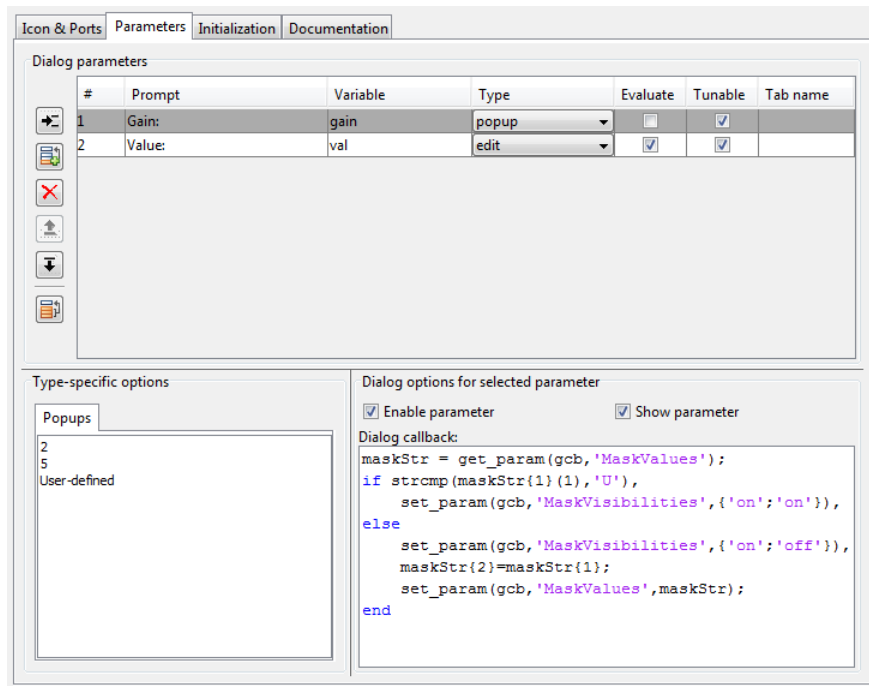
    maskStr{2}=maskStr{1};
    set_param(gcf,'MaskValues',maskStr);
end

```

**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.

## Creating Dynamic Masked Subsystems

### In this section...

“Allow library block to modify its contents” on page 23-68

“Creating Self-Modifying Masks for Library Blocks” on page 23-68

### 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(gcf, 'MaskSelfModifiable', 'on');
```

Then save the block.

### Creating Self-Modifying Masks for Library Blocks

You can create masked library blocks that can modify their structural contents. These self-modifying masks allow you to:

- Modify the contents of a masked subsystem based on parameters in the Mask Parameters dialog box or when the subsystem is initially dragged from the library into a new model.
- Vary the number of ports on a multiport S-Function block that resides in a library.

### Creating Self-Modifying Masks Using the Mask Editor

To create a self-modifying mask using the Mask Editor:

- 1 Unlock the library (see “Modifying and Locking Libraries” on page 25-22).
- 2 Select the block in the library.

- 3** Select **Edit Mask** from the **Edit** menu or the block's context menu. The Mask Editor opens.
- 4** In the Mask Editor's **Initialization** pane, select the **Allow library block to modify its contents** option.
- 5** Enter the code that modifies the masked subsystem in the mask's **Initialization** pane.

---

**Note** Do not enter code that structurally modifies the masked subsystem in a dialog parameter callback (see “Mask Parameters Dialog Box Callback Code” on page 23-25). Doing so triggers an error when a user edits the parameter.

---

- 6** Click **Apply** to apply the change or **OK** to apply the change and dismiss the Mask Editor.
- 7** Lock the library.

## Creating Self-Modifying Masks from the Command Line

To create a self-modifying mask from the command line:

- 1** Unlock the library using the following command:

```
set_param(gcs, 'Lock', 'off')
```

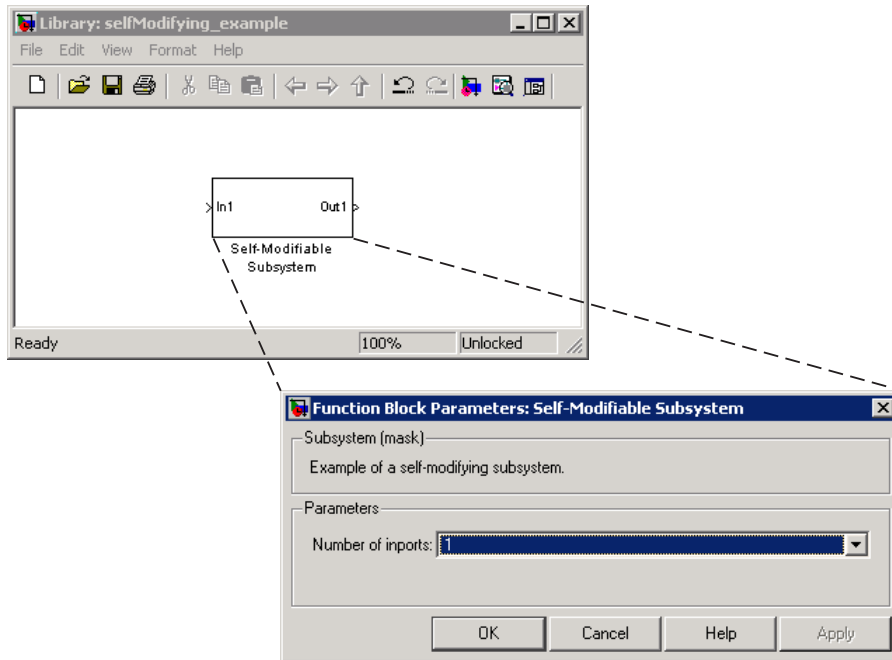
- 2** Specify that the block is self-modifying by using the following command:

```
set_param(block_name, 'MaskSelfModifiable', 'on')
```

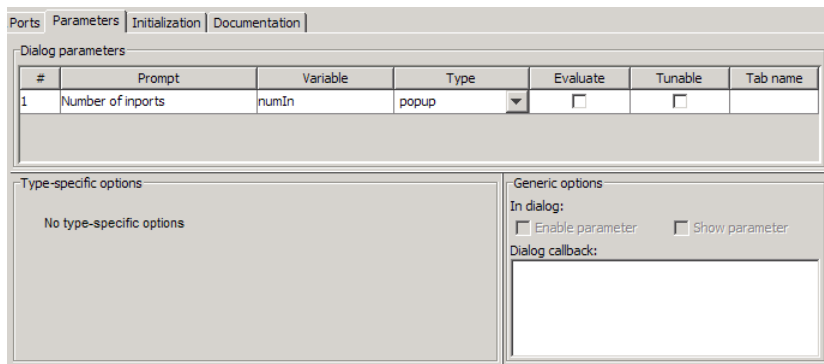
where `block_name` is the full path to the block in the library.

## Self-Modifying Mask Example

The library `selfModifying_example.mdl` contains a masked subsystem that modifies its number of input ports based on a selection made in the subsystem's Mask Parameters dialog box.

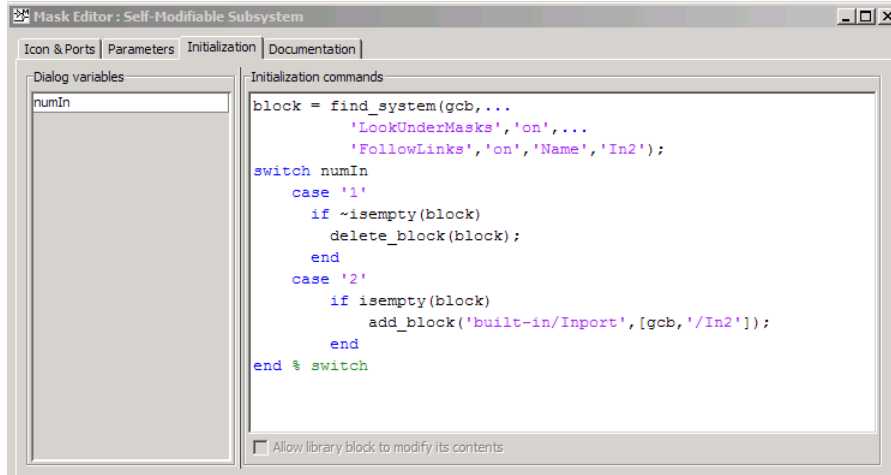


Select the subsystem then select **View Mask** from the **Edit** menu or the block's context menu. The Mask Editor opens. The Mask Editor **Parameters** pane defines one mask parameter variable numIn that stores the value for the **Number of inports** option. This Mask Parameters dialog box callback adds or removes Input ports inside the masked subsystem based on the selection made in the **Number of inports** list.





To allow the dialog box callback to function properly, the **Allow library block to modify its contents** option on the Mask Editor **Initialization** pane is selected. If this option were not selected, copies of the library block could not modify their structural contents and changing the selection in the **Number of inports** list would produce an error.



## Understanding Mask Code Execution

### In this section...

“Partitioning MATLAB Code” on page 23-72

“Drawing Commands Execution” on page 23-72

“Initialization Command Execution” on page 23-73

“Mask Parameters Dialog Box Callback Code Execution” on page 23-74

### Partitioning MATLAB Code

You can specify MATLAB code for masked blocks in both the mask initialization code and in the block icon drawing code. The location of code affects model performance. In general, partition your code to reflect the functionality you need.

- Keep initialization code together in the **Initialization** pane (or in the `MaskInitialization` parameter).
- Keep icon drawing code, including variable definitions, together in the **Icon & Ports** pane (or in the `MaskDisplay` “MaskDisplay” on page 23-59 parameter).
- Keep Mask Parameters dialog box callback code in the **Parameters** pane (or in the `MaskCallbacks` parameter).

### Drawing Commands Execution

Simulink executes the drawing commands in the **Drawing Commands** pane in the sequence in which the commands appear whenever the block has to be drawn or redrawn.

- If the drawing commands are dependent on the mask workspace and the mask workspace changes (that is, mask parameter values change), then the drawing commands execute.
- Rotation and other changes that affect the appearance of the block cause the icon to be redrawn.

## Initialization Command Execution

When you open a model, initialization commands execute for masked blocks that are visible because they reside at the top level of the model or in an open subsystem and that meet either of the following conditions:

- The masked block has icon drawing commands.
- The masked subsystem is from a library and has the **Allow library block to modify its contents** parameter enabled.

A simple masked block that has initialization commands but no icon drawing commands does not execute the initialization commands when you open the model.

Initialization commands for masked blocks that are not initially visible execute when you open the subsystem or model that contains the blocks.

When you load a model into memory without displaying the model graphically, no initialization commands initially run for any masked blocks. See “Loading a Model” on page 1-7 and `load_system` for information about loading a model without displaying it.

Initialization commands for all masked blocks in a model 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 display commands depend on initialization code.

- Change the value of a mask parameter by using the block dialog box or `set_param`
- Copy the masked block within the same model or between different models

## **Mask Parameters Dialog Box Callback Code Execution**

Simulink executes the callback commands when you:

- Open the Mask Parameters dialog box. Callback commands execute top down, starting with the top mask dialog box parameter.
- Modify a parameter value in the Mask Parameters dialog box and then change the cursor's focus (that is, you press the **Tab** key or click into another field in the dialog box).

---

**Note** When you modify the parameter value by using the `set_param` command, the callback commands do not execute.

---

- Modify the parameter value, either in the Mask Parameters dialog box or via a call to `set_param`, and then apply the change by clicking **Apply** or **OK**. Mask initialization commands execute after the callback commands. (See “Initialization Pane”.)
- Hover over the masked block to see the data tip for the block, when the data tip contains parameter names and values. The callback executes again when the block data tip disappears.

---

**Note** The callback commands do not execute if the Mask Parameters dialog box is open when the block data tip appears.

---

- Update a diagram (for example, by pressing **Ctrl-D** or by selecting the **Edit > Update diagram** menu item).

## Debugging Masks That Use MATLAB Code

You can use MATLAB tools to debug mask initialization commands and dialog callbacks in the Mask Editor or the MATLAB Editor/Debugger.

You can debug initialization commands and parameter callbacks entered directly into the Mask Editor in these ways:

- Remove the terminating semicolon from a command to echo its results to the MATLAB Command Window.
- Place a keyboard command in the code to stop execution and give control to the keyboard.

You can debug initialization commands and parameter callbacks written in files using the MATLAB Editor/Debugger in the same way that you would with any other MATLAB program file. When debugging initialization commands, you can view the contents of the mask workspace. When debugging parameter callbacks, you can access only base workspace of the block. If you need the value of a mask parameter, use the `get_param` command.

You *cannot* debug icon drawing commands using the MATLAB Editor/Debugger. Use the syntax examples provided in the Mask Editor's **Icon** pane to help solve errors in the icon drawing commands.



# Creating Custom Blocks

---

- “When to Create Custom Blocks” on page 24-2
- “Types of Custom Blocks” on page 24-3
- “Comparison of Custom Block Functionality” on page 24-7
- “Expanding Custom Block Functionality” on page 24-17
- “Tutorial: Creating a Custom Block” on page 24-18
- “Custom Block Examples” on page 24-43

### 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” on page 24-3
“Subsystem Blocks” on page 24-4
“S-Function Blocks” on page 24-4

### 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 Chapter 25, “Working with Block Libraries” and Chapter 23, “Working with Block Masks”.

## 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 “Writing S-Functions in MATLAB”). You can debug a MATLAB S-function during a simulation using the MATLAB debugger.
- The S-Function block allows you to write your S-function in C or C++, or to incorporate existing code into your model using a C MEX wrapper. (See “Writing S-Functions in C”.)
- The S-Function Builder block assists you in creating a new C MEX S-function or a wrapper function to incorporate legacy C or C++ code. (See “Building S-Functions Automatically”.)
- The Legacy Code Tool transforms existing C or C++ functions into C MEX S-functions. (See “Integrating Existing C Functions into Simulink Models with the Legacy Code Tool”.)

The S-function target in the 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”.

- 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 “Integrating Existing C Functions into Simulink Models with the Legacy Code Tool” for more information.

See “Integration Options” in the Simulink Coder User’s Guide for more information.

See “Example Using S-Functions to Incorporate Legacy C Code” in the Simulink Developing S-Functions for an example.

## Comparison of Custom Block Functionality

### In this section...

“Custom Block Considerations” on page 24-7

“Modeling Requirements” on page 24-10

“Speed and Code Generation Requirements” on page 24-13

### 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)**

<b>Custom Block Type</b>	<b>Supports Multiple Inputs and Outputs</b>	<b>Models State Dynamics</b>	<b>Supports Various Data Attributes</b>
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**

<b>Custom Block Type</b>	<b>Speed of Updating the Diagram</b>	<b>Simulation Overhead</b>	<b>Code Generation Support</b>
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)**

<b>Custom Block Type</b>	<b>Speed of Updating the Diagram</b>	<b>Simulation Overhead</b>	<b>Code Generation Support</b>
	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 24-16 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 <code>SimViewingDevice</code> 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 25-7 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 “Working with Structures and Bus Signals” on page 26-75 for more information.
S-function (MATLAB or C MEX)	Supports multiple input and output ports. In addition, you can modify the number of input and output ports based on user-defined parameters. S-functions generated using the Legacy Code Tool also accept Simulink bus signals. See “Integrating Existing C Functions into Simulink Models with the Legacy Code Tool” for more information.



## State Behavior and the S-Function API

Simulink blocks communicate with the Simulink engine through the S-function API, a set of methods that fully specifies the behavior of blocks. Each custom block type accesses a different sets of the S-function APIs, as follows.

Custom Block Type	S-Function API Support
Subsystem	Communicates directly with the engine. You can model state behaviors using appropriate blocks from the Continuous and Discrete Simulink block libraries.
Fcn, Interpreted MATLAB Function, MATLAB Function	All create an <code>mdlOutputs</code> 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.

<b>Custom Block Type</b>	<b>Data Attribute Support</b>
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.

<b>Custom Block Type</b>	<b>Speed of Updating the Diagram</b>
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 “How the Simulink Engine Interacts with C S-Functions”. When updating the diagram, the Simulink software invokes all relevant methods in the model initialization phase up to, but not including, mdlStart.

## Simulation Overhead

For most applications, any of the custom block types provide acceptable simulation performance. Use the Simulink profiler to obtain an indication of the actual performance. See “Capturing Performance Data” on page 19-30 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	<p>Has a higher interface cost than most blocks and the same algorithm cost as a MATLAB function.</p> <p>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.</p> <p>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.</p>

<b>Custom Block Type</b>	<b>Simulation Overhead</b>
MATLAB Function	<p>Performs simulation through code generation and so incurs the same interface cost as standard blocks.</p> <p>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.</p> <p>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.</p>
MATLAB S-function	<p>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 <code>mdlOutputs</code> method.</p>
C MEX S-function	<p>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.</p>

## 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 <code>SimViewingDevice</code> , 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 “Creating Block Callback Functions” on page 3-58.

GUIDE, the MATLAB graphical user interface development environment, provides tools for easily creating custom user interfaces. See *MATLAB Creating Graphical User Interfaces* for more information on using GUIDE.

## Tutorial: Creating a Custom Block

### In this section...

“How to Design a Custom Block” on page 24-18

“Defining Custom Block Behavior” on page 24-20

“Deciding on a Custom Block Type” on page 24-21

“Placing Custom Blocks in a Library” on page 24-26

“Adding a Graphical User Interface to a Custom Block” on page 24-28

“Adding Block Functionality Using Block Callbacks” on page 24-37

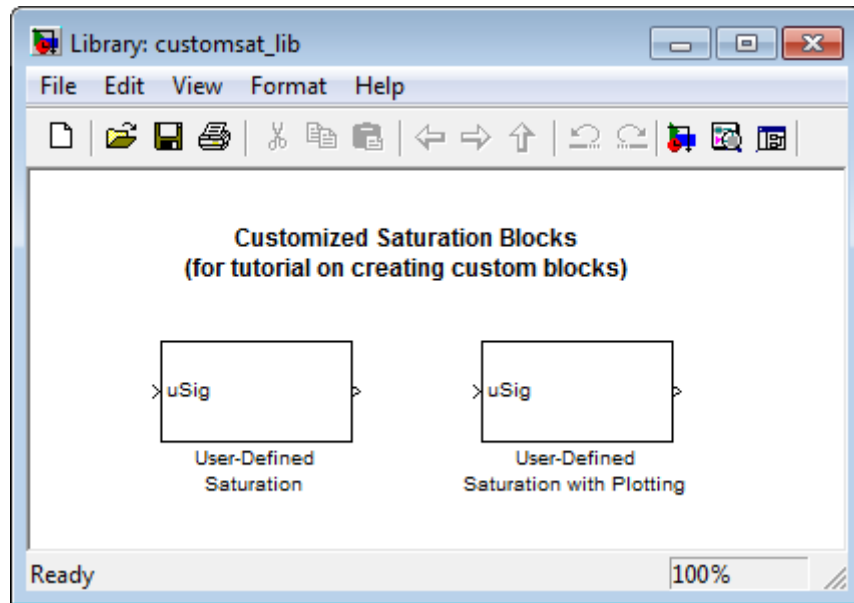
### How to Design a Custom Block

In general, use the following process to design a custom block:

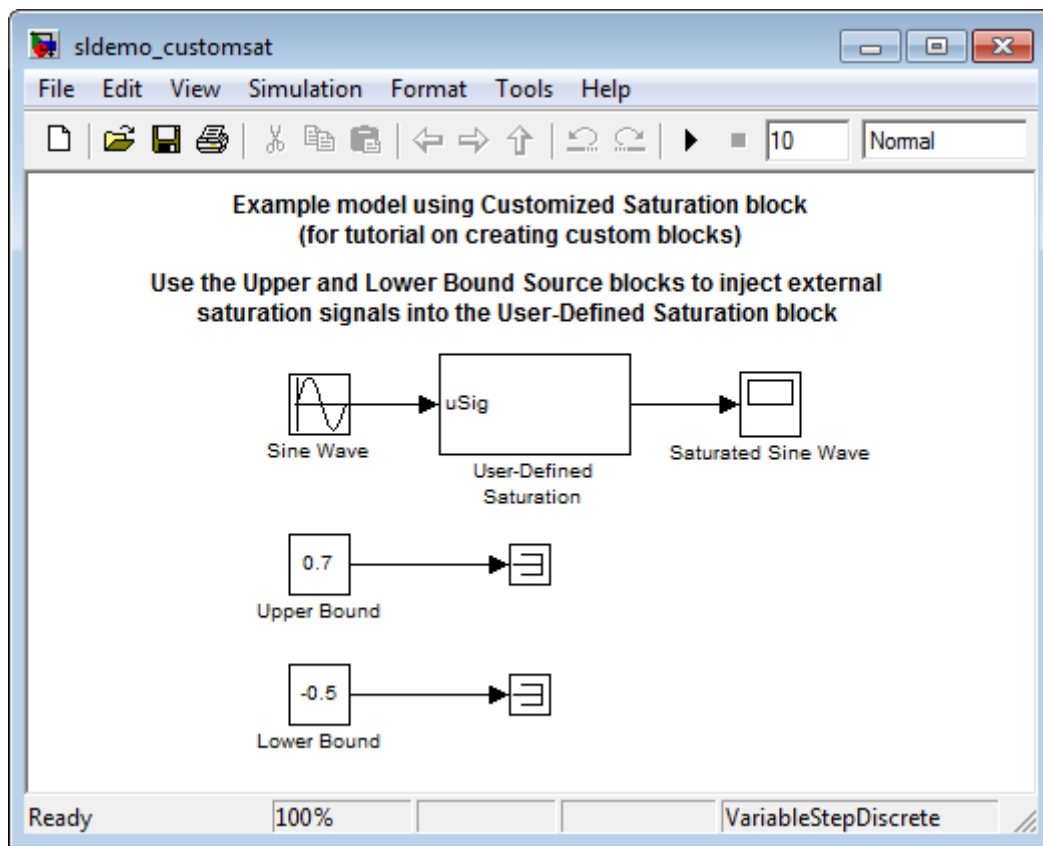
- 1 “Defining Custom Block Behavior” on page 24-20
- 2 “Deciding on a Custom Block Type” on page 24-21
- 3 “Placing Custom Blocks in a Library” on page 24-26
- 4 “Adding a Graphical User Interface to a Custom Block” on page 24-28

Suppose you want to create a customized saturation block that limits the upper and lower bounds of a signal based on either a block parameter or the value of an input signal. In a second version of the block, you want the option to plot the saturation limits after the simulation is finished. The following tutorial steps you through designing these blocks. The library `customsat_lib.mdl` contains the two versions of the customized saturation block.





The example model `sldemo_customsat.mdl` uses the basic version of the block.



## Defining Custom Block Behavior

Begin by defining the features and limitations of your custom block. In this example, the block supports the following features:

- Turning on and off the upper or lower saturation limit.
- Setting the upper and/or lower limits via a block parameters.
- Setting the upper and/or lower limits using an input signal.

It also has the following restrictions:

- The input signal under saturation must be a scalar.
- The input signal and saturation limits must all have a data type of double.
- Code generation is not required.

## Deciding on a Custom Block Type

Based on the custom block 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 24-7 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.');


```

```

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
```

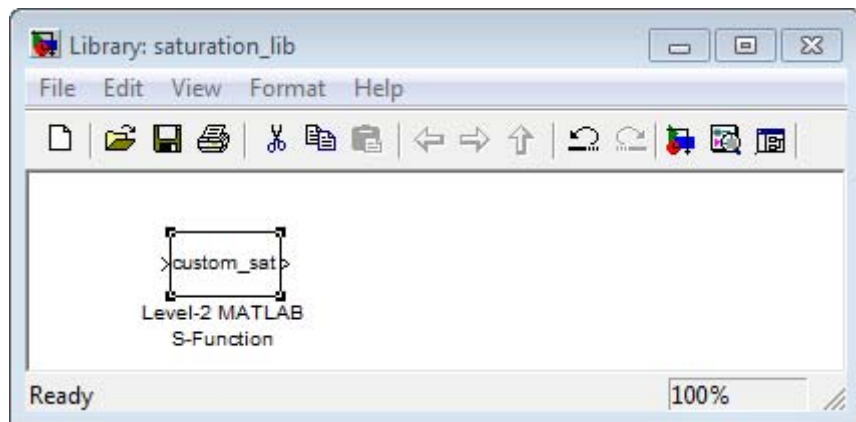
## Placing Custom Blocks in a Library

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

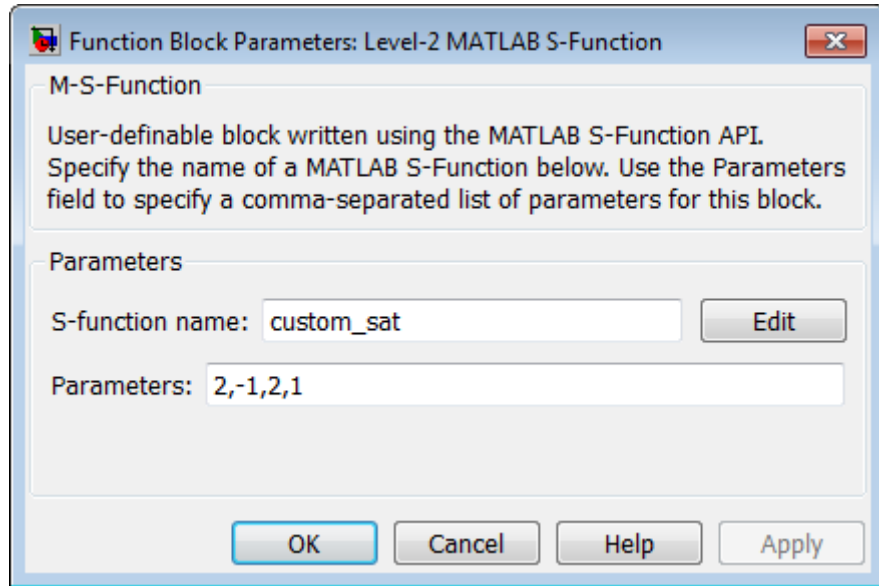


a particular project into a single location. This example places the custom saturation block into a library as follows:

- 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.mdl`.



- 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.

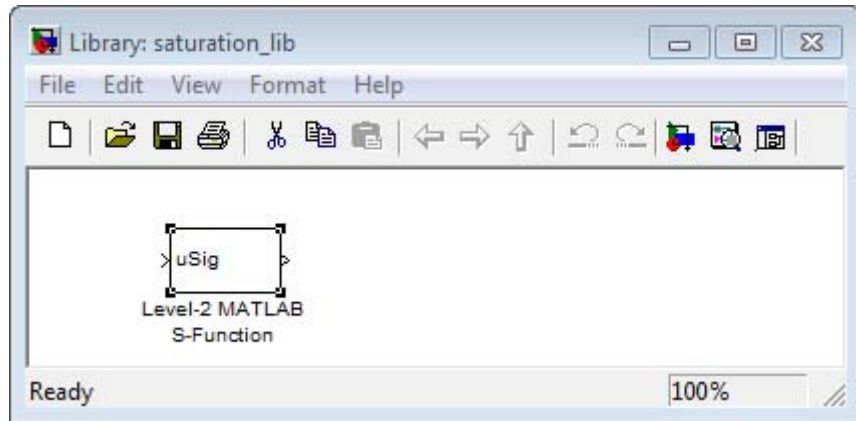
To mask the block:

- 1 Open the custom library you created, `saturation_lib.mdl`. Right-click the custom saturation block, and from the context menu, select **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.

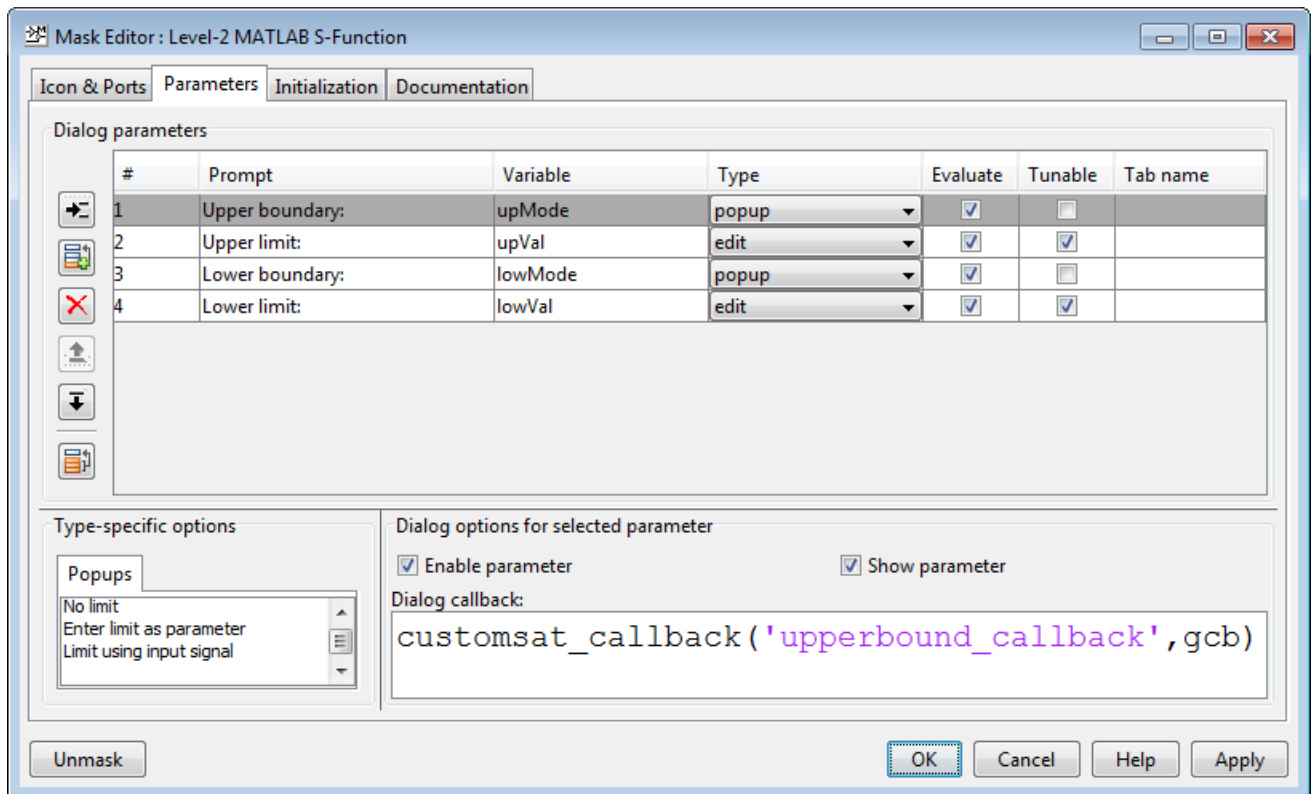
Prompt	Variable	Type	Tunable	Popups	Action for Dialog Callback
Upper boundary:	upMode	popup	No	No limit   Enter limit as parameter   Limit using input signal	'upperbound_callback'
Upper limit:	upVal	edit	Yes	N/A	'upperparam_callback'
Lower boundary:	lowMode	popup	No	No limit   Enter limit as parameter   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.

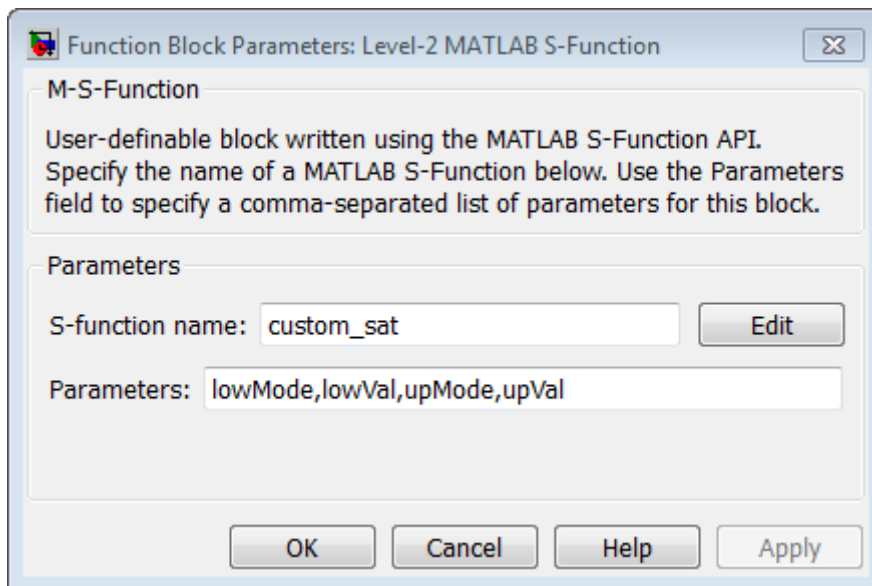
6 On the Mask Editor dialog box, click **OK** to complete the mask parameters dialog.

7 To map the S-function parameters to the mask parameters, right-click the Level-2 MATLAB S-Function block and select **Look Under Mask**. The Function Block Parameters dialog box opens.

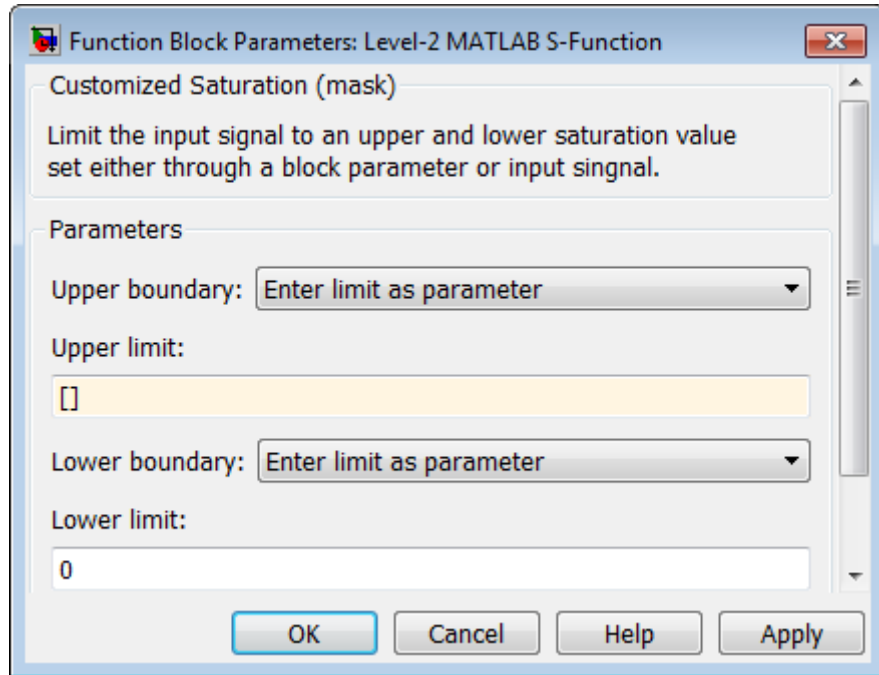
8 Change the entry in the **Parameters** field as follows.

```
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 subfunctions corresponding to each mask parameter through a call to `feval`.

The following subfunction controls the visibility of the upper saturation limit's field based on the selection for the upper saturation limit's mode. The callback begins by obtaining values for all mask parameters using a call to

`get_param` with the property name `MaskValues`. If the callback needed the value of only one mask parameter, it could call `get_param` with the specific mask parameter name, for example, `get_param(block, 'upMode')`. Because this example needs two of the mask parameter values, it uses the `MaskValues` property to reduce the calls to `get_param`.

The callback then obtains the visibilities of the mask parameters using a call to `get_param` with the property name `MaskVisibilities`. This call returns a cell array of strings indicating the visibility of each mask parameter. The callback alters the values for the mask visibilities based on the selection for the upper saturation limit's mode and then updates the port label string.

The callback finally uses the `set_param` command to update the block's `MaskDisplay` property to label the block's input ports.

```
function customsat_callback(action,block)
% CUSTOMSAT_CALLBACK contains callbacks for custom saturation block

% Copyright 2003-2007 The MathWorks, Inc.

%% Use function handle to call appropriate callback
feval(action,block)

%% Upper bound callback
function upperbound_callback(block)

vals = get_param(block,'MaskValues');
vis = get_param(block,'MaskVisibilities');
portStr = {'port_label(''input'',1,'uSig')'};
switch vals{1}
    case 'No limit'
        set_param(block,'MaskVisibilities',[vis(1);{'off'};vis(3:4)]);
    case 'Enter limit as parameter'
        set_param(block,'MaskVisibilities',[vis(1);{'on'};vis(3:4)]);
    case 'Limit using input signal'
        set_param(block,'MaskVisibilities',[vis(1);{'off'};vis(3:4)]);
        portStr = [portStr;{'port_label(''input'',2,'up')'}];
end
if strcmp(vals{3},'Limit using input signal'),
    portStr = [portStr;{'port_label(''input'',',num2str(length(portStr)+1), ...
```



```

        , 'low' )' ]}];
end
set_param(block, 'MaskDisplay', char(portStr));

```

The final call to `set_param` invokes the `setup` function in the MATLAB S-function `custom_sat.m`. Therefore, the `setup` function can be modified to set the number of input ports based on the mask parameter values instead of on the S-function parameter values. This change to the `setup` function keeps the number of ports on the Level-2 MATLAB S-Function block consistent with the values shown in the mask parameter dialog box.

The modified MATLAB S-function `custom_sat_final.m` contains the following new `setup` function. If you are stepping through this tutorial, open the file and save it to your working folder.

```

%% Function: setup =====
function setup(block)

% Register original number of ports based on settings in Mask Dialog
ud = getPortVisibility(block);
numInPorts = 1 + isequal(ud(1),3) + isequal(ud(2),3);

block.NumInputPorts = numInPorts;
block.NumOutputPorts = 1;

% Setup port properties to be inherited or dynamic
block.SetPreCompInpPortInfoToDynamic;
block.SetPreCompOutPortInfoToDynamic;

% Override input port properties
block.InputPort(1).DatatypeID = 0; % double
block.InputPort(1).Complexity = 'Real';

% Override output port properties
block.OutputPort(1).DatatypeID = 0; % double
block.OutputPort(1).Complexity = 'Real';

% Register parameters. In order:
% -- If the upper bound is off (1) or on and set via a block parameter (2)
%    or input signal (3)

```

```

% -- The upper limit value. Should be empty if the upper limit is off or
%   set via an input signal
% -- If the lower bound is off (1) or on and set via a block parameter (2)
%   or input signal (3)
% -- The lower limit value. Should be empty if the lower limit is off or
%   set via an input signal
block.NumDialogPrms      = 4;
block.DialogPrmsTunable = {'Nontunable','Tunable','Nontunable','Tunable'};

% Register continuous sample times [0 offset]
block.SampleTimes = [0 0];

%% -----
%% Options
%% -----
% Specify if Accelerator should use TLC or call back into
% MATLAB script
block.SetAccelRunOnTLC(false);

%% -----
%% Register methods called during update diagram/compilation
%% -----

block.RegBlockMethod('CheckParameters',    @CheckPrms);
block.RegBlockMethod('ProcessParameters',  @ProcessPrms);
block.RegBlockMethod('PostPropagationSetup', @DoPostPropSetup);
block.RegBlockMethod('Outputs',           @Outputs);
block.RegBlockMethod('Terminate',         @Terminate);
%endfunction

```

The `getPortVisibility` subfunction in `custom_sat_final.m` uses the saturation limit modes to construct a flag that is passed back to the `setup` function. The `setup` function uses this flag to determine the necessary number of input ports.

```

%% Function: Get Port Visibilities =====
function ud = getPortVisibility(block)

ud = [0 0];

```

```

vals = get_param(block.BlockHandle, 'MaskValues');
switch vals{1}
    case 'No limit'
        ud(2) = 1;
    case 'Enter limit as parameter'
        ud(2) = 2;
    case 'Limit using input signal'
        ud(2) = 3;
end

switch vals{3}
    case 'No limit'
        ud(1) = 1;
    case 'Enter limit as parameter'
        ud(1) = 2;
    case 'Limit using input signal'
        ud(1) = 3;
end

```

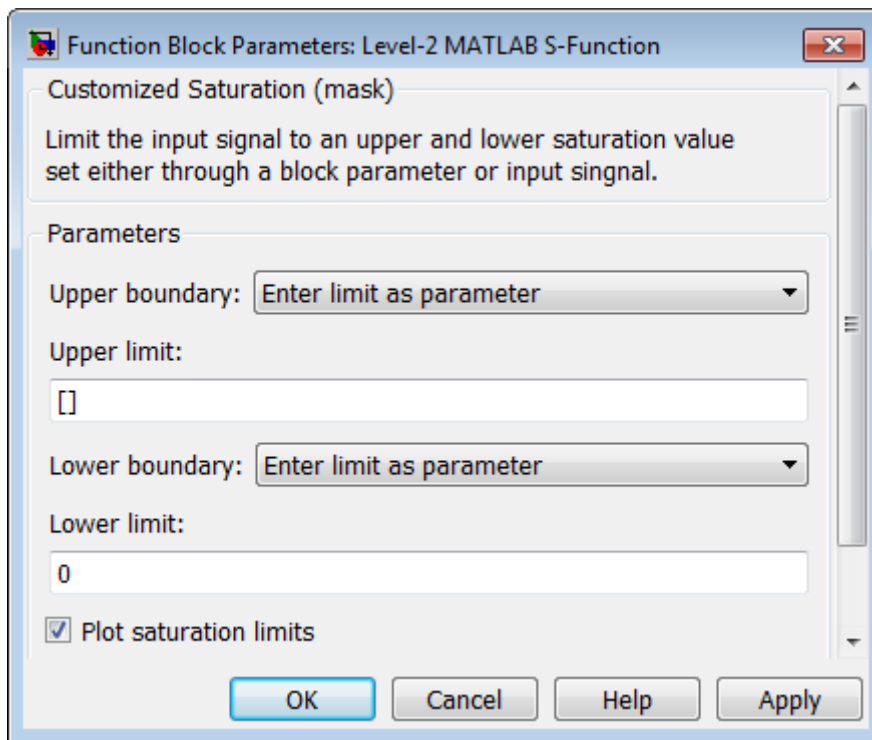
## Adding Block Functionality Using Block Callbacks

The User-Defined Saturation with Plotting block in `customsat_lib.mdl` uses block callbacks to add functionality to the original custom saturation block. This block provides an option to plot the saturation limits when the simulation ends. The following steps show how to modify the original custom saturation block to create this new block.

- 1 Add a check box to the mask parameter dialog box to toggle the plotting option on and off.
  - a Right-click the Level-2 MATLAB S-Function block in `saturation_lib.mdl` 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	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 subfunctions over the previous subfunctions in `customsat_callback.m`.

```
%% Plotting checkbox callback
function plotsaturation(block)

% Reinitialize the block's userdata
vals = get_param(block,'MaskValues');
```

```

ud = struct('time',[],'upBound',[],'upVal',[],'lowBound',[],'lowVal',[]);

if strcmp(vals{1},'No limit'),
    ud.upBound = 'off';
else
    ud.upBound = 'on';
end

if strcmp(vals{3},'No limit'),
    ud.lowBound = 'off';
else
    ud.lowBound = 'on';
end

set_param(gcf,'UserData',ud);

```

- 3** Update the MATLAB S-function Outputs method to store the saturation limits, if applicable, as done in the new MATLAB S-function `custom_sat_plot.m`. If you are following through this example, copy the Outputs method in `custom_sat_plot.m` over the original Outputs method in `custom_sat_final.m`

```

%% Function: Outputs =====
function Outputs(block)

lowMode    = block.DialogPrm(1).Data;
upMode     = block.DialogPrm(3).Data;
sigVal     = block.InputPort(1).Data;
vals = get_param(block.BlockHandle,'MaskValues');
plotFlag = vals{5};
lowPortNum = 2;

% Check upper saturation limit
if isequal(upMode,2)
    upVal = block.RuntimePrm(2).Data;
elseif isequal(upMode,3)
    upVal = block.InputPort(2).Data;
    lowPortNum = 3; % Move lower boundary down one port number
else
    upVal = inf;

```

```

end

% Check lower saturation limit
if isequal(lowMode,2),
    lowVal = block.RuntimePrm(1).Data;
elseif isequal(lowMode,3)
    lowVal = block.InputPort(lowPortNum).Data;
else
    lowVal = -inf;
end

% Use userdata to store limits, if plotFlag is on
if strcmp(plotFlag,'on');
    ud = get_param(block.BlockHandle,'UserData');
    ud.lowVal = [ud.lowVal;lowVal];
    ud.upVal = [ud.upVal;upVal];
    ud.time = [ud.time;block.CurrentTime];
    set_param(block.BlockHandle,'UserData',ud)
end

% Assign new value to signal
if sigVal > upVal,
    sigVal = upVal;
elseif sigVal < lowVal,
    sigVal=lowVal;
end

block.OutputPort(1).Data = sigVal;

%endfunction

```

- 4** Write the function `plotsat.m` to plot the saturation limits. This function takes the handle to the Level-2 MATLAB S-Function block and uses this handle to retrieve the block's `UserData`. If you are following through this tutorial, save `plotsat.m` to your working folder.

```

function plotSat(block)

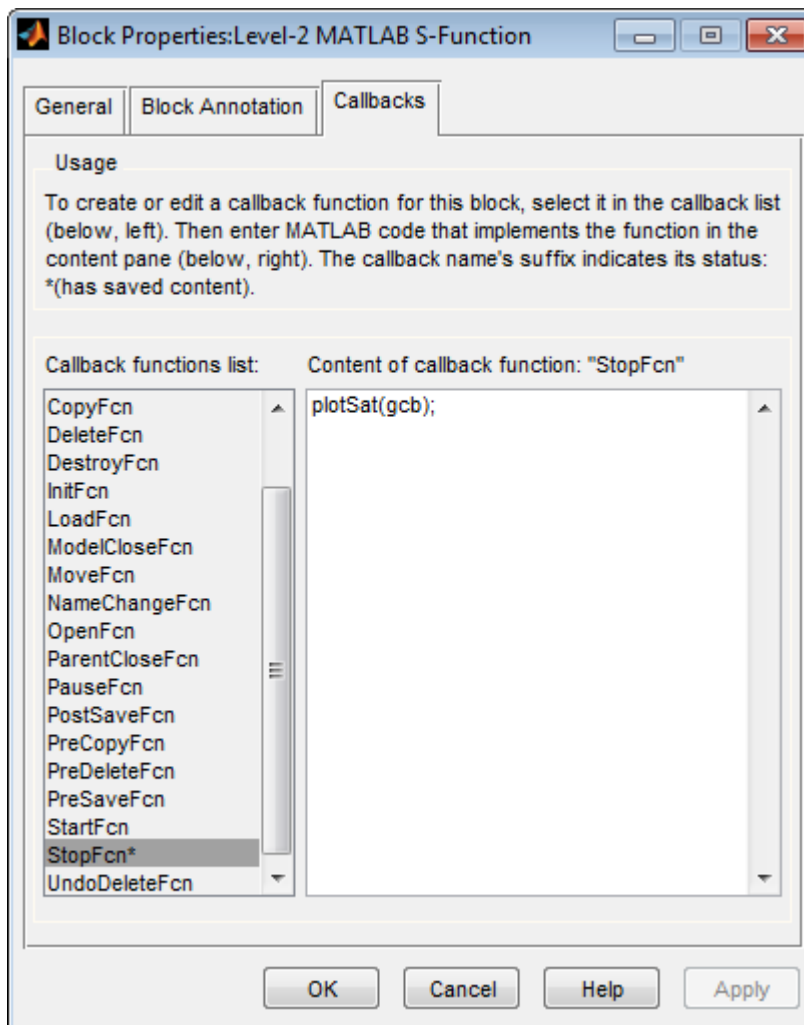
% PLOTSAT contains the plotting routine for custom_sat_plot
% This routine is called by the S-function block's StopFcn.

```

```
ud = get_param(block, 'UserData');
fig=[];
if ~isempty(ud.time)
    if strcmp(ud.upBound, 'on')
        fig = figure;
        plot(ud.time,ud.upVal, 'r');
        hold on
    end
    if strcmp(ud.lowBound, 'on')
        if isempty(fig),
            fig = figure;
        end
        plot(ud.time,ud.lowVal, 'b');
    end
    if ~isempty(fig)
        title('Upper bound in red. Lower bound in blue.')
    end

    % Reinitialize userdata
    ud.upVal=[];
    ud.lowVal=[];
    ud.time = [];
    set_param(block, 'UserData', ud);
end
```

- 5 Right-click the Level-2 MATLAB S-Function block and select **Block Properties**. The Block Properties dialog box opens. On the **Callbacks** pane, modify the StopFcn to call the plotting callback as shown in the following figure, then click **OK**.





## Custom Block Examples

### In this section...

“Creating Custom Blocks from Masked Library Blocks” on page 24-43

“Creating Custom Blocks from MATLAB Functions” on page 24-43

“Creating Custom Blocks from S-Functions” on page 24-44

### Creating Custom Blocks from Masked Library Blocks

The Additional Math and Discrete Simulink library is a group of custom blocks created by extending the functionality of built-in Simulink blocks. The Additional Discrete library contains a number of masked blocks that extend the functionality of the standard Unit Delay block. See Chapter 25, “Working with Block Libraries” for more general information on Simulink libraries.

### Creating Custom Blocks from MATLAB Functions

The Simulink product provides a number of demonstrations that show how to incorporate MATLAB functions into a custom block.

- The Single Hydraulic Cylinder Simulation, `sldemo_hydcyl.mdl`, uses a Fcn block to model the control valve flow. In addition, the Control Valve Flow block is a library link to one of a number of custom blocks in the library `hydlib.mdl`.
- The Radar Tracking Model, `sldemo_radar.mdl`, uses 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 demonstration, `sldemo_em1_galaxy.mdl`, uses several MATLAB Function blocks to construct two galaxies and calculate the effects of gravity as these two galaxies nearly collide. The demo 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.mdl` contains various examples of MATLAB and C MEX S-functions. For more information on writing MATLAB S-functions, see “Writing S-Functions in MATLAB”. For more information on writing C MEX S-functions, see “Writing S-Functions in C”. For a list of available S-function demos, see “S-Function Examples” in Writing S-Functions.

# Working with Block Libraries

---

- “About Block Libraries and Linked Blocks” on page 25-2
- “Creating and Working with Linked Blocks” on page 25-4
- “Working with Library Links” on page 25-8
- “Creating Block Libraries” on page 25-21
- “Adding Libraries to the Library Browser” on page 25-36

## 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 11-17.

### 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 “Populating a Model” on page 3-4 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.

## Creating and Working with Linked Blocks

### In this section...

“About Linked Blocks” on page 25-4

“Creating a Linked Block” on page 25-4

“Updating a Linked Block” on page 25-5

“Modifying Linked Blocks” on page 25-6

“Finding a Linked Block’s Prototype” on page 25-7

“Finding Linked Blocks in a Model” on page 25-7

### 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 (“Updating a Linked Block” on page 25-5). 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 Data Tips” on page 20-2).

---

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 “Modifying Linked Blocks” on page 25-6).

### Creating 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 “Opening the Library Browser” on page 3-4), 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 “Browsing Block Libraries” on page 3-5 and “Searching Block Libraries” on page 3-5).
- 4 Drag the library block from the Library Browser’s **Library** pane and drop it into your model.

## Updating a 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 “Checking and Setting Link Status Programmatically” on page 25-16 ).

---

**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. When you click the Model Editor window, Simulink refreshes any stale links to edited blocks, even if you have not saved the library yet.

To manually refresh links:

- Select **Edit > Update Diagram** (or press **Ctrl+D**).

- Select **Edit > Links and Model Blocks > Refresh** (or press **Ctrl+K**) to refresh links.
- Select **Go To Library Link**.

## Modifying 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 “Disabling Links to Library Blocks” on page 25-11).

## 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 model (.mdl) 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 “Displaying Library Links” on page 25-8.



## 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.

## Finding a Linked Block's Prototype

To find the source library and the prototype of a linked block, select the linked block. Then choose **Go To Library Link** from the **Link Options** submenu of the model window's **Edit** or context menu. If the library is open, Simulink selects and highlights the library block and makes the source library the active window. If the library is not open, Simulink first opens it and then selects the library block.

## Finding 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.

## Working with Library Links

### In this section...

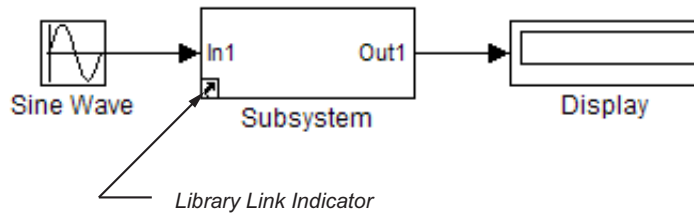
- “Displaying Library Links” on page 25-8
- “Locking Links to Blocks in a Library” on page 25-9
- “Disabling Links to Library Blocks” on page 25-11
- “Restoring Disabled or Parameterized Links” on page 25-12
- “Checking and Setting Link Status Programmatically” on page 25-16
- “Breaking a Link to a Library Block” on page 25-18
- “Fixing Unresolved Library Links” on page 25-19

### Displaying Library Links

A model can have a block linked to a library block, or it can have a local instance of a block that is not linked. To enable the display of library links:

- 1 In the Model Editor window, select **Format > Library Link Display** 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** — displays only links to user libraries
  - d **All** — displays all links
- 2 Observe the library link indicators.

The library link indicator is an arrow in the bottom left corner of each block.



The color of the link arrow indicates the status of the link.

Link Arrow Color	Status
Black	Active link
Grey	Inactive link
Red	Active and modified (parameterized link)
White arrow, black background	Locked link

## Locking 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 **Edit > Lock Links To Library**.
- At the command line, use the `LockLinksToLibrary` property:

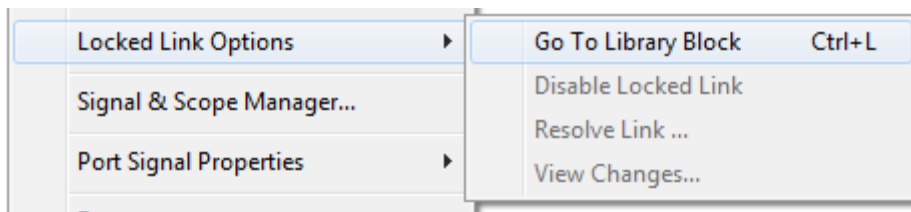
```
set_param('MyModelName', 'LockLinksToLibrary', 'on')
```

where `MyModelName.mdl` 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 **Edit** or right-click the linked block, you see the **Link Options** menu has changed to **Locked Link Options**, 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***.
- 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 **Edit > 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.

## Disabling 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 “Locking Links to Blocks in a Library” on page 25-9.

---

**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, select a linked block.
- 2** From the **Edit** menu, select **Link Options**, and then select **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:

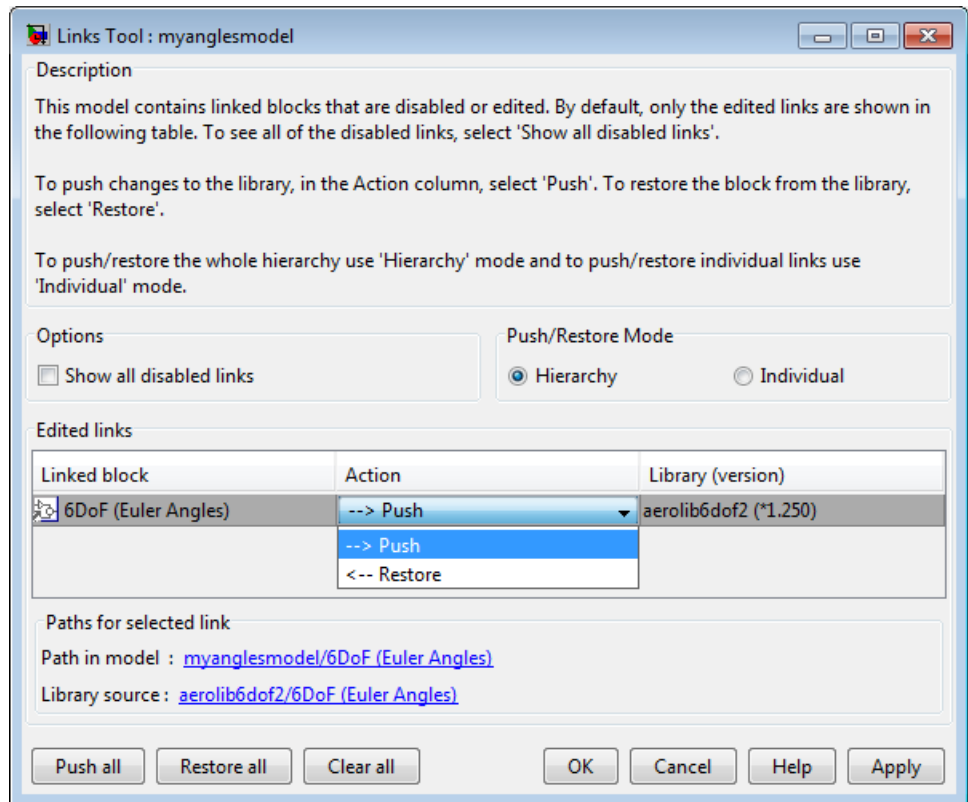
```
set_param(gcb, 'LinkStatus', 'inactive')
```

## Restoring 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 **Edit** menu, select **Link Options**, and then select **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 25-15.

**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 <b>Individual</b> 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 Individual	In <b>Individual</b> 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.

## Checking and Setting 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
<code>none</code>	Block is not a linked block.
<code>resolved</code>	Resolved link.
<code>unresolved</code>	Unresolved link.
<code>implicit</code>	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, <code>get_param(gcb, 'LinkStatus')</code> returns <code>implicit</code> .
<code>inactive</code>	Disabled link.

<b>Set LinkStatus Value</b>	<b>Description</b>
none	Breaks link. Use none to break a link, e.g., <code>set_param(gcb, 'LinkStatus', 'none')</code>
inactive	Disables link. Use Inactive to disable a link, e.g., <code>set_param(gcb, 'LinkStatus', 'inactive')</code>
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, <code>set_param(gcb, 'LinkStatus', 'restore')</code> 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 <b>Restore Individual</b> 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 <b>Push Individual</b> in the Links Tool.
restoreHierarchy	Restores all disabled links in the hierarchy with their corresponding library blocks. This is equivalent to <b>Restore</b> in hierarchy mode in the Links Tool.
propagateHierarchy	Pushes all links with changes in the hierarchy to their libraries. This is equivalent to <b>Push</b> in hierarchy mode in the Links Tool. See “Restoring Disabled or Parameterized Links” on page 25-12.

---

**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.

## Breaking 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 Chapter 23, “Working with Block Masks”).

To break the link between a linked block and its library block, you can use any of the following actions.

- Disable the link, then select the block and choose **Break Link** from the **Link Options** menu.
- 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` in the Simulink reference documentation.

---

**Note** Breaking library links in a model does not guarantee that you can run the model standalone, especially if the model includes blocks from third-party libraries or optional Simulink blocksets. It is possible that a library block invokes functions supplied with the library and hence can run only if the library is installed on the system running the model. Further, breaking a link can cause a model to fail when you install a new version of the library on a system.

---

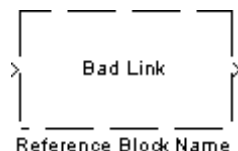
For example, suppose a block invokes a function that is supplied with the library. Now suppose that a new version of the library eliminates the function. Running a model with an unlinked copy of the block results in invocation of a now nonexistent function, causing the simulation to fail. To avoid such problems, you should generally avoid breaking links to libraries.

## Fixing Unresolved Library Links

If Simulink is unable to find either the library block or the source library on your MATLAB path when it attempts to update the 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 **Edit > Update Diagram** or **Edit > Links and Model Blocks > Refresh**.
- 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**.

## Creating Block Libraries

### In this section...

“Creating a Library” on page 25-21

“Creating a Sublibrary” on page 25-22

“Modifying and Locking Libraries” on page 25-22

“Making Backward-Compatible Changes to Libraries” on page 25-23

### Creating a Library

You can create your own block library and add it to the Simulink Library Browser (see “Adding Libraries to the Library Browser” on page 25-36). To create a library:

- 1 Select **Library** from the **New** submenu of the **File** menu.

Simulink creates a model (\*.mdl) file for storing the new library and displays the file in a new model editor window.

---

**Tip** You can also use the `new_system` command to create the library and the `open_system` command to open the new library.

---

- 2 Drag blocks from models or other libraries into the new library.

---

**Note** If you want to be able to create links in models to a block in the library, you may need to provide a mask (see Chapter 23, “Working with Block Masks”) for the block. You can also provide a mask for a subsystem in a library, but you do not need to have a mask to create links to it in models.

---

- 3 Save the library’s file under a new name.

## Creating 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 model (.mdl) file of one library to the model file of another library. The referenced file is called a *sublibrary* of the parent (i.e., referencing) library. The sublibrary is said to be included by reference in the parent library.

To include a library in another library as a sublibrary:

- 1 Open the parent library.
- 2 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.

## Modifying and Locking Libraries

When you open a library, it is automatically locked and you cannot modify its contents. To unlock the library, select **Edit > 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 “Locking Links to Blocks in a Library” on page 25-9.

When you save a library, Simulink checks file permissions and offers to try to make the library writable if necessary.

## Making Backward-Compatible Changes to Libraries

Simulink provides the following features to facilitate making changes to library blocks without invalidating models that use the library blocks.

### Forwarding Tables

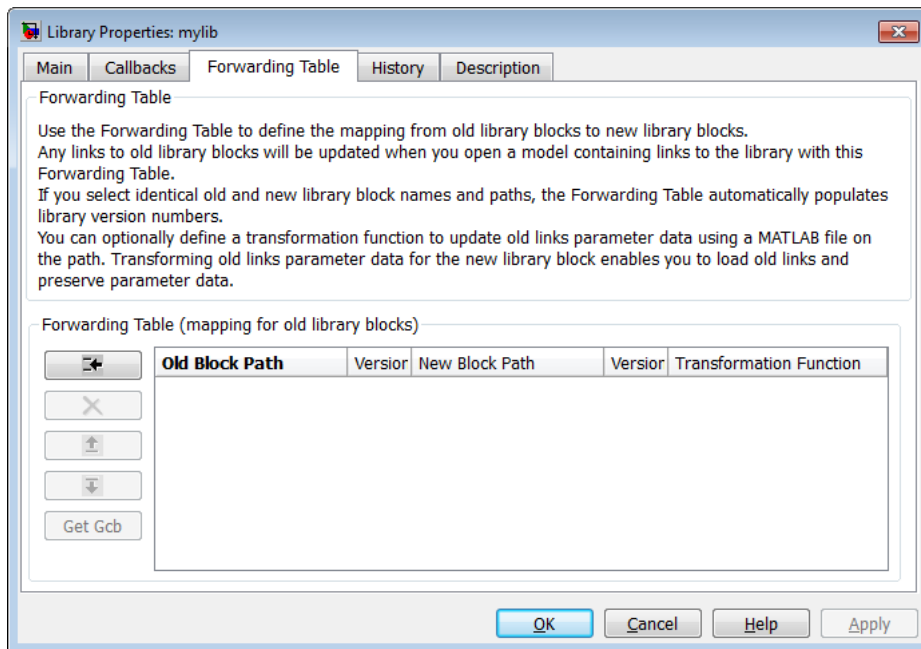
You can create forwarding tables for libraries to specify how to update links in models to reflect changes in the parameters. Use the Forwarding Table to map old library blocks to new library blocks. For example, if you rename or move a block in a library, you can use a forwarding table to enable Simulink 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 **Edit > Unlock Library**.
- 2 Select **File > 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**

- 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.

Forwarding Table (mapping for old library blocks)

	Old Block Path	Version	New Block Path	Version	Transformation Function
	simulink/Discrete/Weighted Moving Average	n/a	simulink_need_slupdate/Moving Average	n/a	No Transformation
	simulink/Lookup Tables/Interpolation (n-D) using PreLookup	n/a	simulink_need_slupdate/using PreLookup	n/a	No Transformation
	simulink/Lookup Tables/PreLookup Index Search	n/a	simulink_need_slupdate/Index Search	n/a	No Transformation
	simulink/Linear/Dot Product	n/a	simulink/Math Operations/Dot Product	n/a	No Transformation
	simulink/Nonlinear/Lookup Table (2-D)	n/a	simulink_need_slupdate/lookup Table (2-D)	n/a	No Transformation
	simulink/Nonlinear/Algebraic Coefficient	n/a	simulink/Math Operations/Algebraic Coefficient	n/a	No Transformation
	simulink/Linear/Slider Gain	n/a	simulink/Math Operations/Slider Gain	n/a	No Transformation
	simulink/Nonlinear/Coulomb Viscous Friction	n/a	simulink/Discontinuities/Coulomb Viscous Friction	n/a	No Transformation
	simulink/Nonlinear/Manual Switch	n/a	simulink/Signal Routing/Manual Switch	n/a	No Transformation
	simulink/Connections/Model Info	n/a	simulink/Model-Wide Utilities/Model Info	n/a	No Transformation
	simulink/Linear/Matrix	n/a	simulink3/Math/Matrix	n/a	No Transformation

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.

Forwarding Table (mapping for old library blocks)

	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 subfunctions defined in it. The function calls the appropriate subfunctions based on old block names and versions. Use this to combine many subfunctions 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 'OutData'
% add the parameter with value 'uint8'.
%
% In the simulink library the 'ForwardingTableEntry' would be of type:
% ||__s1OldName__||A||__s1NewName__||B||__s1TransformationFcn__||TX
%
% Exact entry is:
% ||__s1OldName__||fixpt_lib_4/Logic & Comparison/Compare\nTo Constant||__s1TransformationFcn__||
% simulink/Logic and Bit\nOperations/Compare\nTo Constant||__s1TransformationFcn__||
%
%
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 v
```

```

        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 25-29).

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.mdl` described in Masked Subsystem Example. Drag the masked block named `mx+b` into your new library and rename it to `Line`.
- 3** Right-click the block and select **Block Properties**. In the Block Properties dialog, select the **Block Annotation** tab. In the **Enter text and tokens for annotation** box, enter

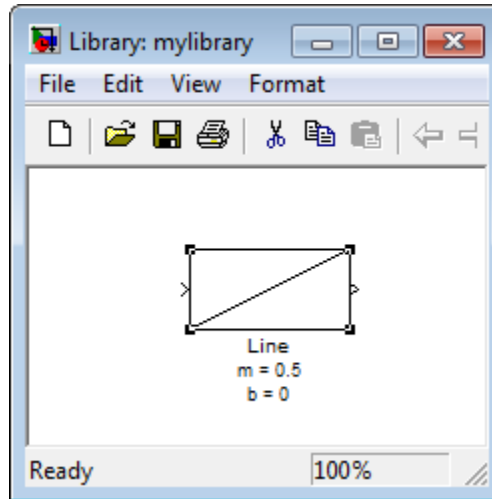
```

m = %<m>
b = %<b>

```

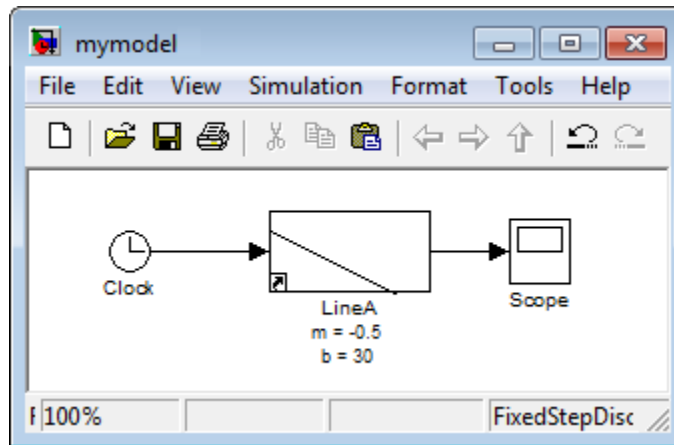
The block displays the value of its `m` and `b` parameters,

- 4 Right-click the block, and select **Mask 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, select **Mask Parameters**. In the Block Parameters dialog, change the value **Slope** to -0.5. and change the value **Intercept** to 30. From the **Format** menu, select **Library Links Display > User**.
- 9 Add a Scope and Clock block to your model. Save the new model with the filename mymodel.





- 10** From the **Simulation** menu, select **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.

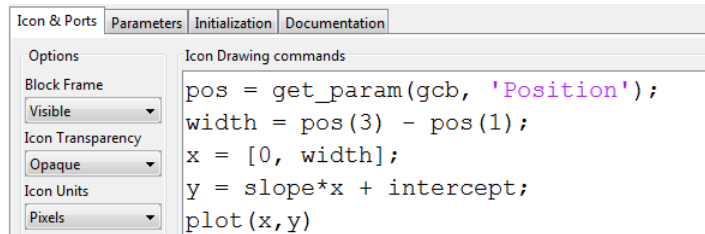
- 12** Open mylibrary.

- 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**.

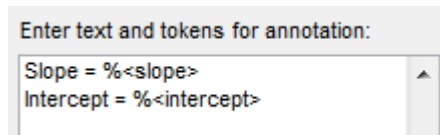
Icon & Ports		Parameters	Initialization	Documentation	
Dialog parameters					
#	Prompt	Variable	Type	Evaluate	Tunable
1	Slope	slope	edit	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
2	Intercept	intercept	edit	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

- Select the **Icon & Ports** tab. In the Icon Drawing comments box, change the variable **m** to **slope** and **b** to **intercept**.

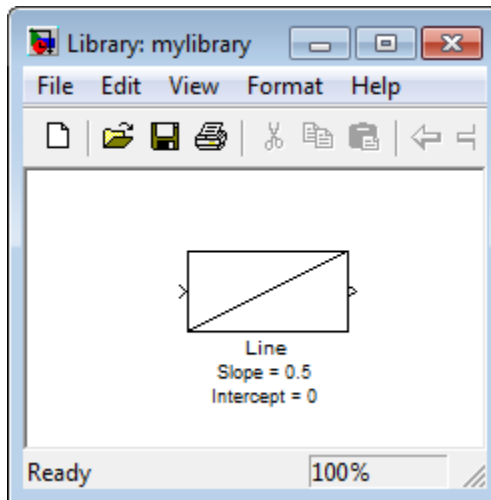


14 Right-click the Line block, select **Block Properties**. In the Block Properties dialog, .

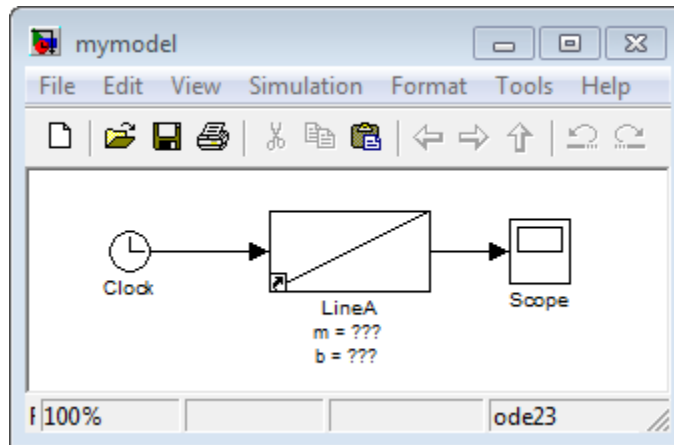
- Select the **Block Annotation** tab . In the **Enter text and tokens of annotation** box, rename the  $m$  parameter to slope and the  $b$  parameter to intercept.



15 Click **Ok** and save mylibrary.



16 Reopen mymodel.



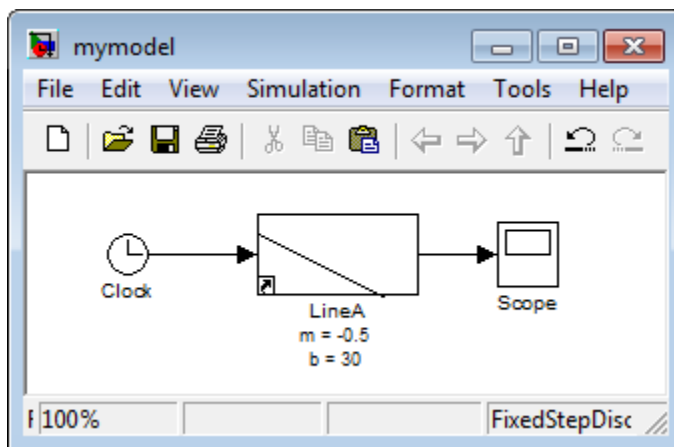
Note that LineA icon has reverted to the appearance of its library master (i.e., mylib/Line) and that its annotation displays question marks for the values of  $m$  and  $b$ . These changes reflect the parameter name changes in the library block. In particular, Simulink cannot find any parameters named  $m$  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(gcf, '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.

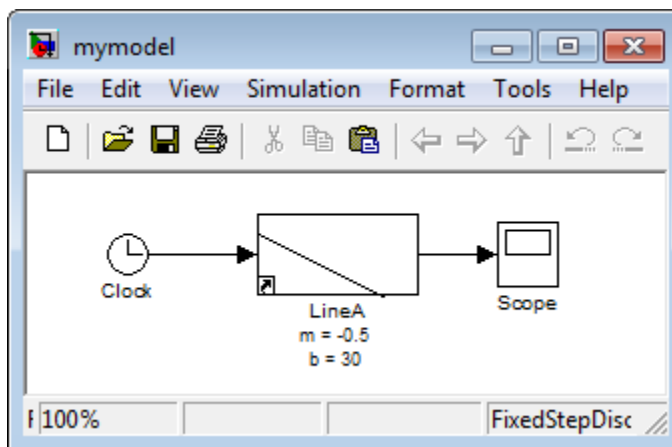
- 21** Change LineA block annotation property to reflect LineA parameter name changes, replace

```
m = %<m>  
b = %<b>
```

with

```
m = %<slope>  
b = %<intercept>
```

LineA now appears as follows.



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.

## Adding Libraries to the Library Browser

### In this section...

“How to Display a Library in the Library Browser” on page 25-36

“Example of a Minimal `slblocks.m` File” on page 25-36

“Adding More Descriptive Information in `slblocks.m`” on page 25-37

### How to Display a Library in the Library Browser

- 1 Create a folder in the MATLAB path for the top-level library and its sublibraries.

You must store each top-level library that you want to appear in the Library Browser in its own folder on the MATLAB path. Two top-level libraries cannot exist in the same folder.

- 2 Create or copy the top-level library and its sublibraries into the folder you created in the MATLAB path.
- 3 In the folder for the top-level library, include a `slblocks.m` file.

The approach you use to create the `slblocks.m` file depends on your requirements for describing the library:

- If a minimal `slblocks.m` file meets your needs, then create a new `slblocks.m` file, based on the example below
- If you want to describe the library more fully, consider copying an existing `slblocks.m` file to use as a template, editing the copy to describe your library (see below).

### Example of a Minimal `slblocks.m` File

To display a library in the Library Browser, at a minimum you must include these lines (adjusted to describe your library; comments are not required) in the `slblocks.m` file.

```
Creating function blkStruct = slblocks
    % Specify that the product should appear in the library browser
```

```
% and be cached in its repository  
Browser.Library = 'mylib';  
Browser.Name    = 'My Library';  
blkStruct.Browser = Browser;
```

## **Adding More Descriptive Information in `sblocks.m`**

You can review other descriptive information you may wish to include in your `sblocks.m` file by examining the comments in the Simulink library `sblocks.m` file: `matlabroot/toolbox/simulink/blocks/sblocks.m`.





# Using the MATLAB Function Block

---

- “Introduction to MATLAB Function Blocks” on page 26-3
- “Creating an Example Model That Uses a MATLAB Function Block” on page 26-7
- “Debugging a MATLAB Function Block” on page 26-14
- “MATLAB Function Block Editor” on page 26-23
- “Working with MATLAB Function Reports” on page 26-46
- “Typing Function Arguments” on page 26-60
- “Sizing Function Arguments” on page 26-69
- “Parameter Arguments in MATLAB Function Block Functions” on page 26-72
- “Resolving Signal Objects for Output Data” on page 26-73
- “Working with Structures and Bus Signals” on page 26-75
- “Using Variable-Size Data in MATLAB Function Blocks” on page 26-86
- “Using Enumerated Data in MATLAB Function Blocks” on page 26-95
- “Using Global Data with the MATLAB Function Block” on page 26-106
- “Working with Frame-Based Signals” on page 26-115
- “Creating Custom Block Libraries with MATLAB Function Blocks” on page 26-121
- “Using Traceability in MATLAB Function Blocks” on page 26-139

- “Including MATLAB Source Code as Comments in the Generated Code” on page 26-144
- “Enhancing Readability of Generated Code for MATLAB Function Blocks” on page 26-150
- “Speeding Up Simulation with the Basic Linear Algebra Subprograms (BLAS) Library” on page 26-159
- “Controlling Run-Time Checks” on page 26-161
- “Tutorial: Integrating MATLAB Code with a Simulink Model for Tracking a Moving Object” on page 26-163
- “Tutorial: Integrating MATLAB Code with a Simulink Model for Filtering an Audio Signal” on page 26-192

## Introduction to MATLAB Function Blocks

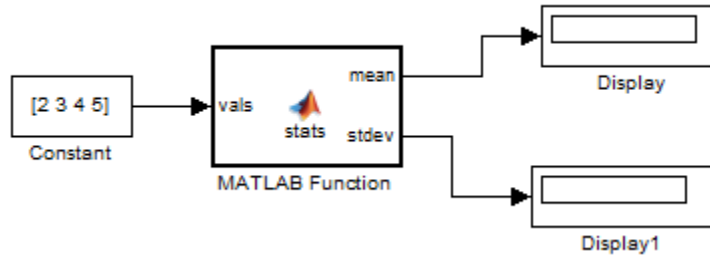
In this section...
“What Is a MATLAB Function Block?” on page 26-3
“Why Use MATLAB Function Blocks?” on page 26-6

### 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. For more information, see “About Code Generation from MATLAB Algorithms”.

### Example: Calculating Statistical Mean and Standard Deviation

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);
coder.extrinsic('plot');
plot(vals, '-+');

function mean = avg(array,size)
mean = sum(array)/size;

function [mean, stdev] = stats(vals)
% Calculates a statistical mean and a standard deviation
% for the values in vals

coder.extrinsic('plot');

len = length(vals);
mean = avg(vals,len);
stdev = sqrt(sum(((vals-avg(vals,len)).^2))/len);
plot(vals, '-+');

function mean = avg(array,size)
mean = sum(array)/size;
```

You will build this model in “Creating an Example Model That Uses a MATLAB Function Block” on page 26-7.

**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 “Preparing MATLAB Code for C/C++ and MEX Code Generation” and “Why Define Variables Differently for Code Generation?”). 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 “When You Can Reassign Variable Properties for C/C++ Code Generation”).

**Declaring Extrinsic Functions.** If your MATLAB algorithm calls functions that are not supported for code generation, you must declare them to be extrinsic by using the `coder.extrinsic` construct. This declaration ensures that the functions are not compiled, but instead dispatched to MATLAB for execution during simulation of the model. The example function `stats` declares the `plot` function to be extrinsic:

```
coder.extrinsic('plot');
```

Here, `plot` is used to visualize the results during simulation, but there is no need to generate code for the function.

See “Calling Functions for Code Generation”.

## Calling Functions in MATLAB Function Blocks

MATLAB Function blocks can call any of the following types of functions:

- **Subfunctions**

Subfunctions are defined in the body of the MATLAB Function block. In the preceding example, `avg` is a subfunction. See “Calling Subfunctions”.

- **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 “Calling Supported Toolbox Functions”. For a complete list of supported functions, see “Functions Supported for Code Generation”.

- **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 “Calling MATLAB Functions”.

## 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 Model Explorer or Ports and Data Manager (see “Ports and Data Manager” on page 26-27).

## Creating an Example Model That Uses a MATLAB Function Block

### In this section...

“Adding a MATLAB Function Block to a Model” on page 26-7

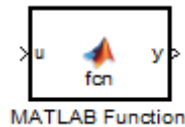
“Programming the MATLAB Function Block” on page 26-8

“Building the Function and Checking for Errors” on page 26-10

“Defining Inputs and Outputs” on page 26-12

### Adding a MATLAB Function Block to a Model

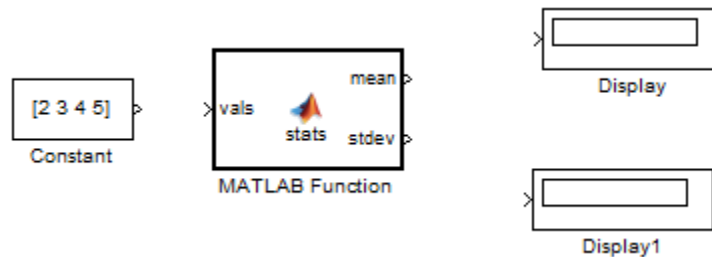
- 1 Create a new model with the Simulink product and add a MATLAB Function block to it from the User-Defined Function library:



- 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 26-7. Double-click the MATLAB Function block `fcn` to open it for editing.

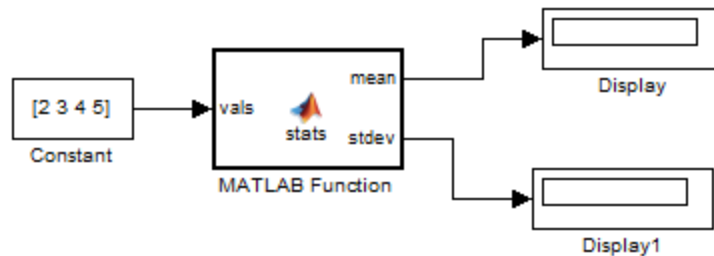
A default function signature appears, along with the `%%codegen` directive. The directive indicates that you intend to generate code from this algorithm and turns on appropriate error checking (see “Adding the Compilation Directive `%%codegen`”).

- 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.

coder.extrinsic('plot');

len = length(vals);
mean = avg(vals,len);
stdev = sqrt(sum(((vals-avg(vals,len)).^2))/len);
plot(vals, '-+');

function mean = avg(array,size)
mean = sum(array)/size;
```

### **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 “Defining and Initializing Persistent Variables”.

### **More about coder.extrinsic('plot');**

The function `plot` does not support code generation so you need to declare it as an extrinsic function. MATLAB executes extrinsic functions during simulation, but does not generate code for them. software during simulation. See “Calling MATLAB 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` in the MATLAB Function Reference. You must run this command even if you use the default C compiler that comes with the MATLAB product for Microsoft Windows platforms. You can also use `mex` to choose and configure a different C compiler, as described in “Building MEX-Files” in the MATLAB External Interfaces documentation.

**Supported Compilers for Simulation Builds.** To view a list of compilers for building models containing 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 26-8.
- 2 Double-click its MATLAB Function block `stats` to open it for editing.
- 3 In the MATLAB Function Block Editor, select **Tools > Build** to compile and build the example model.

If no errors occur, the **Diagnostics Manager** window displays a message indicating success. Otherwise, the **Diagnostics Manager** helps you locate errors, as described in “How to Locate and Fix Errors” on page 26-11.

## 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 subfunction `avg` to a fictitious subfunction `aug` and then compile again to see the following messages in window:

The **Simulation Diagnostics** 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 “Working with MATLAB Function Reports” on page 26-46.

- 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 26-8, 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 26-8. Double-click the MATLAB Function block `stats` to open it for editing.
- 2 In the MATLAB Function Block editor, select **Tools > Model Explorer**.

The Model Explorer window opens. You can use the Model Explorer to define arguments for MATLAB Function blocks. Notice that the MATLAB Function block is highlighted in the left **Model Hierarchy** pane.

The **Contents** pane displays the argument `vals` and the return values `mean` and `stdev` that you have already created for the MATLAB Function block. Notice that `vals` is assigned a **Scope** of **Input**, which is short for **Input from Simulink**. `mean` and `stdev` are assigned the **Scope** of **Output**, which is short for **Output to Simulink**.

You can also use the Ports and Data Manager to define arguments for MATLAB Function blocks (see “Ports and Data Manager” on page 26-27).

- 3 In the **Contents** pane of the Model Explorer window, click anywhere in the row for `vals` to highlight it.

The right pane displays the **Data** properties dialog box for `vals`. By default, the 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 **Contents** pane.

You can specify the type of an input or output argument by selecting a type in the **Type** field of the **Data** properties dialog box, for example, `double`. You can also specify the size of an input or output argument by entering an expression in the **Size** field of the **Data** properties dialog box for the argument. For example, you can enter `[2 3]` in the **Size** field to size `vals` as a 2-by-3 matrix. See “Typing Function Arguments” on page 26-60 and “Sizing Function Arguments” on page 26-69 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.

---

## Debugging a MATLAB Function Block

### In this section...

“How Debugging Affects Simulation Speed” on page 26-14

“Enabling and Disabling Debugging” on page 26-14

“Debugging the Function in Simulation” on page 26-14

“Watching Function Variables During Simulation” on page 26-18

“Checking for Data Range Violations” on page 26-20

“Debugging Tools” on page 26-20

### 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 26-14.

### 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 **Enable Debugging** in the MATLAB Function Block Editor Debug menu. If **Enable Debugging** is unavailable, then the **Simulation Target** pane in the Configuration Parameters dialog is controlling debugging.

### Debugging the Function in Simulation

In “Creating an Example Model That Uses a MATLAB Function Block” on page 26-7, 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.

```
1  function [mean, stdev] = stats(vals)
2  %#codegen
3
4  % Calculates a statistical mean and a standard deviation
5  % for the values in vals
6
7  -  coder.extrinsic('plot');
8
9  ●  len = length(vals);
10 -  mean = avg(vals,len);
11 -  stdev = sqrt(sum((vals-avg(vals,len)).^2)/len);
12 -  plot(vals,'-+');
13
14  function mean = avg(array,size)
15 -  mean = sum(array)/size;
```

**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.

```
1 function [mean, stdev] = stats(vals)
2 %#codegen
3
4 % Calculates a statistical mean and a standard deviation
5 % for the values in vals
6
7 - coder.extrinsic('plot');
8
9 ● → len = length(vals);
10 - mean = avg(vals,len);
11 - stdev = sqrt(sum((vals-avg(vals,len)).^2)/len);
12 - plot(vals,'-+');
13
14 function mean = avg(array,size)
15 - mean = sum(array)/size;
```

**4** Select **Debug > Step** to advance execution.

The execution arrow advances to the next line of `stats`, which calls the subfunction `avg`.

**5** Select **Debug > Step In**.

Execution advances to enter the subfunction `avg`. Once you are in a subfunction, you can use the **Step** or **Step In** commands to advance execution. If the subfunction calls another subfunction, use the **Step In** icon to enter it. If you want to execute the remaining lines of the subfunction, use **Step Out**.

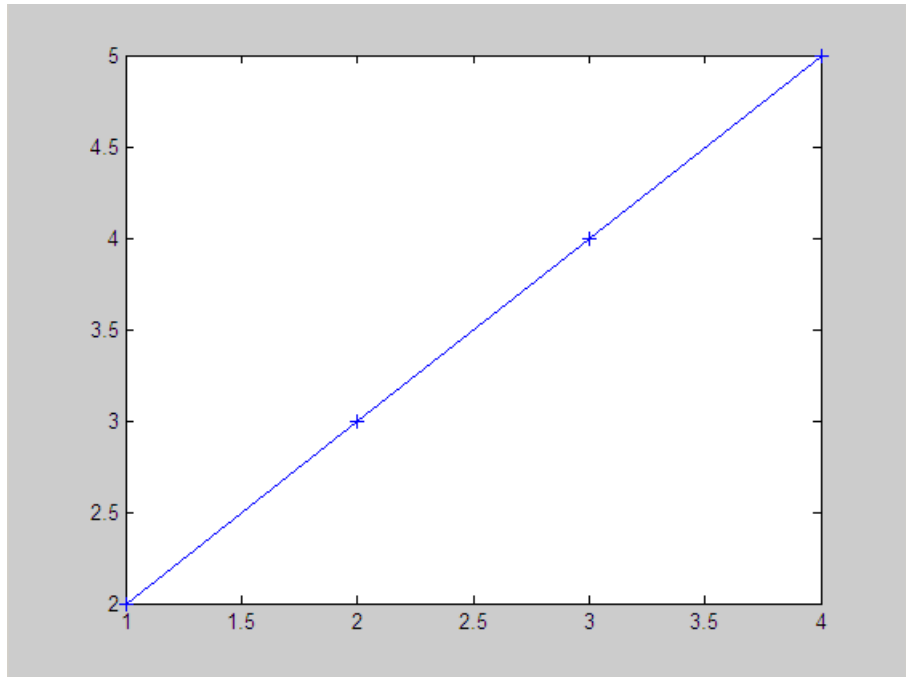
**6** Select **Debug > Step** to execute the only line in the subfunction `avg`.  
When the subfunction `avg` finishes executing, a green arrow pointing down under its last line appears.**7** Select **Debug > Step** again to return to the function `stats`.



Execution advances to the line after the call to the subfunction `avg`.

- 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`.

- Select **Debug > Continue** to continue execution of the model.

The computed values of `mean` and `stdev` now appear in the Display blocks.

- In the MATLAB Function Block Editor, select **Debug > Exit Debug Mode** to stop simulation.

## Watching Function Variables During Simulation

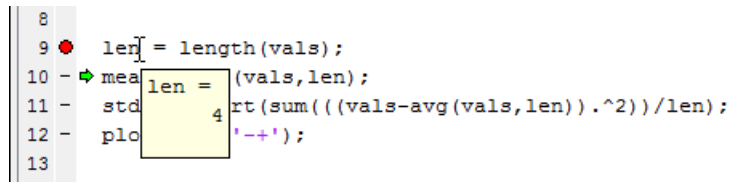
While you simulate a MATLAB Function block, you can use several tools to keep track of variable values in the function.

### 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:



```

8
9 ● len = length(vals);
10 - → mean(len = (vals, len);
11 - std         rt(sum((vals-avg(vals, len)).^2)/len);
12 - plot         '-+');
13

```

The screenshot shows a MATLAB Function Block Editor window. The code is as follows:

```

8
9 ● len = length(vals);
10 - → mean(len = (vals, len);
11 - std         rt(sum((vals-avg(vals, len)).^2)/len);
12 - plot         '-+');
13

```

A red dot is positioned over the variable `len` on line 9. A yellow pop-up display box is overlaid on the code, showing the value of `len` as 4. The pop-up box is positioned over the `len` variable in the `mean` function call on line 10.

### 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
<code>ctrl-c</code>	Quit debugging and terminate simulation.
<code>dbcont</code>	Continue execution to next breakpoint.
<code>dbquit</code>	Quit debugging and terminate simulation.
<code>dbstep</code> [in out]	Advance to next program step after a breakpoint is encountered. Step over or step into/out of a MATLAB subfunction.
<code>help</code>	Display help for command line debugging.
<code>print &lt;var&gt;</code>	Display the value of the variable <code>var</code> in the current scope. If <code>var</code> is a vector or matrix, you can also index into <code>var</code> . For example, <code>var(1,2)</code> .
<code>save</code>	Saves all variables in the current scope to the specified file. Follows the syntax of the MATLAB <code>save</code> command. To retrieve variables to the MATLAB base workspace, use <code>load</code> command after simulation has been ended.
<code>&lt;var&gt;</code>	Equivalent to " <code>print &lt;var&gt;</code> " if variable is in the current scope.
<code>who</code>	Display the variables in the current scope.
<code>whos</code>	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 Model Explorer, select the input or output of interest in the MATLAB Function block.







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 26-36.

### Debugging Tools

Use the following tools during a MATLAB Function block debugging session:

Tool Button	Description	Shortcut Key
 <b>Build</b>	Check for errors and build a simulation application (if no errors are found) for the model containing this MATLAB Function block.  Alternatively, from the <b>Tools</b> menu, select <b>Build</b> .	<b>Ctrl+B</b>
	Start simulation of the model containing the MATLAB Function block. If execution	<b>F5</b>

Tool Button	Description	Shortcut Key
 <p>Start Simulation</p>	is paused at a breakpoint, continues debugging.	
 <p>Stop Simulation</p>	Stop simulation of the model containing the MATLAB Function block. Alternatively, from the <b>Debug</b> menu, select <b>Exit debug mode</b> if execution is paused at a breakpoint.	<b>Shift+F5</b>
 <p>Set/Clear Breakpoint</p>	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 <b>Breakpoint Indicator</b>  appears in the breakpoints column for the selected line. Alternatively, click the hyphen character (-) in the breakpoints column for the line. A breakpoint indicator appears in place of the hyphen. Click the breakpoint indicator to clear the breakpoint.	<b>F12</b>
 <p>Clear All Breakpoints</p>	Clear all existing breakpoints in the MATLAB Function block code.	<b>None</b>
 <p>Step</p>	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. Alternatively, from the <b>Debug</b> menu, select <b>Step</b> .	<b>F10</b>

<b>Tool Button</b>	<b>Description</b>	<b>Shortcut Key</b>
 <p><b>Step In</b></p>	<p>Step through the execution of the next line of code in the MATLAB Function block. If the line calls a subfunction, step into the first line of the subfunction. You can use this tool only after execution has stopped at a breakpoint. Alternatively, from the <b>Debug</b> menu, select <b>Step In</b>.</p>	<p><b>F11</b></p>
 <p><b>Step Out</b></p>	<p>Step out of line-by-line execution of the current function or subfunction. If in a subfunction, the debugger continues to the line following the call to this subfunction. You can use this tool only after execution has stopped at a breakpoint. Alternatively, from the <b>Debug</b> menu, select <b>Step Out</b>.</p>	<p><b>Shift+F11</b></p>
 <p><b>Continue Debugging</b></p>	<p>Continue debugging after a pause, such as stopping at a breakpoint. You can use this tool only after execution has stopped at a breakpoint. Alternatively, from the <b>Debug</b> menu, select <b>Continue</b>.</p>	<p><b>F5</b></p>
 <p><b>Exit Debug Mode</b></p>	<p>Exit debug mode. You can use this tool only after execution has stopped at a breakpoint. Alternatively, from the <b>Debug</b> menu, select <b>Exit Debug Mode</b>.</p>	<p><b>Shift+F5</b></p>

## MATLAB Function Block Editor

### In this section...

“Customizing the MATLAB Function Block Editor” on page 26-23

“MATLAB Function Block Editor Tools” on page 26-23

“Editing and Debugging MATLAB Function Block Code” on page 26-24


“Ports and Data Manager” on page 26-27





### 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” in the MATLAB documentation.

### MATLAB Function Block Editor Tools

Use the following tools to work with the MATLAB Function block:

Tool Button	Description
 <p data-bbox="394 1072 609 1098"><b>Edit Data/Ports</b></p>	<p data-bbox="644 956 1302 1048">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 26-27). You can also open this dialog by selecting <b>Edit Data/Ports</b> from the <b>Tools</b> menu.</p> <p data-bbox="644 1133 1302 1194">To define and modify input and output arguments for any MATLAB Function block in the model hierarchy,</p>

Tool Button	Description
	use the Model Explorer, which you can open from the <b>Tools</b> menu.
 <p><b>Open MATLAB Function Report</b></p>	Opens the MATLAB Function report for the MATLAB Function block. For more information, see “Working with MATLAB Function Reports” on page 26-46.
 <p><b>Simulation Target</b></p>	Opens the <b>Simulation Target</b> pane in the <b>Configuration Parameters</b> dialog to enable debugging or include custom code. See “Enabling and Disabling Debugging” on page 26-14 for more information on debugging
 <p><b>Go To Diagram</b></p>	Displays the MATLAB function in its native diagram without closing the editor.
 <p><b>Update Ports</b></p>	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.

See “Defining Inputs and Outputs” on page 26-12 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 **Comment** from the **Text** menu).

---

**Note** To uncomment a block of code, follow the same steps, but select **Uncomment** instead of **Comment**.

---

For more information, refer to “Add Comments” in the MATLAB Desktop Tools and Development Environment documentation.

## Manual Indenting

To indent a block of code manually:

- 1 Highlight the text that you would like to indent.
- 2 Select one of the following options:
  - **Smart Indent** from the **Text** menu.
  - **Decrease Indent** from the **Text** menu.
  - **Increase Indent** from the **Text** menu.

For more information, refer to “Indent Code” in the MATLAB Desktop Tools and Development Environment documentation.

## Opening a Selection

You can open a subfunction, function, file, or variable from within a file in the 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 “Evaluate or Open Code You Select” in the MATLAB Desktop Tools and Development Environment documentation.

---

**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 26-27.

---

### 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 26-36 in the Ports and Data Manager documentation.

## Ports and Data Manager

The Ports and Data Manager provides a convenient method for defining objects and modifying their properties in a MATLAB Function block that is open and has focus.

The Ports and Data Manager provides the same data definition capabilities as the Model Explorer, but supports only individual MATLAB Function blocks. To learn how to modify objects and properties for blocks across the model hierarchy, see “The Model Explorer: Overview” on page 8-2.

## Ports and Data Manager Dialog

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 consists of two panes:

- The **Contents** pane lists the objects that have been defined for the MATLAB Function block.
- The **Dialog** pane displays fields for modifying the properties of the selected object.

Properties vary according to the scope and type of the object. Therefore, the Ports and Data Manager properties dialogs are dynamic, displaying only the property fields that are relevant for the object you add or modify.



When you first open the dialog 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 **Tools > Edit Data/Ports**. 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
 <b>Go to Block Editor</b>	Displays the MATLAB function in the MATLAB Function Block Editor.
 <b>Show Block Dialog</b>	Displays the default MATLAB function properties (see “MATLAB Function Block Properties” on page 26-28). 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 “Manipulating Block Names” on page 20-26).

**Update method.** Method for activating the MATLAB Function block. You can choose from the following update methods:

Update Method	Description
Inherited (default)	<p>Input from the Simulink model activates the MATLAB Function block.</p> <p>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.</p> <p>If you define data inputs, the MATLAB Function block samples at the rate of the fastest data input. If you do not define data inputs, the MATLAB Function block samples as defined by its parent subsystem’s execution behavior.</p>
Discrete	<p>The MATLAB Function block is sampled at the rate you specify as the block’s <b>Sample Time</b> 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.</p>
Continuous	<p>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.</p>

**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.** Parameter that applies to MATLAB Function blocks in models that use fixed-point or integer data types. You can control how the MATLAB Function block handles Simulink input signals using the **Treat these inherited Simulink signal types as fi objects** parameter.

Property	Description
Treat these inherited Simulink signal types as fi objects	<p>Determines whether to treat inherited fixed-point and integer signals as Fixed-Point Toolbox™ fi objects.</p> <ul style="list-style-type: none"> <li>• When you select Fixed-point, the MATLAB Function block treats all fixed-point inputs as Fixed-Point Toolbox fi objects.</li> <li>• When you select Fixed-Point &amp; Integer, the MATLAB Function block treats all fixed-point and integer inputs as Fixed-Point Toolbox fi objects.</li> </ul>

**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	<p>When you select this option, the block uses the same fimath properties as the current global fimath. The edit box appears dimmed and displays the current global fimath in read-only form.</p> <p>For more information on the global fimath, see in the Fixed-Point Toolbox documentation.</p>



Setting	Description
Specify other	<p>When you select this option, you can specify your own <code>fimath</code> object in the edit box. You can do so in one of two ways:</p> <ul style="list-style-type: none"> <li>• Constructing the <code>fimath</code> object inside the edit box.</li> <li>• Constructing the <code>fimath</code> 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” in the Fixed-Point Toolbox documentation for more information.</li> </ul> <p>For more information on <code>fimath</code> objects, see “Working with <code>fimath</code> Objects” in the Fixed-Point Toolbox documentation.</p>

**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

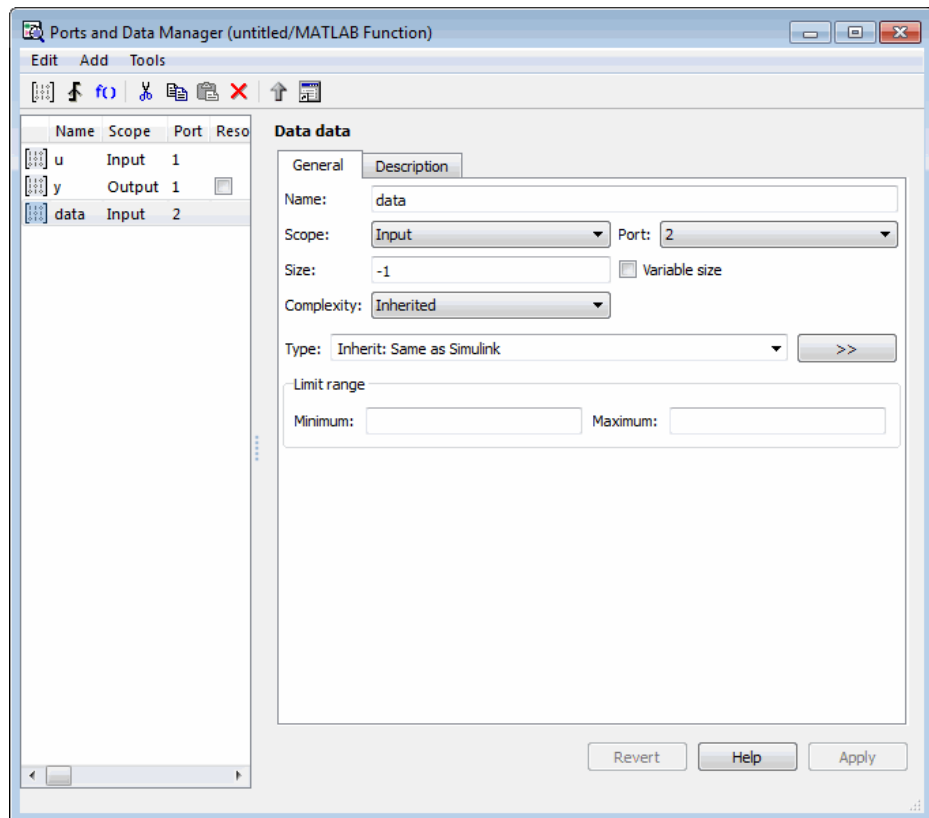
You can define data arguments for MATLAB Function blocks using the following methods:

<b>Method</b>	<b>For Defining</b>	<b>Reference</b>
Define data directly in the MATLAB Function block code	Input and output data	See “Defining Inputs and Outputs” on page 26-12.
Use the Ports and Data Manager	Input, output, and parameter data in the MATLAB Function block that is open and has focus	See “Defining Data in the Ports and Data Manager” on page 26-34.
Use the Model Explorer	Input, output, and parameter data in MATLAB Function blocks at all levels of the model hierarchy	See “Defining Data in the Model Explorer” on page 26-35

**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**.

**Defining Data in the Model Explorer.** The Data properties dialog in the Model Explorer allows you to set and modify the properties of data arguments in MATLAB Function blocks. Properties vary according to the scope and type of the data object. Therefore, the Data properties dialog is dynamic, displaying only the property fields that are relevant for the data argument you are defining.


Open the Data properties dialog by selecting a data argument in the Contents pane. The Data properties dialog provides a set of tabbed panes for defining different features of your data argument:

- The **General** tab lets you define the scope, size, complexity, type, and limit range of the data argument. See “Setting General Properties” on page 26-36.
- The **Description** tab lets you save values to the base workspace, enter a description, and link to documentation about the data argument. See “Setting Description Properties” on page 26-39.

**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 (see “Naming Variables” in the MATLAB documentation).
Scope	<p>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:</p> <ul style="list-style-type: none"> <li>• <b>Parameter</b>— Specifies that the source for this data is a variable of the same name in the MATLAB or model workspace or in the workspace of a masked subsystem containing this block. If a variable of the same name exists in more than one of the workspaces visible to the block, the variable closest to the block in the workspace hierarchy is used (see “Using Model Workspaces” on page 3-67).</li> <li>• <b>Input</b>— Data provided by the model via an input port to the MATLAB Function block.</li> <li>• <b>Output</b>— Data provided by the MATLAB Function block via an output port to the model.</li> <li>• <b>Data Store Memory</b>— Data provided by a Data Store Memory block in the model.</li> </ul>

Property	Description
	For more information, see “Defining Inputs and Outputs” on page 26-12 and “Parameter Arguments in MATLAB Function Block Functions” on page 26-72.
<b>Port</b>	Index of the port associated with the data argument. This property applies only to input and output data.
<b>Tunable</b>	Indicates whether the parameter used as the source of this data item is tunable (see “Tunable Parameters” on page 2-9). This property applies only to parameter data. 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” in the Code Generation from MATLAB documentation).
<b>Data must resolve to Simulink signal object</b>	Specifies that the data argument must resolve to a Simulink signal object. This property applies only to output data. See “Resolving Symbols” on page 3-76 for more information.
<b>Size</b>	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 26-69. This property does not apply to Data Store Memory data. For more details, see “Sizing Function Arguments” on page 26-69.
<b>Variable Size</b>	Indicates whether the size of this data item is variable (see “Using Variable-Size Data in MATLAB Function Blocks” on page 26-86). This property does not apply to Data Store Memory data.
<b>Complexity</b>	Indicates real or complex data arguments. You can set complexity to one of the following values: <ul style="list-style-type: none"> <li>• <b>Off</b>— Data argument is a real number</li> <li>• <b>On</b>— Data argument is a complex number</li> <li>• <b>Inherited</b>— 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.</li> </ul>

Property	Description
<b>Sampling mode</b>	<p>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:</p> <ul style="list-style-type: none"> <li>• <b>Sample based</b>: Propagate the signal sample by sample (default)</li> <li>• <b>Frame based</b>: Propagate the signal in batches of samples</li> </ul>
<b>Type</b>	<p>Type of data object. You can specify the data type by:</p> <ul style="list-style-type: none"> <li>• Selecting a built-in type from the <b>Type</b> drop down list.</li> <li>• Entering an expression in the <b>Type</b> field that evaluates to a data type (see “Working with Data Types” on page 27-2 in the Simulink® User’s Guide on page 1).</li> <li>• Using the Data Type Assistant to specify a data <b>Mode</b>, then specifying the data type based on that mode.</li> </ul> <hr/> <p><b>Note</b> To display the Data Type Assistant, click the Show data type assistant button:</p> <div data-bbox="399 928 555 986" style="text-align: center;">  </div> <hr/> <p>For more information, see “Specifying Argument Types” on page 26-60.</p>
<b>Lock data type setting against changes by the fixed-point tools</b>	<p>Specify whether you want to prevent replacement of the current data type with a type chosen by the Fixed-Point Tool or Fixed-Point Advisor. The default setting allows replacement. See Scaling in the Simulink Fixed Point documentation for instructions on autoscaling fixed-point data.</p>
<b>Limit range</b>	<p>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.</p> <ul style="list-style-type: none"> <li>• <b>Minimum</b> — The smallest value allowed for the data item during simulation. The default value is <code>-inf</code>.</li> </ul>

Property	Description
	<ul style="list-style-type: none"> <li>• <b>Maximum</b> — The largest value allowed for the data item during simulation. The default value is <code>inf</code>.</li> </ul>

**Setting Description Properties.** You can set the following properties on the Description tab:

Property	Description
<b>Save final value to base workspace</b>	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.
<b>Description</b>	Description of the data argument.
<b>Document link</b>	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, <b>Document link</b> , displayed at the bottom of the <b>Data</b> 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 6-17 in the Simulink documentation.

You can define the following types of triggers in MATLAB Function blocks:

- Rising
- Falling
- Either (rising or falling)
- Function call

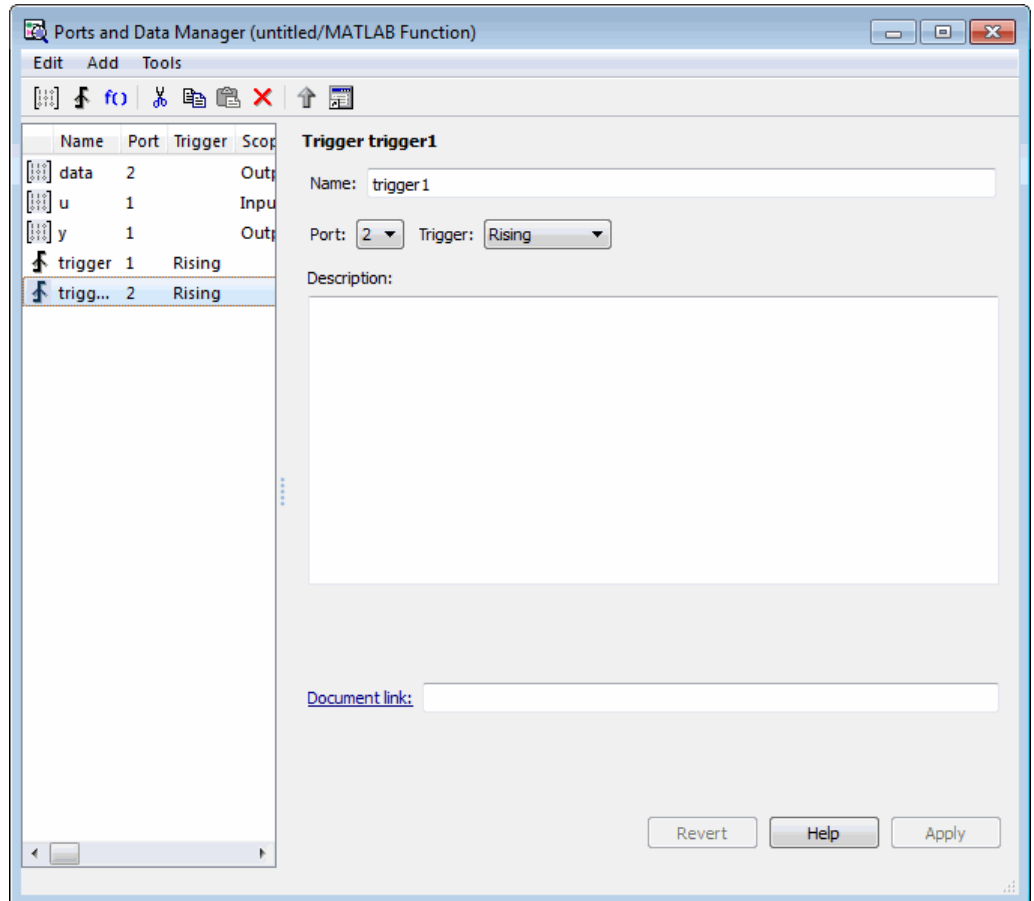
For a description of each trigger type, see “Setting Input Trigger Properties” on page 26-42.

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
<b>Name</b>	Name of the input trigger, following the same naming conventions used in MATLAB (see “Naming Variables” in the MATLAB documentation).
<b>Port</b>	Index of the port associated with the input trigger. The default value is 1.
<b>Trigger</b>	Type of event that triggers execution of the MATLAB Function block. You can select one of the following types of triggers: <ul style="list-style-type: none"> <li>• <b>Rising</b> (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).</li> <li>• <b>Falling</b>— 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).</li> <li>• <b>Either</b>— Triggers execution of the MATLAB Function block when the control signal is either rising or falling.</li> <li>• <b>Function call</b>— Triggers execution of the MATLAB Function block from a block that outputs function-call events, or from an S-function</li> </ul>
<b>Description</b>	Description of the input trigger.
<b>Document link</b>	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 <b>Document link</b> displayed at the bottom of the <b>Trigger</b> properties dialog, the MATLAB Function block evaluates the link and displays the documentation.

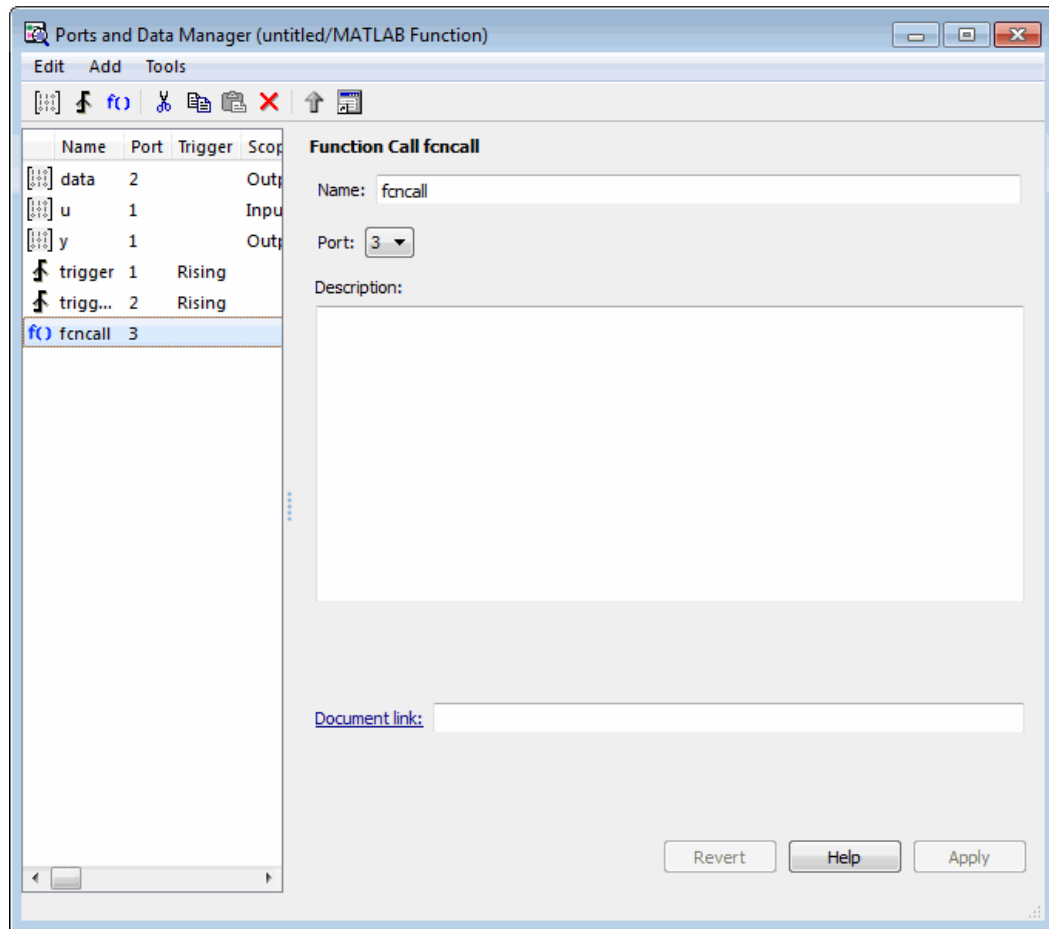
## **Adding Function Call Outputs to a MATLAB Function Block**

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 6-26 in the Simulink documentation.

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:

<b>Property</b>	<b>Description</b>
<b>Name</b>	Name of the function call output, following the same naming conventions used in MATLAB (see in the MATLAB documentation).
<b>Port</b>	Index of the port associated with the function call output. Function call output ports are numbered sequentially after input and output ports.
<b>Description</b>	Description of the function call output.
<b>Document link</b>	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 <b>Document link</b> displayed at the bottom of the <b>Function Call</b> properties dialog, the MATLAB Function block evaluates the link and displays the documentation.

## Working with MATLAB Function Reports

### In this section...

- “About MATLAB Function Reports” on page 26-46
- “Location of MATLAB Function Reports” on page 26-46
- “Opening MATLAB Function Reports” on page 26-47
- “Description of MATLAB Function Reports” on page 26-47
- “Viewing Your MATLAB Function Code” on page 26-47
- “Viewing Call Stack Information” on page 26-49
- “Viewing the Compilation Summary Information” on page 26-49
- “Viewing Error and Warning Messages” on page 26-49
- “Viewing Variables in Your MATLAB Code” on page 26-51
- “Keyboard Shortcuts for the MATLAB Function Report” on page 26-57
- “Report Limitations” on page 26-58

### 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** 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 **Tools > Open MATLAB Function Report** .
- In the **Diagnostics Manager** 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 Subfunctions

The report annotates the subfunction with the name of the parent function in the list of functions on the **MATLAB code** tab.

For example, if the MATLAB function `fcn1` contains the subfunction `subfcn` and `fcn2` contains the subfunction `subfcn2`, the report displays:

```
fcn1 > subfcn1  
fcn2 > subfcn2
```

### Viewing Specializations

If your 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 subfunctions that each function calls.

### Viewing Function Call Sites in the Callers List

If a function is called from more than one function, this list provides details of each call site. To navigate between call sites, select a call site from the **Callers** list. If the function is not called more than once, this list is disabled.

## Viewing the Compilation Summary Information

To view a summary of the compilation results, including type of target and number of errors or warnings, click the **Summary** tab.

## Viewing Error and Warning Messages

The 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.

- Highlighting all errors and warnings in the MATLAB code pane

### Viewing Errors and Warnings in the All Messages Tab

If errors or warnings occurred during compilation, click the **All Messages** tab to view a complete list of these messages. The report lists the messages in the order that the compiler detects them. It is best practice to address the first message in the list, because often subsequent errors and warnings are related to the first message. The report marks messages as follows:

 Error

 Warning

To locate the offending line of code for an error or warning in the list, click the message in the list. The 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.

---

Function: stats
Callers: Select a function caller:

```



1 function [mean, stdev] = stats(vals)
2 %#codegen
3
4 % Calculates a statistical mean and a standard deviation
5 % for the values in vals
6
7 coder.extrinsic('plot');
8
9 len = length(vals);
10 mean = avg(vals, len);
11 stdev = sqrt(sum((vals - avg(vals, len)).^2)/len);
12 plot(vals, '-+');
13

```

Summary

All Messages (2)

Variables

Order	Type	Function	Line	Description
1		stats	10	Undefined function or variable 'avg'.
2		stats	11	Undefined function or variable 'avg'.

## 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” in the Fixed-Point Toolbox documentation.
- Signed — sign information for built-in data types, signedness information for fixed-point data types
- Word length (WL) — for fixed-point data types only
- Fraction length (FL) — for fixed-point data types only

---

**Note** For more information on viewing fixed-point data types, see “Working with Fixed-Point Code Generation Reports” in the Fixed-Point Toolbox documentation.

---

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.

Summary	All Messages (0)	Variables				
Order	Variable	Type	Size	Complex	Class	
☐ 1	s	Output	1 x 1	-	struct	
1.1	s.a	Field	1 x 1	No	double	
1.2	s.b	Field	1 x 1	No	double	
2	a	Input	1 x 1	No	double	
3	b	Input	1 x 1	No	double	


If you sort the variables by type, size, complexity or class, a structure and its fields might not appear sequentially in the list. To restore the list to the original order, click the **Order** column heading.

**Viewing Information About Variable-Size Arrays in the Variables Tab.** For variable-size arrays, the **Size** field includes information on the computed maximum size of the array. The size of each array dimension that varies is prefixed with a colon **:**.

In the following report, variable *A* is variable-size. Its maximum computed size is 1×100.

Summary		All Messages (0)	Variables			
Order	Variable	Type	Size	Complex	Class	
1	B	Output	1 x :100	No	double	
2	A	Input	1 x :100	No	double	
3	tol	Input	1 x 1	No	double	
4	k	Local	1 x 1	No	double	
5	i	Local	1 x 1	No	double	

If the code generation software cannot compute the maximum size of a variable-size array, the report displays the size as :?.

Summary		All Messages (1)	Variables			
Order	Type	Function	Line	Description		
1		emldemo_uniquetol	10	Computed maximum size is not bounded. Static memory allocation requires all sizes to be bounded. The computed size is [1 x :?]. This error may be reported due to a limitation of the underlying analysis.		

If you declare a variable-size array and then subsequently fix the dimensions of this array in the code, the report appends \* to the size of the variable. In the generated C code, this variable appears as a variable-size array, but the size of its dimensions do not change during execution.

Summary		All Messages (0)	Variables	Target Build Log		
Order	Variable	Type	Size	Complex	Class	
1	y	Output	1 x 10 *	No	double	

For more information on how to use the size information for variable-sized arrays, see “How Working with Variable-Size Data Is Different for Code Generation” in the Code Generation from MATLAB documentation.

**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 “Reusing the Same Variable with Different Properties” in the Code Generation from MATLAB documentation. 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.

```

6  if all(all(u))
7      % First time t is used to hold a scalar double value
8      t = mean(mean(u)) / numel(u);
9      u = u - t;
10 end

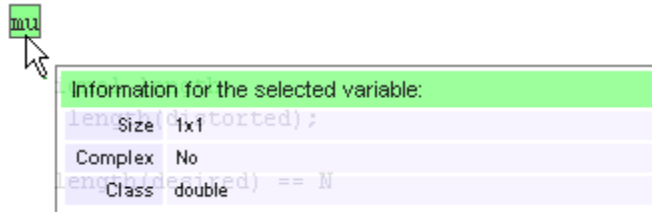
```

Summary	All Messages (0)	Variables				
Order	Variable	Type	Size	Complex	Class	
1	u	Input	5 x 5	No	double	
2	t > 1	Local	5 x 5	No	double	
3	t > 2	Local	1 x 1	No	double	

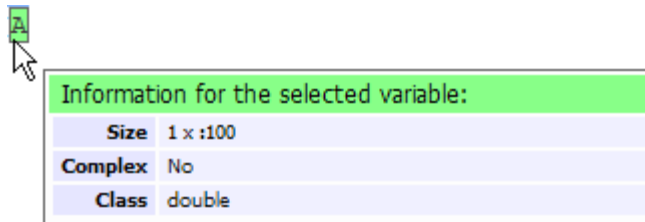
## Viewing Information About Variables and Expressions in Your MATLAB Function Code

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:

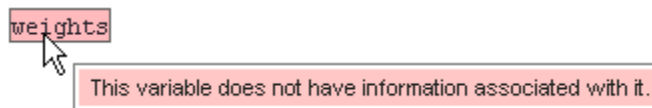
**Green, when the variable has data type information at this location in the code.**



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`.

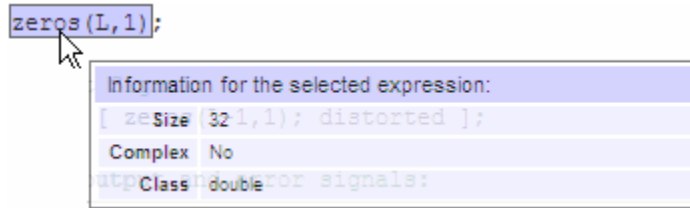


**Pink, when the variable has no data type information.**

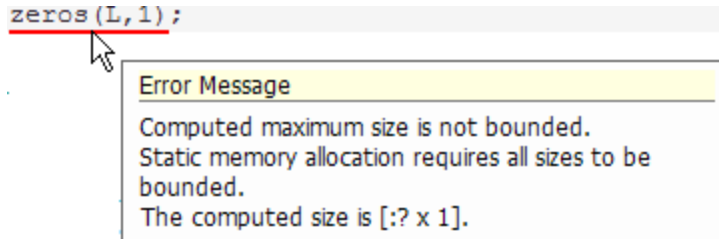


**Purple, information about expressions.** You can also view information about expressions in your MATLAB code. On the MATLAB code pane, place your pointer over an expression. The report highlights expressions in purple and provides more detailed information.





**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];
```

## Typing Function Arguments

### In this section...

“About Function Arguments” on page 26-60

“Specifying Argument Types” on page 26-60

“Inheriting Argument Data Types” on page 26-62

“Built-In Data Types for Arguments” on page 26-63

“Specifying Argument Types with Expressions” on page 26-64

“Specifying Simulink® Fixed Point™ Data Properties” on page 26-64

### 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*.

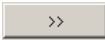
By default, the data type mode for MATLAB Function block function arguments is **Inherited**. This means that the function argument inherits its data type from the incoming or outgoing signal. To override the default type, you first choose a data type mode and then select a data type based on the mode. The following procedure describes how to use the Model Explorer to set data types for function arguments. You can also use the Ports and Data Manager tool (see “Ports and Data Manager” on page 26-27).

### Specifying Argument Types

To specify the type of a MATLAB Function block function argument:

- 1 From the MATLAB Function Block Editor, select **Tools > Model Explorer**.

Model Explorer appears with the MATLAB Function block highlighted in the **Model Hierarchy** pane.

- 2 In the **Contents** pane (in the middle), click the row containing the argument of interest.
- 3 In the **Data** properties dialog (on the right), click the Show data type assistant button  to display the Data Type Assistant. Then, choose an option from the **Mode** drop-down menu.

The **Data** properties dialog changes dynamically to display additional fields for specifying the data type associated with the mode.

- 4 Based on the mode you select, specify a desired data type:

Mode	What to Specify
Inherit (default)	<p>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:</p> <ul style="list-style-type: none"> <li>• If scope is <b>Input</b>, data type is inherited from the input signal on the designated port.</li> <li>• If scope is <b>Output</b>, data type is inherited from the output signal on the designated port.</li> <li>• If scope is <b>Parameter</b>, data type is inherited from the associated parameter, which can be defined in the Simulink masked subsystem or the MATLAB workspace.</li> </ul> <p>See “Inheriting Argument Data Types” on page 26-62.</p>
Built in	<p>In the <b>Data type</b> field, select from the drop-down list of supported data types, as described in “Built-In Data Types for Arguments” on page 26-63.</p>
Fixed point	<p>Specify the fixed-point data properties as described in “Specifying Simulink® Fixed Point™ Data Properties” on page 26-64.</p>

Mode	What to Specify
Expression	Enter an expression that evaluates to a data type, as described in “Specifying Argument Types with Expressions” on page 26-64.
Bus Object	<p>In the <b>Bus object</b> field, enter the name of a <code>Simulink.Bus</code> object to define the properties of a MATLAB structure. You must define the bus object in the base workspace. See “Working with Structures and Bus Signals” on page 26-75.</p> <hr/> <p><b>Note</b> You can click the <b>Edit</b> button to create or modify <code>Simulink.Bus</code> objects using the Simulink Bus Editor (see “Using the Bus Editor” on page 32-18 in the Simulink User’s Guide).</p>

## 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. Select the argument of interest in the Contents pane of the Model Explorer or Ports and Data Manager, and set data type mode using one of these methods:

- In the **Data** properties dialog, select **Inherit: Same as Simulink** from the **Type** drop-down menu.
- In the Contents pane, set the **Data Type** column to **Inherit: Same as Simulink**.

See “Built-In Data Types for Arguments” on page 26-63 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 Model Explorer or 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 **Contents** pane of the Model Explorer or Ports and Data Manager. The supported data types are:

Data Type	Description
<code>double</code>	64-bit double-precision floating point
<code>single</code>	32-bit single-precision floating point
<code>int32</code>	32-bit signed integer
<code>int16</code>	16-bit signed integer
<code>int8</code>	8-bit signed integer
<code>uint32</code>	32-bit unsigned integer
<code>uint16</code>	16-bit unsigned integer
<code>uint8</code>	8-bit unsigned integer
<code>boolean</code>	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 Model Explorer or Ports and Data Manager. Follow these steps:

- 1 Select `<data type expression>` from the **Type** drop-down menu of the Data properties dialog.
- 2 In the **Type** field, replace “`<data type expression>`” with an expression that evaluates to a data type. The following expressions are allowed:
  - Alias type from the MATLAB workspace, as described in “Creating a Data Type Alias” in the Simulink reference documentation.
  - `fixdt` function to create a `Simulink.NumericType` object describing a fixed-point or floating-point data type
  - `type` operator, to base the type on previously defined data

In the following figure, the data type of input argument `data1` is `int32`. The data type of input argument `data2` is based on `data1` using the expression `type(data1)`.

When the model is compiled, the actual type of `data2` appears in the **Compiled Type** column in the **Contents** pane:

The screenshot shows the MATLAB Function Block Properties dialog. On the left is the **Contents** pane with the following table:

	Narr	Scope	Port	Data Type	Compiled Type
	vals	Input	1	Inherit: Same as Simulink	double
	stdev	Out...	2	Inherit: Same as Simulink	double
	mean	Out...	1	Inherit: Same as Simulink	double
	data2	Input	2	type(data1)	int32
	data1	Input	3	int32	int32

The **General** tab of the dialog is also shown, with the following settings:

- Name: data2
- Scope: Input
- Port: 2
- Size: -1
- Complexity: Inherited
- Type: type(data1)
- Limit range: Minimum: , Maximum:

## 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



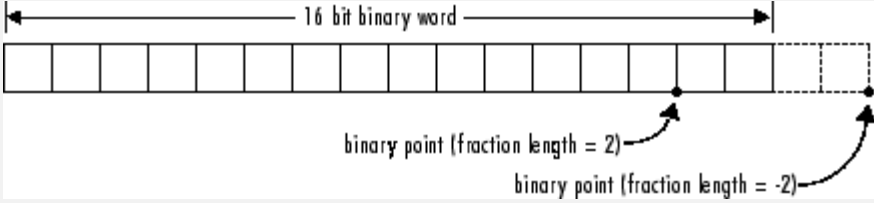
MATLAB Function blocks, you must install the Simulink Fixed Point product on your system (see in the Simulink Fixed Point documentation).

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)	<p>If you select this mode, the Data Type Assistant displays the <b>Fraction Length</b> field, specifying the binary point location.</p> <p>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:</p> 

Scaling Mode	Description
	The default is 0.
Slope and bias	<p>If you select this mode, the Data Type Assistant displays fields for entering the <b>Slope</b> and <b>Bias</b>.</p> <ul style="list-style-type: none"> <li>• Slope can be any <i>positive</i> real number. The default is 1.0.</li> <li>• Bias can be any real number. The default value is 0.0.</li> </ul> <p>You can enter slope and bias as expressions that contain parameters defined in the MATLAB workspace.</p>

---

**Note** You should use binary-point scaling whenever possible to simplify the implementation of fixed-point data in generated code. Operations with fixed-point data using binary-point scaling are performed with simple bit shifts and eliminate the expensive code implementations required for separate slope and bias values.

---

**Data type override.** Specify whether the data type override setting is Inherit (default) or Off.

**Calculate Best-Precision Scaling.** The Simulink software can automatically calculate “best-precision” values for both Binary point and Slope and bias scaling, based on the Limit range properties you specify on the **Value Attributes** tab.

To automatically calculate best precision scaling values:

- 1 Select the **Value Attributes** tab.
- 2 Specify **Minimum**, **Maximum**, or both Limit range properties.
- 3 Select the **General** tab.
- 4 Click **Calculate Best-Precision Scaling**.

The Simulink software calculates the scaling values, then displays them in either the **Fraction Length**, or **Slope** and **Bias** fields.

---

**Note** The Limit range properties do not apply to Constant or Parameter scopes. Therefore, 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. See “Scaling” in the Simulink Fixed Point documentation for instructions on autoscaling fixed-point data.

### **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 “Using the MATLAB Function Block with Data Type Override” in the Fixed-Point Toolbox User’s Guide for more information). You must check the data types of your inherited input signals and parameters and use the Ports and Data Manager (see “Ports and Data Manager” on page 26-27) to set explicit types for any inputs that should not be fixed-point. Some operations, such as `sin`, are not applicable to fixed-point objects.

---

**Note** If you do not set the correct input types explicitly, you may encounter compilation problems after setting Data Type Override.

---

### **How Do I Set Data Type Override?**

To set Data Type Override, follow these steps:

- 1** From the Simulink Tools menu, select **Fixed-Point Tool**.

The Fixed-Point Tool appears.

- 2** Set the value of the **Data type override** parameter to `Double` or `Single`.

## Sizing Function Arguments

In this section...
“Specifying Argument Size” on page 26-69
“Inheriting Argument Sizes from Simulink” on page 26-69
“Specifying Argument Sizes with Expressions” on page 26-70

### Specifying Argument Size

To examine or specify the size of an argument, follow these steps:

- 1 From the MATLAB Function Block Editor, select **Tools > Model Explorer** or **Tools > Edit Data/Ports**.
- 2 In the **Contents** pane, click the row that contains the data argument.
- 3 Enter the size of the argument in one of two places:
  - Size field of the Data properties dialog, located in the **Dialog** pane
  - Size column in the row that contains the data argument, located in the **Contents** pane

---

**Note** The default value is -1, indicating that size is inherited, as described in “Inheriting Argument Sizes from Simulink” on page 26-69.

---

### Inheriting Argument Sizes from Simulink

Size defaults to -1, which means that the data argument inherits its size from Simulink based on its scope:

For Scope	Inherits Size
Input	From the Simulink input signal connected to the argument.
Output	From the Simulink output signal connected to the argument.
Parameter	From the Simulink or MATLAB parameter to which it is bound. See “Parameter Arguments in MATLAB Function Block Functions” on page 26-72.

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

- The number of dimensions equals the length of the vector.
- The size of each dimension corresponds to the value of each element of the vector.

For example, a value of [2 4] defines a 2-by-4 matrix. To define a row vector of size 5, set the **Size** field to [1 5]. To define a column vector of size 6, set the **Size** field to [6 1] or just 6. You can enter a MATLAB expression for each [row column] element in the **Size** field. Each expression can use one or more of the following elements:

- Numeric constants

- Arithmetic operators, restricted to +, -, \*, and /
- Parameters defined in the MATLAB Workspace or the parent Simulink masked subsystem
- Calls to the MATLAB functions `min`, `max`, and `size`

The following examples are valid expressions for **Size**:

```
k+1  
size(x)  
min(size(y),k)
```

In these examples, `k`, `x`, and `y` are variables of scope **Parameter**.

Once you build the model, the **Compiled Size** column in the **Contents** pane displays the actual size used in the compiled simulation application.

## Parameter Arguments in MATLAB Function Block Functions

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.

Use the following procedure 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 “Simulink Mask Editor”.

- 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 **Tools > Model Explorer** or **Tools > Edit Data/Ports**.
- 4 In the **Contents** pane, click the row that contains the new argument.
- 5 Set **Scope** to **Parameter**.
- 6 Examine the 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. This lets you test functions in a MATLAB Function block by copying and pasting them to MATLAB.

---



## Resolving Signal Objects for Output Data

### In this section...

“Implicit Signal Resolution” on page 26-73

“Eliminating Warnings for Implicit Signal Resolution in the Model” on page 26-73

“Disabling Implicit Signal Resolution for a MATLAB Function Block” on page 26-74

“Forcing Explicit Signal Resolution for an Output Data Signal” on page 26-74

### 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 in the Reference documentation.

By default, implicit signal resolution generates a warning when you update the chart in the Simulink model. The following sections show you how to manage implicit signal resolution at various levels of the model hierarchy. See “Resolving Symbols” on page 3-76 and “Explicit and Implicit Symbol Resolution” on page 3-79 for more information.

### Eliminating Warnings for Implicit Signal Resolution in the Model

To enable implicit signal resolution for all signals in a model, but eliminate the attendant warnings, follow these steps:

- 1 In the Simulink Model Editor, select **Simulation > Configuration Parameters**.

The Configuration Parameters dialog appears.

- 2** In the left pane of the Configuration Parameters dialog, under Diagnostics, select **Data Validity**.

Data Validity configuration parameters appear in the right pane.

- 3** In the Signal resolution field, select **Explicit and implicit**.

## **Disabling Implicit Signal Resolution for 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 **Subsystem Parameters** in the context menu.

The Block Parameters dialog opens.

- 2** In the Permit hierarchical resolution field, select **ExplicitOnly** or **None**, and click **OK**.

## **Forcing Explicit Signal Resolution for an Output Data Signal**

To force signal resolution for an output signal in 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 **Signal Properties** from the context menu.
- 2** In the Signal Properties dialog, enter a name for the signal that corresponds to the signal object.
- 3** Select the **Signal name must resolve to Simulink signal object** check box and click **OK**.

## Working with Structures and Bus Signals

### In this section...

“About Structures in MATLAB Function Blocks” on page 26-75

“Example of Structures in a MATLAB Function Block” on page 26-76

“How Structure Inputs and Outputs Interface with Bus Signals” on page 26-78

“Rules for Defining Structures in MATLAB Function Blocks” on page 26-79

“Workflow for Creating Structures in MATLAB Function Blocks” on page 26-79

“Indexing Substructures and Fields” on page 26-81

“Assigning Values to Structures and Fields” on page 26-81

“Working with Structure Parameters in MATLAB Function Blocks” on page 26-83

“Limitations of Structures and Buses in MATLAB Function Blocks” on page 26-85

### About 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 “Combining Buses into an Array of Buses” on page 32-75). You can also define structures inside MATLAB functions that are not part of MATLAB Function blocks (see “Code Generation for MATLAB Structures”).

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 “Workflow for Creating Structures in MATLAB Function Blocks” on page 26-79.
Output	Create structure data with scope of Output.	
Local	Create a local variable implicitly in a MATLAB function.	See “Defining Scalar Structures for Code Generation”.
Persistent	Declare a variable to be persistent in a MATLAB function.	See “Making Structures Persistent”.
Parameter	Create structure data with scope of Parameter	See “Working with Structure Parameters in MATLAB Function Blocks” on page 26-83.

Structures in MATLAB Function blocks can contain fields of any type and size, including muxed signals, buses, and arrays of structures.

### Example of Structures in a MATLAB Function Block




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 `e1e1`, `e1e2`, and `e1e3`. The signal `e1e3` 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 `e1e3` of structure `inbus`.

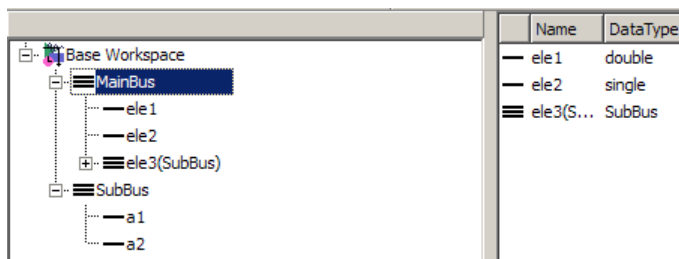
## Structure Definitions in Example

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	Data Type	Compiled Type
	<code>inbus</code>	Input	1	<input type="checkbox"/>	Inherit: Same as Simulink	MainBus
	<code>outbus</code>	Output	1	<input type="checkbox"/>	Bus: MainBus	MainBus
	<code>outbus1</code>	Output	2	<input type="checkbox"/>	Bus: SubBus	SubBus

## Bus Objects Define Structure Inputs and Outputs

Each structure input and output must be defined by a `Simulink.Bus` object in the base workspace (see “Workflow for Creating Structures in MATLAB Function Blocks” on page 26-79). This means that the structure shares the same properties as the bus object, including number, name, type, and sequence of fields. In this example, the following bus objects define the structure inputs and outputs:



The `Simulink.Bus` object `MainBus` defines structure input `inbus` and structure output `outbus`. The `Simulink.Bus` object `SubBus` defines structure output `outbus1`. Based on these definitions, `inbus` and `outbus` have the same properties as `MainBus` and, therefore, reference their fields by the same names as the fields in `MainBus`, using dot notation (see “Indexing Substructures and

Fields” on page 26-81). 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
<code>inbus</code>	<code>inbus.ele1</code>	<code>inbus.ele2</code>	<code>inbus.ele3</code>
<code>outbus</code>	<code>outbus.ele1</code>	<code>outbus.ele2</code>	<code>outbus.ele3</code>
<code>outbus1</code>	<code>outbus1.a1</code>	<code>outbus1.a2</code>	—

To learn how to define structures in MATLAB Function blocks, see “Workflow for Creating Structures in MATLAB Function Blocks” on page 26-79.

## 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 32-56 in the Simulink User’s Guide). 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 26-78).

## Workflow for Creating 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 “About Structures in MATLAB Function Blocks” on page 26-75).
- 2 Based on the scope, follow these guidelines for creating the structure:

For Structure Scope:	Follow These Steps:
Input	<ol style="list-style-type: none"> <li>1 Create a <code>Simulink.Bus</code> object in the base workspace to define the structure input.</li> <li>2 Add data to the MATLAB Function block, as described in “Adding Data to a MATLAB Function Block” on page 26-33. The data should have the following properties <ul style="list-style-type: none"> <li>• <b>Scope</b> = Input</li> <li>• <b>Type</b> = Bus: &lt;object name&gt;</li> </ul> </li> </ol>

<b>For Structure Scope:</b>	<b>Follow These Steps:</b>
	<p>For &lt;object name&gt;, enter the name of the Simulink.Bus object that defines the structure input</p> <p>See “Rules for Defining Structures in MATLAB Function Blocks” on page 26-79.</p>
Output	<ol style="list-style-type: none"> <li><b>1</b> Create a Simulink.Bus object in the base workspace to define the structure output.</li> <li><b>2</b> Add data to the MATLAB Function block with the following properties: <ul style="list-style-type: none"> <li>• <b>Scope</b> = Output</li> <li>• <b>Type</b> = Bus: &lt;object name&gt;</li> </ul> <p>For &lt;object name&gt;, enter the name of the Simulink.Bus object that defines the structure output</p> </li> <li><b>3</b> Define and initialize the output structure implicitly as a variable in the MATLAB function, as described in “Code Generation for MATLAB Structures” in the Code Generation from MATLAB documentation.</li> <li><b>4</b> Make sure the number, type, and size of fields in the output structure variable definition match the properties of the Simulink.Bus object.</li> </ol>
Local	<p>Define the structure implicitly as a local variable in the MATLAB function, as described in “Code Generation for MATLAB Structures” in the Code Generation from MATLAB documentation. By default, local variables in MATLAB Function blocks are temporary.</p>
Persistent	<p>Define the structure implicitly as a persistent variable in the MATLAB function, as described in “Making Structures Persistent” in the Code Generation from MATLAB documentation.</p>
Parameter	<ol style="list-style-type: none"> <li><b>1</b> Create a structure variable in the base workspace.</li> <li><b>2</b> Add data to the MATLAB Function block with the following properties: <ul style="list-style-type: none"> <li>• <b>Name</b> = same name as the structure variable you created in step 1.</li> <li>• <b>Scope</b> = Parameter</li> </ul> <p>See “Working with Structure Parameters in MATLAB Function Blocks” on page 26-83.</p> </li> </ol>



## Indexing 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 “How Working with Structures Is Different for Code Generation” in the Code Generation from MATLAB documentation).

For example, in the `emldemo_bus_struct` model described in “Example of Structures in a MATLAB Function Block” on page 26-76, 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
<code>substruct.a1</code>	Field <code>a1</code> of local structure <code>substruct</code>
<code>inbus.ele3.a1</code>	Value of field <code>a1</code> of field <code>ele3</code> , a substructure of structure <code>inputinbus</code>
<code>inbus.ele3.a2(1,1)</code>	Value in row 1, column 1 of field <code>a2</code> of field <code>ele3</code> , a substructure of structure <code>input inbus</code>

## Assigning Values to Structures and Fields

You can assign values to any structure, substructure, or field in a MATLAB Function block. Here are the guidelines:

<b>Operation</b>	<b>Conditions</b>
Assign one structure to another structure	You must define each structure with the same number, type, and size of fields, either as <code>Simulink.Bus</code> objects in the base workspace or locally as implicit structure declarations (see “Workflow for Creating Structures in MATLAB Function Blocks” on page 26-79).
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 <code>Simulink.Bus</code> objects in the base workspace or locally as implicit structure declarations.
Assign an element of one structure to an element of another structure	The elements must have the same type and size.

For example, the following table presents valid and invalid structure assignments based on the specifications for the model described in “Example of Structures in a MATLAB Function Block” on page 26-76:

<b>Assignment</b>	<b>Valid or Invalid?</b>	<b>Rationale</b>
<code>outbus = mystruct;</code>	Valid	Both <code>outbus</code> and <code>mystruct</code> have the same number, type, and size of fields. The structure <code>outbus</code> is defined by the <code>Simulink.Bus</code> object <code>MainBus</code> and <code>mystruct</code> is defined locally to match the field properties of <code>MainBus</code> .
<code>outbus = inbus;</code>	Valid	Both <code>outbus</code> and <code>inbus</code> are defined by the same <code>Simulink.Bus</code> object, <code>MainBus</code> .
<code>outbus1 = inbus.ele3;</code>	Valid	Both <code>outbus1</code> and <code>inbus.ele3</code> have the same type and size because each is defined by the <code>Simulink.Bus</code> object <code>SubBus</code> .
<code>outbus1 = inbus;</code>	Invalid	The structure <code>outbus1</code> is defined by a different <code>Simulink.Bus</code> object than the structure <code>inbus</code> .

## Working with Structure Parameters in MATLAB Function Blocks

### 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 Chapter 21, “Working with Block Parameters”.

- 2 In the Ports and Data Manager or Model Explorer, 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

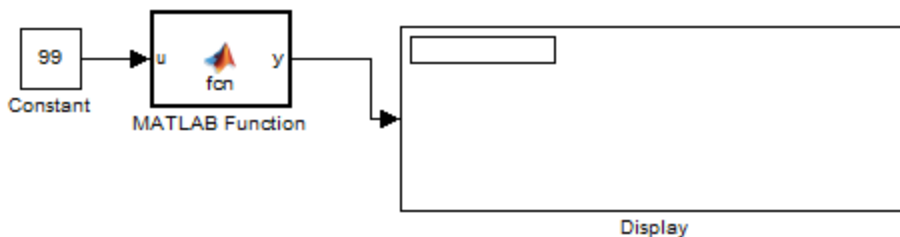
- 3 Click **Apply**.

### FIMATH Properties of Non-Tunable Structure Parameters

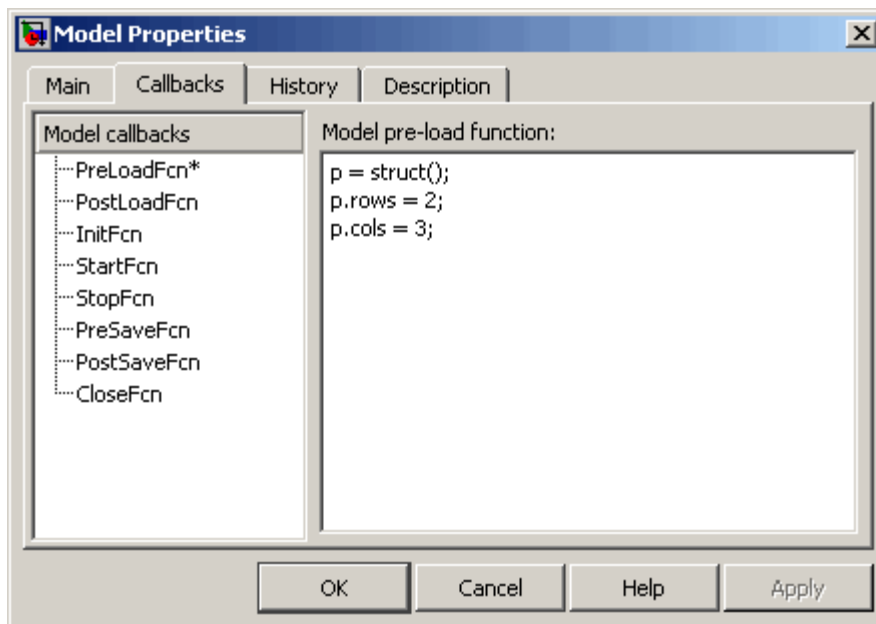
FIMATH properties for non-tunable structure parameters containing fixed-point values are based on the initial values of the structure. They do *not* come from the FIMATH properties specified for fixed-point input signals to the parent MATLAB Function block. (These FIMATH properties appear in the properties dialog box for MATLAB Function blocks.)

### Example: Using a Non-Tunable Structure Parameter to Initialize a Matrix

The following simple example uses a non-tunable structure parameter input to initialize a matrix output. The model looks like this:



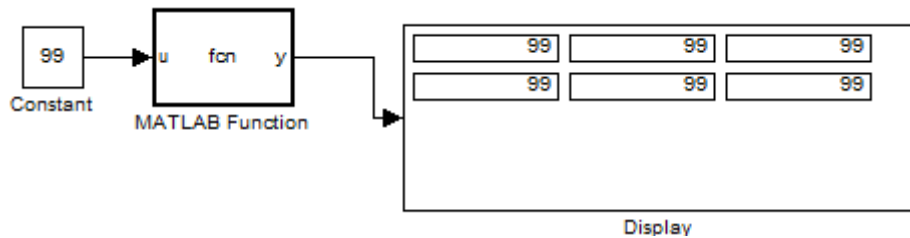
This model defines a structure variable `p` in its pre-load callback function, as follows:



The structure `p` has two fields, `rows` and `cols`, which specify the dimensions of a matrix. The MATLAB Function block uses a constant input `u` to initialize the matrix output `y`. Here is the code:

```
function y = fcn(u, p)
y = zeros(p.rows,p.cols) + u;
```

Running the model initializes each element of the 2-by-3 matrix `y` to 99, the value of `u`:



## Limitations of Structures and Buses in MATLAB Function Blocks

- Structures in MATLAB Function blocks support a subset of the operations available for MATLAB structures (see “How Working with Structures Is Different for Code Generation” in the Code Generation from MATLAB documentation).
- You cannot use variable-size data with arrays of buses (see “Array of Buses Limitations” on page 32-79).

## Using Variable-Size Data in MATLAB Function Blocks

### In this section...

“What Is Variable-Size Data?” on page 26-86

“How MATLAB Function Blocks Implement Variable-Size Data” on page 26-86

“Enabling Support for Variable-Size Data” on page 26-86

“Declaring Variable-Size Inputs and Outputs” on page 26-87

“Declaring Variable-Size Data Locally” on page 26-87

“Simple Example: Defining and Using Variable-Size Data in MATLAB Function Blocks” on page 26-87

### 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 working with variable-size data, see “How Working with Variable-Size Data Is Different for Code Generation” in the Code Generation from MATLAB documentation. For more information about using variable-size data in Simulink, see Chapter 33, “Working with Variable-Size Signals” in the Simulink documentation.

### Enabling 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 **Tools > Edit Data/Ports**

The Ports and Data Manager dialog box opens.

- 2 Select or clear the check box **Support variable-size arrays**.

## Declaring Variable-Size Inputs and Outputs

- 1 In the MATLAB Function Block Editor, select **Tools > Edit Data/Ports**

The Ports and Data Manager dialog box opens.

- 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.

## Declaring Variable-Size Data Locally

Use the function coder.`varsize` to declare variable-size data locally, as described in “Defining Variable-Size Data for Code Generation” in the Code Generation from MATLAB documentation.

## Simple Example: Defining and Using Variable-Size Data in MATLAB Function Blocks

- “About the Example” on page 26-88
- “Simulink Model” on page 26-88

- “Source Signal” on page 26-89
- “MATLAB Function Block: uniquify” on page 26-89
- “MATLAB Function Block: avg” on page 26-91
- “Variable-Size Results” on page 26-93

### 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 <code>uniquify</code>	Filters out signal values that are not unique to within a specified tolerance of each other.
MATLAB Function <code>avg</code>	Outputs the average of a specified number of unique signal values.



Simulink Block	Description
Unique values	Scope that displays the unique signal values output from the <code>uniquify</code> function.
Average values	Scope that displays the average signal values output from the <code>avg</code> function.

### Source Signal

The band-limited white noise signal has these properties:

Parameters

Noise power:  
[0.1 0.2 0.3 0.4 0.5 0.6 0.1 0.2 0.3]

Sample time:  
0.1

Seed:  
[2223334]

Interpret vector parameters as 1-D

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  $\text{abs}(B(i) - B(j)) > \text{tol}$  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`:

**Data y**

General | Description

Name:

Scope:  Port:

Data must resolve to Simulink signal object

Size:   Variable size

Complexity:

Sampling mode:

Type:  <<

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:

<b>If number of signal values:</b>	<b>The MATLAB Function block:</b>
> 1 and divisible by 2	Averages every consecutive pair of values
> 1 but <i>not</i> 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

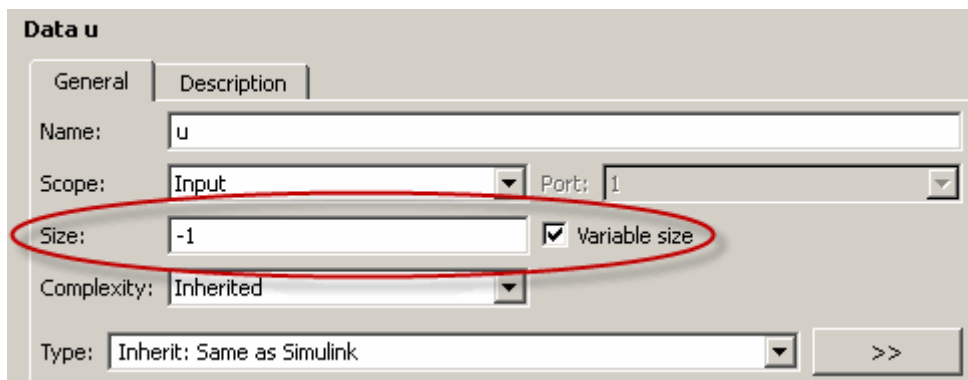
if numel(u) == 1
    y = u;
```

```

else
    k = numel(u)/2;
    if k ~= floor(k)
        u = u(2:numel(u));
    end
    y = nway(u,2);
end
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));

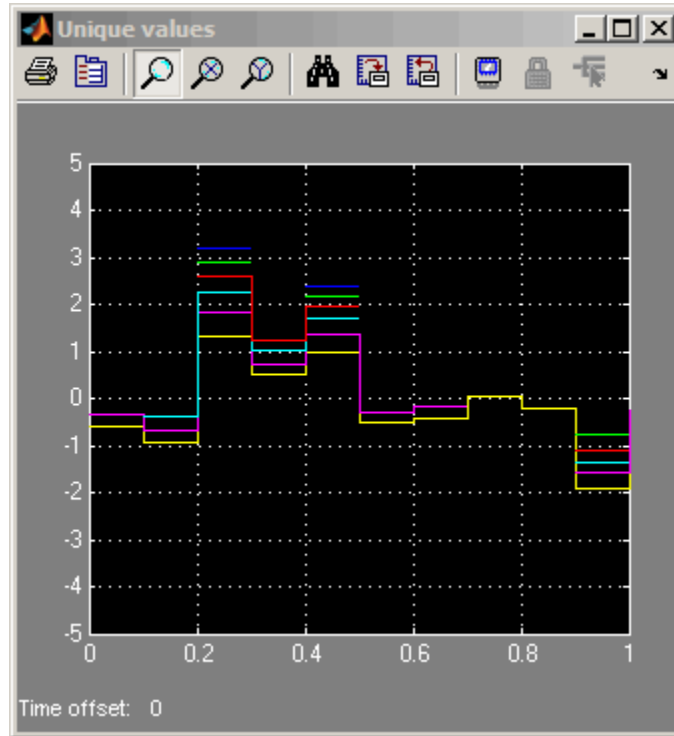
B = zeros(1,numel(A)/n);
k = 1;
for i = 1 : numel(A)/n
    B(i) = mean(A(k + (0:n-1)));
    k = k + n;
end

```

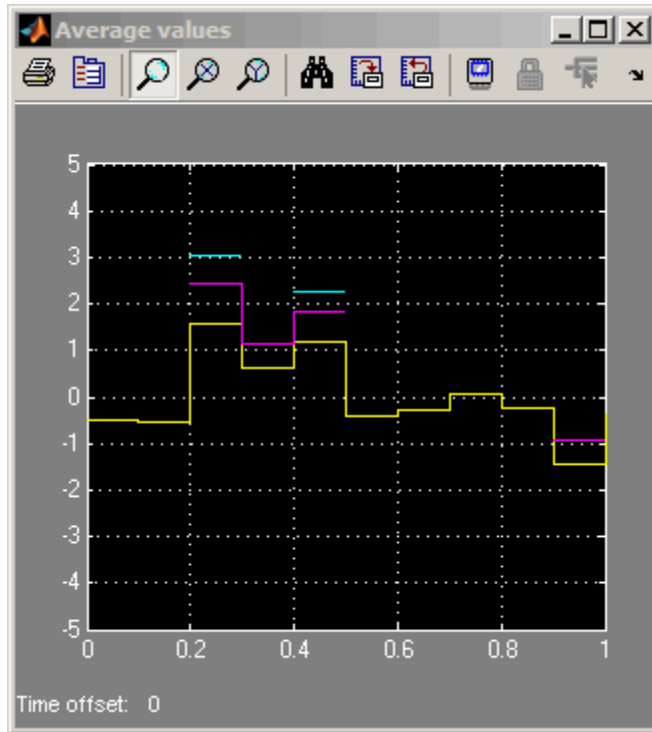
## Variable-Size Results

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:



## Using Enumerated Data in MATLAB Function Blocks

### In this section...

“Enumerated Data in MATLAB Function Blocks” on page 26-95

“When to Use Enumerated Data” on page 26-96

“Simple Example: Defining and Using Enumerated Types in MATLAB Function Blocks” on page 26-97

“Using Enumerated Data in MATLAB Function Blocks” on page 26-101

“How to Define Enumerated Data Types for MATLAB Function Blocks” on page 26-101

“How to Add Enumerated Data to MATLAB Function Blocks” on page 26-102

“How to Instantiate Enumerated Data in MATLAB Function Blocks” on page 26-104

“Operations on Enumerated Data” on page 26-104

“Limitations of Enumerated Types” on page 26-105

## Enumerated Data 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 27-6 in the Simulink documentation.

## When to Use Enumerated Data

You can use enumerated types to represent program states and to control program logic, especially when you need to restrict data to a finite set of values and refer to these values by name. Even though you can sometimes achieve these goals by using integers or strings, enumerated types offer the following advantages:

- Provide more readable code than integers
- Allow more robust error checking than integers or strings

For example, if you mistype the name of an element in the enumerated type, 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.

## Simple Example: Defining and Using Enumerated Types in MATLAB Function Blocks

- “About the Example” on page 26-97
- “Class Definition: switchmode” on page 26-98
- “Class Definition: led” on page 26-98
- “Simulink Model” on page 26-98
- “MATLAB Function Block: checkState” on page 26-99
- “How the Model Displays Enumerated Data” on page 26-100

### About the Example

The following example appears throughout this section to illustrate 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.

### See Also.

- “Using Enumerated Data in MATLAB Function Blocks” on page 26-101
- “How to Define Enumerated Data Types for MATLAB Function Blocks” on page 26-101
- “How to Instantiate Enumerated Data in MATLAB Function Blocks” on page 26-104

**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.

Simulink Block	Description
Data Type Conversion from int32 to enumerated type switchmode	<p>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:</p> <ul style="list-style-type: none"> <li>• Output minimum: [ ]</li> <li>• Output maximum: [ ]</li> <li>• Output data type: Enum:switchmode</li> </ul> <p>For more information about specifying enumerated types in Simulink models, see “Specifying an Enumerated Data Type” on page 27-26.</p>
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 26-99.
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	<input type="checkbox"/>	Enum: led	led
state	Input	1		Inherit: Same as Simulink	switchmode

Explicit enumerated type declarations must include the prefix `Enum:`. For more information, see “Using Enumerated Data in MATLAB Function Blocks” on page 26-101.

### 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 28-24.

## Using Enumerated Data in 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 <code>Simulink.IntEnumType</code> .	See “How to Define Enumerated Data Types for MATLAB Function Blocks” on page 26-101.
2	Add the enumerated data to your MATLAB Function block.	See “How to Add Enumerated Data to MATLAB Function Blocks” on page 26-102.
3	Instantiate the enumerated type in your MATLAB Function block.	See “How to Instantiate Enumerated Data in MATLAB Function Blocks” on page 26-104.
4	Simulate and/or generate code.	See “Enumerations” in the Simulink Coder documentation.

## How to 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. The basic workflow is:

- 1 Create a class definition file.
- 2 Define enumerated values in an enumeration section.
- 3 Optionally override default methods in a methods section.
- 4 Save the MATLAB file on the MATLAB path.

For complete descriptions of each procedure, see “Specifying an Enumerated Data Type” on page 27-26.

## How to Add Enumerated Data to MATLAB Function Blocks

You can add inputs, outputs, and parameters as enumerated data, according to these guidelines:

For:	Do This:
Inputs	Inherit from the enumerated type of the connected Simulink signal or specify the enumerated type explicitly.
Outputs	Always specify the enumerated type explicitly.
Parameters	For tunable parameters, specify the enumerated type explicitly.  For non-tunable parameters, derive properties from an enumerated parameter in a parent Simulink masked subsystem or enumerated variable defined in the MATLAB base workspace.

To add enumerated data to a MATLAB Function block:

- 1 In the MATLAB Function Block Editor, select **Tools > Edit Data/Ports**.

The Ports and Data Manager dialog box appears with the **General** pane selected.

- 2 In the **Name** field, enter a name for the enumerated data.

For parameters, the name must match the enumerated masked parameter or workspace variable name.

- 3 In the **Type** field, specify an enumerated type.

To specify an explicit enumerated type:

- a Select Enum:<class name> from the drop-down menu in the **Type** field.
- b Replace <class name> with the name of an enumerated data type that you defined in a MATLAB file on the MATLAB path.

For example, you can enter `Enum:led` in the **Type** field. (See “How to Define Enumerated Data Types for MATLAB Function Blocks” on page 26-101.)

---

**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`:

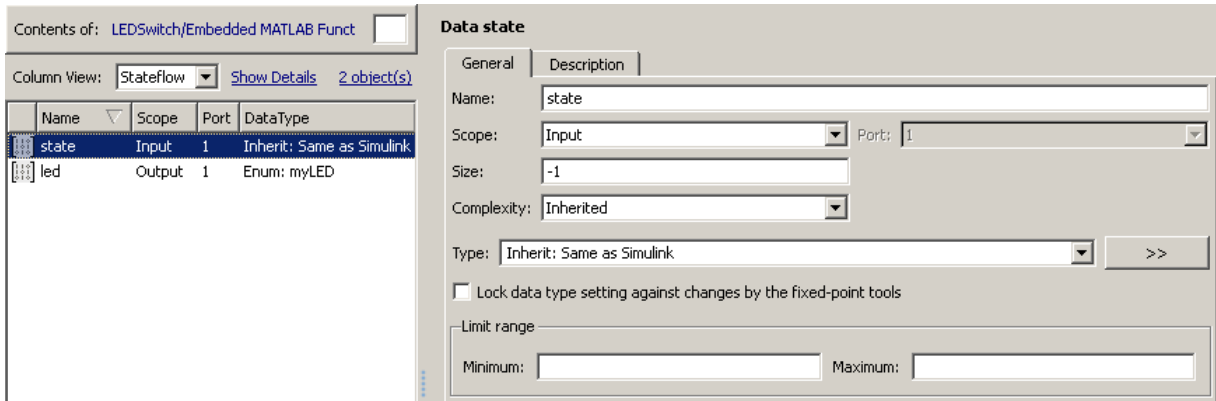
The screenshot shows the MATLAB Function Block Editor interface. On the left, the 'Contents of: LEDSwitch/Embedded MATLAB Funct' window displays a table with columns 'Name', 'Scope', 'Port', and 'DataType'. The table contains two rows: 'state' (Input, 1, Inherit: Same as Simulink) and 'led' (Output, 1, Enum: myLED). The 'led' row is selected. On the right, the 'Data led' configuration window is open, showing the 'General' tab. The 'Name' field is 'led', 'Scope' is 'Output', and 'Port' is '1'. The 'Type' field is 'Enum: myLED'. Other fields include 'Size' (-1), 'Sampling mode' (Sample based), and a checkbox for 'Data must resolve to Simulink signal object' which is unchecked. There is also a checkbox for 'Lock data type setting against changes by the fixed-point tools' which is unchecked.

Name	Scope	Port	DataType
state	Input	1	Inherit: Same as Simulink
led	Output	1	Enum: myLED

To inherit the enumerated type from a connected Simulink signal (for inputs only):

- Select `Inherit:Same as Simulink` from the drop-down menu in the **Type** field.

For example, the following input `state` inherits its enumerated type `myMode` from a Simulink signal:



4 Click **Apply**.

## How to Instantiate Enumerated Data in 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 “Simple Example: Defining and Using Enumerated Types in MATLAB Function Blocks” on page 26-97. 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
end
```

## Operations on Enumerated Data

Simulink software prevents enumerated values from being used as numeric values in mathematical computation (see “Enumerated Values in Computation” on page 28-18).



The code generation software supports the following enumerated data operations:

- Assignment (=)
- Relational operations (==, ~=, <, >, <=, >=, )
- Cast
- Indexing

For more information, see “Operations on Enumerated Data Allowed for Code Generation”.

## **Limitations of Enumerated Types**

Enumerated types in MATLAB Function blocks are subject to the limitations imposed by the code generation software. See “How Working with Enumerated Data Is Different for Code Generation” in the Code Generation from MATLAB documentation.

## Using Global Data with the MATLAB Function Block

### In this section...

“When Do You Need to Use Global Data?” on page 26-106

“Using Global Data with the MATLAB Function Block” on page 26-106

“Choosing How to Store Global Data” on page 26-107

“How to Use Data Store Memory Blocks” on page 26-109

“How to Use Simulink.Signal Objects” on page 26-111

“Using Data Store Diagnostics to Detect Memory Access Issues” on page 26-113

“Limitations of Using Shared Data in MATLAB Function Blocks” on page 26-114

### 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 30-2 in the Simulink documentation.) How you store global data depends on how many global variables you are using and the scope of these variables. For more information, see “Choosing How to Store Global Data” on page 26-107.

## 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 26-109 and “How to Use Simulink.Signal Objects” on page 26-111.

## Choosing How to Store Global Data

The following table summarizes whether to use Data Store Memory blocks or `Simulink.Signal` objects.

<b>If you want to:</b>	<b>Use:</b>	<b>For more information:</b>
<p>Use a small number of global variables in a single model that does not use model reference.</p>	<p>Data Store Memory blocks.</p> <hr/> <p><b>Note</b> Using Data Store Memory blocks scopes the data to the model.</p>	<p>“How to Use Data Store Memory Blocks” on page 26-109</p>
<p>Use a large number of global variables in a single model that does not use model reference.</p>	<p>Simulink.Signal objects defined in the model workspace. Simulink.Signal objects offer these advantages:</p> <ul style="list-style-type: none"> <li>• You do not have to add numerous Data Store Memory blocks to your model.</li> <li>• You can load the Simulink.Signal objects in from a MAT-file.</li> </ul>	<p>“How to Use Simulink.Signal Objects” on page 26-111</p>
<p>Share data between multiple models (including referenced models).</p>	<p>Simulink.Signal objects defined in the base workspace</p> <hr/> <p><b>Note</b> 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.</p>	<p>“How to Use Simulink.Signal Objects” on page 26-111</p>

## How to Use Data Store Memory Blocks

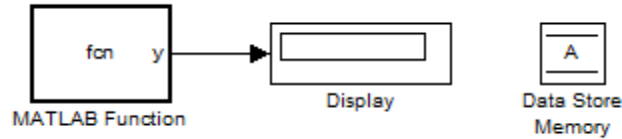
- 1 Add a MATLAB Function block to your model.
- 2 Double-click the MATLAB Function block to open its editor.
- 3 Declare a global variable in the MATLAB Function block code, or in any MATLAB file that the MATLAB Function block code calls. For example:

```
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 26-27.

### 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** From the menu in the MATLAB Function Block Editor, select **Tools > Edit Data/Ports**.

The Ports and Data Manager opens.

- 4** Select the data A in the left pane.

The Ports and Data Manager displays the data attributes in the right pane. Note that A has a scope of Data Store Memory.

- 5** In the model, double-click the Data Store Memory block A.

The Block Parameters dialog box opens. Note that A has an initial value of 25.

## 6 Simulate the model.

The 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.

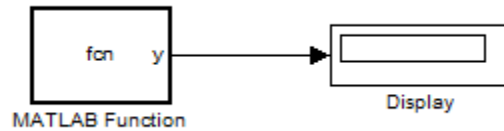
**b** Set the **Scope** of the data to **Data Store Memory**.

- 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 26-27.

**Example: Using a Simulink.Signal Object with a MATLAB Function Block**



- 1**
- 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 **Tools > Edit Data/Ports**.

The Ports and Data Manager opens.

- 4** Select the data A in the left pane.

The Ports and Data Manager displays the data attributes in the right pane. Note that A has a scope of Data Store Memory.



- 5** From the model menu, select **View > Model Explorer**.

The Model Explorer opens.

- 6** In the left pane, select the model workspace for the `simulink_signal_local` model.

The **Contents** pane displays the data in the model workspace.

- 7** Click the `Simulink.Signal` object A.

The right pane displays the attributes for A.

Attribute	Value
Data type	double
Complexity	real
Dimensions	1
Sample mode	Sample based
Initial value	5

- 8** Simulate the model.

The MATLAB Function block reads the initial value of global data stored in A and updates the value of A each time it executes.

## Using Data Store Diagnostics to Detect Memory Access Issues

You can configure your model to provide run-time and compile-time diagnostics for avoiding problems with data stores. Diagnostics are available in the Configuration Parameters dialog box and the parameters dialog box for the Data Store Memory block. These diagnostics are available for Data Store Memory blocks only, not for `Simulink.Signal` objects. For more information on using data store diagnostics, see “Using Data Store Diagnostics” on page 30-33 in the Simulink documentation.

---

**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

## Working with Frame-Based Signals

### In this section...

“About Frame-Based Signals” on page 26-115

“Supported Types for Frame-Based Data” on page 26-115

“Adding Frame-Based Data in MATLAB Function Blocks” on page 26-116

“Examples of Frame-Based Signals in MATLAB Function Blocks” on page 26-117

### 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?” in the DSP System Toolbox documentation.

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.

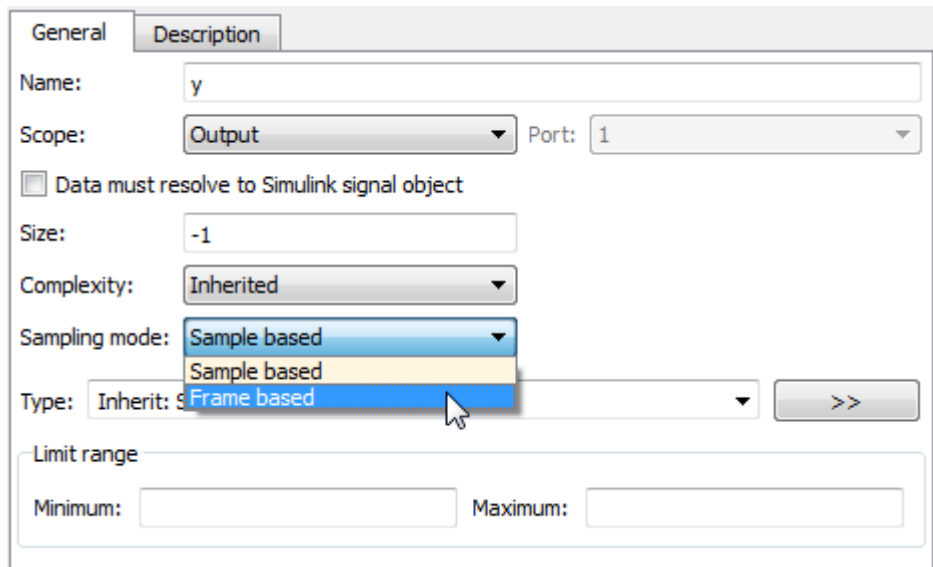
### Supported Types for Frame-Based Data

MATLAB Function blocks accept frame-based signals of any data type *except* bus objects. For a list of supported types, see “Supported Variable Types” in the Code Generation from MATLAB documentation.

## 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 26-33.
- 2 If your data is an output, set **Sampling mode** to **Frame based**.



---

**Note** If your data is an input, **Sampling mode** is not an option.

---

---

**Note** For more information on how to set data properties, see “Defining Data in the Model Explorer” on page 26-35.

---

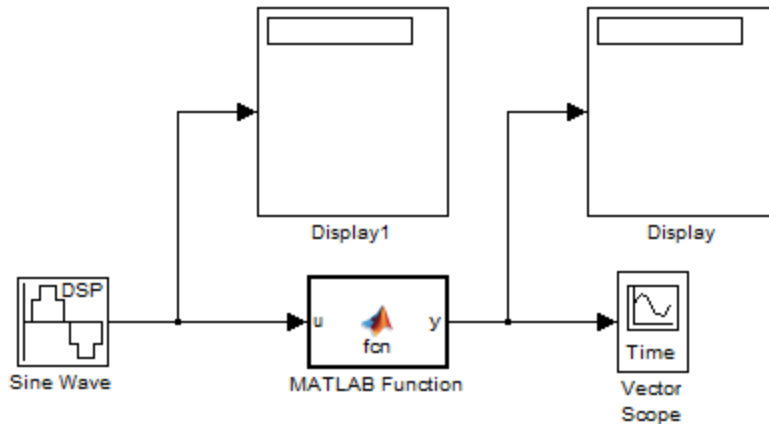
## Examples of Frame-Based Signals in MATLAB Function Blocks

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” on page 26-117
- “Adding a Channel to a Frame-Based Signal” on page 26-118

### 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.

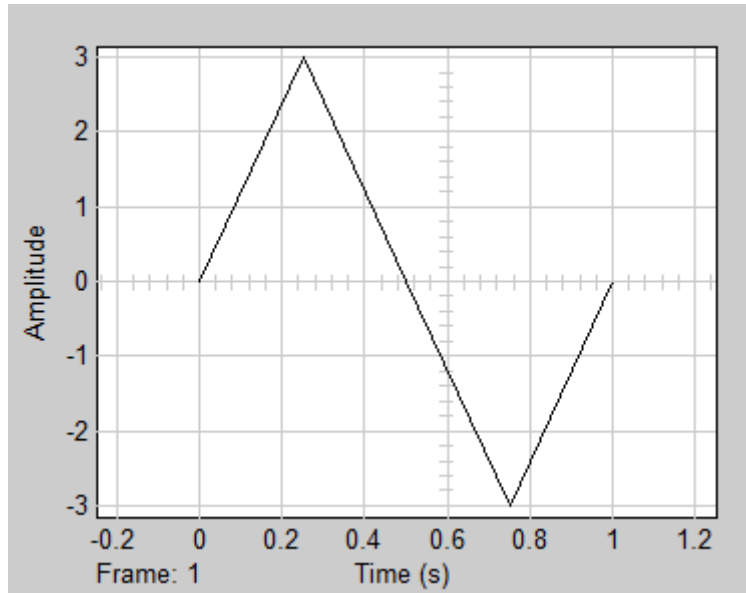


The MATLAB Function block contains the following code:

```
function y = fcn(u)
y = u*3;
```

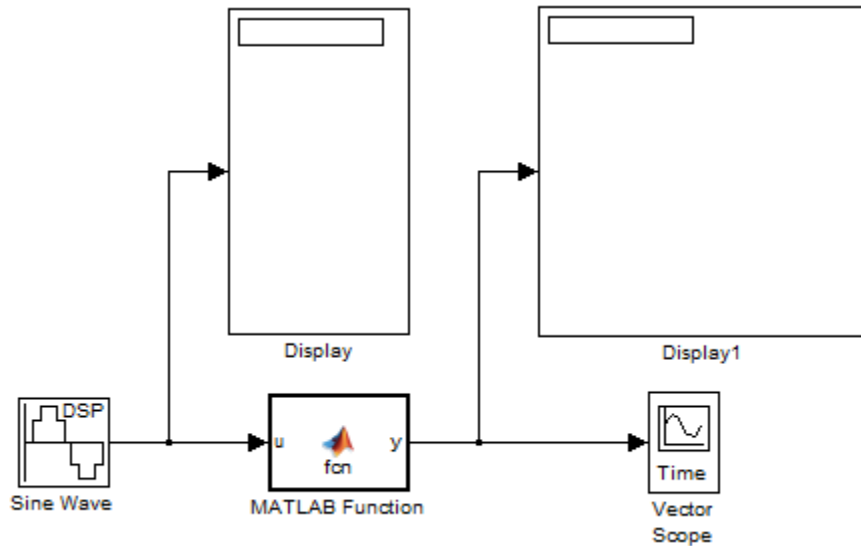
Input  $u$  and output  $y$  inherit size, complexity, and data type from the input sine wave signal, a 5-by-1 vector of signed, generalized fixed-point values. For  $y$  to output a frame of data, you must explicitly set **Sampling mode to Frame based** (see “Adding Frame-Based Data in MATLAB Function Blocks”)

on page 26-116). 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**

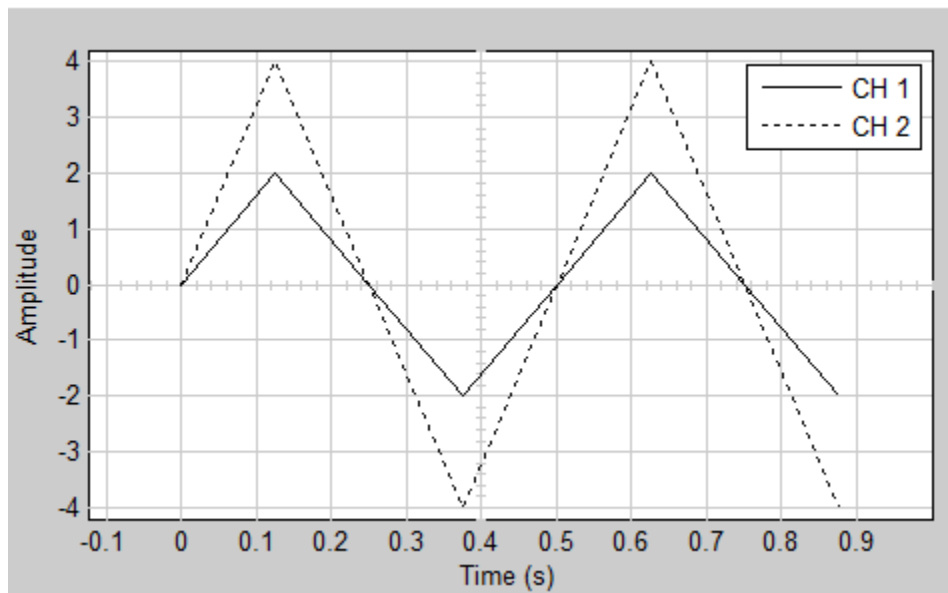
In the following example, a MATLAB Function block adds a channel to a frame-based single-channel input and outputs the multichannel result. The input signal is a sine wave that contains 8 samples per frame.



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 26-116). 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.





# Creating Custom Block Libraries with MATLAB Function Blocks

## In this section...

“When to Use MATLAB Function Block Libraries” on page 26-121

“How to Create Custom MATLAB Function Block Libraries” on page 26-121

“Example: Creating a Custom Signal Processing Filter Block Library” on page 26-122

“Code Reuse with Library Blocks” on page 26-133

“Debugging MATLAB Function Library Blocks” on page 26-137

“Properties You Can Specialize Across Instances of Library Blocks” on page 26-138

## 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 26-133).

For more information about Simulink block libraries, see Chapter 25, “Working with Block Libraries”

## 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 26-122.

- 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 26-138.

- 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” on page 26-122
- “About the Filter Algorithms” on page 26-123
- “Step 1: Add the Filter Algorithms to MATLAB Function Library Blocks” on page 26-123
- “Step 2: Configure Blocks to Inherit Properties You Want to Specialize” on page 26-124
- “Step 3: Customize Your Library Using Masking” on page 26-125
- “Step 4: Add Instances of MATLAB Library Blocks to a Simulink Model” on page 26-130

### **What You Will Learn**

This simple example takes you through the workflow described in “How to Create Custom MATLAB Function Block Libraries” on page 26-121 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 **Tools > Edit Data/Ports**.

The Ports and Data Manager opens.

- 2 In the left pane of the Ports and Data Manager, select the data of interest.

- 3 In the right pane, configure the data to inherit properties from Simulink:

To Inherit	What to Specify
Size	Enter -1 in Size field
Complexity	Select <b>Inherited</b> from the Complexity menu
Type	Select <b>Inherit: Same as Simulink</b> 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 26-27
- “Inheriting Argument Data Types” on page 26-62

### Step 3: Customize Your Library Using Masking

In this exercise you will modify the convolution filter `my_conv` to use a custom parameter shape that specifies what subsection of the convolution to output.

To customize this algorithm for your library, place the `my_conv_filter` block under a masked subsystem and define `shape` as a mask parameter.

**1** Convert the block to a masked subsystem:

- a** Click the `my_conv_filter` block and select **Edit > Create Subsystem**.

The `my_conv_filter` block changes to a subsystem block.

- b** Change the name of the subsystem to `my_conv_filter`.

- c** Right-click the `my_conv_filter` subsystem and select **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:



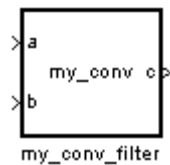
- f** Assign the following properties to the new dialog parameter:

Property	What to Specify
Prompt	Type Shape
Variable	Type shape

Property	What to Specify
Type	<ul style="list-style-type: none"> <li>• Select <b>popup</b></li> <li>• Enter type-specific options, each on a separate line:                             <ul style="list-style-type: none"> <li>- full</li> <li>- same</li> <li>- valid</li> </ul> </li> <li>• Check <b>Enable parameter</b></li> <li>• Check <b>Show parameter</b></li> </ul>
Evaluate	Check the box
Tunable	Clear the box  <hr/> <p><b>Note</b> 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.</p> <hr/>
Tab name	Leave blank

**a** Click **OK**.

Your subsystem should now look like this:



**2** Set subsystem properties for code reuse:

- a Right-click the `my_conv_filter` subsystem and select **Subsystem Parameters** from the context menu.

The subsystem parameters dialog box opens.

- b Select the **Treat as atomic unit** check box.

The dialog box expands to display new fields.

- c To generate a reusable function, 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.

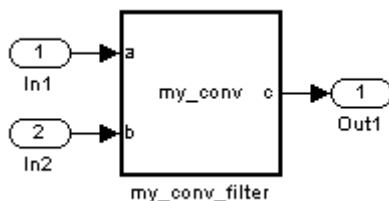
---

- d Click **OK**.

- 3 Define the shape parameter in the MATLAB Function `my_conv`:

- a Right-click the `my_conv_filter` subsystem and select **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 **Tools > Edit Data/Ports**.

The Ports and Data Manager opens.

- e In the Ports and Data Manager, select **Add > Data**.

A new data element appears selected, along with its properties dialog.

- f Enter the following properties:

Property	What To Specify
Name	Enter shape.
Scope	Select <b>Parameter</b> .
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 26-124.
  - 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.**

- Chapter 23, “Working with Block Masks”

**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.

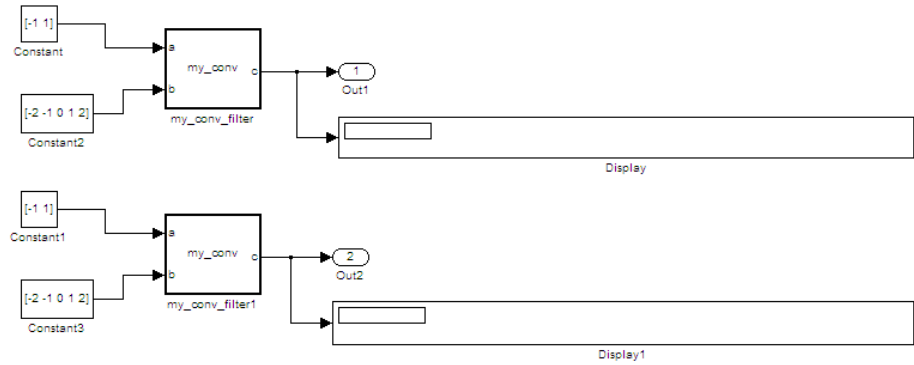
**1** Open a new Simulink model.

For purposes of this exercise, set the following configuration parameters for simulation:

Pane	Section	What to Specify
Solver	Solver options	<ul style="list-style-type: none"> <li>• Select <b>Fixed-Step</b> for Type</li> <li>• Select <b>discrete (no continuous states)</b> for Solver</li> <li>• Enter <b>1</b> for Fixed-step size</li> </ul>
Data Import/Export	Save options	<b>Structure</b> 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:



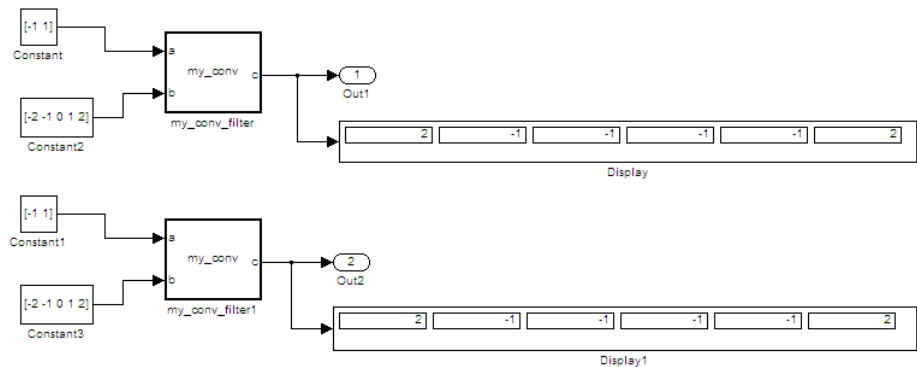
Both library instances share the same size, type, and complexity for inputs a and b respectively.

**4** Double-click each library instance.

The shape parameter defaults to **full** for both instances.

**5** Simulate the model.

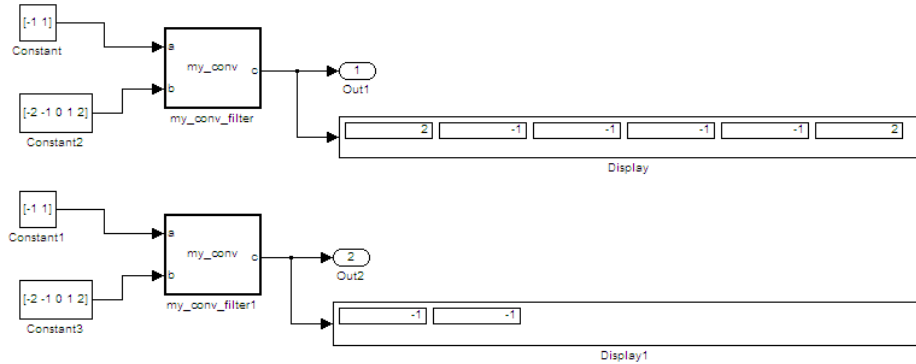
Each library instance outputs the same result, the full 2D convolution:



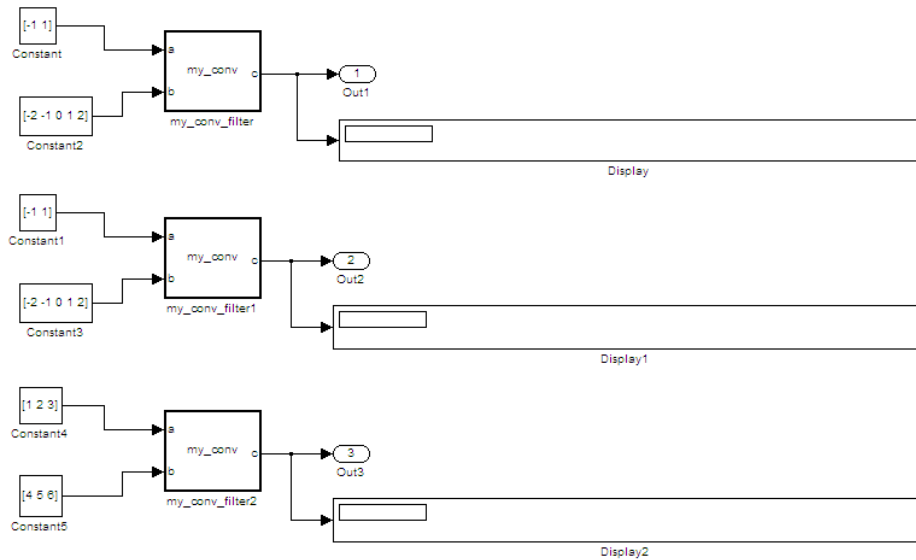
**6** Specialize the second instance, my\_conv\_filter1 by setting the value of its shape parameter to **same**.

**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`:

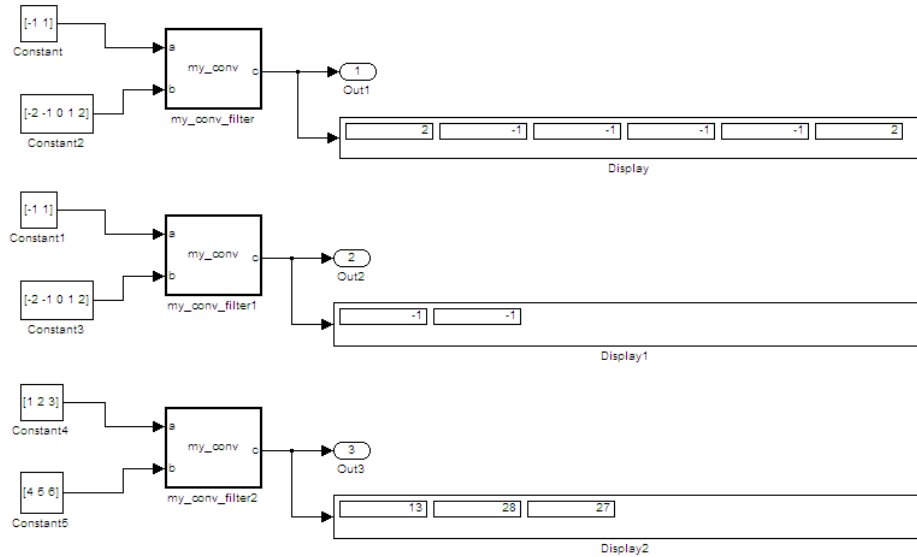


- 8** Now, add a third instance by copying `my_conv_filter1`. Specialize the new instance, `my_conv_filter2`, so that it does not inherit the same size inputs as the first two instances:



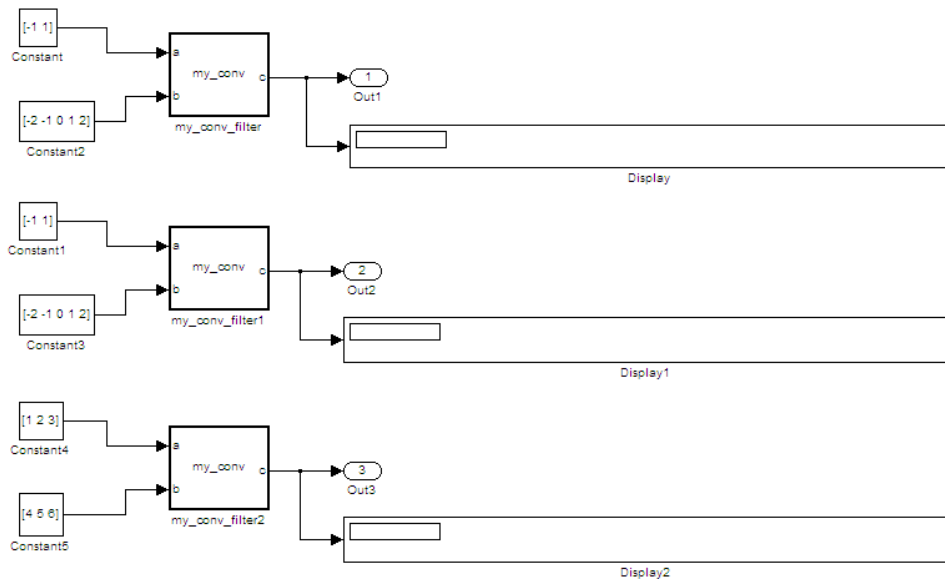
- 9** Simulate the model again.

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 26-130:



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 **Subsystem Parameters** from the context menu.
  - b In the Function Block Parameters dialog box, set these parameters:
    - Select the **Treat as atomic unit** check box.

- In the **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 <code>ert.tlc</code> for System target file
Code Generation > Report		Select <b>Create code generation report</b> 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 26-14

## 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 <b>Inherit: Same as Simulink</b> .
Size	Yes	Set data size property to <b>-1</b> .
Complexity	Yes	Set data complexity property to <b>Inherited</b> .
Limit range	No	Specify minimum and maximum values as Simulink parameters. For example, if minimum value = $aParam + 3$ , 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 <b>Inherit</b> .
Sample time (block)	Yes	Set block sample time property to <b>-1</b> .

## Using Traceability in MATLAB Function Blocks

### In this section...

“Extent of Traceability in MATLAB Function Blocks” on page 26-139

“Traceability Requirements” on page 26-139

“Basic Workflow for Using Traceability” on page 26-140

“Tutorial: Using Traceability in a MATLAB Function Block” on page 26-141

### 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 “Including MATLAB Source Code as Comments in the Generated Code” on page 26-144.

For information about how traceability works in Simulink blocks, see “Code Tracing” in the Embedded Coder documentation.

### 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 “Report Generation” in the Embedded Coder User’s Guide. 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, open **Simulation > 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 **Launch 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 <b>Code Generation &gt; Navigate to Code</b> 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 26-141

## 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 > 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 **Launch report automatically** and **Code-to-model** options.

- 6 Select the **Model-to-code** option in the **Navigation** section. Then click **Apply**.

This action automatically selects all options in the **Traceability Report Contents** section.

---

**Note** For large models that contain over 1000 blocks, disable the **Model-to-code** option to speed up code generation.

---

- 7 Go to the **Code Generation > Interface** pane. In the **Software environment** section, select the **continuous time** option. Then click **Apply**.

---

**Note** Because this demo model contains a block with a continuous sample time, you must perform this step before generating code.

---

- 8 In the **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`.

## Including MATLAB Source Code as Comments in the 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 “Using Traceability in MATLAB Function Blocks” on page 26-139.

For examples and information on the location of the comments in the generated code, see “Location of Comments in Generated Code” on page 26-145.

- 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 26-148.

---



## 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 > Configuration Parameters**.
- 2 In the **Code Generation > Comments** pane, select **MATLAB code as comments** and click **Apply**.

## Location of Comments in Generated Code

The automatically generated comments containing the source code appear after the traceability tag in the generated code as follows.

### Straight-Line Source Code

The comment containing the source code precedes the generated code that implements the source code statement. This comment appears after any comments that you add that precede the generated code. The comments are separated from the generated code because the statements are assigned to function outputs.

#### MATLAB Code.

```
function [x y] = straightline(r,theta)
%#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);

/* Output: '<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 > MLCfn_U.v) {
    /* Outputport: '<Root>/y' */
    /* '<S1>:1:4' y = v + 10; */
    MLCfn_Y.y = MLCfn_U.v + 10.0;
} else if (MLFcn_U.u == MLCfn_U.v) {
    /* Outputport: '<Root>/y' */
    /* '<S1>:1:5' elseif u == v */
    /* '<S1>:1:6' y = u * 2; */
    MLCfn_Y.y = MLCfn_U.u * 2.0;
} else {

```

```

/* Output: '<Root>/y' */
/* '<S1>:1:7' else */
/* '<S1>:1:8' y = v - 10; */
MLFcn_Y.y = MLCfn_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 <= MLCfn_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 > 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.

## Enhancing Readability of Generated Code for MATLAB Function Blocks

### In this section...

“Requirements for Using Readability Optimizations” on page 26-150

“Converting If-Elseif-Else Code to Switch-Case Statements” on page 26-150

“Example of Converting Code for If-Elseif-Else Decision Logic to Switch-Case Statements” on page 26-153

### 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 26-155
2	Enable the conversion.	“Enabling the Conversion” on page 26-156
3	Generate code for your model.	“Generating Code for Your Model” on page 26-157

## 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	<p>Must have two or more <i>unique</i> conditions, in addition to a default.</p> <p>For more information, see “How the Conversion Handles Duplicate Conditions” on page 26-152.</p>
Each condition	<p>Must test equality only.</p> <p>Must use the same variable or expression for the LHS.</p> <hr/> <p><b>Note</b> You can reverse the LHS and RHS.</p> <hr/>

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.

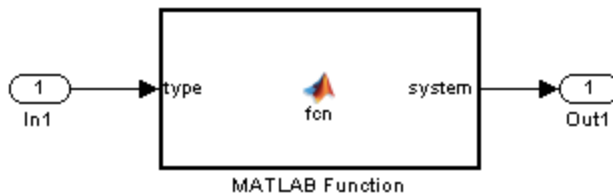
Example of Generated Code	Code After Conversion
<pre> if (x == 1) {     block1 } else if (x == 2) {     block2 } else if (x == 1) { // duplicate     block3 } else if (x == 3) {     block4 } else if (x == 1) { // duplicate     block5 } else { </pre>	<pre> switch (x) {     case 1:         block1; break;     case 2:         block2; break;     case 3:         block4; break;     default:         block6; break; </pre>



Example of Generated Code	Code After Conversion
<pre>                 block6             }         </pre>	<pre>         }     </pre>
<pre> if (x == 1) {     block1 } else if (x == 1) { // duplicate     block2 } else {     block3 }         </pre>	<p>No change, because only one unique condition exists</p>

### 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. (See “How to Define Enumerated Data Types for MATLAB Function Blocks” on page 26-101 for more information.)



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 “Using Traceability in MATLAB Function Blocks” on page 26-139.

### Verifying the Contents of the Block

Check that the block follows all the rules in “Rules for Conversion” on page 26-151.

<b>Construct</b>	<b>How the Construct Follows the Rules</b>
MATLAB Function block	Five unique conditions exist, in addition to the default: <ul style="list-style-type: none"> <li>• (type == Controller.P)</li> <li>• (type == Controller.I)</li> <li>• (type == Controller.PD)</li> <li>• (type == Controller.PI)</li> <li>• (type == Controller.PID)</li> </ul>
Each condition	Each condition: <ul style="list-style-type: none"> <li>• Tests equality</li> <li>• Uses the same input for the LHS</li> </ul>
Each LHS	Each LHS: <ul style="list-style-type: none"> <li>• Contains a single variable</li> <li>• Is the input to the block and therefore not a constant</li> <li>• Is of enumerated type <code>Controller</code>, which you define in <code>Controller.m</code> on the MATLAB path</li> <li>• Has no side effects on simulation</li> </ul>
Each RHS	Each RHS: <ul style="list-style-type: none"> <li>• Is an enumerated value and therefore a constant</li> <li>• Is of enumerated type <code>Controller</code></li> </ul>

## 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 Generated 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.

# Speeding Up Simulation with the Basic Linear Algebra Subprograms (BLAS) Library

## In this section...

“How MATLAB Function Blocks Use the BLAS Library” on page 26-159

“When to Disable BLAS Library Support” on page 26-159

“How to Disable BLAS Library Support” on page 26-160

“Supported Compilers” on page 26-160

## How MATLAB Function Blocks Use the BLAS Library

The Basic Linear Algebra Subprograms (BLAS) Library is a library of external linear algebra routines optimized for fast computation of low-level matrix operations. By default, 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 **Tools > Open 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 “Building MEX-Files” in the MATLAB External Interfaces documentation.



## Controlling Run-Time Checks

In this section...
“Types of Run-Time Checks” on page 26-161
“When to Disable Run-Time Checks” on page 26-161
“How to Disable Run-Time Checks” on page 26-162

### 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:

<b>Consider disabling:</b>	<b>Only if:</b>
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 **Tools > Open 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**.

# Tutorial: Integrating MATLAB Code with a Simulink Model for Tracking a Moving Object

## In this section...

“Learning Objectives” on page 26-163

“Tutorial Prerequisites” on page 26-164

“Example: The Kalman Filter” on page 26-164

“Files for the Tutorial” on page 26-167

“Tutorial Steps” on page 26-169

“Best Practices Used in This Tutorial” on page 26-189

“Key Points to Remember” on page 26-189

“Where to Learn More” on page 26-190

## 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 Chapter 26, “Using the MATLAB Function Block” in the Simulink® User’s Guide on page 1.

- 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” on page 26-164
- “Required Products” on page 26-164

## 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. For more information, see “Simulink Software Basics” in the Simulink documentation.

## 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 26-170.

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

- “Description” on page 26-165
- “Algorithm” on page 26-165

- “Filtering Process” on page 26-166
- “Reference” on page 26-167

## 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 ( $V_x$  and  $V_y$ ), and acceleration ( $A_x$  and  $A_y$ ) 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`, `Vx`, `Vy`, `Ax`, and `Ay`.

```
% 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” on page 26-167
- “Location of Files” on page 26-168
- “Names and Descriptions of Files” on page 26-168

## 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 26-169.

### Names and Descriptions of Files

Type	Name	Description
MATLAB function files	<code>ex_kalman01.m</code>	Baseline MATLAB implementation of a scalar Kalman filter.
	<code>ex_kalman02.m</code>	Version of the original algorithm suitable for code generation.
	<code>ex_kalman03.m</code>	Version of Kalman filter suitable for code generation and for use with frame-based and packet-based inputs.
	<code>ex_kalman04.m</code>	Disabled inlining for code generation.
Simulink model files	<code>ex_kalman00.mdl</code>	Simulink model without a MATLAB Function block.
	<code>ex_kalman11.mdl</code>	Complete Simulink model with a MATLAB Function block for scalar Kalman filter.
	<code>ex_kalman22.mdl</code>	Simulink model with a MATLAB Function block for a Kalman filter that accepts fixed-size (frame-based) inputs.
	<code>ex_kalman33.mdl</code>	Simulink model with a MATLAB Function block for a Kalman filter that accepts variable-size (packet-based) inputs.
	<code>ex_kalman44.mdl</code>	Simulink model to call <code>ex_kalman04.m</code> , which has inlining disabled.
MATLAB data file	<code>position.mat</code>	Contains the input data used by the algorithm.
Plot files	<code>plot_trajectory.m</code>	Plots the trajectory of the object and the Kalman filter estimated position.



## Tutorial Steps

- “Copying Files Locally” on page 26-169
- “Setting Up Your C Compiler” on page 26-170
- “About the ex\_kalman00 Model” on page 26-170
- “Adding a MATLAB Function Block to Your Model” on page 26-172
- “Checking the ex\_kalman11 Model” on page 26-174
- “Simulating the ex\_kalman11 Model” on page 26-175
- “Modifying the Filter to Accept a Fixed-Size Input” on page 26-177
- “Using the Filter to Accept a Variable-Size Input” on page 26-182
- “Debugging the MATLAB Function Block” on page 26-185
- “Generating C Code” on page 26-186

## 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.m`
  - `ex_kalman00.mdl`
  - `position.mat`
  - `plot_trajectory.m`

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 `ex_kalman00.mdl` in Simulink:
  - a** Set your MATLAB current folder to the folder that contains your working files for this tutorial. At the MATLAB command line, enter:

```
cd work
```

where *work* is the full path name of the folder containing your files. See “Using the Current Folder Browser” in the MATLAB Desktop Tools and Development Environment documentation for more information.

- b** At the MATLAB command line, enter:

```
ex_kalman00
```

The model opens.

This model is an incomplete model to demonstrate how to integrate MATLAB code with Simulink. The complete model is `ex_kalman11.mdl`, 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**.
- 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  $2 \times 310$  position matrix, and the index data increments from 1 to 310, the Selector block simply outputs one  $2 \times 1$  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.mdl` 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.mdl` model:

- 1 Open `ex_kalman00.mdl` 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.mdl`.

**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.

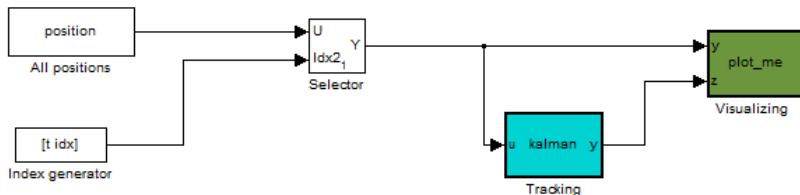
```
function y = kalman(u)
%#codegen

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 “Connecting Blocks” on page 3-15 in the Simulink documentation 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 26-174.

## Checking the `ex_kalman11` Model

To check the model:

- 1 In the Simulink model window, select **Edit > Update Diagram**.

Simulink checks the model and generates a warning telling you to add the `%#codegen` compilation directive to the `ex_kalman01.m` file. Adding this directive indicates that the file is intended for code generation and turns on code generation error checking.

- 2 Open the `ex_kalman01.m` 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.

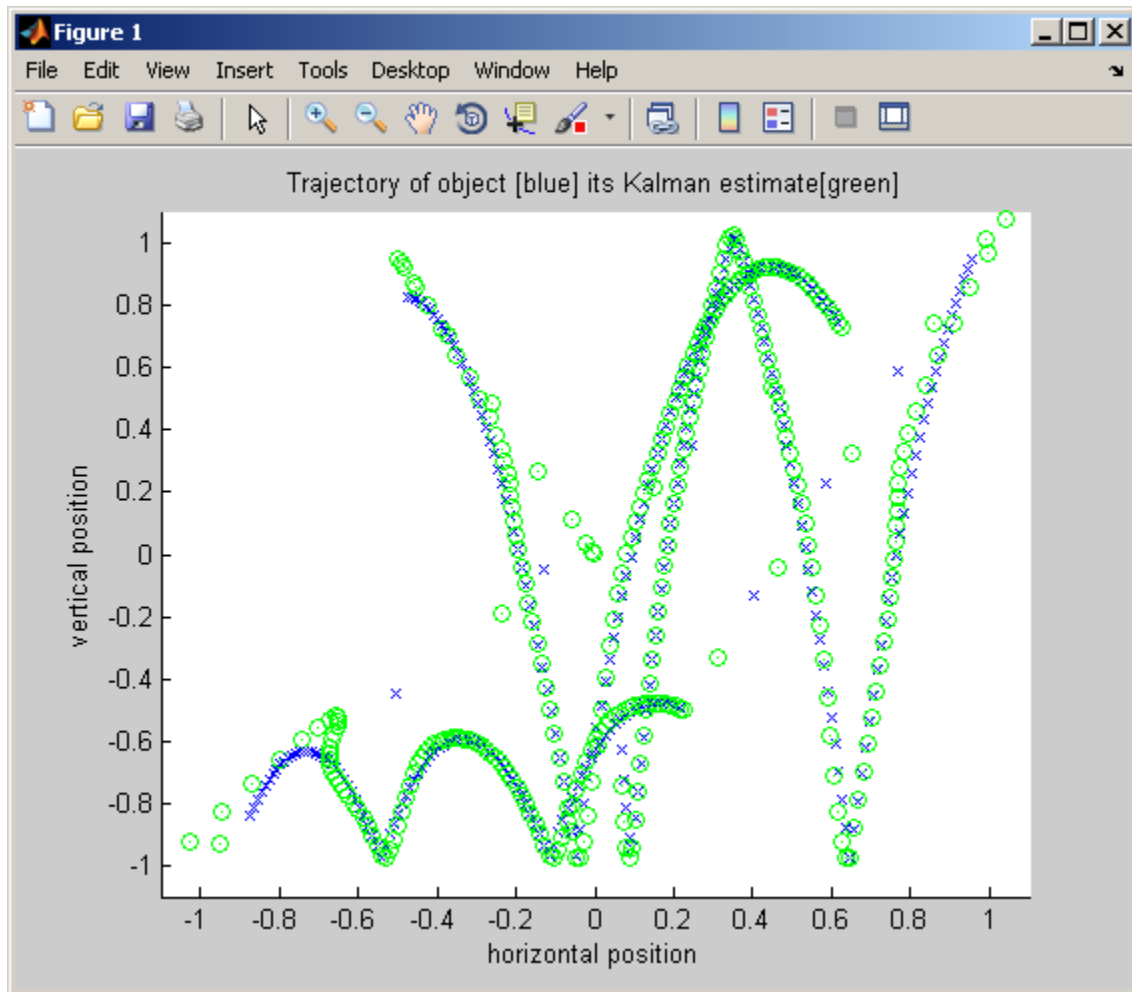
You are now ready to simulate your model, as described in “Simulating the `ex_kalman11` Model” on page 26-175.

## Simulating the `ex_kalman11` Model

To simulate the model:

- 1 In the Simulink model window, select **Simulation > Start**.

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 26-177.



## 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  $i^{\text{th}}$  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  $i^{\text{th}}$  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.

For more information on using the code analyzer, see “Using the MATLAB Code Analyzer Report” in the MATLAB Desktop Tools and Development documentation.

### 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” in *MATLAB Mathematics*.

- 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 26-180.

**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.mdl` 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**.

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 > Configuration Parameters**.

The Configuration Parameters dialog box opens.
  - b In the left pane, 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 > Start**.

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 26-182.

### 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 Chapter 33, “Working with Variable-Size Signals” in the Simulink documentation.

**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**.

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 **Tools > Edit Data/Ports**.

The Ports and Data Manager opens.

**c** In the Ports and Data Manager left pane, select the input  $u$ .

The Ports and Data Manager displays information about  $u$ .

**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 **Tools > Edit Data/Ports**.

The Ports and Data Manager opens.
  - 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 > Start**.

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 26-185.



## 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 > Start**.

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 **Debug > Step In**.

The `kalman03.m` file opens in the editor and you can now step through this code using the **Debug** menu options.

- 6 Select **Debug > 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 **Debug > Exit Debug Mode** to stop debugging.

**10** Close the editor.

**11** Close the figure window.

Now you are ready for the next task, “Generating C Code” on page 26-186.

## 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 > 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 **Launch 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, right-click the Tracking block to select it and open the context menu.
  - b From the context menu, select **Code Generation > Build Subsystem**.

The **Build code for subsystem** dialog box appears. Click the **Build** button.
- 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 > 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 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 “Report Generation” in the Simulink Coder documentation.
- 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** In the model, right-click the Tracking block to select it and open the context menu.
- b** From the context menu, select **Code Generation > Build 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 26-190
- “Product Help” on page 26-190

### Next Steps

To:	See:
Learn more about using the MATLAB Function block	Chapter 26, “Using the MATLAB Function Block” in the <i>Simulink User’s Guide</i>
Learn how to generate C code from your MATLAB code using <code>codegen</code>	“Generating C Code from MATLAB Code at the Command Line”
Learn more about code generation from MATLAB	<i>Code Generation from MATLAB User’s Guide</i>
Use variable-size data	“How Working with Variable-Size Data Is Different for Code Generation” in the Code Generation from MATLAB documentation
Speed up fixed-point MATLAB code	See “Code Acceleration and Code Generation from MATLAB for Fixed-Point Algorithms” in the Fixed-Point Toolbox documentation.
Integrate custom C code into generated code	“Custom C/C++ Code Integration”
Integrate custom C code into a MATLAB function	<code>coder.ceval</code> in the Code Generation from MATLAB documentation
Generate HDL from MATLAB code	<a href="http://www.mathworks.com/products/slhdlcoder">www.mathworks.com/products/slhdlcoder</a>

### Product Help

MathWorks product documentation is available online from the Help menu on the MATLAB desktop.

<b>For:</b>	<b>See:</b>
Code generation from MATLAB code	“About Code Generation from MATLAB Algorithms” in the Code Generation from MATLAB documentation
A list of functions that are suitable for code generation	<i>Code Generation from MATLAB Reference</i>
What’s new	<i>Code Generation from MATLAB Release Notes</i>

## Tutorial: Integrating MATLAB Code with a Simulink Model for Filtering an Audio Signal

### In this section...

“Learning Objectives” on page 26-192

“Tutorial Prerequisites” on page 26-193

“Example: The LMS Filter” on page 26-194

“Files for the Tutorial” on page 26-196

“Tutorial Steps” on page 26-198

### 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 Chapter 26, “Using the MATLAB Function Block” in the Simulink® User’s Guide on page 1.

- 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 this 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 26-193
- “Required Products” on page 26-193

## What You Need to Know

To work through this tutorial, you should have basic familiarity with MATLAB software. You should also understand how to create a basic Simulink model and how to simulate that model. For more information, see “Simulink Software Basics” in the Simulink documentation.

## Required Products

To complete this tutorial, you must install the following products:

- MATLAB
- MATLAB Coder
- Simulink
- Simulink Coder
- DSP System Toolbox

---

**Note** If you do not have a DSP System Toolbox license, see “Tutorial: Integrating MATLAB Code with a Simulink Model for Tracking a Moving Object” on page 26-163.

---

- 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” in the MATLAB Coder documentation.

## Example: The LMS Filter

- “Description” on page 26-194
- “Algorithm” on page 26-194
- “Filtering Process” on page 26-195
- “Reference” on page 26-196

### 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” on page 26-196
- “Location of Files” on page 26-197
- “Names and Descriptions of Files” on page 26-197

## 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 26-198.

## Names and Descriptions of Files

Type	Name	Description
MATLAB files	lms_01.m	Baseline MATLAB implementation of batch filter. Not suitable for code generation.
	lms_02.m	Filter modified from batch to streaming.
	lms_03.m	Frame-based streaming filter with Reset and Adapt controls.
	lms_04.m	Frame-based streaming filter with Reset and Adapt controls. Suitable for code generation.
	lms_05.m	Disabled inlining for code generation.
	lms_06.m	Demonstrates use of <code>coder.nullcopy</code> .
Simulink model files	acoustic_environment.mdl	Simulink model that provides an overview of the acoustic environment.
	noise_cancel_00.mdl	Simulink model without a MATLAB Function block.
	noise_cancel_01.mdl	Complete noise_cancel_00 model including a MATLAB Function block.
	noise_cancel_02.mdl	Simulink model for use with lms_02.m.
	noise_cancel_03.mdl	Simulink model for use with lms_03.m.
	noise_cancel_04.mdl	Simulink model for use with lms_04.m.
	noise_cancel_05.mdl	Simulink model for use with lms_05.m.
	noise_cancel_06.mdl	Simulink model for use with lms_06.m.

Type	Name	Description
	design_templates.mdl	Simulink model containing Adapt and Reset controls.

## Tutorial Steps

- “Copying Files Locally” on page 26-198
- “Setting Up Your C Compiler” on page 26-199
- “Running the acoustic\_environment Model” on page 26-200
- “Adding a MATLAB Function Block to Your Model” on page 26-201
- “Calling Your MATLAB Code As an Extrinsic Function for Rapid Prototyping” on page 26-201
- “Simulating the noise\_cancel\_01 Model” on page 26-205
- “Modifying the Filter to Use Streaming” on page 26-207
- “Adding Adapt and Reset Controls” on page 26-212
- “Generating Code” on page 26-217
- “Optimizing the LMS Filter Algorithm” on page 26-222

## 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.m`
  - `lms_02.m`
  - `noise_cancel_00.mdl`
  - `acoustic_environment.mdl`
  - `design_templates.mdl`

Your *work* folder now contains all the files that you need to get started.

You are now ready to set up your C compiler.

## Setting Up Your C Compiler

Before generating code for your Simulink model, you must set up your C compiler. For most platforms, MathWorks supplies a default compiler with MATLAB. If your installation does not include a default compiler, for a list of supported compilers for the current release of MATLAB, see and install a compiler that is suitable for your platform.

To install a compiler:

- 1 At the MATLAB command line, enter:  

```
mex -setup
```
- 2 Enter `y` to see the list of installed compilers.
- 3 Select a supported compiler.
- 4 Enter `y` to verify your choice.

## Running the acoustic\_environment Model

Run the `acoustic_environment` model supplied with the tutorial to understand the problem that you are trying to solve using the LMS filter. This model adds band-limited white noise to an audio signal and outputs the resulting signal to a speaker.

To simulate the model:

**1** Open `acoustic_environment.mdl` in Simulink:

- a** Set your MATLAB current folder to the folder that contains your working files for this tutorial. At the MATLAB command line, enter:

```
cd work
```

where *work* is the full path name of the folder containing your files. See “Using the Current Folder Browser” in the MATLAB Desktop Tools and Development Environment documentation for more information.

- b** At the MATLAB command line, enter:

```
acoustic_environment
```

The model opens.

**2** Ensure that your speakers are on.

**3** To simulate the model, from the Simulink model window, select **Simulation > Start**.

As Simulink runs the model, you hear the audio signal distorted by noise.

**4** While the simulation is running, double-click the Manual Switch to select the audio source.

Now you hear the desired audio input without any noise.

The goal of this tutorial is to use a MATLAB LMS filter algorithm to remove the noise from the noisy audio signal. You do this by adding 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 26-201.



## 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.mdl` 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.mdl` model supplied with the tutorial. In practice, you would have to develop your own test bench starting with an empty Simulink model.

To add a MATLAB Function block to the `noise_cancel_00` model:

- 1 Open `noise_cancel_00.mdl` 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 “Editing and Debugging MATLAB Code” in the MATLAB documentation.

**How to Call MATLAB Code As an Extrinsic Function.** To call your MATLAB code from the 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_01');

    % Compute LMS:
    [ ~, Signal_Out, Weights ] = lms_01(Noise_In, Signal_In);
end
```

### **Why Use the Tilde (~) Operator?**

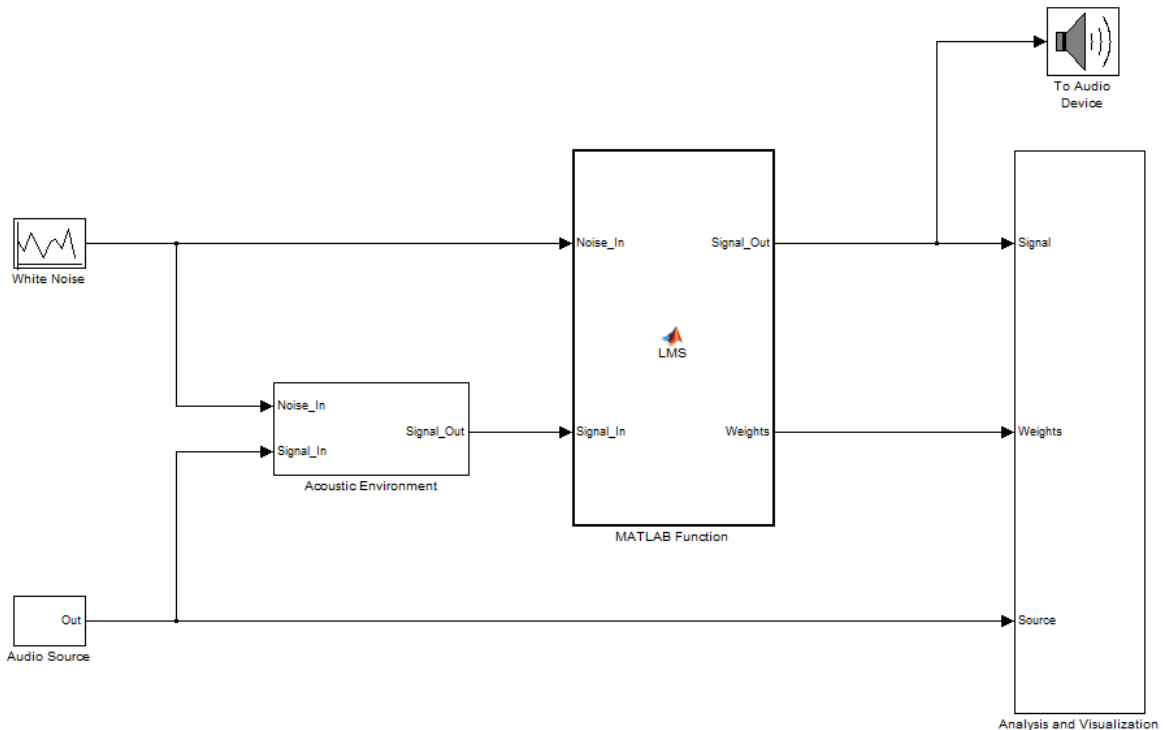
Because the LMS function does not use the first output from `lms_01`, replace this output with the MATLAB `~` operator. MATLAB ignores inputs and outputs specified by `~`. This syntax helps avoid confusion in your program code and unnecessary clutter in your workspace, and allows you to reuse existing algorithms without modification.

- 4** Save the model.

The `lms_01` function inputs `Noise_In` and `Signal_In` now appear as input ports to the block and the function outputs `Signal_Out` and `Weights` appear as output ports.

## 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 “Connecting Blocks” on page 3-15 in the Simulink documentation 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 “Defining MATLAB Variables for C/C++ Code Generation”.

#### **3** Save the model.

You are now ready to check your model for errors.

### Checking the noise\_cancel\_01 Model.

#### **1** In the Simulink model window, select **Edit > Update Diagram**.

Simulink fails to update diagram.

Because the Analysis and Visualization block expects to receive a frame-based signal from the LMS filter, you must configure the 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 **Tools > Edit Data/Ports** to open the Ports and Data Manager.
  - c** Select the signal called `Signal_Out` from the list in the left pane.
  - d** On the **General** tab, change the **Sampling mode** from `Sample based` to `Frame based`.
  - e** Click the **Apply** button and close the Ports and Data Manager and the MATLAB Function Block Editor.
  - f** Save the model.
- #### **2** Check the model again; select **Edit > Update Diagram** in the Simulink model window.

Simulink updates diagram successfully. You are ready for the next task, “Simulating the noise\_cancel\_01 Model” on page 26-205

## **Simulating the noise\_cancel\_01 Model**

To simulate the model:

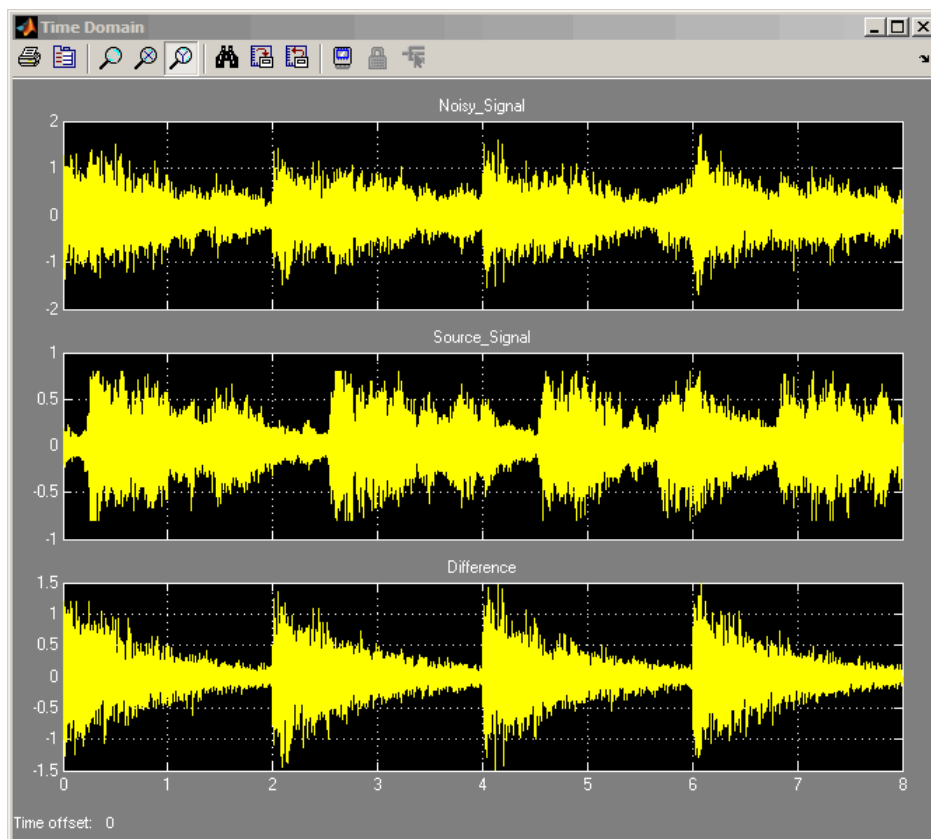
- 1** Ensure that you can see the **Time Domain** plots.

To view the plots, in the `noise_cancel_01` model, open the Analysis and Visualization block and then open the Time Domain block.

- 2** In the Simulink model window, select **Simulation > Start**.

As Simulink runs the model, you see and hear outputs. Initially, you hear the audio signal distorted by noise. Then the filter attenuates the noise gradually, until you hear only the music playing with very little noise remaining. After two seconds, you hear the distorted noisy signal again and the filter attenuates the noise again. This cycle repeats continuously.

MATLAB displays the following plot showing this cycle.



**3** Stop the simulation.

### Why Does the Filter Reset Every 2 Seconds?

The filter resets every 2 seconds because the model uses 16384 samples per frame and a sampling rate of 8192, so the 16384 samples represent 2 seconds of audio.

To see the model configuration:

- 1** Double-click the White Noise subsystem and note that it uses a **Sample time** of  $1/F_s$  and **Samples per frame** of `FrameSize`. The music in the Audio Source subsystem also uses these values.
- 2** `FrameSize` is set in the model `InitFcn` callback. To view this callback:
  - a** Select **File > Model Properties**.
  - b** Select the **Callback** tab.
  - c** Select `InitFcn` in the **Model callbacks** pane.

Note that `FrameSize` =  $16 \times 1024$ , which is 16384.

- 3** `F_s` is set in the model `PostLoadFcn` callback. To view this callback:
  - a** Select **File > Model Properties**.
  - b** Select the **Callback** tab.
  - c** Select `PostLoadFcn` in the **Model callbacks** pane.

The following MATLAB commands set up `F_s`:

```
data = load('handel.mat');  
music = data.y;  
F_s = data.Fs;
```

## Modifying the Filter to Use Streaming

- “What Is Streaming?” on page 26-208
- “Why Use Streaming?” on page 26-208
- “Viewing the Modified MATLAB Code” on page 26-208
- “Summary of Changes to the Filter Algorithm” on page 26-209
- “Modifying Your Model to Call the Updated Algorithm” on page 26-210
- “Simulating the Streaming Algorithm” on page 26-211

**What Is Streaming?.** A streaming filter is called repeatedly to process fixed-size chunks of input data, or *frames*, until it has processed the entire input signal. The frame size can be as small as a single sample, in which case the filter would be operating in a sample-based mode, or up to a few thousand samples, for frame-based processing.

**Why Use Streaming?.** The design of the filter algorithm in `lms_01` has the following disadvantages:

- The algorithm does not use memory efficiently.  
Preallocating a fixed amount of memory for each input signal for the lifetime of the program means more memory is allocated than is in use.
- You must know the size of the input signal at the time you call the function.  
If the input signal is arriving in real time or as a stream of samples, you would have to wait to accumulate the entire signal before you could pass it, as a batch, to the filter.
- The signal size is limited to a maximum size.

In an embedded application, the filter is likely to be processing a continuous input stream. As a result, the input signal can be substantially longer than the maximum length that a filter working in batch mode could possibly handle. To make the filter work for any signal length, it must run in real time. One solution is to convert the filter from batch-based processing to stream-based processing.

**Viewing the Modified MATLAB Code.** The conversion to streaming involves:

- Introducing a first-in, first-out (FIFO) queue  
The FIFO queue acts as a temporary storage buffer, which holds a small number of samples from the input data stream. The number of samples held by the FIFO queue must be exactly the same as the number of samples in the filter's impulse response, so that the function can perform the convolution operation between the filter coefficients and the input signal.
- Making the FIFO queue and the filter weights persistent



The filter is called repeatedly until it has processed the entire input signal. Therefore, the FIFO queue and filter weights need to persist so that the adaptation process does not have to start over again after each subsequent call to the function.

Open the supplied file `lms_02.m` in your *work* subfolder to see the modified algorithm.

**Summary of Changes to the Filter Algorithm.** Note the following important changes to the filter algorithm:

- The filter weights and the FIFO queue are declared as persistent:

```
persistent weights;
persistent fifo;
```

- The FIFO queue is initialized:

```
fifo = zeros(FilterLength,ChannelCount);
```

- The FIFO queue is used in the filter update loop:

```
% For each channel:
for ch = 1:ChannelCount

    % For each sample time:
    for n = 1:FrameSize

        % Update the FIFO shift register:
        fifo(1:FilterLength-1,ch) = fifo(2:FilterLength,ch);
        fifo(FilterLength,ch) = signal_in(n,ch);

        % Compute the output sample using convolution:
        signal_out(n,ch) = weights' * fifo(:,ch);

        % Update the filter coefficients:
        err(n,ch) = desired(n,ch) - signal_out(n,ch) ;
        weights = weights + mu*err(n,ch)*fifo(:,ch);

    end
end
```

- You cannot output a persistent variable. Therefore, a new variable, `weights_out`, is used to output the filter weights:

```
function [ signal_out, err, weights_out ] = ...
    lms_02(distorted, desired)

weights_out = weights;
```

**Modifying Your Model to Call the Updated Algorithm.** To modify the model yourself, work through the exercises in this section. Otherwise, open the supplied model `noise_cancel_02.mdl` in your *solutions* subfolder to see the modified model.

- 1 In the `noise_cancel_01` model, double-click the 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:

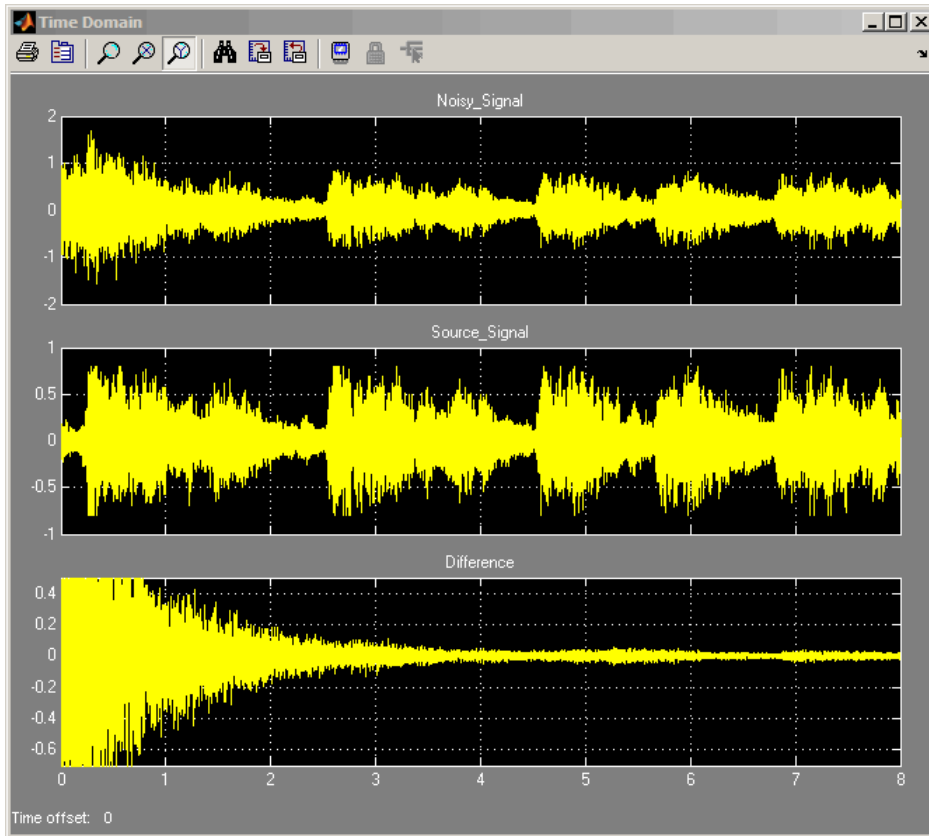
```
function [ Signal_Out, Weights ] = LMS(Noise_In, Signal_In)
% Extrinsic:
coder.extrinsic('lms_02');
% Outputs:
Signal_Out = zeros(size(Signal_In));
Weights = zeros(32,1);
% Compute LMS:
[ ~, Signal_Out, Weights ] = lms_02(Noise_In, Signal_In);
end
```

- 3** Change the frame size from 16384 to 64, which represents a more realistic value.
  - a** In the Simulink model window, select **File > Model Properties**.  
The **Model Properties** dialog box opens.
  - b** Select the **Callbacks** tab.
  - c** In the **Model callbacks** list, select `InitFcn`.
  - d** Change the value of `FrameSize` to 64.
  - e** Click **Apply** and close the dialog box.
- 4** Save your model as `noise_cancel_02.mdl`.

**Simulating the Streaming Algorithm.** To simulate the model:

- 1** Ensure that you can see the **Time Domain** plots.
- 2** Start the simulation.

As Simulink runs the model, you see and hear outputs. Initially, you hear the audio signal distorted by noise. Then, during the first few seconds, the filter attenuates the noise gradually, until you hear only the music playing with very little noise remaining. MATLAB displays the following plot showing filter convergence after only a few seconds.



**3** Stop the simulation.

The filter algorithm is now suitable for Simulink. You are ready to elaborate your model to use Adapt and Reset controls.

### **Adding Adapt and Reset Controls**

- “Why Add Adapt and Reset Controls?” on page 26-213
- “Modifying Your MATLAB Code” on page 26-213
- “Modifying Your Model to Use Reset and Adapt Controls” on page 26-214
- “Simulating the Model with Adapt and Reset Controls” on page 26-216

**Why Add Adapt and Reset Controls?.** In this part of the tutorial, you add Adapt and Reset controls to your filter. Using these controls, you can turn the filtering on and off. When Adapt is enabled, the filter continuously updates the filter weights. When Adapt is disabled, the filter weights remain at their current values. If Reset is set, the filter resets the filter weights.

**Modifying Your MATLAB Code.** To modify the code yourself, work through the exercises in this section. Otherwise, open the supplied file `lms_03.m` in your *solutions* subfolder to see the modified algorithm.

To modify your filter code:

**1** Open `lms_02.m`.

**2** In the Set up section, replace

```
if ( isempty(weights) )
```

with

```
if ( reset || isempty(weights) )
```

**3** In the filter loop, update the filter coefficients only if Adapt is ON.

```
if adapt
    weights = weights + mu*err(n,ch)*fifo(:,ch);
end
```

**4** Change the function signature to use the Adapt and Reset inputs and change the function name to `lms_03`.

```
function [ signal_out, err, weights_out ] = ...
    lms_03(signal_in, desired, reset, adapt)
```

**5** Save the file in the current folder as `lms_03.m`:

### Summary of Changes to the Filter Algorithm

Note the following important changes to the filter algorithm:

- The new input parameter `reset` is used to determine if it is necessary to reset the filter coefficients:

```

if ( reset || isempty(weights) )
    % Filter coefficients:
    weights = zeros(L,1);
    % FIFO Shift Register:
    fifo = zeros(L,1);
end

```

- The new parameter `adapt` is used to control whether the filter coefficients are updated or not.

```

if adapt
    weights = weights + mu*err(n)*fifo;
end

```

**Modifying Your Model to Use Reset and Adapt Controls.** To modify the model yourself, work through the exercises in this section. Otherwise, open the supplied model `noise_cancel_03.mdl` in your *solutions* subfolder to see the modified model.

- 1 Open the `noise_cancel_02` model.
- 2 Double-click the 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.

```

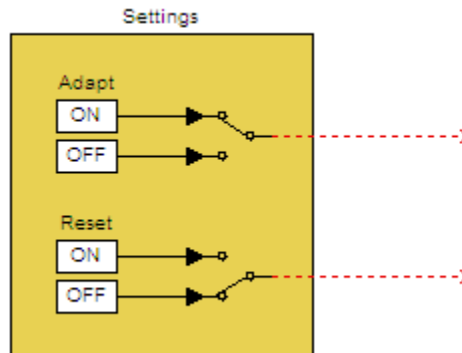
% Compute LMS:
[ ~, Signal_Out, Weights ] = ...
    lms_03(Noise_In, Signal_In, Reset, Adapt);

```

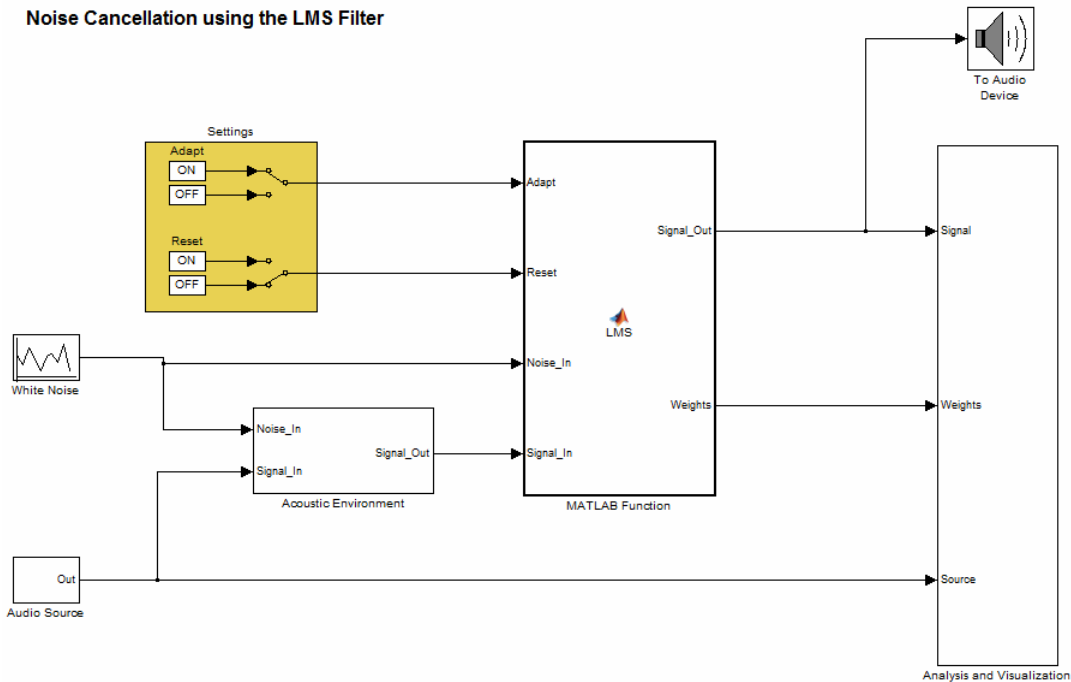
- d Close the MATLAB Function Block Editor.

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.mdl`.

**Simulating the Model with Adapt and Reset Controls.** To simulate the model and see the effect of the Adapt and Reset controls:

1 In the `noise_cancel_03` model, view the Convergence scope:

a Double-click the Analysis and Visualization subsystem.

The contents of the Analysis and Visualization subsystem appear.

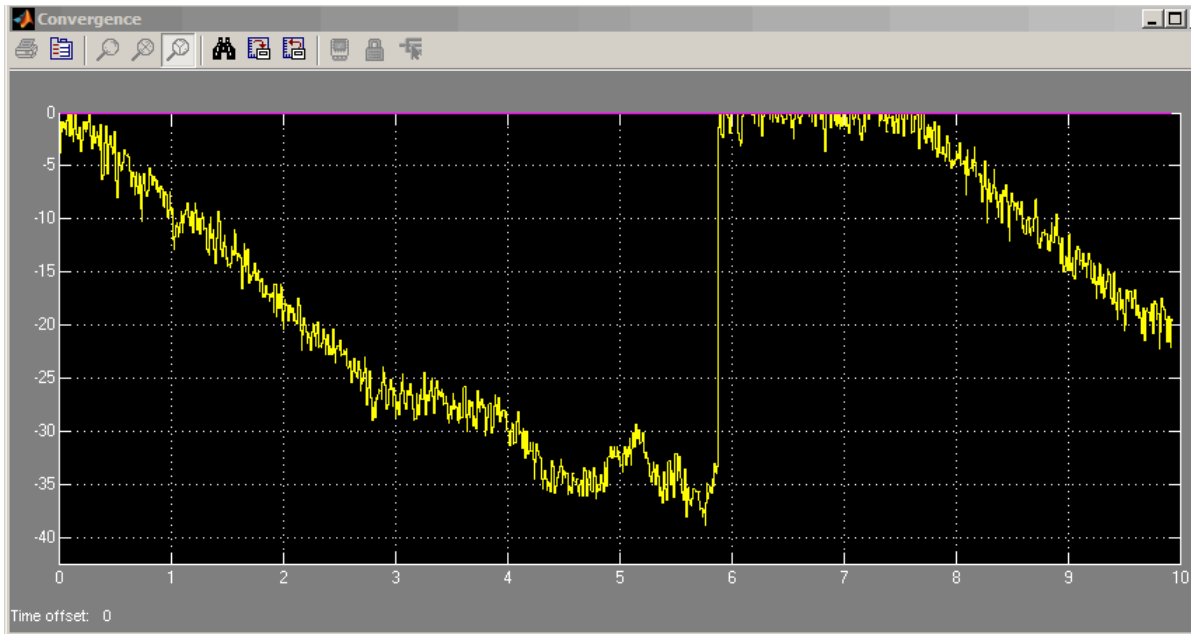
b Double-click the Convergence scope.

2 In the Simulink model window, select **Simulation > Start**.

Simulink runs the model as before. While the model is running, toggle the Adapt and Reset controls and view the Convergence scope to see their effect on the filter.



The filter converges when Adapt is ON and Reset is OFF, then resets when you toggleReset. 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.mdl` and file `lms_04.m` in your `solutions` subfolder to see the modifications.

- 1** Rename the MATLAB Function block to `LMS_Filter`. Double-click 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” in *MATLAB Mathematics*.

The red error markers for the two lines of code disappear. The code analyzer message indicator in the top right edge of the code turns green, which indicates that you have fixed all the errors and warnings detected by the code analyzer.

For more information on using the code analyzer, see “Using the MATLAB Code Analyzer Report” in the MATLAB Desktop Tools and Development documentation.

- 11 Save the file as `lms_04.m`.

## Generating Code for noise\_cancel\_04.mdl.

**1** Before generating code, ensure that 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 > Configuration Parameters**.

The Configuration Parameters dialog box opens.

- 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, right-click the LMS Filter subsystem to select it and open the context menu.

- b** From the context menu, select **Code Generation > Build 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 in the Simulink Coder documentation.

- c** In the left pane of the code generation report, click the `LMS_Filter.c` link to view the generated C code. Note that the `lms_04` function has no code because inlining is enabled by default.

**3** Modify your filter algorithm to disable inlining:

- a** In `lms_04.m`, after the function declaration, add:

```
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.mdl`.

#### 4 Generate code for the updated model.

- a** In the model, right-click the LMS Filter subsystem to select it and open the context menu.
- b** From the context menu, select **Code Generation > Build Subsystem**.

The **Build code for subsystem** dialog box appears.

- c** Click the **Build** button.

The Simulink Coder software generates C code for the subsystem and launches the code generation report.

- d** In the left pane of the code generation report, click the `LMS_Filter.c` link to view the generated C code.

This time the `lms_05` function has code because you disabled inlining.

```

/* Forward declaration for local functions */
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> % Pre-allocate output and error signals: signal_out = zeros(FrameSize,ChannelCount); err = zeros(FrameSize,ChannelCount); </pre>	<pre> /* Pre-allocate output and error signals: */ 79 for (i = 0; i &lt; 64; i++) { 80 signal_out[i] = 0.0; 81 err[i] = 0.0; 82 } </pre>

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. For more information, see “Eliminating Redundant Copies of Variables in Generated Code” in the *Code Generation from MATLAB User’s Guide*.

---

- 2** Change the function name to `lms_06` and save the file as `lms_06.m` in the current folder.
- 3** In your `noise_cancel_05` model, double-click the 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.mdl`.

Generate code for the updated model.

- 1 Right-click the LMS Filter subsystem to select it and open the context menu.
- 2 From the context menu, select **Code Generation > Build 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`.



# Managing Data

---

- Chapter 27, “Working with Data”
- Chapter 28, “Enumerations and Modeling”
- Chapter 29, “Importing and Exporting Simulation Data”
- Chapter 30, “Working with Data Stores”



# Working with Data

---

- “Working with Data Types” on page 27-2
- “Working with Data Objects” on page 27-37
- “Define Level-2 Data Classes Using MATLAB Class Syntax” on page 27-53
- “Supported Property Types” on page 27-57
- “Upgrade Level-1 Data Classes to Level-2” on page 27-58
- “New Infrastructure for Extending Simulink Data Classes” on page 27-60
- “Define Level-1 Data Classes Using Data Class Designer” on page 27-62
- “Associating User Data with Blocks” on page 27-79
- “Design Minimum and Maximum” on page 27-80

## Working with Data Types

### In this section...

- “About Data Types” on page 27-2
- “Data Types Supported by Simulink” on page 27-3
- “Fixed-Point Data” on page 27-4
- “Enumerations” on page 27-6
- “Bus Objects” on page 27-6
- “Block Support for Data and Numeric Signal Types” on page 27-7
- “Creating Signals of a Specific Data Type” on page 27-7
- “Specifying Block Output Data Types” on page 27-8
- “Using the Data Type Assistant” on page 27-15
- “Displaying Port Data Types” on page 27-28
- “Data Type Propagation” on page 27-28
- “Data Typing Rules” on page 27-29
- “Typecasting Signals” on page 27-30
- “Validating a Floating-Point Embedded Model” on page 27-30
- “Tutorial: Validating a Single-Precision Model” on page 27-31

### 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 27-29). In that way, you can avoid introducing data type errors that prevent your model from running to completion or simulating at all.

## Data Types Supported by Simulink

Simulink supports all built-in MATLAB data types except `int64` and `uint64`. The term *built-in data type* refers to data types defined by MATLAB itself as opposed to data types defined by MATLAB users. Unless otherwise specified, the term data type in the Simulink documentation refers to built-in data types. The following table lists the built-in MATLAB data types supported by Simulink.

Name	Description
<code>double</code>	Double-precision floating point
<code>single</code>	Single-precision floating point
<code>int8</code>	Signed 8-bit integer
<code>uint8</code>	Unsigned 8-bit integer
<code>int16</code>	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 27-6.

Many Simulink blocks also support fixed-point data types. See “Blocks — Alphabetical List” in the online documentation for information on the data types supported by specific blocks for parameter and input and output values. If the documentation for a block does not specify a data type, the block inputs or outputs only data of type `double`.

To view a table that summarizes the data types supported by the blocks in the Simulink block libraries, execute the following command at the MATLAB command line:

```
showblockdatatypetable
```

## Fixed-Point Data

The Simulink software allows you to create models that use fixed-point numbers to represent signals and parameter values. Use of fixed-point data can reduce the memory requirements and increase the speed of code generated from a model.

To execute a model that uses fixed-point numbers, you must have the Simulink Fixed Point product installed on your system. Specifically, you must have the product to:

- Update a Simulink diagram (**Ctrl+D**) containing fixed-point data types
- Run a model containing fixed-point data types
- Generate code from a model containing fixed-point data types

- Log the minimum and maximum values produced by a simulation
- Automatically scale the output of a model using the autoscaling tool

If the Simulink Fixed Point product is not installed on your system, you can execute a fixed-point model as a floating-point model by enabling automatic conversion of fixed-point data to floating-point data during simulation. See “Overriding Fixed-Point Specifications” on page 27-5 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 27-19.

---

## 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 `fioref` to prevent the checkout of a Fixed-Point Toolbox license. For more information, see “Licensing” in the Fixed-Point Toolbox documentation.

---

To simulate a model without using Simulink Fixed Point:

- 1** In the **Model Hierarchy** pane, select the root model.
- 2** From the Simulink model **Tools** menu, select **Fixed-Point Tool**.

The Fixed-Point Tool opens.

**3** In the **Current system settings** panel:

- Set the **Fixed-point instrumentation mode** parameter to `Force off`.
- Set the **Data type override** parameter to `Double` or `Single`.
- Set the **Data type override applies to** parameter to `All numeric types`.

**4** If you use `fi` objects or embedded numeric data types in your model, set the `fi`pref `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 = fi(pref('DataTypeOverride', 'TrueDoubles', ...  
          'DataTypeOverrideAppliesTo', 'AllNumericTypes');
```

## Enumerations

An *enumeration* is a user-defined data type with a fixed set of names that represent a single type of value. When the data type of an entity is an enumeration, the value of the entity must be one of the values defined that enumeration. For information about enumerations, see Chapter 28, “Enumerations and Modeling”. Do not confuse enumerations with enumerated property types (see “Enumerated Property Types” on page 27-75).

## 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 “Specifying a Bus Object Data Type” on page 27-27 for information about how to specify a bus object as a data type for blocks and classes.

## Block Support for Data and Numeric Signal Types

All Simulink blocks accept signals of type `double` by default. Some blocks prefer `boolean` input and others support multiple data types on their inputs. See Simulink Blocks in *Simulink Reference* for information on the data types supported by specific blocks for parameter and input and output values. If the documentation for a block does not specify a data type, the block inputs or outputs only data of type `double`.

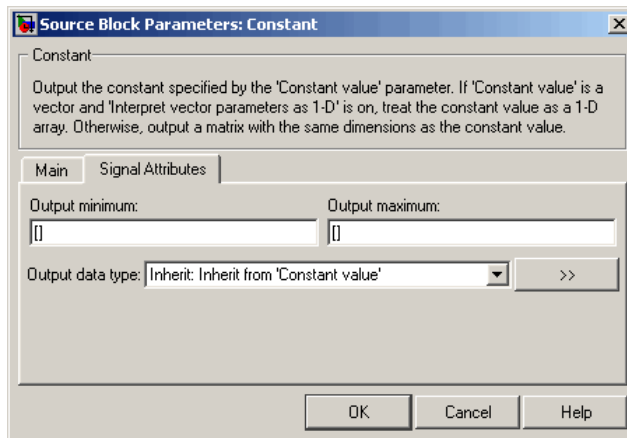
## Creating Signals of a Specific Data Type

You can introduce a signal of a specific data type into a model in any of the following ways:

- Load signal data of the desired type from the MATLAB workspace into your model via a root-level Inport block or a From Workspace block.
- Create a Constant block in your model and set its parameter to the desired type.
- Use a Data Type Conversion block to convert a signal to the desired data type.

## Specifying Block Output Data Types

Simulink blocks determine the data type of their outputs by default. Many blocks allow you to override the default type and explicitly specify an output data type, using a block parameter that is typically named **Output data type**. For example, the **Output data type** parameter appears on the **Signal Attributes** pane of the **Constant** block dialog box.



See the following topics for more information:

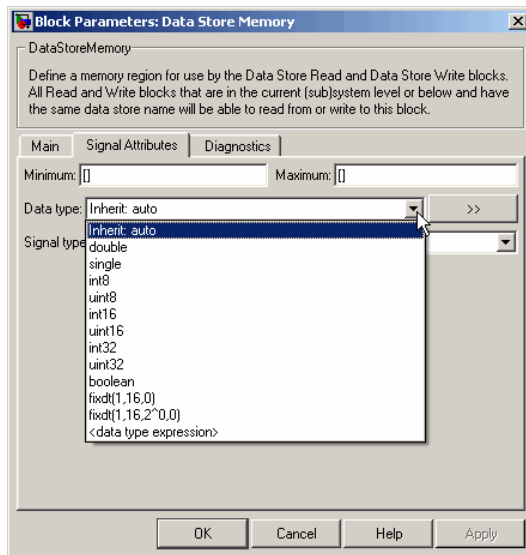
For Information About...	See...
Valid data type values that you can specify	“Entering Valid Data Type Values” on page 27-9
An assistant that helps you specify valid data type values	“Using the Data Type Assistant” on page 27-15
Specifying valid data type values for multiple blocks simultaneously	“Using the Model Explorer for Batch Editing” on page 27-12

## 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 27-10)
- The name of a built-in data type (see “Built-In Data Types” on page 27-11)
- An expression that evaluates to a data type (see “Data Type Expressions” on page 27-11)

Valid data type values vary among blocks. You can use the pull-down menu associated with a block data type parameter to view the data types that a particular block supports. For example, the **Data type** pull-down menu on the Data Store Memory block dialog box lists the data types that it supports, as shown here.



For more information about the data types that a specific block supports, see the documentation for the block in the *Simulink Reference*.

**Data Type Inheritance Rules.** Blocks can inherit data types from a variety of sources, including signals to which they are connected and particular block parameters. You can specify the value of a data type parameter as a rule that determines how the output signal inherits its data type. To view the inheritance rules that a block supports, use the data type pull-down menu on the block dialog box. The following table lists typical rules that you can select.

Inheritance Rule	Description
Inherit: Inherit via back propagation	Simulink automatically determines the output data type of the block during data type propagation (see “Data Type Propagation” on page 27-28). 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 27-3 for a list of all built-in data types that are supported.

**Data Type Expressions.** You can specify the value of a data type parameter as an expression that evaluates to a numeric data type object. Simply enter the expression in the data type field on the block dialog box. In general, enter one of the following expressions:

- **fixdt Command**

Specify the value of a data type parameter as a command that invokes the `fixdt` function. This function allows you to create a `Simulink.NumericType` object that describes a fixed-point or floating-point data type. See the documentation for the `fixdt` function in the *Simulink Reference* for more information.

- **Data Type Object Name**

Specify the value of a data type parameter as the name of a data object that represents a data type. Simulink data objects that you instantiate from classes, such as `Simulink.NumericType` and `Simulink.AliasType`, simplify the task of making model-wide changes to output data types and

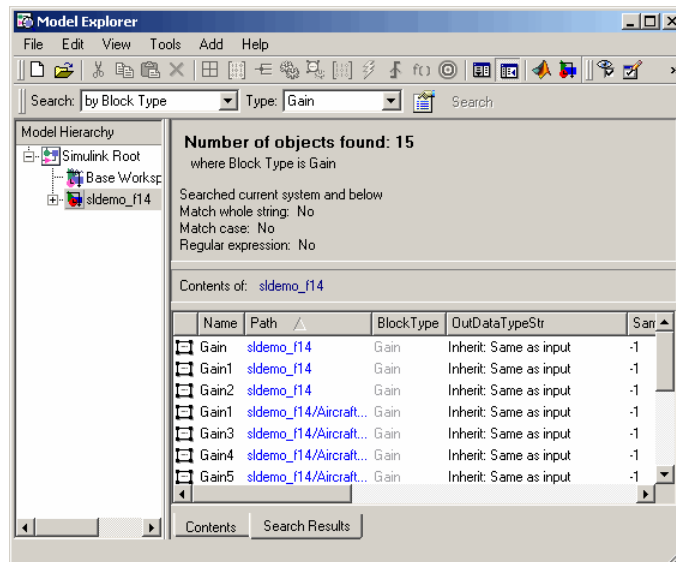
allow you to use custom aliases for data types. See “Working with Data Objects” on page 27-37 for more information about Simulink data objects.

## Using the Model Explorer for Batch Editing

Using the Model Explorer (see “The Model Explorer: Overview” on page 8-2), you can assign the same output data type to multiple blocks simultaneously. For example, the `sldemo_f14` model that comes with the Simulink product contains numerous Gain blocks. Suppose you want to specify the **Output data type** parameter of all the Gain blocks in the model as `single`. You can achieve this task as follows:

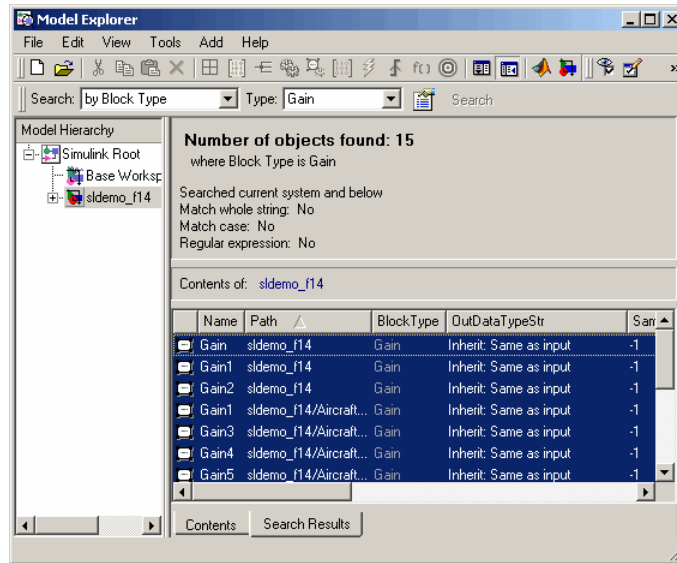
- 1 Use the Model Explorer search bar (see “The Model Explorer: Search Bar” on page 8-61) to identify all blocks in the `sldemo_f14` model of type Gain.

The Model Explorer **Contents** pane lists all Gain blocks in the model.



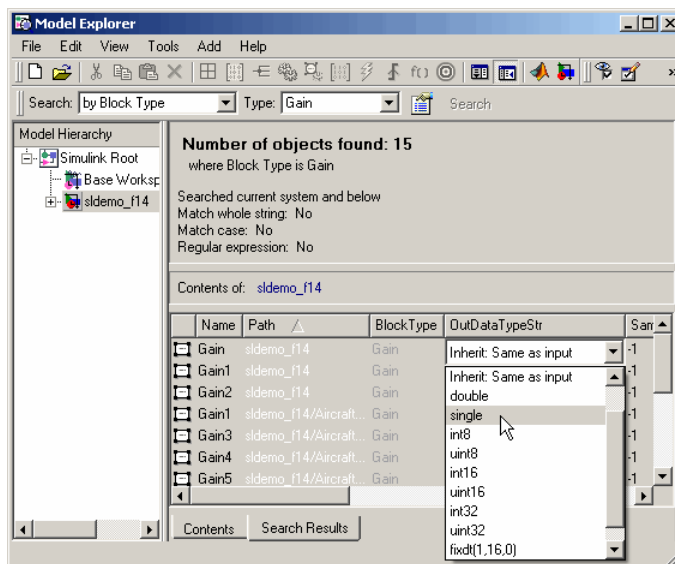
- 2 In the Model Explorer **Contents** pane, select all the Gain blocks whose **Output data type** parameter you want to specify.

Model Explorer highlights the rows corresponding to your selections.



- 3 In the Model Explorer **Contents** pane, click the data type associated with one of the selected Gain blocks.

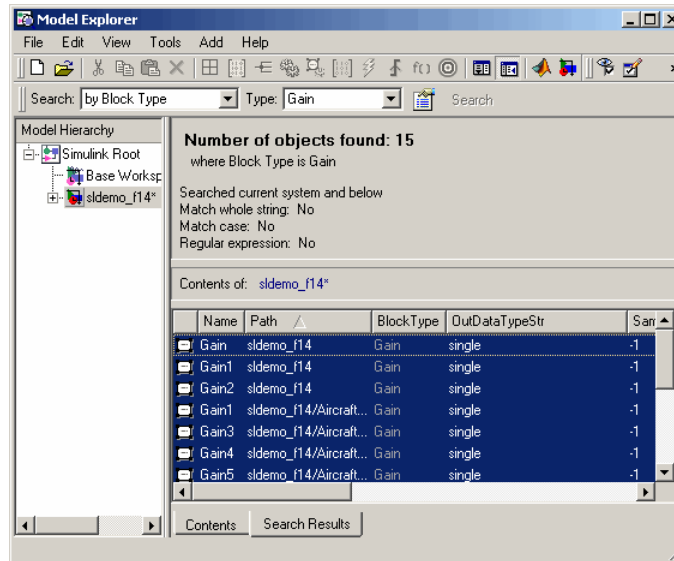
Model Explorer displays a pull-down menu with valid data type options.



- 4 In the pull-down menu, enter or select the desired data type, for example, single.

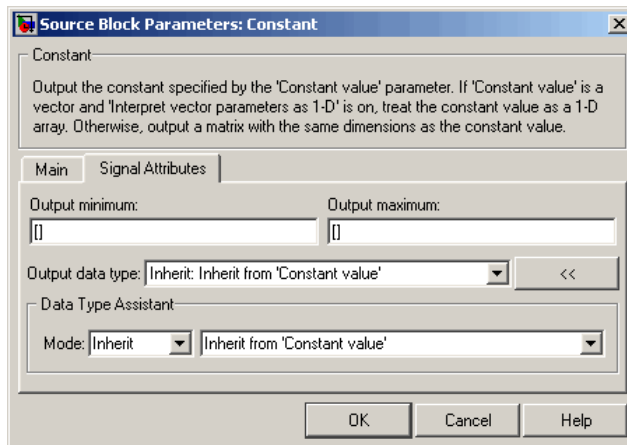
Model Explorer specifies the data type of all selected items as single.







## Using the Data Type Assistant

The **Data Type Assistant** is an interactive graphical tool that simplifies the task of specifying data types for blocks and data objects. The assistant appears on block and object dialog boxes, adjacent to parameters that provide data type control, such as the **Output data type** parameter. For example, it appears on the **Signal Attributes** pane of the Constant block dialog box shown here.



You can selectively show or hide the **Data Type Assistant** by clicking the applicable button:

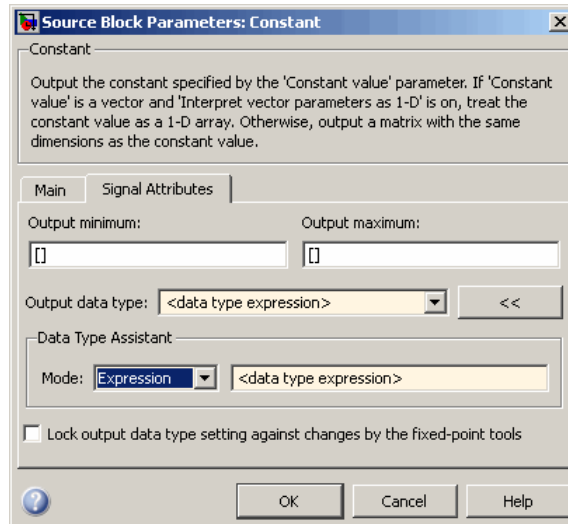
- Click the **Show data type assistant** button  to display the assistant.
- Click the **Hide data type assistant** button  to hide a visible assistant.

Use the **Data Type Assistant** to specify a data type as follows:

- 1 In the **Mode** field, select the category of data type that you want to specify. In general, the options include the following:

Mode	Description
Inherit	Inheritance rules for data types
Built in	Built-in data types
Fixed point	Fixed-point data types
Enumerated	Enumerated data types
Bus object	Bus object data types
Expression	Expressions that evaluate to data types

The assistant changes dynamically to display different options that correspond to the selected mode. For example, setting **Mode** to **Expression** causes the Constant block dialog box to appear as follows.

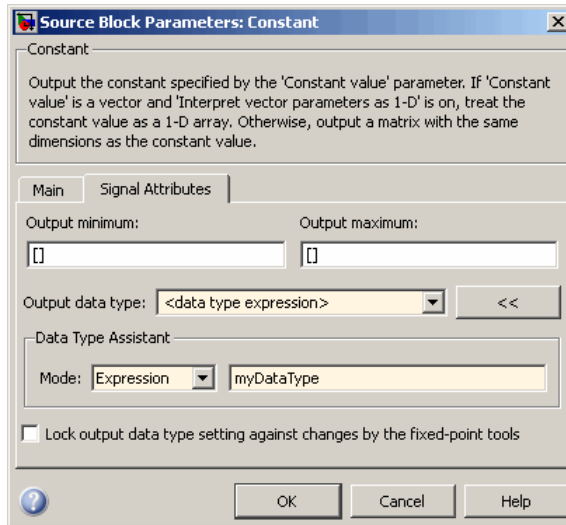


- 2 In the field that is to the right of the **Mode** field, select or enter a data type.

For example, suppose that you designate the variable `myDataType` as an alias for a `single` data type. You create an instance of the `Simulink.AliasType` class and set its `BaseType` property by entering the following commands:

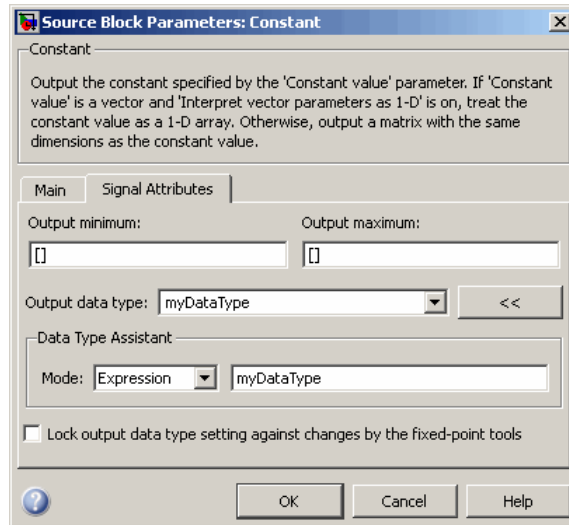
```
myDataType = Simulink.AliasType
myDataType.BaseType = 'single'
```

You can use this data type object to specify the output data type of a Constant block. Enter the data type alias name, `myDataType`, as the value of the expression in the assistant.



- 3 Click the **OK** or **Apply** button to apply your changes.

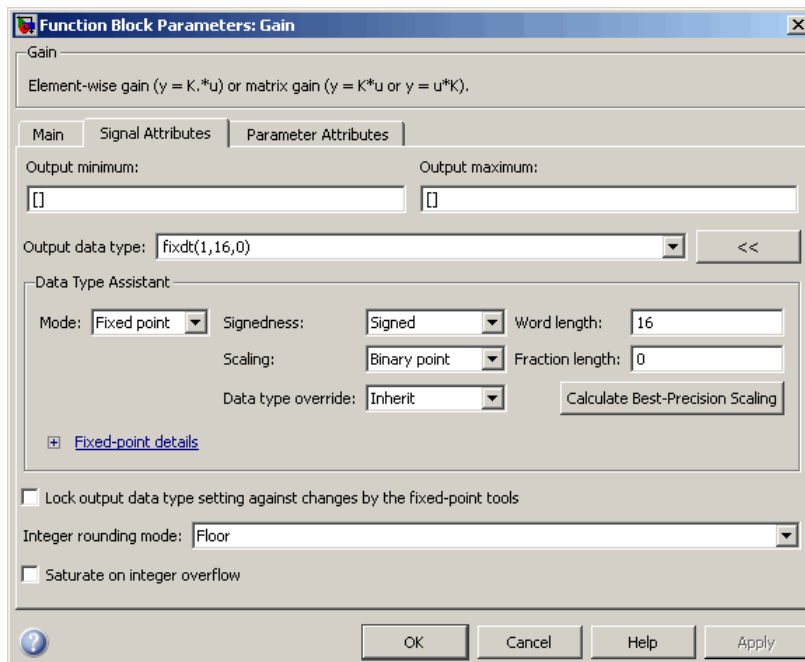
The assistant uses the data type that you specified to populate the associated data type parameter in the block or object dialog box. In the following example, the **Output data type** parameter of the Constant block specifies the same expression that you entered using the assistant.



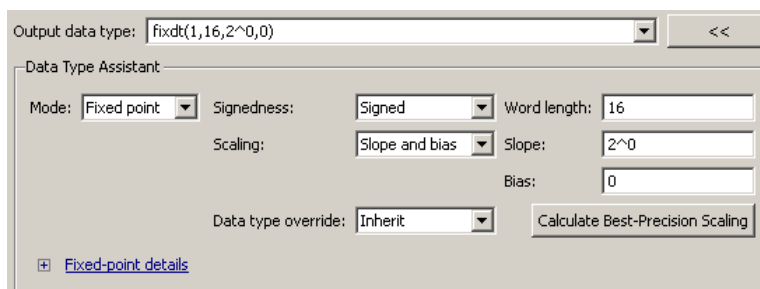
For more information about the data types that you can specify using the **Data Type Assistant**, see “Entering Valid Data Type Values” on page 27-9. See “Specifying Fixed-Point Data Types with the Data Type Assistant” in the *Simulink Fixed Point User’s Guide* for details about specifying fixed-point data types.

### Specifying a Fixed-Point Data Type

When the Data Type Assistant **Mode** is **Fixed point**, the Data Type Assistant displays fields for specifying information about your fixed-point data type. For a detailed discussion about fixed-point data, see “Fixed-Point Concepts” in the *Simulink Fixed Point User’s Guide*. For example, the next figure shows the Block Parameters dialog box for a Gain block, with the **Signal Attributes** tab selected and a fixed-point data type specified.



If the **Scaling** is Slope and bias rather than Binary point, the Data Type Assistant displays a **Slope** field and a **Bias** field rather than a **Fraction length** field:

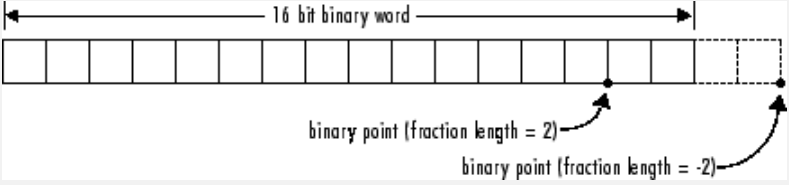


You can use the Data Type Assistant to set these fixed-point properties:

**Signedness.** Specify whether you want the fixed-point data to be Signed or Unsigned. Signed data can represent positive and negative values, but unsigned data represents positive values only. The default setting is Signed.

**Word length.** Specify the bit size of the word that will hold the quantized integer. Large word sizes represent large values with greater precision than small word sizes. Word length can be any integer between 0 and 32. The default bit size is 16.

**Scaling.** Specify the method for scaling your fixed-point data to avoid overflow conditions and minimize quantization errors. The default method is Binary point scaling. You can select one of two scaling modes:

Scaling Mode	Description
Binary point	<p>If you select this mode, the Data Type Assistant displays the <b>Fraction Length</b> field, which specifies the binary point location.</p> <p>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:</p>  <p>The diagram shows a horizontal row of 16 small squares representing bits. Above the squares, a double-headed arrow spans the entire width and is labeled "16 bit binary word". Below the squares, two arrows point to specific positions. The first arrow points to the second square from the right and is labeled "binary point (fraction length = 2)". The second arrow points to the right of the 16th square and is labeled "binary point (fraction length = -2)".</p> <p>The default binary point is 0.</p>
Slope and bias	<p>If you select this mode, the Data Type Assistant displays fields for entering the <b>Slope</b> and <b>Bias</b>.</p> <p>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.</p>

---

**Note** Use binary-point scaling whenever possible to simplify the implementation of fixed-point data in generated code. Operations with fixed-point data using binary-point scaling are performed with simple bit shifts and eliminate expensive code implementations, which are required for separate slope and bias values.

---

For more information about fixed-point scaling, see “Scaling” in the *Simulink Fixed Point User’s Guide*.

**Data type override.** When the **Mode** is **Built in** or **Fixed point**, you can use the **Data type override** option to specify whether you want this data type to inherit or ignore the data type override setting specified for its context, that is, for the block, `Simulink.Signal` object or Stateflow chart in Simulink that is using the signal. The default behavior is **Inherit**.

Data Type Override Mode	Description
Inherit (default)	Inherits the data type override setting from its context, that is, from the block, <code>Simulink.Signal</code> object or Stateflow chart in Simulink that is using the signal.
Off	Ignores the data type override setting of its context and uses the fixed-point data type specified for the signal.

The ability to turn off data type override for an individual data type provides greater control over the data types in your model when you apply data type override. For example, you can use this option to ensure that data types meet the requirements of downstream blocks regardless of the data type override setting.



**Calculate Best-Precision Scaling.** Click this button to calculate best-precision values for both Binary point and Slope and bias scaling, based on the specified minimum and maximum values. The Simulink software displays the scaling values in the **Fraction Length** field or the **Slope** and **Bias** fields. For more information, see “Constant Scaling for Best Precision” in the *Simulink Fixed Point User’s Guide*.

**Showing Fixed-Point Details.** When you specify a fixed-point data type, you can use the **Fixed-point details** subpane to see information about the fixed-point data type that is currently displayed in the Data Type Assistant. To see the subpane, click the expander next to **Fixed-point details** in the Data Type Assistant. The **Fixed-point details** subpane appears at the bottom of the Data Type Assistant:

Output minimum:  Output maximum:

Output data type:

Data Type Assistant

Mode:  Signedness:  Word length:

Scaling:  Slope:

Bias:

Data type override:

[Fixed-point details](#)

Representable maximum:	32767
Output maximum:	<input type="text" value="[]"/>
Constant value:	90
Output minimum:	<input type="text" value="[]"/>
Representable minimum:	-32768

Precision:

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 31-45 and “Checking Parameter Values” on page 21-9 for more information.

The rows labeled **Representable minimum**, **Representable maximum**, and **Precision** always appear. These rows show the minimum value, maximum value, and precision that can be represented by the fixed-point data type currently displayed in the Data Type Assistant. See “Fixed-Point Concepts” in the *Simulink Fixed Point User’s Guide* for information about these three quantities.

The values displayed by the **Fixed-point details** subpane *do not* automatically update if you click **Calculate Best-Precision Scaling**, or change the range limits, the values that define the fixed-point data type, or anything elsewhere in the model. To update the values shown in the **Fixed-point details** subpane, click **Refresh Details**. The Data Type Assistant then updates or recalculates all values and displays the results.

Clicking **Refresh Details** does not change anything in the model, it only changes the display. Click **OK** or **Apply** to put the displayed values into effect. If the value of a field cannot be known without first compiling the model, the **Fixed-point details** subpane shows the value as Unknown.

If any errors occur when you click **Refresh Details**, the **Fixed-point details** subpane shows an error flag on the left of the applicable row, and a description of the error on the right. For example, the next figure shows two errors:

Output minimum:  Output maximum:

Output data type:  <<

Data Type Assistant

Mode:  Signedness:  Word length:

Scaling:  Fraction length:

Data type override:

[Fixed-point details](#)

Representable maximum:	32767	
Output maximum:	50000	Outside representable range by 17233 (17233 x precision)
Output minimum:	MySymbol	Cannot evaluate
Representable minimum:	-32768	

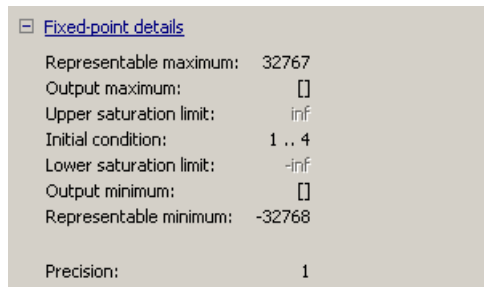
Precision:

The row labeled `Output minimum` shows the error `Cannot evaluate` because evaluating the expression `MySymbol`, specified in the **Output minimum** field, did not return an appropriate numeric value. When an expression does not evaluate successfully, the **Fixed-point details** subpane displays the unevaluated expression (truncating to 10 characters if necessary to save space) in place of the unavailable value.

To correct the error in this case, you would need to define `MySymbol` in an accessible workspace to provide an appropriate numeric value. After you clicked **Refresh Details**, the value of `MySymbol` would appear in place of its unevaluated text, and the error indicator and error description would disappear.

To correct the error shown for `Output maximum`, you would need to decrease **Output maximum**, increase **Word length**, or decrease **Fraction length** (or some combination of these changes) sufficiently to allow the fixed-point data type to represent the maximum value that it could have.

Other values relevant to a particular block can also appear in the **Fixed-point details** subpane. For example, on a Discrete-Time Integrator block's **Signal Attributes** tab, the subpane could look like this:



Note that the values displayed for `Upper saturation limit` and `Lower saturation limit` are greyed out. This appearance indicates that the corresponding parameters are not currently used by the block. The greyed-out values can be ignored.

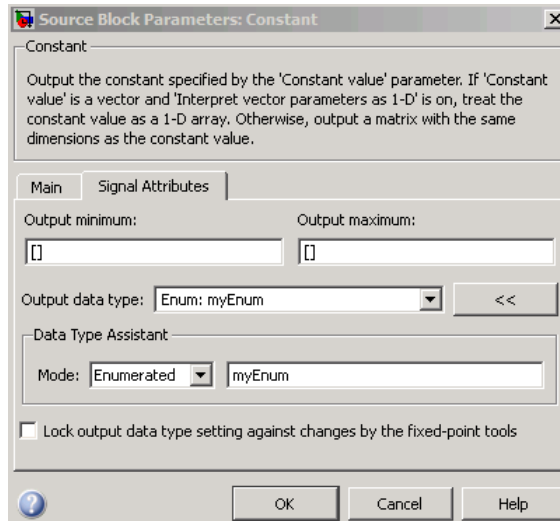
Note also that `Initial condition` displays the value `1 .. 4`. The actual value is a vector or matrix whose smallest element is 1 and largest element is 4. To conserve space, the **Fixed-point details** subpane shows only the smallest and largest element of a vector or matrix. An ellipsis (`..`) replaces the omitted values. The underlying definition of the vector or matrix is unaffected.

**Lock output data type setting against changes by the fixed-point tools.** Select this check box to prevent replacement of the current data type with a type that the Fixed-Point Tool or Fixed-Point Advisor chooses. See “Scaling” in the *Simulink Fixed Point User’s Guide* for instructions on autoscaling fixed-point data.

### Specifying an Enumerated Data Type

You can specify an enumerated data type by selecting the Enum: `<class name>` option and specify an enumerated object.

In the **Data Type Assistant**, you can use the **Mode** parameter to specify a bus as a data object for a block. Select the Enumerated option and specify an enumerated object.

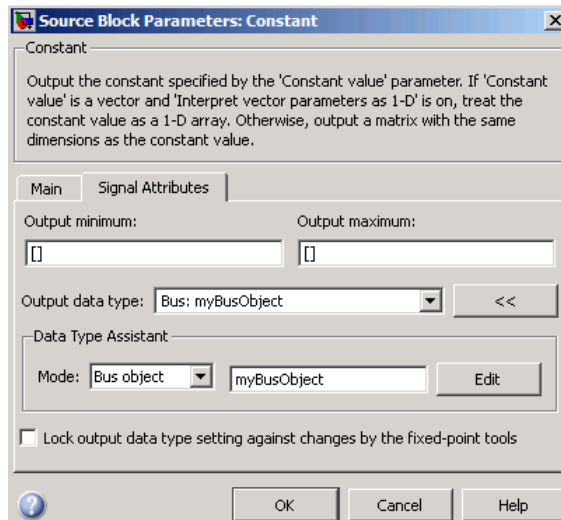


For details about enumerated data types, see Chapter 28, “Enumerations and Modeling”.

### Specifying a Bus Object Data Type

The blocks listed in the section called “Bus Objects” on page 27-6 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 32-16

## Displaying Port Data Types

To display the data types of ports in your model, select **Format > Port/Signal Displays > Port Data Types**. The port data type display is not automatically updated when you change the data type of a diagram element. To refresh the display, press **Ctrl+D**.

## Data Type Propagation

Whenever you start a simulation, enable display of port data types, or refresh the port data type display, the Simulink software performs a processing step called data type propagation. This step involves determining the types of signals whose type is not otherwise specified and checking the types of signals

and input ports to ensure that they do not conflict. If type conflicts arise, an error dialog is displayed that specifies the signal and port whose data types conflict. The signal path that creates the type conflict is also highlighted.

---

**Note** You can insert typecasting (data type conversion) blocks in your model to resolve type conflicts. See “Typecasting Signals” on page 27-30 for more information.

---

## Data Typing Rules

Observing the following rules can help you to create models that are typesafe and, therefore, execute without error:

- Signal data types generally do not affect parameter data types, and vice versa.

A significant exception to this rule is the Constant block, whose output data type is determined by the data type of its parameter.

- If the output of a block is a function of an input and a parameter, and the input and parameter differ in type, the Simulink software converts the parameter to the input type before computing the output.
- In general, a block outputs the data type that appears at its inputs.

Significant exceptions include Constant blocks and Data Type Conversion blocks, whose output data types are determined by block parameters.

- Virtual blocks accept signals of any type on their inputs.

Examples of virtual blocks include Mux and Demux blocks and unconditionally executed subsystems.

- The elements of a signal array connected to a port of a nonvirtual block must be of the same data type.
- The signals connected to the input data ports of a nonvirtual block cannot differ in type.
- Control ports (for example, Enable and Trigger ports) accept any data type.
- Solver blocks accept only `double` signals.

- Connecting a non-double signal to a block disables zero-crossing detection for that block.

## Typecasting Signals

An error is displayed whenever it detects that a signal is connected to a block that does not accept the signal's data type. If you want to create such a connection, you must explicitly typecast (convert) the signal to a type that the block does accept. You can use the Data Type Conversion block to perform such conversions.

## Validating a Floating-Point Embedded Model

You can use data type override mode to switch the data types in your model. This capability allows you to maintain one model but simulate and generate code for multiple data types, and also validate the numerical behavior for each type. For example, if you implement an algorithm using double-precision data types and want to check whether the algorithm is also suitable for single-precision use, you can apply a data type override to floating-point data types to replace all doubles with singles without affecting any other data types in your model.

## How to Apply a Data Type Override to Floating-Point Data Types

To apply a data type override, you must specify the data type that you want to apply and the data type that you want to replace.

You can set a data type override using one of the following methods. In these examples, both methods change all floating-point data types to single.

**From the Command Line.** For example:

```
set_param(gcs, 'DataTypeOverride', 'Single');  
set_param(gcs, 'DataTypeOverrideAppliesTo', 'Floating-point');
```

**Using the Fixed-Point Tool.** For example:

- 1 From the model menu, select **Tools > Fixed-Point Tool**.

The Fixed-Point Tool opens.



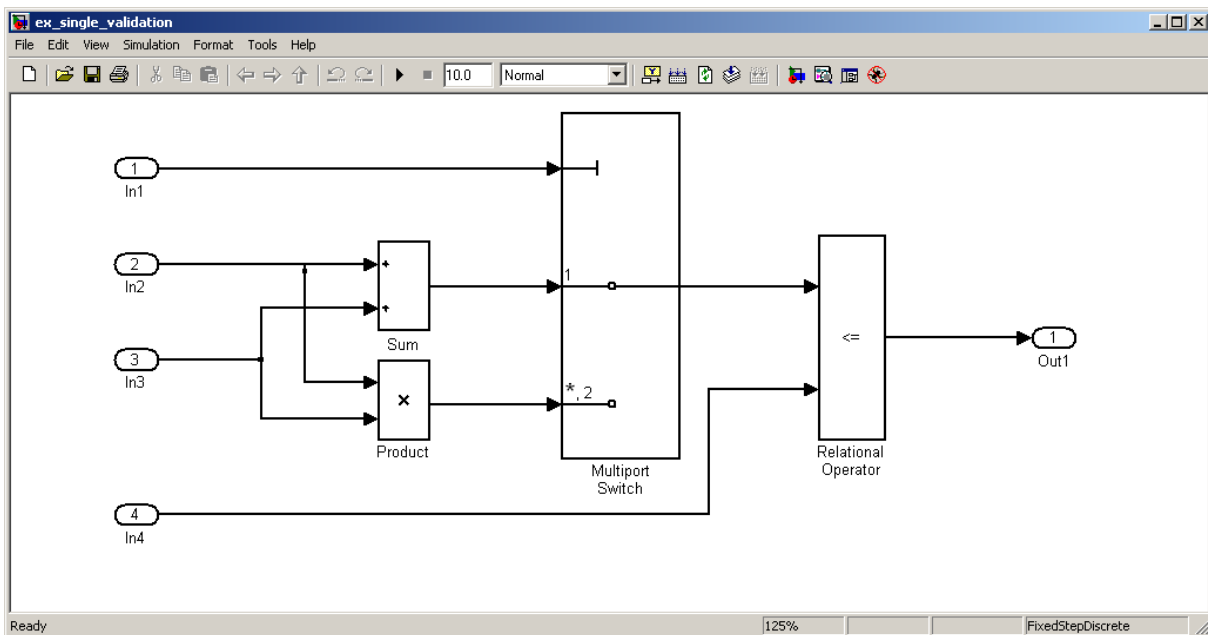
- 2 If you cannot see the **Current system settings** panel on the right side of the Fixed-Point Tool dialog box, from the Fixed-Point Tool **View** menu, select **Show Current System Settings**.
- 3 In the Fixed-Point Tool **Current system settings** panel, set:
  - a **Data type override** to Single.
  - b **Data type override applies to** Floating-point.

For more information on data type override settings, see `fxptdlg`.

## Tutorial: Validating a Single-Precision Model

This tutorial uses the `ex_single_validation` model to show how you can use data type overrides. It proves that an algorithm, which implements double-precision data types, is also suitable for single-precision embedded use.

### About the Model



- The inputs In2 and In3 are double-precision inputs to the Sum and Product blocks.
- The outputs of the Sum and Product blocks are data inputs to the Multiport Switch block.
- The input In1 is the control input to the Multiport Switch block. The value of this control input determines which of its other inputs, the sum of In2 and In3 or the product of In2 and In3, passes to the output port. Because In1 is a control input, its data type is `int8`.
- The Relational Operator block compares the output of the Multiport Switch block to In4, and outputs a Boolean signal.

## About the Procedure

In this tutorial, you follow these steps:

**1** “Generate Code for the Double-Precision Model” on page 27-33

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 27-34

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 27-35

Finally, you generate code for this single-precision model and verify that this code is suitable for single-precision embedded use.

## Running the Tutorial

### Open the Model.

- 1 Open the `ex_single_validation` model. At the MATLAB command line, enter:

```
run(docpath(fullfile(docroot,'toolbox','simulink','examples','ex_single_validation.mdl')))
```

### Generate Code for the Double-Precision Model.

- 1 From the model menu, select **Simulation > Configuration Parameters**.

The Configuration Parameters dialog box opens.

- 2 In the left pane, under **Code Generation**, 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 From the Simulink model menu, select **Tools > Code Generation > 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 outputs, the input `In1` has the type `int8_T`, all the remaining inputs are double-precision `real_T`, and the output `Out1` is `boolean_T`.

```
/* External inputs (root inport signals with auto storage) */
typedef struct {
    int8_T In1;
    real_T In2;
    real_T In3;
```

```
    real_T In4;
} ExternalInputs_ex_single_valida;

typedef struct {
    boolean_T Out1;
} ExternalOutputs_ex_single_valid;
```

- b** In the left pane of the report, click the `ex_single_validation.c` link.

The report displays the C code in the right pane. The code for the double-precision model contains only double-precision operations.

```
real_T rtb_MultiportSwitch;

if (ex_single_validation_U.In1 == 1) {
    rtb_MultiportSwitch = ex_single_validation_U.In2 +
        ex_single_validation_U.In3;
} else {
    rtb_MultiportSwitch = ex_single_validation_U.In2 *
        ex_single_validation_U.In3;
}
ex_single_validation_Y.Out1 = (rtb_MultiportSwitch <=
    ex_single_validation_U.In4);
```

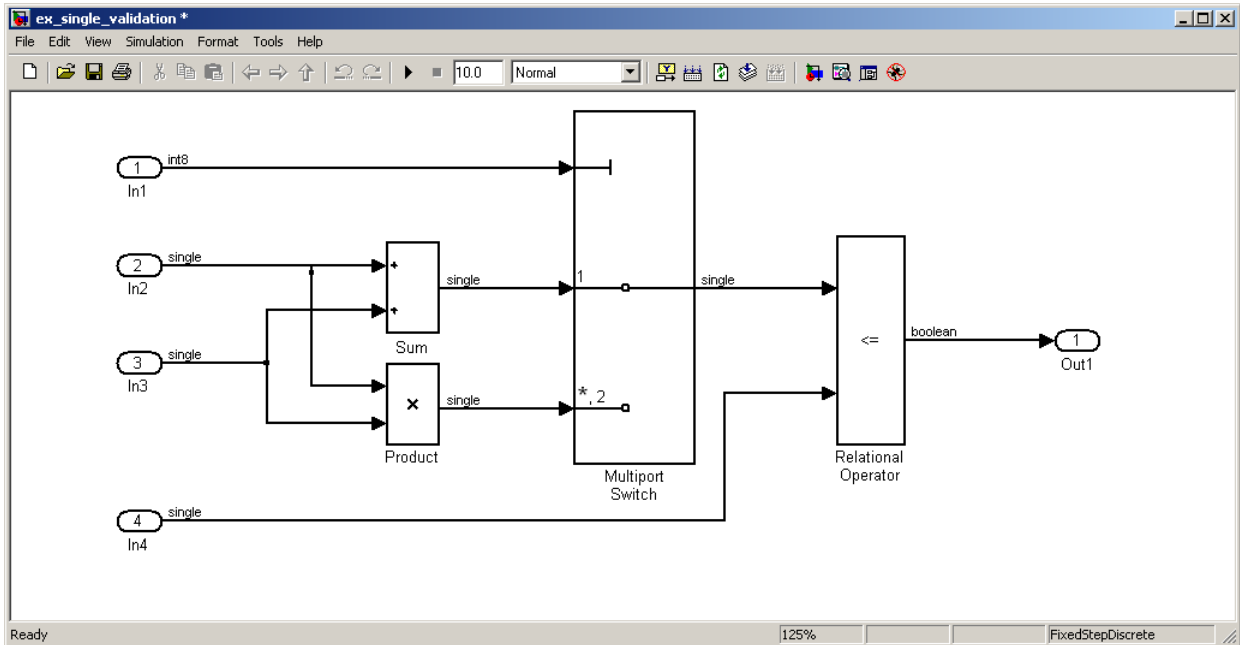
### **Convert the Model to Single Precision.**

- 1** From the model menu, select **Tools > Fixed-Point Tool**.

The Fixed-Point Tool opens.

- 2** If you cannot see the **Settings for selected system** panel on the right side of the Fixed-Point Tool dialog box, from the Fixed-Point Tool **View** menu, select **Show Settings for Selected System**.
- 3** In the Fixed-Point Tool **Settings for selected system** panel:
  - a** Set the **Data type override** parameter to **Single**.
  - b** Set the **Data type override applies to** parameter to **Floating-point**.
  - c** Click **Apply**.
- 4** From the Fixed-Point Tool menu, select **Simulation > Start**.

The simulation runs. The data type override replaces all the floating-point (double) data types in the model with `single` data types, but does not affect the integer or Boolean data types.



### Generate Code for the Single-Precision Model.

- 1 From the model menu, select **Tools > Code Generation > 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.

## Working with Data Objects

### In this section...

- “About Data Object Classes” on page 27-37
- “About Data Object Methods” on page 27-38
- “Using the Model Explorer to Create Data Objects” on page 27-40
- “About Object Properties” on page 27-42
- “Changing Object Properties” on page 27-42
- “Handle Versus Value Classes” on page 27-44
- “Comparing Data Objects” on page 27-46
- “Saving and Loading Data Objects” on page 27-46
- “Using Data Objects in Simulink Models” on page 27-46
- “Creating Persistent Data Objects” on page 27-47
- “Data Object Wizard” on page 27-47

### About Data Object Classes

You can create entities called data objects that specify values, data types, tunability, value ranges, and other key attributes of block outputs and parameters. You can create various types of data objects and assign them to workspace variables. You can use the variables in Simulink dialog boxes to specify parameter and signal attributes. This allows you to make model-wide changes to parameter and signal specifications simply by changing the values of a few variables. With Simulink objects you can parameterize the specification of a model's data attributes. For information on working with specific kinds of data objects, see “Simulink Classes”.

---

**Note** This section uses the term *data* to refer generically to signals and parameters.

---

The Simulink software uses objects called data classes to define the properties of specific types of data objects. The classes also define functions, called

methods, for creating and manipulating instances of particular types of objects. A set of built-in classes are provided for specifying specific types of attributes (see “Simulink Classes” for information on these built-in classes). Some MathWorks products based on Simulink, such as the 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 Using Data Class Designer” on page 27-62).

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 27-44).

## Using the Model Explorer to Create Data Objects

You can use the Model Explorer (see “The Model Explorer: Overview” on page 8-2) as well as MATLAB commands to create data objects. To use the Model Explorer,

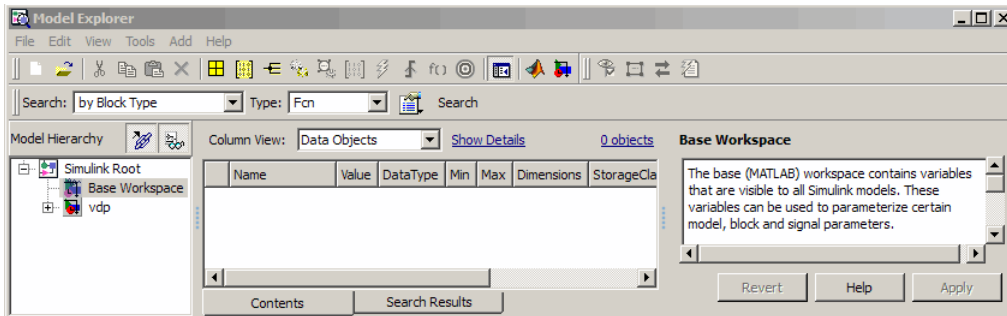
- 1 Select the workspace in which you want to create the object in the Model Explorer **Model Hierarchy** pane.

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

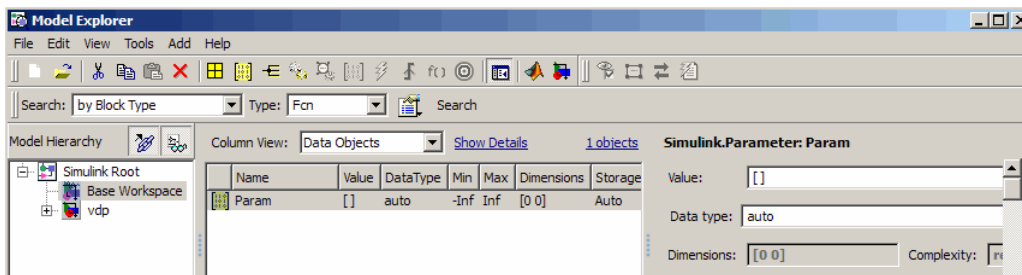
---

**Note** Subclasses of `Simulink.Parameter` and `Simulink.Signal` classes, such as `mpt.Parameter` and `mpt.Signal` objects (Embedded Coder license required), can reside in a model workspace only if their storage class is set to `Auto`.

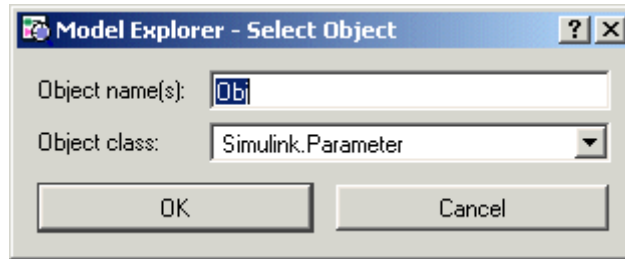
---



- 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.

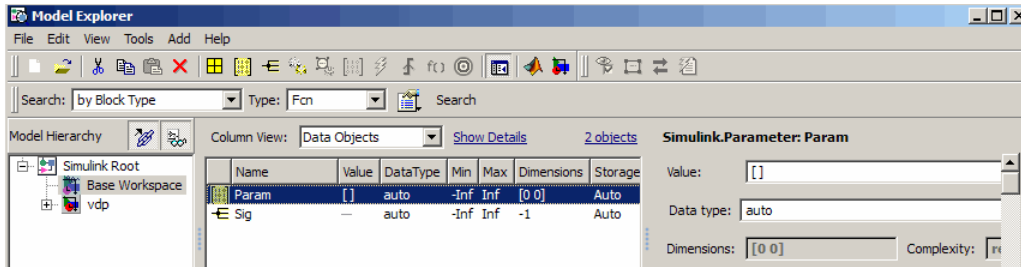
## Changing Object Properties

You can use either the Model Explorer (see “Using the Model Explorer to Change an Object's Properties” on page 27-42) or MATLAB commands to change a data object's properties (see “Using MATLAB Commands to Change Workspace Data” on page 3-70).

### Using the Model Explorer to Change an Object's Properties

To use the Model Explorer to change an object's properties, select the workspace that contains the object in the Model Explorer's **Model Hierarchy** pane. Then select the object in the Model Explorer's **Contents** pane.

The Model Explorer displays the object's property dialog box in its **Dialog** pane (if the pane is visible).



You can configure the Model Explorer to display some or all of the properties of an object in the **Contents** pane (see “The Model Explorer: Contents Pane” on page 8-18). To edit a property, click its value in the **Contents** or **Dialog** pane. The value is replaced by a control that allows you to change the value.

## Using MATLAB Commands to Change an Object's Properties

You can also use MATLAB commands to get and set data object properties. Use the following dot notation in MATLAB commands and programs to get and set a data object's properties:

```
VALUE = OBJ.PROPERTY;
OBJ.PROPERTY = VALUE;
```

where OBJ is a variable that references either the object if it is an instance of a value class or a handle to the object if the object is an instance of a handle class (see “Handle Versus Value Classes” on page 27-44), 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 27-40) returns an instance of the class and the instance is permanently associated with the MATLAB variable to which it is initially assigned. Reassigning or passing the variable to a function causes MATLAB to create and assign or pass a copy of the original object.

For example, `Simulink.NumericType` is a value class. Executing the following statements

```
>> x = Simulink.NumericType;  
>> y = x;
```

creates two instances of class `Simulink.NumericType` in the workspace, one assigned to the variable `x` and the other to `y`.

### About Handle Classes

The constructor for a *handle* class returns a handle object. The handle can be assigned to multiple variables or passed to functions without causing a copy of the original object to be created. For example, `Simulink.Parameter` class is a handle class. Executing

```
>> x = Simulink.Parameter;  
>> y = x;
```

creates only one instance of `Simulink.Parameter` class in the MATLAB workspace. Variables `x` and `y` both refer to the instance via its handle.

A program can modify an instance of a handle class by modifying any variable that references it, e.g., continuing the previous example,

```
>> x.Description = 'input gain';  
>> y.Description
```

```
ans =
```

```
input gain
```

Most Simulink data object classes are value classes. Exceptions include `Simulink.Signal` and `Simulink.Parameter` class.

You can determine whether a variable is assigned to an instance of a class or to a handle to that class by evaluating it at the MATLAB command line. MATLAB appends the text (`handle`) to the name of the object class in the value display, e.g.,

```
>> gain = Simulink.Parameter

gain =

Simulink.Parameter (handle)
      Value: []
      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 Using MATLAB Class Syntax” on page 27-53) or at the command line and save them in a MAT-file (see “Saving and Loading Data Objects” on page 27-46). Then use either the script or a load command as the `PreLoadFcn` callback routine for the model that uses the objects. For example, suppose you save the data objects in a file named `data_objects.mat` and the model to which they apply is open and active. Then, entering the following command

```
set_param(gcs, 'PreLoadFcn', 'load data_objects');
```

at the MATLAB command line sets `load data_objects` as the model’s preload function. This in turn causes the data objects to be loaded into the model workspace whenever you open the model.

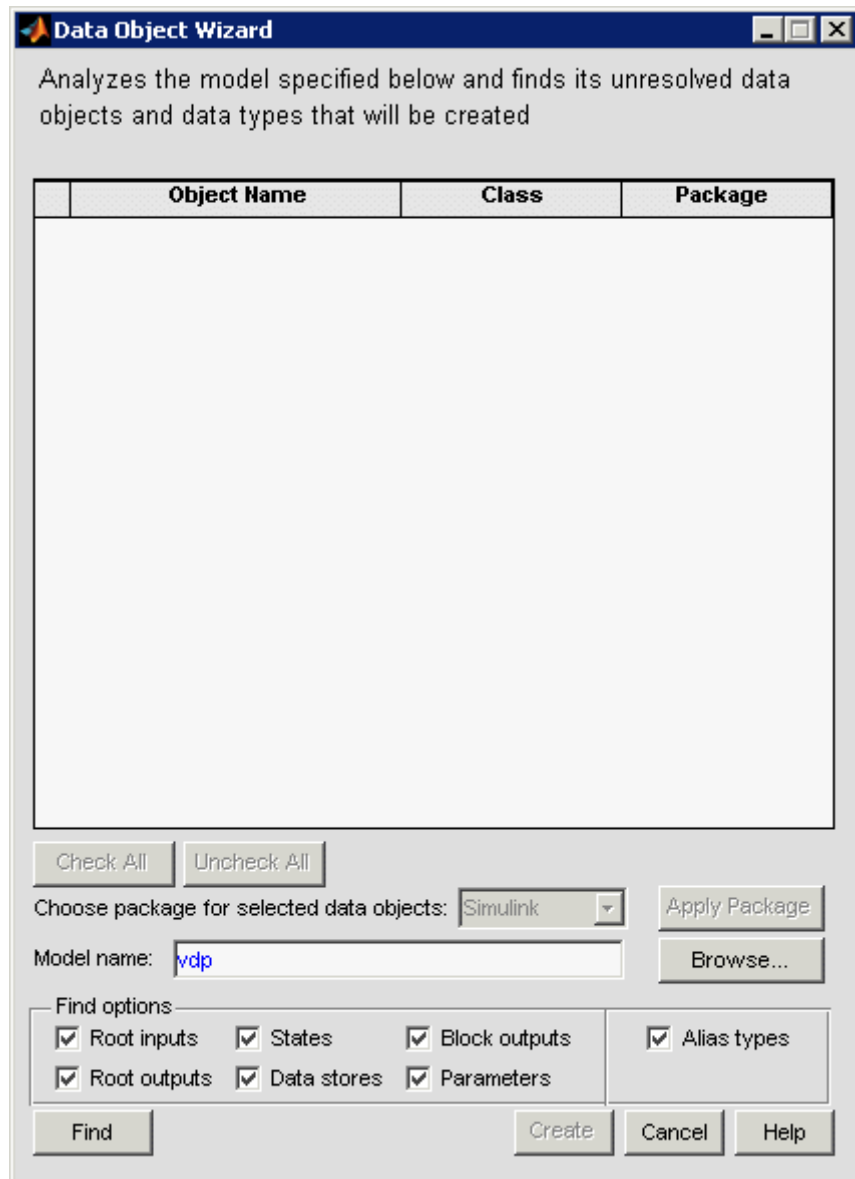
## Data Object Wizard

The Data Object Wizard allows you to determine quickly which model data are not associated with data objects and to create and associate data objects with the data.

To use the wizard to create data objects:

- 1 Select **Tools > Data Object Wizard** from the Model Editor’s tool bar.

The Data Object Wizard appears.



- 2** Enter, if necessary, the name of the model you want to search in the wizard's **Model name** field.

By default the wizard displays the name of the model from which you opened the wizard. You can enter the name of another model in this field. If the model is not open, the wizard opens the model.

- 3** In **Find options**, uncheck any of the data object types that you want the search to ignore.

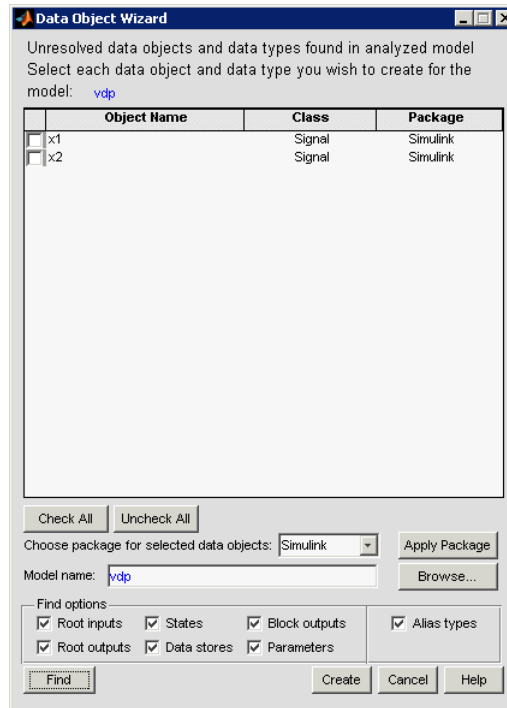
The search options include:

<b>Option</b>	<b>Description</b>
<b>Root inputs</b>	Named signals from root-level input ports
<b>Root outputs</b>	Named signals from root-level output ports
<b>States</b>	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
<b>Data stores</b>	Data stores (see Chapter 30, "Working with Data Stores" )
<b>Block outputs</b>	Named signals emitted by non-root-level blocks.

<b>Option</b>	<b>Description</b>
<b>Parameters</b>	<ul style="list-style-type: none"> <li>• Parameters of any instances of the following block types:               <ul style="list-style-type: none"> <li>Constant</li> <li>Gain</li> <li>Relay</li> </ul> </li> <li>• Stateflow data with a <b>Scope</b> of Parameter. See “Sharing Simulink Parameters with Charts” in the Stateflow documentation for more information.</li> </ul>
<b>Alias types</b>	Data whose data type is a registered custom data type. This option applies only if you are generating code from the model. See “Create Simulink 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 Using MATLAB Class Syntax

---

**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 “New Infrastructure for Extending Simulink Data Classes” on page 27-60

To use the Data Class Designer, run the following commands to enable level-1 data class infrastructure.

```
sldataclasssetup (1)
savepath
```

---

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 on 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 27-57.

```
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.

---

**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**

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 obj = Parameter()
            useLocalCustomStorageClasses(obj, 'mypkg');
        end
    end % methods
end % classdef

```

- 2** Launch the Custom Storage Class Designer for your package.

```
cscdesigner('mypkg')
```

- 3** Define custom storage classes. See “Use the 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

```

```
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  
  
    methods  
        function props = getInstanceSpecificProps(obj)  
            props = findprop(obj, 'InstanceSpecificName');  
        end  
    end % methods  
end % classdef
```

#### **Alternate way of defining level-2 data classes**

- 1 Locate the `+SimulinkDemos` data class package on the MATLAB path.  
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`.
- 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	<code>properties(PropertyType = 'double scalar')</code>
int32 number	<code>properties(PropertyType = 'int32 scalar')</code>
Logical number	<code>properties(PropertyType = 'logical scalar')</code>
String (char)	<code>properties(PropertyType = 'char')</code>
String with limited set of allowed values	<code>properties(PropertyType = 'char', AllowedValues = {'a', 'b', 'c'})</code>

## Upgrade Level-1 Data Classes to Level-2

Run the following utility function while specifying the destination folder for the upgraded classes.

- 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. Level-2 classes need to be higher on the MATLAB path so that they are found by MATLAB.

---

`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 completely upgraded all of them to level-2.

Any MAT files that still reference 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.

---

## New Infrastructure for Extending Simulink Data Classes

### In this section...

“Disadvantages of Level-1 Data Class Infrastructure” on page 27-60

“Features of Level-2 Data Class Infrastructure” on page 27-60

“Other Differences between Level-1 and Level-2 Data Classes” on page 27-61

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 to Level-2” on page 27-58.

- 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 Using MATLAB Class Syntax” on page 27-53.

## 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 Using Data Class Designer

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 Using MATLAB Class Syntax” on page 27-53.

---

**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” on page 27-62
“Define Level-1 Data Classes” on page 27-63
“Working with Classes” on page 27-66
“Enumerated Property Types” on page 27-75
“Enabling Custom Storage Classes” on page 27-78

### About Packages and Data Classes

Simulink packages and data classes are introduced in “About Data Object Classes” on page 27-37 and “Data, Function, and File Definition”. 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 27-78.

Custom storage classes are defined and stored in different files than packages and data classes use, and different rules apply to changing them. See “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**.

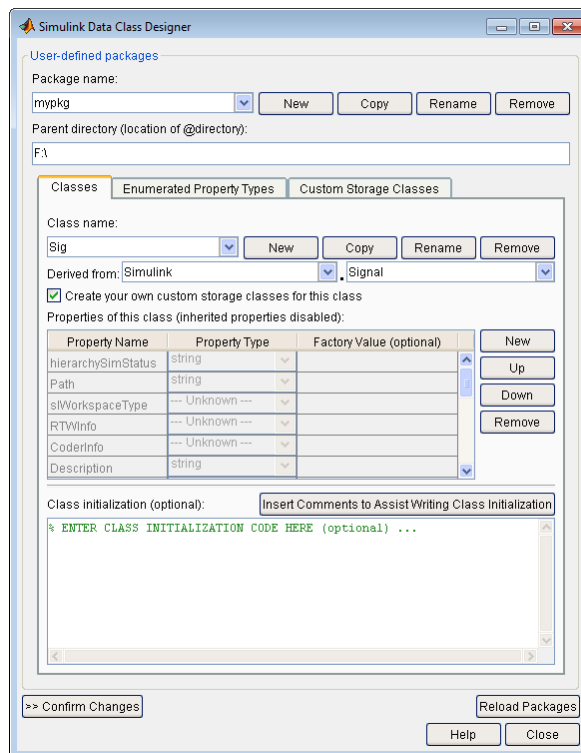
- 2 Specify the parent class using the **Derived from** menus. Select `Simulink.Signal` or `Simulink.Parameter`.
- 3 Select the option to **Create your own custom storage classes for this class**.

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.

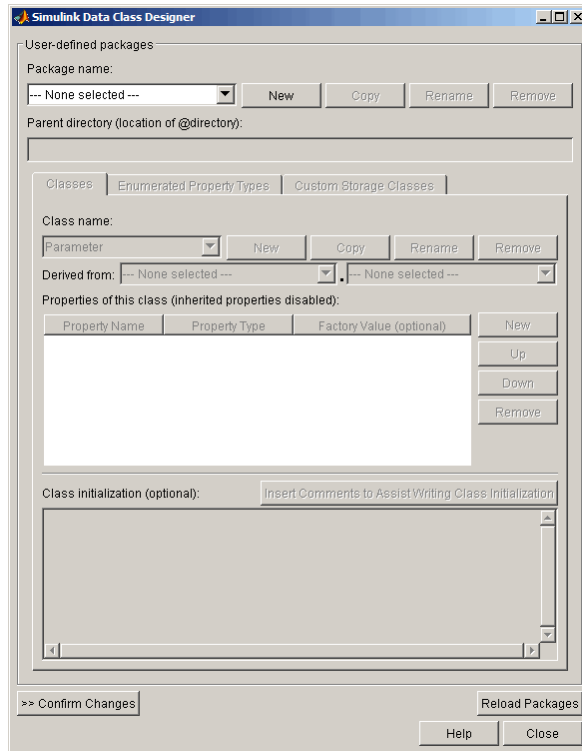
- 4 Click **Close**.

**Optional: Define custom storage classes**

Define custom storage classes. See “Use the 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 27-66.

## Creating a Data Object Class

To create a class within the currently selected package:

- 1 Select **Data Class Designer** from the Simulink **Tools** menu.

The **Data Class Designer** dialog box appears.

The designer initially scans the MATLAB path and loads any packages that it finds.

- 2 Select the name of the package in which you want to create the class from the **Package name** list.

Do not create a class in any of the Simulink built-in packages, i.e., packages in *matlabroot/toolbox/simulink*, or any folder under *matlabroot*.

- 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.

---

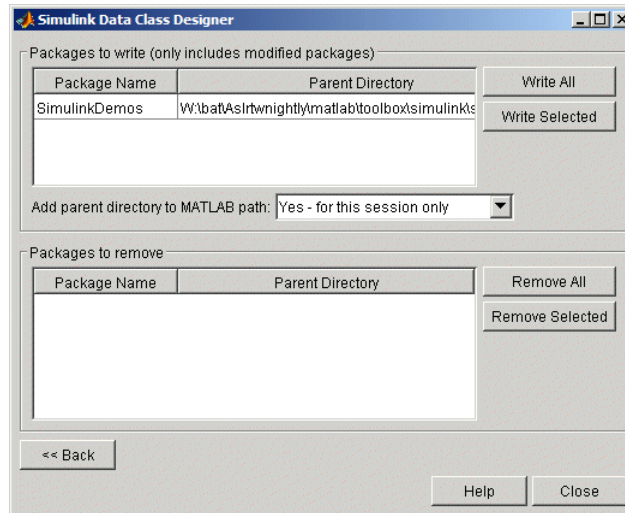
**Note** The name of the new class must be unique in the package to which the new class belongs. Class names are case sensitive. For example, **Signal** and **signal** is considered to be names of different classes.

---

- 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 27-70).
- 7 Optionally enable custom storage classes for the class (see “Enabling Custom Storage Classes” on page 27-78).
- 8 Define the properties of the new class (see “Defining Class Properties” on page 27-71).
- 9 If necessary, create initialization code for the new class (see “Creating Initialization Code” on page 27-73).

**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.

---

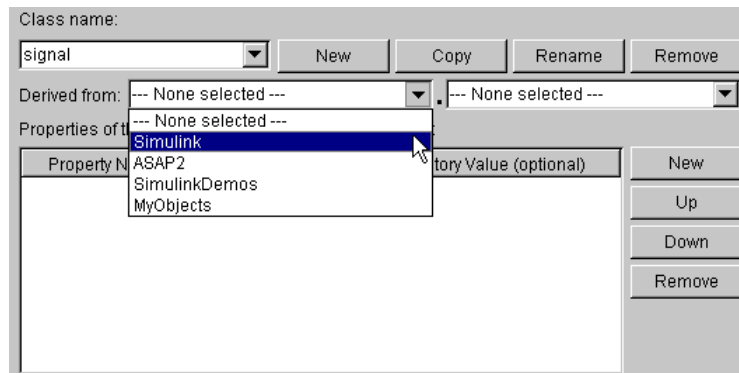
## Removing a class from a package

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

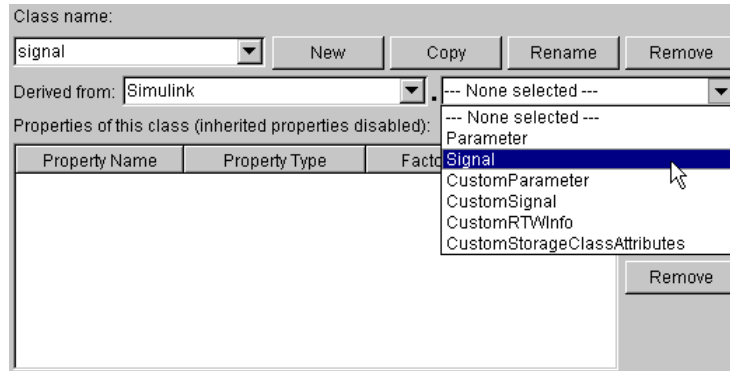
To specify a parent for a class:

- 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.

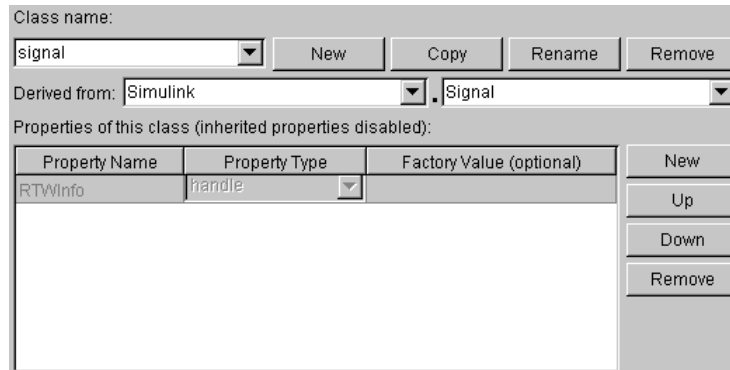




**3** Select the parent class from the right-hand **Derived from** list.



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.

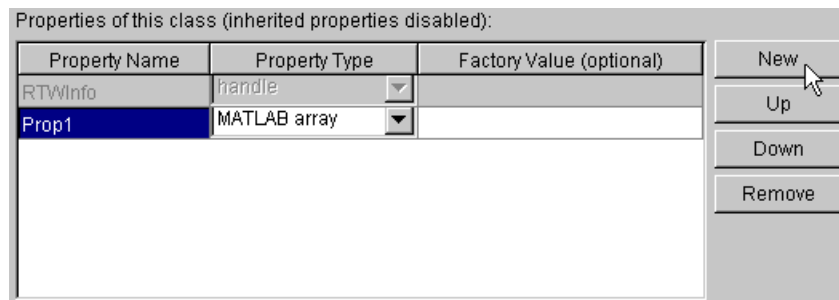
---

**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 27-75).

- 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 27-73 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.

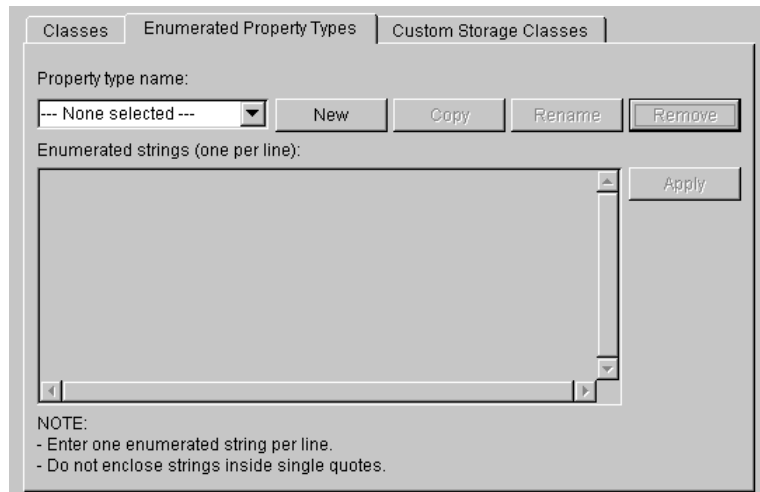
---

**Note** Do not confuse an *enumerated property type* with an *enumeration*. For information on enumerations, see “Using Enumerated Data in Simulink Models” on page 28-10. 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.

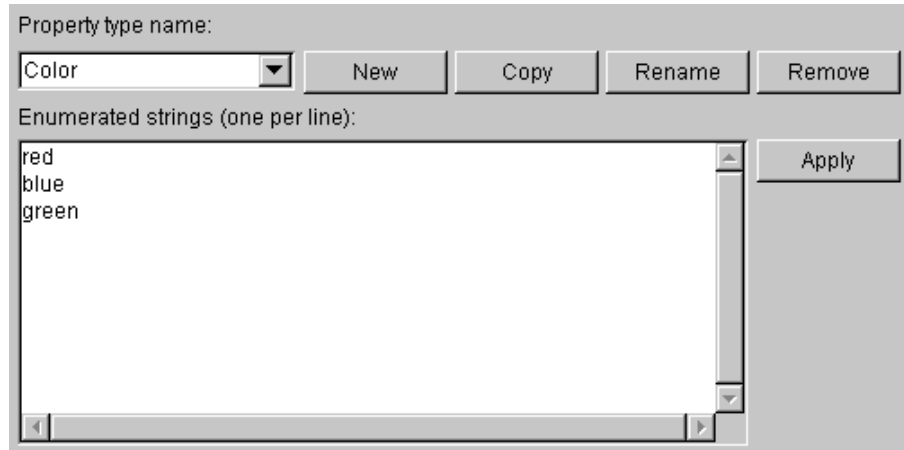
The currently selected package defines an enumerated property type and the type can be referenced only in the package that defines it. However, the name of the enumerated property type must be globally unique. There cannot be any other built-in or user-defined enumerated property type with the same name. 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(gcf, '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(gcf, 'UserData')
```

The following command saves the user data associated with a block in the model file of the model containing the block.

```
set_param(gcf, '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” on page 27-80
“Valid Values for Design Minimum and Maximum” on page 27-80

### 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  $-\text{Inf}/\text{Inf}$ . The default design minimum or maximum is  $[\ ]$ .

Previously, you could specify the design minimum and maximum as  $-\text{Inf}/\text{Inf}$ . 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  $-\text{Inf}/\text{Inf}$ .

---

## 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  $-\text{Inf}/\text{Inf}$ . 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  $-\text{Inf}/\text{Inf}$ .
  - b** Either remove these lines of code from the MATLAB file or replace instances of  $-\text{Inf}$  and  $\text{Inf}$  with `[]`.
- 2** MAT-file: Resave the MAT-file
- 3** MDL file: Resave the MDL file



# Enumerations and Modeling

---

- “About Simulink Enumerations” on page 28-2
- “Defining Simulink Enumerations” on page 28-3
- “Using Enumerated Data in Simulink Models” on page 28-10
- “Simulink Constructs that Support Enumerations” on page 28-21
- “Simulink Enumeration Limitations” on page 28-24

## About Simulink Enumerations

Simulink enumerations are built on enumerations defined for the MATLAB language. They are subclasses of the abstract superclass `Simulink.IntEnumType`, and inherit from that superclass the capabilities necessary to be used in the Simulink environment.

Before you begin to use enumerations in a modeling context, you should understand information provided in “Enumerations”.

The following demos show you how to use enumerations in Simulink and Stateflow:

<b>Demo...</b>	<b>Shows How To Use...</b>
Data Typing in Simulink	Data types in Simulink, including enumerated data types
Modeling a CD Player/Radio Using Enumerated Data Types	Enumerated data types in a Simulink model that contains a Stateflow chart

For information on using enumerations in Stateflow, see “Using Enumerated Data in Stateflow Charts”.

## Defining Simulink Enumerations

### In this section...

“Basic Workflow for Defining a Simulink Enumeration” on page 28-3

“Creating a Simulink Enumeration Class” on page 28-3

“Customizing a Simulink Enumeration” on page 28-5

“Saving an Enumeration in a MATLAB File” on page 28-7

“Changing and Reloading Enumerations” on page 28-7

“Importing Enumerations Defined Externally to MATLAB” on page 28-8

### Basic Workflow for Defining a Simulink Enumeration

- 1 Create a class definition.
- 2 Optionally, customize the enumeration.
- 3 Optionally, save the enumeration in a MATLAB file.

For complete information about the MATLAB Object System, see *Object-Oriented Programming*.

### Creating a Simulink Enumeration Class

To create a Simulink enumeration class, in the class definition:

- Define the class as a subclass of `Simulink.IntEnumType`
- Add an enumeration block that specifies enumeration values with underlying integer values

Consider the following example:

```
classdef BasicColors < Simulink.IntEnumType
    enumeration
        Red(0)
        Yellow(1)
        Blue(2)
```

```

    end
end

```

The first line defines an integer-based enumeration that is derived from built-in class `Simulink.IntEnumType`. The enumeration is integer-based because `IntEnumType` is derived from `int32`.

The enumeration section specifies three enumerated values.

Enumerated Value	Enumerated Name	Underlying Integer
Red(0)	Red	0
Yellow(1)	Yellow	1
Blue(2)	Blue	2

When defining an enumeration class for use in the Simulink environment, consider the following:

- The name of the enumeration class must be unique among data type names and base workspace variable names, and is case-sensitive.
- Underlying integer values in the enumeration section need not be unique within the class and across types.
- Often, the underlying integers of a set of enumerated values are consecutive and monotonically increasing, but they need not be either consecutive or ordered.
- For simulation, an underlying integer can be any `int32` value. Use the MATLAB functions `intmin` and `intmax` to get the limits.
- For code generation, every underlying integer value must be representable as an integer on the target hardware, which may impose different limits. See “Target” and “Hardware Implementation Pane” for more information.

For more information on superclasses, see “Converting to Superclass Value”.



## Customizing a Simulink Enumeration

### About Simulink Enumeration Customizations

You can customize a Simulink enumeration by using the same techniques that work with MATLAB classes, as described in “Modifying Superclass Methods and Properties”.

A primary source of customization are the methods associated with an enumeration.

### Inherited Methods

Enumeration class definitions can include an optional `methods` section. Simulink enumerated classes inherit 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
<code>getDescription</code>	Returns a description of the enumeration.	<code>''</code>	Code generation
<code>getHeaderFile</code>	Specifies the file in which the enumeration is defined for code generation.	<code>''</code>	Code generation
<code>addClassNameToEnumNames</code>	Specifies whether the class name becomes a prefix in generated code.	<code>false</code> — 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
```

end

This example defines the default as `BasicColors.Blue`. If this method does not appear, the default value would be `BasicColors.Red`, because that is the first value listed in the enumerated class definition.

The seemingly redundant specification of `ThisClass` inside the definition of that same class is necessary because `getDefaultvalue` returns an instance of the default enumerated value, not just the name of the value. The method, therefore, needs a complete specification of what to instantiate. See “Instantiating Enumerations” on page 28-15 for more information.

## Saving an Enumeration in a MATLAB File

You can define an enumeration within a MATLAB file.

- The name of the definition file must match the name of the enumeration exactly, including case. For example, the definition of enumeration `BasicColors` must reside in a file named `BasicColors.m`. Otherwise, MATLAB will not find the definition.
- You must define each class definition in a separate file.
- Save each definition file on the MATLAB search path. MATLAB searches the path to find a definition when necessary.

To add a file or folder to the MATLAB search path, type `addpath pathname` at the MATLAB command prompt. For more information, see “Using the MATLAB Search Path”, `addpath`, and `savepath`.

- You do not need to execute an enumeration class definition to use the enumeration. The only requirement, as indicated in the preceding bullet, is that the definition file be on the MATLAB search path.

## Changing and Reloading Enumerations

You can change the definition of an enumeration by editing and saving the file that contains the definition. You do not need to inform MATLAB that a class definition has changed. MATLAB automatically reads the modified definition when you save the file. However, the class definition changes do not take full effect if any class instances (enumerated values) exist that reflect the previous class definition. Such instances might exist in the base workspace or might be cached.

The following table explains options for removing instances of an enumeration from the base workspace and cache.

If In Base Workspace...	If In Cache...
<p>Do one of the following:</p> <ul style="list-style-type: none"> <li>• Locate and delete specific obsolete instances.</li> <li>• Delete everything from the workspace by using the <code>clear</code> command.</li> </ul>	<ul style="list-style-type: none"> <li>• Delete obsolete instances by closing all models that you updated or simulated while the previous class definition was in effect.</li> <li>• Clear functions and close models that are caching instances of the class.</li> </ul>

For more information about applying enumeration changes, see “Modifying and Reloading Classes”.

## Importing Enumerations Defined Externally to MATLAB

If you have enumerations defined externally to MATLAB—for example, in a data dictionary, that you want to import for use within the Simulink environment, you can do so programmatically with calls to the function `Simulink.defineIntEnumType`. This function defines an enumeration that you can use in MATLAB as if it is defined by a class definition file. In addition to specifying the enumeration class name and values, each function call can specify:

- String that describes the enumeration class.
- Which of the enumeration values is the default.

For code generation, you can specify:

- Header file 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);

```

## Using Enumerated Data in Simulink Models

### In this section...

“Simulating with Enumerations” on page 28-10

“Specifying Enumerations as Data Types” on page 28-12

“Getting Information About Enumerations” on page 28-13

“Enumeration Value Display” on page 28-13

“Instantiating Enumerations” on page 28-15

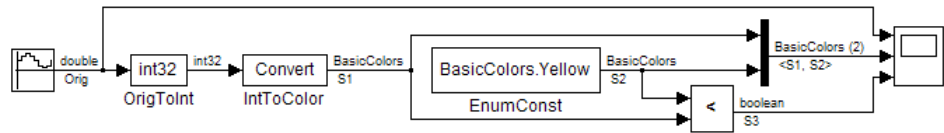
“Enumerated Values in Computation” on page 28-18

### Simulating with Enumerations

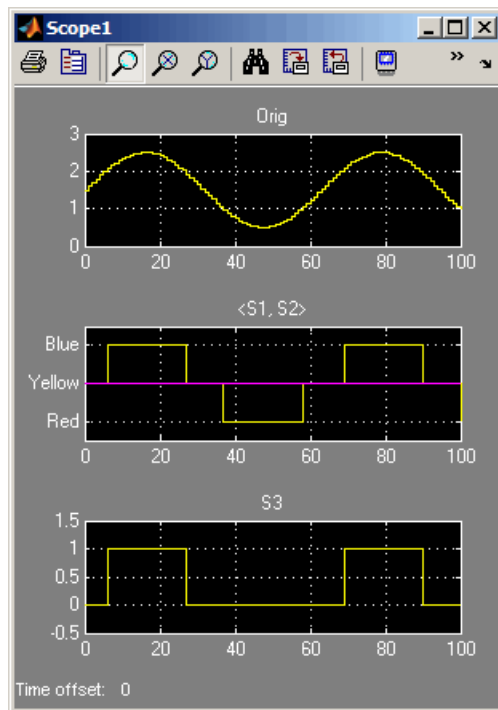
Consider the following enumeration class definition—`BasicColors` with enumerated values `Red`, `Yellow`, and `Blue`, with `Blue` as the default value:

```
classdef BasicColors < Simulink.IntEnumType
    enumeration
        Red(0)
        Yellow(1)
        Blue(2)
    end
    methods (Static)
        function retVal = getDefaultValue()
            retVal = BasicColors.Blue;
        end
    end
end
```

Once this class definition is known to MATLAB, you can use the enumeration in Simulink and Stateflow models. Information specific to enumerations in Stateflow appears in “Using Enumerated Data in Stateflow Charts”. The following Simulink model uses the enumeration defined above:



The output of the model looks like this:



The Data Type Conversion block **OrigToInt** specifies an **Output data type** of int32 and **Integer rounding mode: Floor**, so the block converts the Sine Wave block output, which appears in the top graph of the Scope display, to a cycle of integers: 1, 2, 1, 0, 1, 2, 1. The Data Type Conversion block **IntToColor** uses these values to select colors from the enumerated type **BasicColors** by referencing their underlying integers.

The result is a cycle of colors: **Yellow, Blue, Yellow, Red, Yellow, Blue, Yellow**, as shown in the middle graph. The Enumerated Constant block

**EnumConst** outputs **Yellow**, which appears in the second graph as a straight line. The Relational Operator block compares the constant **Yellow** to each value in the cycle of colors. It outputs 1 (**true**) when **Yellow** is less than the current color, and 0 (**false**) otherwise, as shown in the third graph.

The sort order used by the comparison is the numeric order of the underlying integers of the compared values, *not* the lexical order in which the enumerated values appear in the enumerated class definition. In this example the two orders are the same, but they need not be. See “Specifying Enumerations as Data Types” on page 28-12 and “Enumerated Values in Computation” on page 28-18 for more information.

## Specifying Enumerations as Data Types

Once you define an enumeration, you can use it much like any other data type. Because an enumeration is a class rather than an instance, you must use the prefix `?` or `Enum:` when specifying the enumeration as a data type. You must use the prefix `?` in the MATLAB Command Window (see “Information from Class Metadata”). 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:

The screenshot shows the Data Type Assistant dialog box. At the top, there are two input fields: "Output minimum:" and "Output maximum:", both containing empty text boxes. Below these is a dropdown menu for "Output data type:" showing "Enum: BasicColors" and a "<<" button. At the bottom, there is a "Data Type Assistant" section with a "Mode:" dropdown set to "Enumerated" and a text field containing "BasicColors".



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 28-18 for more information.

## Getting Information About Enumerations

Use the enumeration function to:

- Return an array that contains all enumeration values for an enumeration class in the MATLAB Command Window
- Get the enumeration values programmatically
- Provide the values to a Simulink block parameter that accepts an array or vector of enumerated values, such as the **Case conditions** parameter of the Switch Case block

See the enumeration function for details.

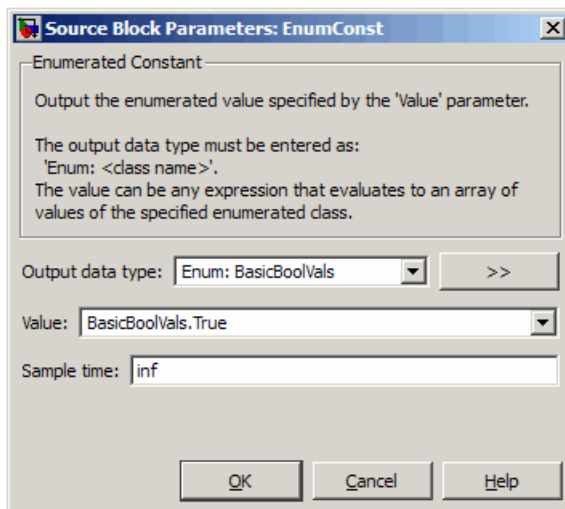
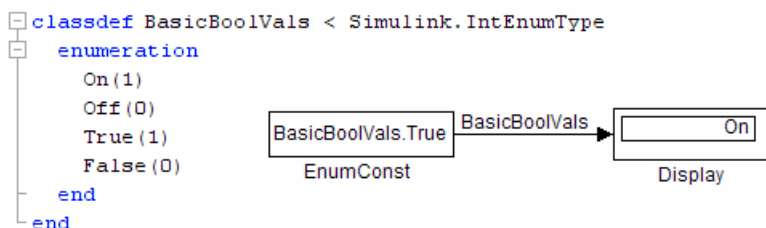
## Enumeration Value Display

Wherever possible, Simulink software displays enumeration values by name, not by the underlying integer value. However, the underlying integers can affect value display in Scope and Floating Scope blocks.

Block...	Affect on Value Display...
Scope	When displaying an enumerated signal, the names of the enumerated values appear as labels on the Y axis. The names appear in the order given by their underlying integers, with the lowest value at the bottom.
Floating Scope	When displaying signals that are of the same enumeration, names appear on the Y axis as they would for a Scope block. If the Floating Scope block displays mixed data types, no names appear, and any enumerated values are represented by their underlying integers.

## Enumerated Values with Non-Unique Integers

More than one value in an enumeration can have the same underlying integer value, as described in “Specifying Enumerations as Data Types” on page 28-12. 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:



Although the Enumerated Constant block outputs True, both On and True have the same underlying integer, and On is defined first in the class definition enumeration section. Therefore, the Display block shows On. Similarly, a Scope axis would show only On, never True, no matter which of the two values is input to the Scope block.

## Instantiating Enumerations

Before you can use an enumeration, you must instantiate it. You can instantiate an enumeration in MATLAB, in a Simulink model, or in a Stateflow chart. The syntax is the same in all contexts.

### Instantiating Enumerations in MATLAB

To instantiate an enumeration in MATLAB, enter `ClassName.EnumName` in the MATLAB Command Window. The instance is created in the base workspace. For example, if `BasicColors` is defined as in “Creating a Simulink Enumeration Class” on page 28-3, you can type:

```
bcy = BasicColors.Yellow
```

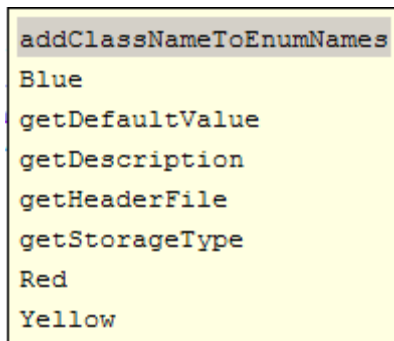
```
bcy =
```

```
    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:



```
addClassNameToEnumNames
Blue
getDefaultvalue
getDescription
getHeaderFile
getStorageType
Red
Yellow
```

Double-click an element or method to insert it at the position where you pressed <tab>. See “Complete Names in the Command Window Using the Tab Key” 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 =
```

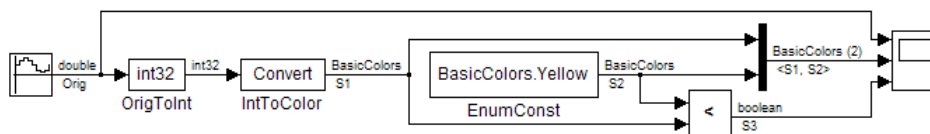
```
2
```

In either case, MATLAB returns the result of the cast in a 1x1 array of the relevant data type.

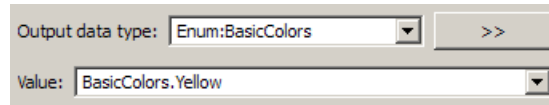
Although casting is possible, use of enumeration values is not robust in cases where enumeration values and the integer equivalents defined for an enumeration class might change.

## 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:



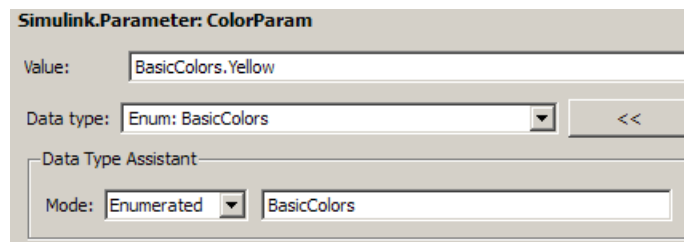
The Enumerated Constant block **EnumConst**, which outputs the enumerated value Yellow, defines that value as follows:



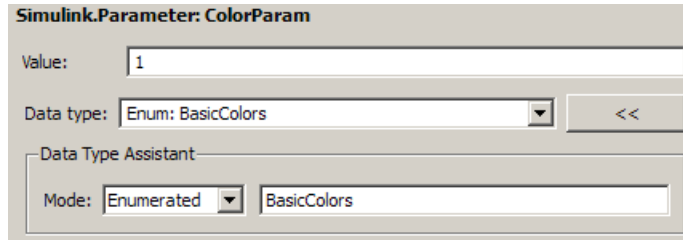
You can enter any valid MATLAB expression that evaluates to an enumerated value, including arrays and workspace variables. For example, you could enter `BasicColors(1)`, or if you had previously executed `bcy = BasicColors.Yellow` in the MATLAB Command Window, you could enter `bcy`. As another example, 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 “Specifying Enumerations as Data Types” on page 28-12.



You *cannot* specify the integer value of an enumeration member for the **Value** parameter. See “Enumerated Values in Computation” on page 28-18 for more information. Thus, the following fails even though the integer value for `BasicColors.Yellow` is 1.



The same syntax and considerations apply in Stateflow. See “Using Enumerated Data in Stateflow Charts” for more information.

## Enumerated Values in Computation

By design, Simulink prevents enumerated values from being used as numeric values in mathematical computation, even though an enumerated class is a subclass of the MATLAB `int32` class. Thus, an enumerated type does not function as a numeric type despite the existence of its underlying integers. For example, you cannot input an enumerated signal directly to a Gain block.

You can use a Data Type Conversion block to convert in either direction between an integer type and an enumerated type, or between two enumerated types. That is, you can use a Data Type Conversion block to convert an enumerated signal to an integer signal (consisting of the underlying integers of the enumerated signal values) and input the resulting integer signal to a Gain block. See “Casting Enumerated Signals” on page 28-19 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.

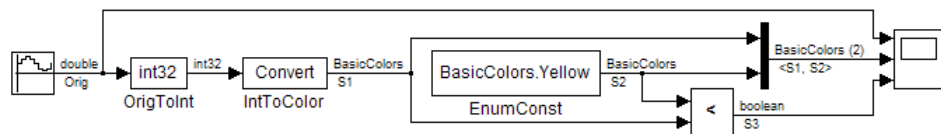
When a block like the Switch block or Multiport Switch block selects among multiple data signals, and any data signal is of an enumerated type, all the data signals must be of that same enumerated type. When a block inputs both control and data signals, as Switch and Multiport Switch do, the control 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.

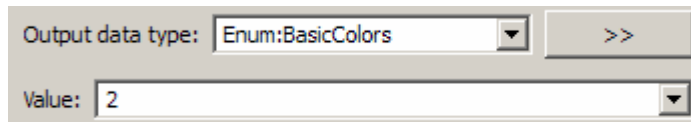
You cannot use a Data Type Conversion block to cast a numeric signal of any non-integer data type to an enumerated type. For example, the model used in “Simulating with Enumerations” on page 28-10 needed two Data Conversion blocks to convert a sine wave to enumerated values.



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

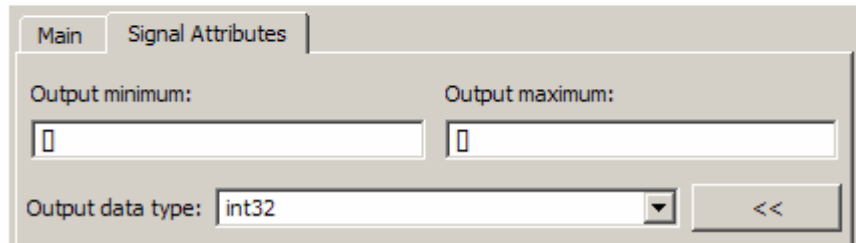
You cannot cast a block parameter of any numeric data type to an enumerated data type. For example, suppose that an Enumerated Constant block specifies a **Value** of 2 and an **Output data type** of Enum: BasicColors:



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” on page 28-21
“Block Support” on page 28-21
“Class Support” on page 28-23
“Logging Enumerated Data” on page 28-23
“Importing Enumerated Data” on page 28-23

### 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 28-18 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 28-24 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 32-14)
- 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 outputs, To Workspace blocks, and Scope blocks can all export enumerated values. Signal and State logging work with enumerated data in the same way as with any other data. All logging formats are supported. The From File block does not support enumerated data. Use the From Workspace block instead, combined with some technique for transferring data between a file and a workspace. See Chapter 29, “Importing and Exporting Simulation Data” for more information.

## Importing Enumerated Data

Root-level inports and From Workspace blocks can output enumerated signals during simulation. Data must be provided in a `Structure`, `Structure with Time`, or `TimeSeries` object. No interpolation occurs for enumerated values between the specified simulation times. From File blocks produce only data of type `double`, so they do not support enumerated types. See Chapter 29, “Importing and Exporting Simulation Data” for more information.

## Simulink Enumeration Limitations

### In this section...

“Enumerations and Scopes” on page 28-24

“Enumerated Types for Switch Blocks” on page 28-24

“Nonsupport of Enumerations” on page 28-24

### 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” on page 29-3
- “Exporting Simulation Data” on page 29-4
- “Selecting the Data Format for Exported Simulation Data” on page 29-8
- “Specifying the Amount of Exported Data” on page 29-14
- “Specifying Which Samples to Export for Models with Variable-Step Solvers” on page 29-16
- “Exporting Signal Data Using Signal Logging” on page 29-19
- “Configuring a Signal for Signal Logging” on page 29-21
- “Viewing the Signal Logging Configuration” on page 29-27
- “Enabling Signal Logging for a Model” on page 29-34
- “Overriding Signal Logging Settings” on page 29-38
- “Accessing Signal Logging Data” on page 29-50
- “Importing Signal Data in Simulink” on page 29-61
- “Importing Data to Model a Continuous Plant” on page 29-64
- “Importing Data to Test a Discrete Algorithm” on page 29-67
- “Importing Data to Create an Input Test Case” on page 29-68
- “Importing Signal Logging Data” on page 29-72
- “Importing Data to Root-Level Input Ports” on page 29-74
- “Importing MATLAB timeseries Data” on page 29-78

- “Importing Structures of MATLAB timeseries Objects for Bus Signals to a Root-Level Input Port” on page 29-80
- “Importing Simulink.Timeseries and Simulink.TsArray Data to a Root-Level Input Port” on page 29-85
- “Importing Data Arrays to a Root-Level Input Port” on page 29-86
- “Importing MATLAB Time Expression Data” on page 29-88
- “Importing Data Structures to a Root-Level Input Port” on page 29-89
- “Importing and Exporting States” on page 29-94



## 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.

## Exporting Simulation Data

In this section...
“Simulation Data” on page 29-4
“Approaches for Exporting Signal Data” on page 29-4
“Enabling Simulation Data Export” on page 29-6
“Viewing Logged Simulation Data With the Simulation Data Inspector” on page 29-7

### 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.	<p>If you want to use a Scope block for viewing results during simulation, consider using it to export data.</p> <p>Document in the diagram the workspace variables used to store signal data.</p> <p>Save output at a sample rate other than the base sample rate.</p>	Scope

Export Approach	Usage	Documentation
	Scopes store data and can be memory intensive.	
Connect a signal to a To File block.	<p>Consider using a To File block for exporting large amounts of data.</p> <p>Document in the diagram the workspace variables used to store signal data.</p> <p>Save output at a sample rate other than the base sample rate.</p> <p>Use the MAT-file only after the simulation has completed.</p>	To File
Connect a signal to a To Workspace block.	<p>Document in the diagram the workspace variables used to store signal data.</p> <p>Save output at a sample rate other than the base sample rate.</p>	To Workspace
Connect a signal to a root-level Outport block.	Consider using 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.	<p>Eliminate the need to add blocks.</p> <p>Log signals based on individual signal rates.</p> <p>Data is available only when simulation is paused or completed.</p>	“Exporting Signal Data Using Signal Logging” on page 29-19

<b>Export Approach</b>	<b>Usage</b>	<b>Documentation</b>
Configure Simulink to export time, state, and output data.	<p>Capture information about the simulation run as a whole.</p> <p>Outputs and states are logged at the base sample rate of the model.</p>	<p>“Selecting the Data Format for Exported Simulation Data” on page 29-8</p> <p>“Specifying the Amount of Exported Data” on page 29-14</p> <p>“Specifying Which Samples to Export for Models with Variable-Step Solvers” on page 29-16</p>
Log a data store.	Share data throughout a model hierarchy, capturing the order of all data store writes.	“Logging Data Stores” on page 30-25
Use the <code>sim</code> command to log simulation data programmatically.	<p>Export to one data object the time, states, and signals simulation data.</p> <p>Select the <b>Return as single object</b> parameter when simulating the model using the <code>sim</code> command inside a function or a <code>parfor</code> loop.</p>	<code>sim</code>

## Enabling 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, you 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:
  - “Selecting the Data Format for Exported Simulation Data” on page 29-8
  - “Specifying the Amount of Exported Data” on page 29-14
  - “Specifying Which Samples to Export for Models with Variable-Step Solvers” on page 29-16

## **Viewing 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 15-84.

## Selecting the Data Format for Exported Simulation Data

### In this section...

“Data Format for Block-Based Exported Data” on page 29-8

“Data Format for Model-Based Exported Data” on page 29-8

“Signal Logging Format” on page 29-8

“Logged Data Store Format” on page 29-9

“State and Output Data Format” on page 29-9

### Data Format for Block-Based Exported Data

You can use the Scope, To File, and 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 29-8
- “Logged Data Store Format” on page 29-9
- “State and Output Data Format” on page 29-9

### Signal Logging Format

Use the Dataset or ModelDataLogs format for signal logging data. Select the format using the **Configuration Parameters > Data Import/Export > Signal logging format** parameter.

For details, see “Specifying the Signal Logging Data Format” on page 29-34.

## 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 30-28.

## State and Output Data Format

For exported state, final state, and output data, use one of the following formats:

- “Array” on page 29-9
- “Structure with Time” on page 29-10
- “Structure” on page 29-12
- “Per-Port Structure” on page 29-12

### 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 29-10) 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 29-92 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.

## Specifying the Amount of Exported Data

### In this section...

“Decimation” on page 29-14  
 “Limit Data Points to Last” on page 29-14

### 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 <b>Decimation</b> parameter.
Data store logging	From the block parameters dialog box for that block, open the <b>Logging</b> tab. Apply a decimation factor using the <b>Decimation</b> parameter.
State and output	Enter a value in the field to the right of the <b>Decimation</b> 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.

<b>Kind of Data</b>	<b>How to Specify</b>
Signal logging	Right-click the signal. In the Signal Properties dialog box, select the <b>Limit Data Points to Last</b> parameter.
Data store logging	From the block parameters dialog box for that block, open the <b>Logging</b> tab. Select the <b>Limit Data Points to Last</b> parameter.
State and output	Enter a value in the field to the right of the <b>Limit Data Points to Last</b> label.

## Specifying Which Samples to Export for Models with Variable-Step Solvers

### In this section...

“Output Options” on page 29-16

“Refining Output” on page 29-16

“Producing Additional Output” on page 29-17

“Producing Specified Output Only” on page 29-18

### 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”.

### Refining 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 2-24).

---

## Producing Additional Output

The `Produce additional output` choice enables you to specify directly those additional times at which the solver generates output. When you select this option, an **Output times** field is displayed on the **Data Import/Export** pane. Enter a MATLAB expression in this field that evaluates to an additional time or a vector of additional times. The solver will produce 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 2-24).

---

## **Producing Specified Output Only**

The Produce specified output only choice provides simulation output *only* at the simulation start time, simulation stop time, and the specified output times.

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 2-24).

---



## Exporting Signal Data Using Signal Logging

### In this section...

“Signal Logging” on page 29-19

“Signal Logging Workflow” on page 29-19

“Signal Logging Limitations” on page 29-20

### 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 “Configuring a Signal for Signal Logging” on page 29-21 and “Enabling Signal Logging for a Model” on page 29-34.

For a summary of other approaches to capture signal data, see “Exporting Simulation Data” on page 29-4.

### 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 “Configuring a Signal for Signal Logging” on page 29-21.
- 2** (Optional) Review the signal logging configuration for a model. See “Viewing the Signal Logging Configuration” on page 29-27.
- 3** Enable signal logging globally for a model. See “Enabling Signal Logging for a Model” on page 29-34.
- 4** Specify the format for the logged signal data. See “Specifying the Signal Logging Data Format” on page 29-34.
- 5** (Optional) Specify a name for the signal logging data. See “Specifying a Logging Name” on page 29-23.
- 6** (Optional) Specify which samples to export for models with variable-step solvers. See “Limiting the Data Logged for a Signal” on page 29-25.

- 7** (Optional) Configure the model to display signal logging data in the Simulation Data Inspector. See “Viewing Logged Signal Data with the Simulation Data Inspector” on page 29-51.
- 8** (Optional) Override the signal logging property settings in the model or referenced models. See “Overriding Signal Logging Settings” on page 29-38.
- 9** Simulate the model.
- 10** Access the signal logging data. See “Accessing Signal Logging Data” on page 29-50.

## **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 19-17.

Top-model software-in-the-loop (SIL) and processor-in-the-loop (PIL) simulation modes support signal logging for signals connected to root-level inports and outports. For a description of limitations of signal logging using SIL and PIL modes, see “Signal Logging” in the Embedded Coder documentation.

- You cannot log local data in Stateflow Truth Table blocks.

## Configuring a Signal for Signal Logging

### In this section...

“Enabling Logging for a Signal” on page 29-21

“Specifying a Logging Name” on page 29-23

“Limiting the Data Logged for a Signal” on page 29-25


### Enabling Logging for a Signal

Enable logging for a signal with one of the following techniques:

- “Using the Signal Properties Dialog Box” on page 29-21
- “Using the Model Explorer” on page 29-22
- “Using the Programmatic Interface” on page 29-22

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.

### Using the Signal Properties Dialog Box

- 1 In the Model 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**.

## Using the Model Explorer

---

**Note** The only signals that Model Explorer displays are named signals. See “Signal Names” on page 31-19.

---

- 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 “The Model Explorer: Controlling Contents Using Views” on page 8-25.
- 3 Enable the `DataLogging` property for one or more signals.

## Using the Programmatic Interface

To enable signal logging programmatically for selected blocks, use the output `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 output signal.

```
ph = get_param('vdp/Mu','PortHandles')
```

- 3 Enable signal logging for the desired output signal.

```
set_param(ph.Outputport(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 29-42.

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 31-59. However, MathWorks recommends using the `Dataset` format for signal logging. For a description of the benefits of using the `Dataset` format, see “Benefits of Using the Dataset Format for Signal Logging” on page 29-35. `Dataset` format does not support using test points for logging in referenced models.

## Specifying a 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 `logout`. For details about the signal logging name, see “Specifying a Name for the Signal Logging Data” on page 29-37.

---

To specify a logging name, use one of the following approaches:

- “Using the Signal Properties Dialog Box to Specify a Logging Name” on page 29-24
- “Using the Model Explorer to Specify a Logging Name” on page 29-24
- “Programmatically Specifying a Logging Name” on page 29-24

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 Model 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 “The Model Explorer: Controlling Contents Using Views” on page 8-25.
- 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 output 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 output signal:

```
ph = get_param('vdp/Mu','PortHandles');
```

- 3 Enable signal logging for the desired output signal:

```
set_param(ph.Outputport(1),'DataLogging','on');
```

The logged signal indicator appears.

- 4 Issue commands that use the `DataLoggingNameMode` and `DataLoggingName` parameters. For example:

```
set_param(ph.Outputport(1),'DataLoggingNameMode','Custom');
set_param(ph.Outputport(1),'DataLoggingName','x2_log');
```

## Limiting 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 “Specifying the Amount of Exported Data” on page 29-14.

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 Model 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 “The Model Explorer: Controlling Contents Using Views” on page 8-25.
- 3** To specify a decimation factor, edit the `Decimation` and `DecimateData` properties. To limit the number of samples logged, edit the `LimitDataPoints` property.



## Viewing the Signal Logging Configuration

### In this section...

“Approaches for Viewing the Signal Logging Configuration” on page 29-27

“Using the Model Editor to View the Signal Logging Configuration” on page 29-28

“Using the Signal Logging Selector to View the Signal Logging Configuration” on page 29-30

“Using the Model Explorer to View the Signal Logging Configuration” on page 29-33

### Approaches for Viewing the Signal Logging Configuration

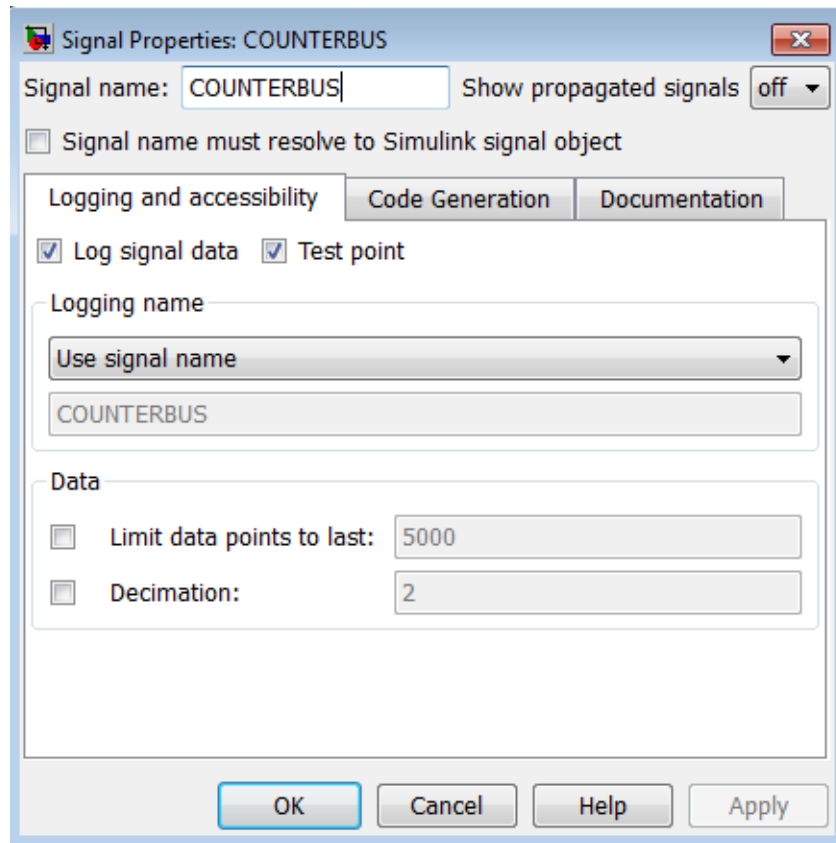
Signal Logging Configuration Viewing Approach	Usage	Documentation
In the Model Editor, view signal logging indicators.	<p>Consider for models with few signals configured for signal logging and the model hierarchy is shallow.</p> <p>Avoid leaving the Model Editor.</p> <p>Open Signal Properties dialog box for each signal.</p>	“Using the Model Editor to View the Signal Logging Configuration” on page 29-28
Use the Signal Logging Selector.	<p>Consider using for models with deep hierarchies.</p> <p>View a model that has signal logging override settings for some signals.</p> <p>View the configuration as part of specifying a subset of</p>	“Using the Signal Logging Selector to View the Signal Logging Configuration” on page 29-30

<b>Signal Logging Configuration Viewing Approach</b>	<b>Usage</b>	<b>Documentation</b>
	<p>signals to log from all signals configured for signal logging.</p> <p>View signal logging configuration without displaying the signal logging indicators in the model.</p> <p>View signal logging configuration information such as decimation and output options in one window.</p>	
<p>Use the Model Explorer.</p>	<p>View signal logging configuration in the context of other model component properties.</p> <p>You may need to adjust the column view to display signal logging properties.</p>	<p>“Using the Model Explorer to View the Signal Logging Configuration” on page 29-33</p>

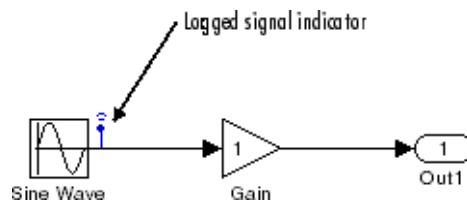
## **Using the Model Editor to View the Signal Logging Configuration**

By default, Simulink Model 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 Model Editor continues to display the sign logging indicator for that signal

in the Model 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 “Configuring a Signal for Signal Logging” on page 29-21.

A logged signal can also be a test point. See “Working with Test Points” on page 31-59 for information about test points.

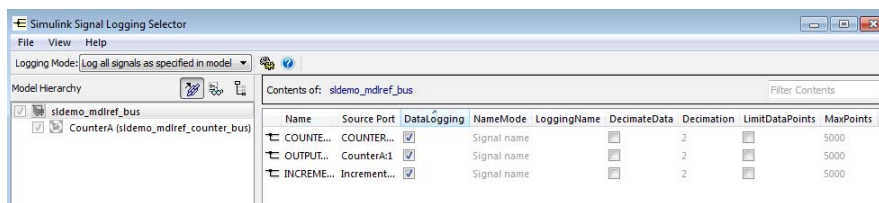
To turn the display of logging indicators off, clear **Format > Port/Signal Displays > Testpoint/Logging Indicators**.

## Using the Signal Logging Selector to View the 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 Model 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 boxes to the left of a model node indicates the override configuration of the node:




Check Box	Signal Logging Configuration
	<p>For the top-level model node, logs all logged signals in the top model.</p> <p>For a Model block node, logs all logged signals in the model reference hierarchy for that block.</p>
	<p>For the top-level model node, disables logging for all logged signals in the top model.</p> <p>For a Model block node, logs disables logging for all signals in the model reference hierarchy for that block.</p>
	<p>For the top-level model node, logs all logged signals that have the DataLogging setting enabled.</p> <p>For a Model block node, logs all logged signals in the model reference hierarchy for that block that have the DataLogging setting enabled.</p>

### 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 8-12 and “Displaying Masked Subsystems” on page 8-12.

- 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

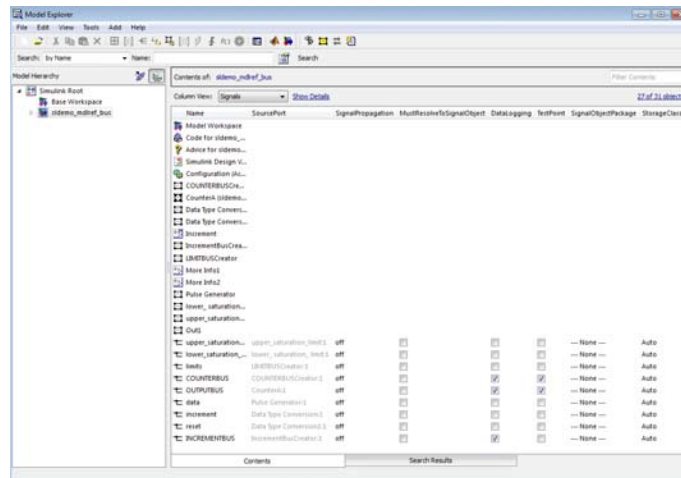
To find a specific signal or property value for a signal, use the **Filter Contents** edit box. Use the same approach as you use in the Model Explorer; for details, see “Filtering Contents” on page 8-49.

### 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**.

## Using the Model Explorer to View the 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 “The Model Explorer: Model Hierarchy Pane” on page 8-9 and “The Model Explorer: Contents Pane” on page 8-18.

## Enabling Signal Logging for a Model

### In this section...

“Enabling and Disabling Logging Globally for a Model” on page 29-34

“Specifying the Signal Logging Data Format” on page 29-34

“Specifying a Name for the Signal Logging Data” on page 29-37

### Enabling and Disabling 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 either 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 “Overriding Signal Logging Settings” on page 29-38.

### Specifying 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.



## Setting 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` or `ModelDataLogs`.
- Use the `SignalLoggingSaveFormat` parameter, with a value of `Dataset` or `ModelDataLogs`. For example:

```
set_param(bdroot, 'SignalLoggingSaveFormat', 'Dataset')
```

## Benefits of Using the Dataset Format for Signal Logging

Using the `Dataset` format for signal logging offers several advantages, compared to the `ModelDataLogs` format. 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.
- Supports the `Simulation Data Inspector` tool.
- Avoids the limitations of the `ModelDataLogs` format, which Bug Report 495436 describes (for example, for a virtual bus, logging only one of multiple signals that share the same source block).

## Signal Viewer Limitation of Using the Dataset Format for Signal Logging

If you use the `Dataset` format for signal logging, then Simulink does not log the signals configured to use the `Signal Viewer`.

## Dataset Format

When you specify the `Dataset` format, Simulink stores the data using a `Simulink.SimulationData.Dataset` object.

If you use the `Dataset` format for a model in a model reference hierarchy, use the `Dataset` format for all the models in the hierarchy. To convert a model reference hierarchy to use the `Dataset` format for all its models, use the `Simulink.SimulationData.updateDatasetFormatLogging` function. For example, to convert the referenced models in the `sldemo_md1ref_variants` demo:

If you have already logged signal data in the `ModelDataLogs` format, you can use the `Simulink.ModelDataLogs.convertToDataset` function to update the `ModelDataLogs` dataset to use `Dataset` format. For example, to update the `vdp_dataset` from `ModelDataLogs` format to `Dataset` format:

```
dataset = logout.convertToDataset('vdp_dataset')
```

### **ModelDataLogs Format**

When you use the default `ModelDataLogs` format, Simulink stores the data using a `Simulink.ModelDataLogs` object. Prior to R2011a, signal logging always used the `ModelDataLogs` format.

### **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:

- Update all models referenced by the top model to use the `Dataset` signal logging format. Use the `Simulink.SimulationData.updateDatasetFormatLogging` function. For example, to convert the referenced models in the `sldemo_md1ref_variants` demo:

```
sldemo_md1ref_variants;  
Simulink.SimulationData.updateDatasetFormatLogging('sldemo_md1ref_variants', 'AllVariants')
```

- Update all models referenced by the referenced model cited in the error message to use Dataset format, by using the `Simulink.SimulationData.updateDatasetFormatLogging` function.
- 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 **Model Hierarchy** pane, clear the check box for the top Model block in the model reference hierarchy that generated the error.

## Specifying 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 `logout`. 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')
```

## Overriding Signal Logging Settings

### In this section...

- “Benefits of Overriding Signal Logging Settings” on page 29-38
- “Two Interfaces for Overriding Signal Logging Settings” on page 29-38
- “Scope of Signal Logging Setting Overrides” on page 29-39
- “Signal Logging Selector” on page 29-39
- “Command-Line Interface for Overriding Signal Logging Settings” on page 29-45

### 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 Model 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 29-39
- “Command-Line Interface for Overriding Signal Logging Settings” on page 29-45

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.

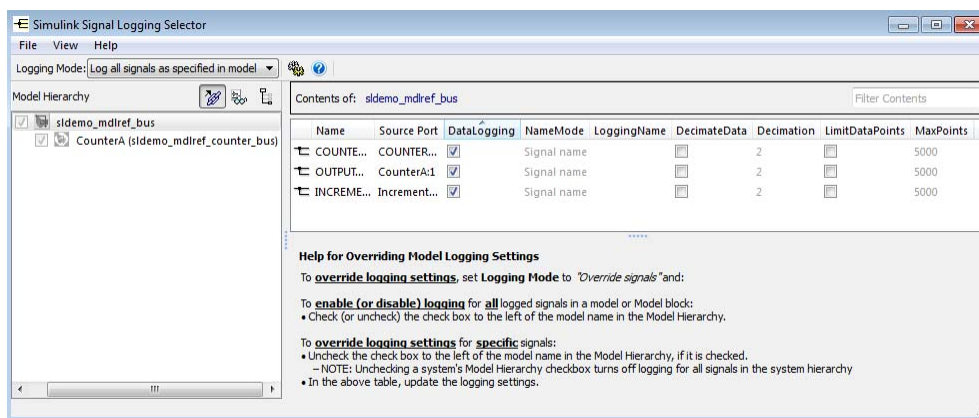
## Signal Logging Selector

- 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 Model 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 "Using the Signal Logging Selector to View the Signal Logging Configuration" on page 29-30.

**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 29-41
- “Models with Model Referencing: Overriding Signal Logging Settings” on page 29-42

---

**Note** To open the **Configuration Parameters > Data Import/Export** pane from the Signal Logging Selector, use the  button.

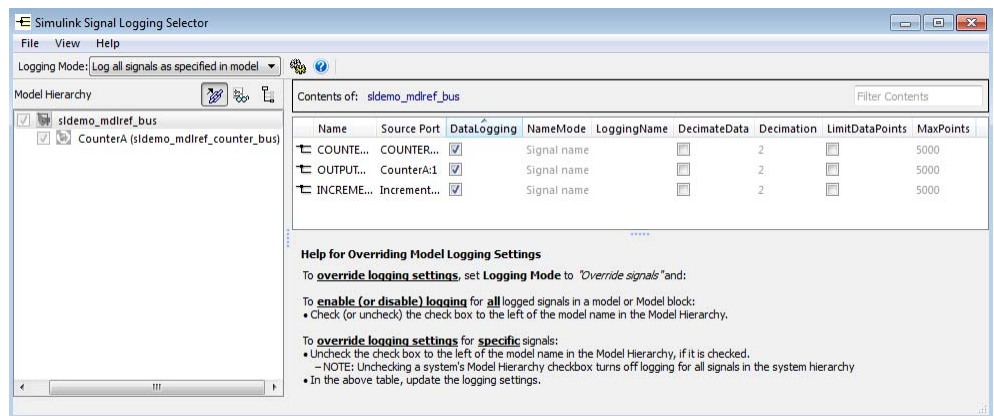
---

## 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 “Using the Signal Logging Selector to View the Signal Logging Configuration” on page 29-30.
- 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 29-42
- “Disable Logging for All Logged Signals in a Model Node” on page 29-44
- “Override Signal Logging for a Subset of Signals” on page 29-44
- “Override Other Signal Logging Properties” on page 29-44

**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.

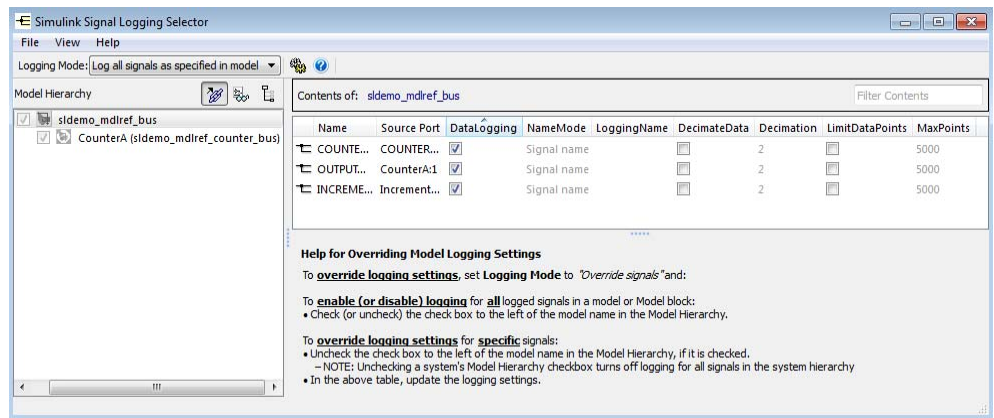
If logging is disabled for any logged signals in the top-level model or in the top-level Model block in a model reference hierarchy, then in the **Model Hierarchy** pane, the check box to the left of that node is either ) or empty





To enable logging of all logged signals for a node:

- 1 Perform the steps 1–3 in “Signal Logging Selector” on page 29-39.
- 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 “Using the Signal Logging Selector to View the Signal Logging Configuration” on page 29-30.
- 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 29-39.
- 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 29-39.
- 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 29-39.

**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.

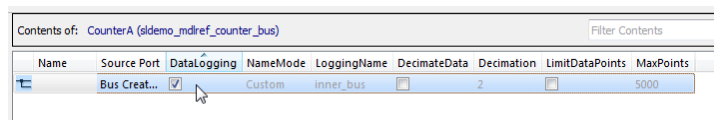
To enable logging for multiple signals, hold the **Shift** or **Ctrl** key and select a range of signals or individual signals. Select the check box in the DataLogging column of one of the highlighted signals.

**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:



Name	Source Port	DataLogging	NameMode	LoggingName	DecimateData	Decimation	LimitDataPoints	MaxPoints
Bus Creat...		<input checked="" type="checkbox"/>	Custom	inner_bus	<input type="checkbox"/>	2	<input type="checkbox"/>	5000

- 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_md1ref_bus` demo model.

- “Create a Model Logging Information Object” on page 29-46
- “Specify Which Models to Log” on page 29-47
- “Log a Subset of Signals” on page 29-48
- “Override Other Signal Logging Properties” on page 29-49

### **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_md1ref_bus` model and automatically add each logged signal in the model to that object:

```
mi = Simulink.SimulationData.ModelLoggingInfo.createFromModel(...
'sldemo_md1ref_bus')

mi =

    Simulink.SimulationData.ModelLoggingInfo
    Package: Simulink.SimulationData

    Properties:
        Model: 'sldemo_md1ref_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_mdhref_bus;  
mi = Simulink.SimulationData.ModelLoggingInfo...  
    ('sldemo_mdhref_bus');  
mi.LoggingMode = 'LogAllAsSpecifiedInModel'  
  
mi =
```

```
Simulink.SimulationData.ModelLoggingInfo
```

```
Package: Simulink.SimulationData
```

```
Properties:
```

```

        Model: 'sldemo_mdhref_bus'
        LoggingMode: 'LogAllAsSpecifiedInModel'
    LogAsSpecifiedByModels: {}
        Signals: []

```

```
Methods
```

```
set_param(sldemo_mdhref_bus, 'DataLoggingOverride', mi);
```

The following example shows how to log only signals in the top model:

```

mi = Simulink.SimulationData.ModelLoggingInfo...
    ('sldemo_mdhref_bus');
mi.LoggingMode = 'OverrideSignals';
mi = mi.setLogAsSpecifiedInModel('sldemo_mdhref_bus', true);
set_param(sldemo_mdhref_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_mdhref_bus;
mi = Simulink.SimulationData.ModelLoggingInfo.createFromModel(...
    'sldemo_mdhref_bus');
pos = mi.findSignal({'sldemo_mdhref_bus/CounterA' ...
    'sldemo_mdhref_counter_bus/Bus Creator'}, 1)

pos =
     4
for idx=1:length(mi.Signals)
    mi.Signals(idx).LoggingInfo.DataLogging = (idx == pos);
end

set_param(sldemo_mdhref_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_mdref_bus');  
pos = mi.findSignal({'sldemo_mdref_bus/CounterA' ...  
                  'sldemo_mdref_counter_bus/Bus Creator'}, 1);  
mi.Signals(pos).LoggingInfo.DecimateData = true;  
mi.Signals(pos).LoggingInfo.Decimation = 2;
```

## Accessing Signal Logging Data

In this section...
“Viewing Signal Logging Data” on page 29-50
“The Signal Logging Object” on page 29-51
“Viewing Logged Signal Data with the Simulation Data Inspector” on page 29-51
“Programmatically Accessing Logged Signal Data Saved in Dataset Format” on page 29-52
“Programmatically Accessing Logged Signal Data Saved in ModelDataLogs Format” on page 29-53

### Viewing Signal Logging Data

To generate signal logging data, simulate the model. You can view the signal logging data for a paused or completed simulation.

To view the signal logging data, use either the Simulation Data Inspector or 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 Accessing Logged Signal Data Saved in Dataset Format” on page 29-52
- “Programmatically Accessing Logged Signal Data Saved in ModelDataLogs Format” on page 29-53



---

**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 “Viewing the Signal Logging Configuration” on page 29-27 and “Overriding Signal Logging Settings” on page 29-38.

---

## The 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 “Specifying the Signal Logging Data Format” on page 29-34.

- Dataset format — Uses a `Simulink.SimulationData.Dataset` object
- ModelDataLogs format — Uses a `Simulink.ModelDataLogs` object

The default name of the signal logging variable is `logout`. You can change the signal logging name. For details, see “Specifying a Name for the Signal Logging Data” on page 29-37.

## Viewing 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 Model Editor, use one of the following approaches:

- To display logged signals whenever a simulation ends or you pause a simulation, select **Simulation > Configuration Parameters > Inspect signals when simulation is stopped/paused**.
- To launch the Simulation Data Inspector tool to display the data immediately, select **Tools > Inspect Logged Signals**.

For additional information about using the Simulation Data Inspector, see Simulation Data Inspector and “Inspecting and Comparing Logged Signal Data” on page 15-33.

## Programmatically Accessing Logged Signal Data Saved in Dataset Format

When you use the 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
<code>getElement</code>	Get element or collection of elements from the dataset, based on index, name, or block path.
<code>getLength</code>	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_md1ref_bus` demo 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 **Signal 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 Accessing Logged Signal Data Saved in ModelDataLogs 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	<code>Simulink.ModelDataLogs</code>
Subsystem in a model	<code>Simulink.SubsysDataLogs</code>
Scope block in a model	<code>Simulink.ScopeDataLogs</code>
Signal other than a bus or Mux signal	<code>Simulink.Timeseries</code>
Bus signal or Mux signal	<code>Simulink.TsArray</code>

## 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 31-11.

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

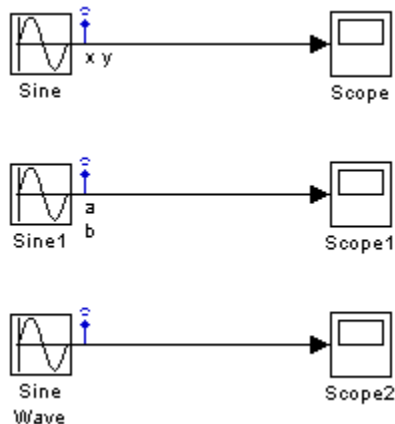
Chapter 32, “Using Composite Signals” and “Using Bus Objects” on page 32-15 for information about those capabilities.

### 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 you:

- Use `ModelDataLogs` for the signal logging format
- Use the default of `logsout` for the signal logging data

```

logout =

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:

```

>> logout.x y

??? logout.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:

```

>> logout.('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')
>> logout.(['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:

```
>> logout(['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.

---

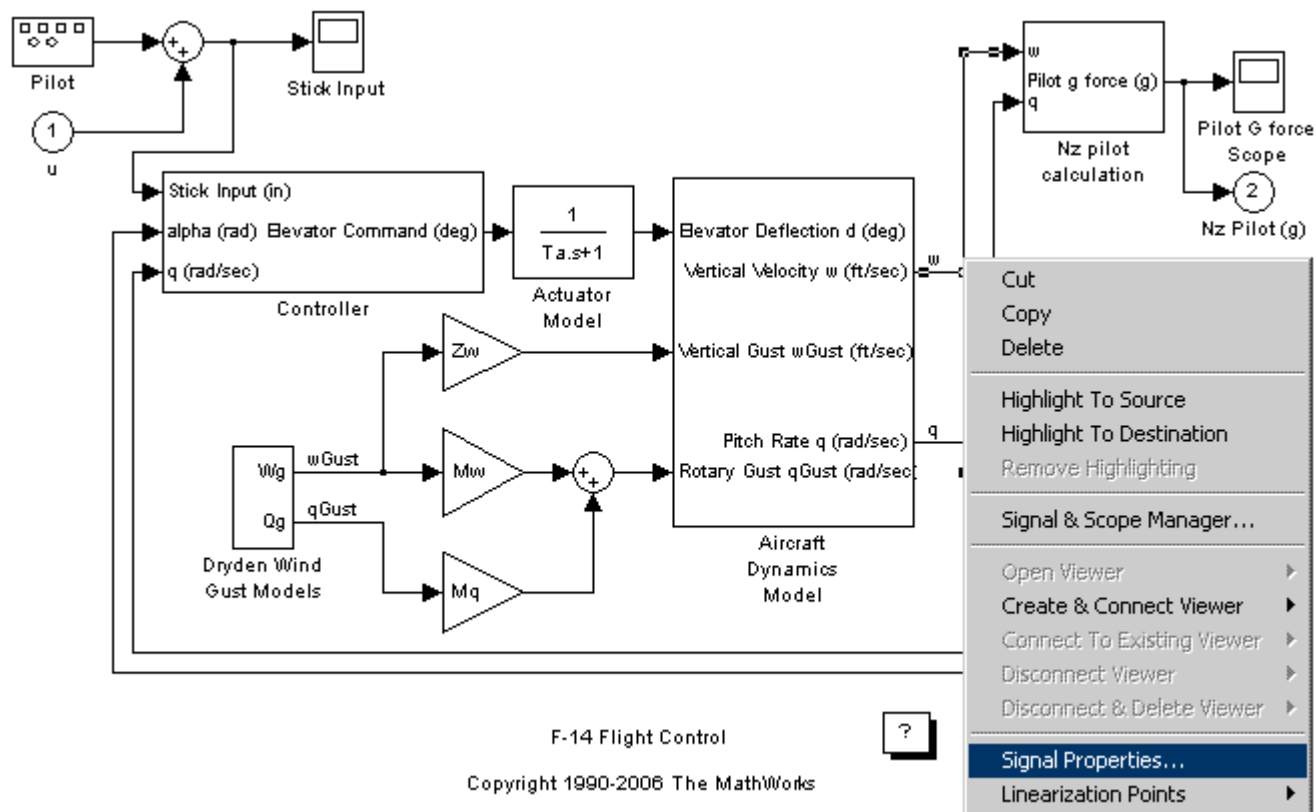
**Note** You cannot use these techniques for TAB name completion.

---

### **Example: Logging Signal Data in the F14 Model (Using ModelDataLogs Format)**

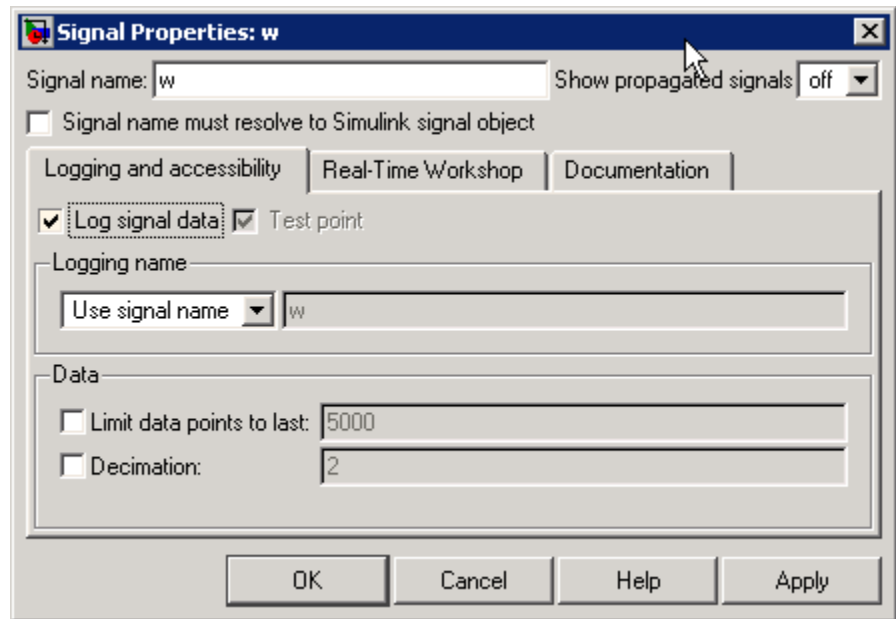
Enabling signal logging on a signal-by-signal basis allows you to store signal data without modifying the structure of the Simulink diagram. For example, use the following steps to log and access the signal data for the vertical velocity signal *w* in the F14 model.


- 1** Open the F14 model by typing `f14` at the MATLAB command prompt.
- 2** Right-click on the signal labeled *w*. Select the **Signal Properties** menu.



- 3 When the **Signal Properties** dialog box opens, select the **Log signal data** option. The logging name initializes to the signal's name.





- 4 Click the **OK** button on the **Signal Properties** dialog box. The blue antenna icon  appears on the signal labeled w, indicating that this signal will be logged during simulation.
- 5 Ensure that **Configuration Parameters > Data Import/Export > Signal logging** is selected and that the logging name is set to the default variable `logouts`.
- 6 Run the F14 simulation. The logged signal data is stored in a `Simulink.ModelDataLogs` object named `logouts` in the MATLAB workspace. Typing `logouts` at the MATLAB command prompt displays the following

```
logouts =
```

```
Simulink.ModelDataLogs (f14):
```

Name	Elements	Simulink Class
w	1	Timeseries

- 7 Type `logout.w` to view the information stored for the signal `w`.

```
logout.w
      Name: 'w'
      BlockPath: 'f14/Aircraft Dynamics Model'
      PortIndex: 1
      SignalName: 'w'
      ParentName: 'w'
      TimeInfo: [1x1 Simulink.TimeInfo]
              Time: [1353x1 double]
              Data: [1353x1 double]
```

- 8 Inspect the signal using the Simulation Data Inspector tool. From the `f14` model diagram window, select **Tools > Inspect Logged Signals** . (See “Inspecting and Comparing Logged Signal Data” on page 15-33.)

## Importing Signal Data in Simulink

### In this section...

“Techniques for Importing Signal Data” on page 29-61

“Guidelines for Specifying Time and Signal Values for Imported Data” on page 29-61

### Techniques for Importing Signal Data

To import data from a workspace, use one or more of the following techniques:

- From Workspace or From File blocks (for details, see “Importing Data to Create an Input Test Case” on page 29-68)
- A Signal Builder block (for details, see “Importing Data to Create an Input Test Case” on page 29-68)
- A root-level Inport or Trigger block (for details, see “Importing Data to Root-Level Input Ports” on page 29-74)
- A `Simulink.SimulationData.Signal` object (for details, see “Importing Signal Logging Data” on page 29-72)

### Guidelines for Specifying Time and Signal Values for Imported Data

Depending on your model development or testing goal, consider using the approach described in the following table.

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).	In the Inport block parameters dialog box, select <b>Interpolate data</b> .  To ensure that the Simulink variable time solver executes at the times that you specify

<b>Modeling Goal</b>	<b>Time and Signal Values</b>	<b>Additional Notes</b>
	<p>Use any of the data formats listed in “Input Data” on page 29-74. Here are recommended formats for the following imported data sources:</p> <ul style="list-style-type: none"> <li>• Another simulation — Dataset</li> <li>• An equation — MATLAB time expression</li> <li>• Experimental data — MATLAB timeseries, data array, or structure</li> </ul> <p>For details, see “Specifying Time Data” on page 29-91. For an example of using a structure to specify the time and signal values, see “Importing Data to Model a Continuous Plant” on page 29-64.</p>	<p>in the imported data, set the <b>Configuration Parameters &gt; Data Import/Export &gt; Output options</b> parameter to Produce additional output.</p>
<p>Test a discrete algorithm</p>	<p>Use a structure, with an empty time vector.</p> <p>Specify signal values, but no time vector. (One signal value is read at each time step, using the sample time of the source block.)</p> <p>For an example of using a structure to specify the signal values, see “Importing Data to Test a</p>	<p>In the Inport block parameters dialog box, clear <b>Interpolate data</b>.</p>

<b>Modeling Goal</b>	<b>Time and Signal Values</b>	<b>Additional Notes</b>
	Discrete Algorithm” on page 29-67.	
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 “Specifying Time Data” on page 29-91. Use any of the input data formats described in “Input Data” on page 29-74, except for MATLAB time expressions.	Select the <b>Interpolate data</b> 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 a Signal Builder block, see “Importing Data to Create an Input Test Case” on page 29-68.

## Importing Data to Model a Continuous Plant

### In this section...

“Sharing Simulation Data Across Models” on page 29-64

“Example of Importing Data to Model a Continuous Plant” on page 29-64

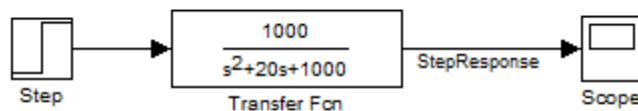
### Sharing Simulation Data Across Models

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 “Importing Signal Logging Data” on page 29-72.

### 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.

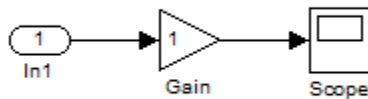
---

**3** Simulate the model.

Simulating the model saves a variable-step signal to the workspace, using the `logout` variable. The signal logging output 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`.

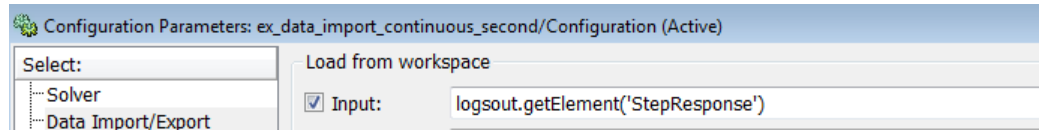
**4** Open a second model, named `ex_data_import_continuous_second`.



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 2-24.

---



## Importing Data to Test a Discrete Algorithm

### In this section...

“Specify a Signal-Only Structure” on page 29-67

“Example of Importing Data to Test a Discrete Algorithm” on page 29-67

### 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 “Specifying Signal Data” on page 29-90.

- 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.

## Importing Data to Create an Input Test Case

In this section...
“Guidelines for Importing a Test Case” on page 29-68
“Example of Test Case Data” on page 29-68
“Using a From Workspace Block to Import an Input Test Case” on page 29-69
“Using a Signal Builder Block to Import an Input Test Case” on page 29-70

### Guidelines for Importing a Test Case

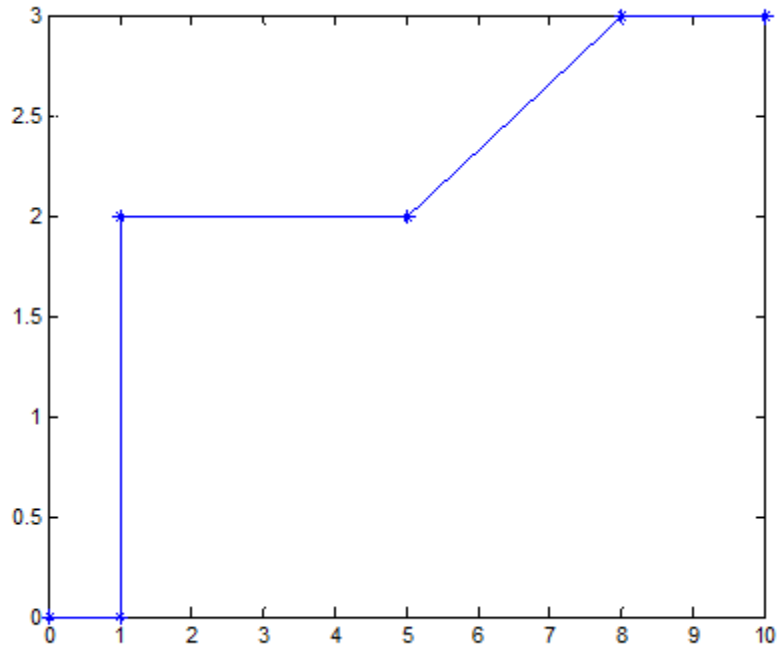
Typically when importing a test case in Simulink, you want to:

- 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

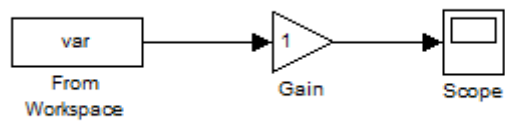
The following is an example of test case data:



The following two examples use this test case data.

## Using a From Workspace Block to Import an Input Test Case

- 1 Open the `ex_data_import_test_case_from_workspace.mdl` model.



- 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:

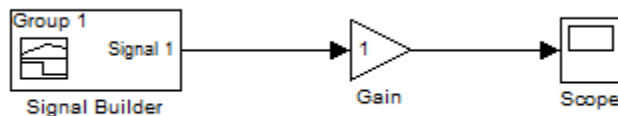
```
var.time = [0 1 1 5 5 8 8 10];
var.signals.values = [0 0 2 2 2 3 3 3]';
var.signals.dimensions = 1;
```

- 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.

## Using a 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”.

## Importing 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 “Exporting Signal Data Using Signal Logging” on page 29-19.

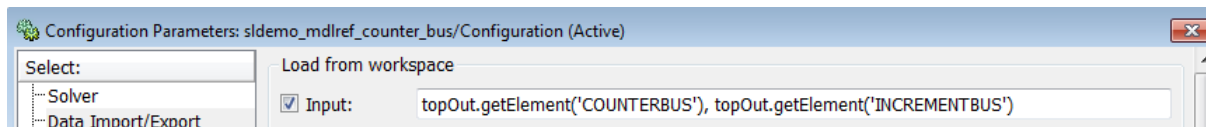
The imported signal logging data provides the input for simulating the model. You can use imported signal logging data to perform standalone simulation of a referenced model.

- 1 Set the **Configuration Parameters > Data Import/Export > Signal logging format** parameter to Dataset.
- 2 Use the default signal logging output variable, `logout`, 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_md1ref_bus` demo.
- 2** In the right corner of the demo, double-click the left question mark block.
- 3** See the “Logging Model Reference Signals” and “Loading Data” sections.

## Importing Data to Root-Level Input Ports

### In this section...

“Root-Level Input Ports” on page 29-74

“Enabling Data Import” on page 29-74

“Input Data” on page 29-74

“Importing Bus Data” on page 29-77

### 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 “Importing Data to Create an Input Test Case” on page 29-68.

### Enabling 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 29-74.

### Input Data

Use the **Configuration Parameters > > 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 “Resolving Symbols” on page 3-76. 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:
  - “Importing MATLAB timeseries Data” on page 29-78
  - “Importing Structures of MATLAB timeseries Objects for Bus Signals to a Root-Level Input Port” on page 29-80
- Array — See “Importing Data Arrays to a Root-Level Input Port” on page 29-86.
- `Simulink.SimulationData.Signal` — For details, see “Importing Signal Logging Data” on page 29-72
- Structure — See “Importing Data Structures to a Root-Level Input Port” on page 29-89.
- 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 “Importing MATLAB Time Expression Data” on page 29-88.
- `Simulink.Timeseries` and `Simulink.TsArray` — See “Importing Simulink.Timeseries and Simulink.TsArray Data to a Root-Level Input Port” on page 29-85.

## 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  $UT = [T, U1, \dots, Un]$ , where  $T = [t1, \dots, tm]'$
- 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 29-76

**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 “Initializing Signals and Discrete States” on page 31-52.

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
```

## Importing Bus Data

To import bus data to root input ports, use a structure of MATLAB `timeseries` objects. For details, see “Importing Structures of MATLAB `timeseries` Objects for Bus Signals to a Root-Level Input Port” on page 29-80.

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
```

## Importing MATLAB timeseries Data

### In this section...

“Specifying the Time Dimension” on page 29-78

“Models with Multiple Root Inport Blocks” on page 29-79

A root-level Inport, Enable, Trigger, and From Workspace block can import data specified by a MATLAB `timeseries` object residing in a workspace.

### Specifying the 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;
```

## Importing Structures of MATLAB timeseries Objects for Bus Signals to a Root-Level Input Port

### In this section...

“Defining a Structure of MATLAB timeseries Objects for a Bus Signal” on page 29-80

“When to Use a Structure of MATLAB timeseries Objects Instead of a Simulink.TsArray Object” on page 29-81

“How to Use a Structure of MATLAB timeseries Objects to Import Bus Signals” on page 29-82

### Defining a 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.

## When to Use a Structure of MATLAB timeseries Objects Instead of a Simulink.TsArray Object

Although you can use `Simulink.TsArray` objects for time series data, using MATLAB timeseries objects provides the following benefits:

- Creating a `Simulink.TsArray` object can be difficult and often involves having a harness of models or custom scripts.
- Using a structure of MATLAB timeseries objects supports using a partial specification of bus elements (using ground values for those elements that you do not specify in the structure).
- The From Workspace block does not support `Simulink.TsArray` objects.

When the **Configuration Parameters > Data Import/Export > Signal logging format** parameter is set to `ModelDataLogs`, the data that comes directly from a logged signal during simulation is stored as `Simulink.TsArray` objects. Although you can convert the `Simulink.TsArray` objects to MATLAB timeseries objects, in most situations it makes sense to leave the data in `Simulink.TsArray` format.

If **Signal logging format** is set to `Dataset`, then the data is logged as a structure of MATLAB timeseries objects. For an example of using the `Dataset` format for signal logging, see `sldemo_md1ref_bus`.

---

**Note** If you use a structure of MATLAB timeseries objects for a root Inport block in a model that has multiple root Inport blocks, convert all of the other root Inport block data that uses `Simulink.TsArray` or `Simulink.Timeseries` objects to MATLAB timeseries objects.

---

You can create a structure of MATLAB timeseries objects from a `Simulink.TsArray` object. For example, if `tsa` is a `Simulink.TsArray` object:

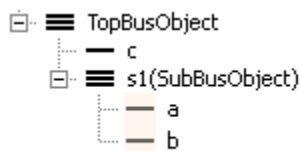
```
input = Simulink.SimulationData.createStructOfTimeseries(tsa);
```

## How to Use a Structure of MATLAB timeseries Objects to Import Bus Signals

Use the following procedure to set up a model to import bus data to a root Inport block or Trigger blocks.

The examples in this procedure assume you have a model that is set up as follows:

- The TopBusObject bus object has two elements:
  - c
  - s1, which is a sub-bus that has two elements: a and b.



- The model has two root Inport blocks: In1 and In2.
    - The In1 Inport block imports non-bus data.
    - The In2 Inport block imports bus data of type TopBusObject.
- 1 Create a MATLAB timeseries object for each root Inport or Trigger block for which you want to import non-bus data.

For example:

```

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 = timeseries(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):

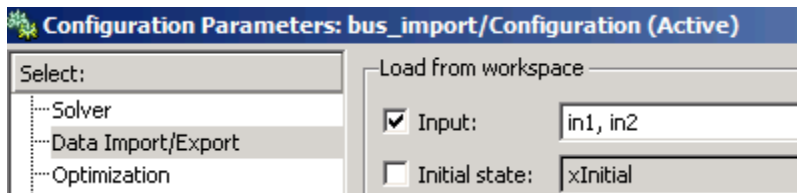
```
num_el = MyBus.getNumLeafBusElements;  
el_list = MyBus.getLeafBusElements;
```

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.



## Importing Simulink.Timeseries and Simulink.TsArray Data to a Root-Level Input Port

### In this section...

“Alternative to Using MATLAB timeseries Data” on page 29-85

“Simulink.TsArray Data” on page 29-85

### Alternative to Using MATLAB timeseries Data

As an alternative to importing MATLAB timeseries data (see “Importing MATLAB timeseries Data” on page 29-78), any root-level Inport block or Trigger block can import a Simulink.Timeseries object.

Importing Simulink.Timeseries objects allows you to import data logged by a previous simulation run that used the ModelDataLogs format for signal logging (see “Exporting Signal Data Using Signal Logging” on page 29-19). For example, suppose that you have a model that references several other models. You can log data from the inputs of the referenced models during the simulation of the top model. Then you can use that logged data as inputs for the referenced models when you simulate the referenced models individually. This approach allows you to test the referenced models independently of the top model and each other.

However, using a structure of MATLAB timeseries objects provides several benefits. See “Importing Structures of MATLAB timeseries Objects for Bus Signals to a Root-Level Input Port” on page 29-80.

### 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.TsArrayobjects for mux or bus signals. The name of each property is the log name of the corresponding signal.

## Importing Data Arrays to a Root-Level Input Port

### In this section...

“Data Array Format” on page 29-86

“Specifying the Input Expression” on page 29-86

### 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.

### Specifying 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`.

---

## Importing MATLAB Time Expression Data

### Specifying 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 **Input** that accepts two signals. Furthermore, suppose that `timefcn` is a user-defined function that returns a row vector two elements long. The following are valid input time expressions for such a model:

```
'[3*sin(t), cos(2*t)]'
```

```
'4*timefcn(w*t)+7'
```

The expression is evaluated at each step of the simulation, applying the resulting values to the model's input ports. Note that the Simulink software defines the variable `t` when it runs the simulation. Also, you can omit the time variable in expressions for functions of one variable. For example, the expression `sin` is interpreted as `sin(t)`.

## Importing Data Structures to a Root-Level Input Port

### In this section...

“Data Structures” on page 29-89

“One Structure for All Ports or a Structure for Each Port” on page 29-90

“Specifying Signal Data” on page 29-90

“Specifying Time Data” on page 29-91

“Examples of Specifying Signal and Time Data” on page 29-92

### 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 “Structures” 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 “Specifying Signal Data” on page 29-90. 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 29-90.

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:

- “Importing Data to Test a Discrete Algorithm” on page 29-67

- “Importing Data to Model a Continuous Plant” on page 29-64
- “Importing Data to Create an Input Test Case” on page 29-68

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 “Specifying Signal Data” on page 29-90.

For continuous signals, you may want to specify a `time` field, which contains a time vector. See “Guidelines for Specifying Time and Signal Values for Imported Data” on page 29-61.

### **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.

### **Specifying 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.

---

### Specifying Time Data

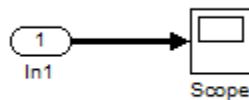
You can specify a time vector as part of the data structure to import. The “Guidelines for Specifying Time and Signal Values for Imported Data” on page 29-61 section indicates when you may want to add a time vector.

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:  <code>TimeVector = Ts * (0:N);</code>  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, <code>[1:5 5:10]</code> or <code>(1 6 10 15)</code> .  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';
```

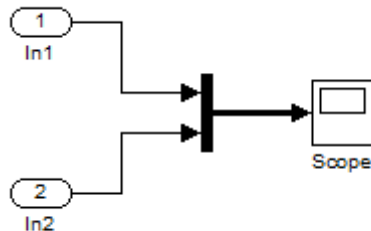
```

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 Input 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**.

---

## Importing and Exporting States

### In this section...

“State Information” on page 29-94

“Saving State Information” on page 29-94

“Importing Initial States” on page 29-99

“Importing and Exporting State Information for Referenced Models” on page 29-101

### 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.

### Saving 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 13-38.

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:

- “Saving Complete State Information with `SimState`” on page 29-95
- “Saving Partial Final State Information” on page 29-95

### **Saving 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 “Saving and Restoring the Simulation State as the `SimState`” on page 13-32.

### **Saving 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 29-96
- 4** Simulate the model.

For details about examining the saved state information, see

### **Saving 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 29-96.
- 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

### **Examining 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.

---



## Importing 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 “Importing Saved State Information” on page 29-99.

The initial values that the variable specifies override the initial state values that the blocks in the model specify in initial condition parameters.

## Importing 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**.

<b>Setting for the “Save complete SimState in final state” parameter</b>	<b>State Information</b>
Enabled	Complete state information. For details, see “Saving and Restoring the Simulation State as the SimState” on page 13-32.
Cleared	State information for logged states (the continuous and discrete states of blocks), in the format specified in <b>Configuration Parameters &gt; Data Import/Export &gt; Format</b> . For details, see “Format for Saved State Information” on page 29-96.

For example, the following commands create an initial state structure that initialize the x2 state of the vdp model. The x1 state is not initialized in the structure. Therefore, during simulation, Simulink uses the value in the Integrator block associated with the state.

```
% Open the vdp demo model
vdp

% Use getInitialState to obtain an initial state structure
states = Simulink.BlockDiagram.getInitialState('vdp');

% Set the initial value of the signals structure element
% associated with x2 to 2.
states.signals(2).values = 2;

% Remove the signals structure element associated with x1
states.signals(1) = [];
```

To use the `states` variable, for the vdp model, enable the **Configuration Parameters > Data Import/Export > Initial state** option (in the **Load from workspace** area). Enter `states` into the associated edit field. When you run the model, note that both states have the initial value of 2. The initial

value of the x2 state is assigned in the `states` structure, while the initial value of the x1 state is assigned in its Integrator block.

## Importing and Exporting 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_md1ref_basic/CounterA|sldemo_md1ref_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.

# Working with Data Stores

---

- “About Data Stores” on page 30-2
- “Defining Data Stores with Data Store Memory Blocks” on page 30-8
- “Defining Data Stores with Signal Objects” on page 30-12
- “Accessing Data Stores with Simulink Blocks” on page 30-14
- “Data Store Examples” on page 30-22
- “Logging Data Stores” on page 30-25
- “Ordering Data Store Access” on page 30-30
- “Using Data Store Diagnostics” on page 30-33
- “Data Stores and Software Verification” on page 30-41

## About Data Stores

### In this section...

“Local and Global Data Stores” on page 30-2

“When to Use a Data Store” on page 30-3

“Creating Data Stores” on page 30-3

“Accessing Data Stores” on page 30-4

“Workflow for Configuring Data Stores” on page 30-5

“Using Data Stores with Buses and Arrays of Buses” on page 30-5

### 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 store 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 30-22.

For information about using referenced models, see Chapter 5, “Referencing a Model”.

## 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 “Custom Storage Classes” and “GetSet Custom Storage Class for Data Store Memory”.

## When to Use a Data Store

Data stores can be useful when multiple signals at different levels of a model need the same global values, and connecting all the signals explicitly would clutter the model unacceptably or take too long to be feasible. Data stores are analogous to global variables in programs, and have similar advantages and disadvantages, such as making verification more difficult. See “Data Stores and Software Verification” on page 30-41 for more information.

In some cases, you may be able to use a simpler technique, Goto blocks and From blocks, to obtain results similar to those provided by data stores. The principal disadvantage of data Goto/From links is that they generally are not accessible across nonvirtual subsystem boundaries, while an appropriately configured data store can be accessed anywhere. See the Goto and From block reference pages for more information about Goto/From links.

## Creating Data Stores

To create a data store, you create a Data Store Memory block or a `Simulink.Signal` object. The block or 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 “Defining Data Stores with Data Store Memory Blocks” on page 30-8.
- A `Simulink.Signal` object can act as a local or global data store. See “Defining Data Stores with Signal Objects” on page 30-12.

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.

## Accessing Data Stores

To write a signal to a data store, use a Data Store Write block, which inputs the value of a signal and writes that value to the data store.

To read a signal from a data store, use a Data Store Read block, which reads the value 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 “Accessing Data Stores with Simulink Blocks” on page 30-14 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 “Logging Data Stores” on page 30-25.



---

## Workflow for Configuring 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 30-6.

---

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 30-41.
- 2** Create data stores using the techniques described in “Defining Data Stores with Data Store Memory Blocks” on page 30-8 or “Defining Data Stores with Signal Objects” on page 30-12. For greater reliability, consider assigning rather than inheriting data store attributes, as described in “Specifying Data Store Memory Block Attributes” on page 30-8.
- 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 “Accessing Data Stores with Simulink Blocks” on page 30-14.
- 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 “Ordering Data Store Access” on page 30-30.
- 5** Apply the techniques described in “Using Data Store Diagnostics” on page 30-33 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.

## Using 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 “Workflow for Configuring Data Stores” on page 30-5.

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 “Using the Bus Editor” on page 32-18.
- 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 “Specifying a Bus Object Data Type” on page 27-27.
- 4** In the **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 **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 **Configuration Parameters > Diagnostics > Data Validity** pane, set the **Underspecified initialization detection** diagnostic to error. For details, see “Specifying Initial Conditions for Bus Signals” on page 32-63 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 30-16.

## Defining Data Stores with Data Store Memory Blocks

### In this section...

“Creating the Data Store” on page 30-8

“Specifying Data Store Memory Block Attributes” on page 30-8

### 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 30-9 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:

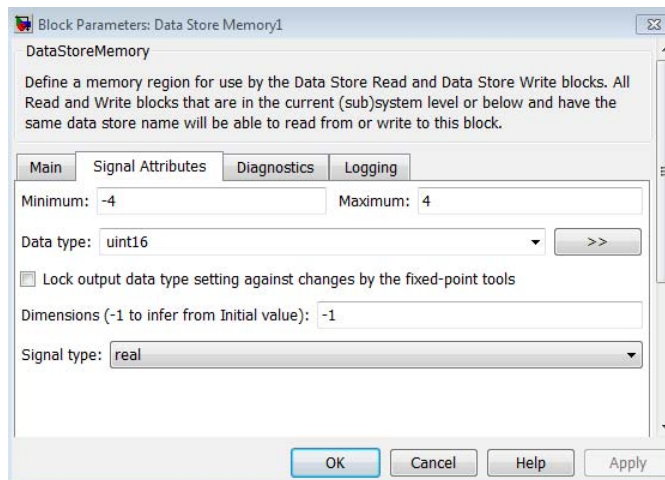
- Data type

- 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`.

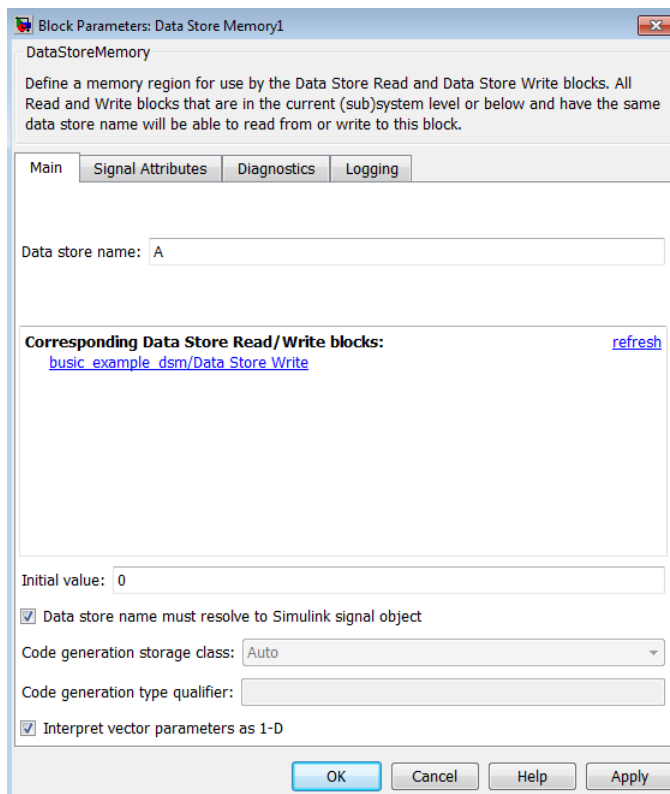


### Specifying Attributes Using a Signal Object

You can use a `Simulink.Signal` object to specify data store attributes. To establish an implicit data store, as described in “Defining Data Stores with Signal Objects” on page 30-12, 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: ''
```

## Defining Data Stores with Signal Objects

### In this section...

“Creating the Data Store” on page 30-12

“Local and Global Data Stores” on page 30-12

“Specifying Signal Object Data Store Attributes” on page 30-12

### 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;
```

## Accessing Data Stores with Simulink Blocks

### In this section...

“Writing to a Data Store” on page 30-14

“Reading from a Data Store” on page 30-14

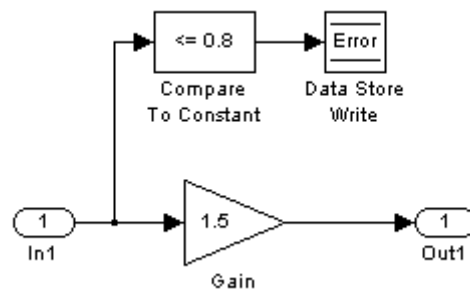
“Accessing a Global Data Store” on page 30-15

“Accessing Specific Bus and Matrix Elements” on page 30-16

### 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.

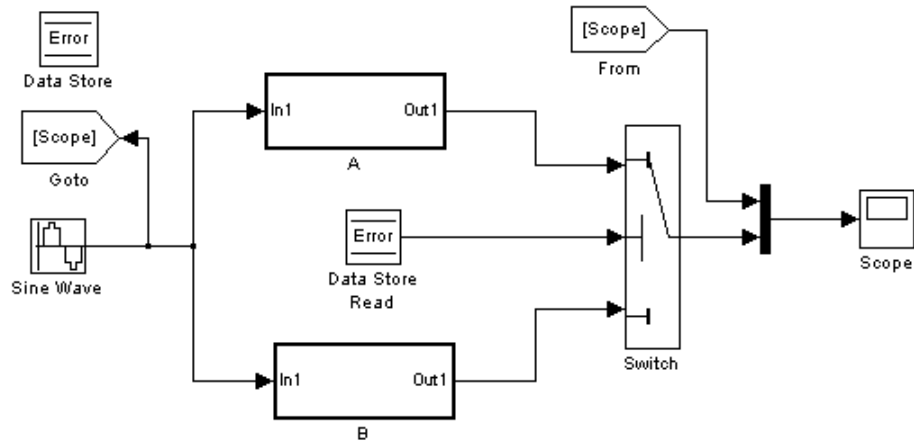


### Reading from a Data Store

To get the value of a data store at each time step:

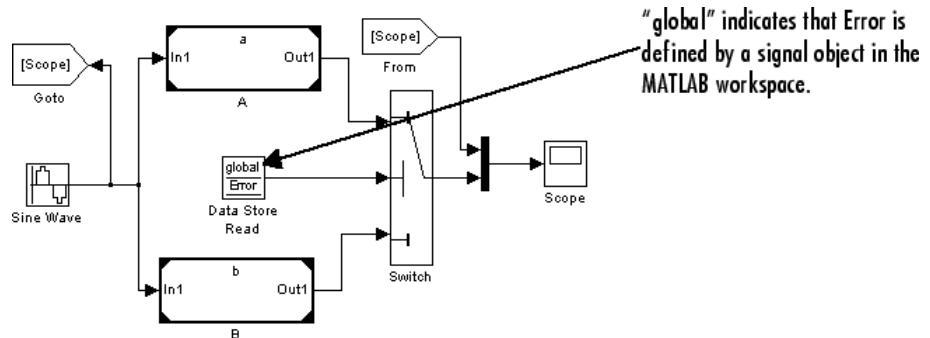
- 1 Create an instance of a Data Store Read block at the level of your model that needs the value.

- 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

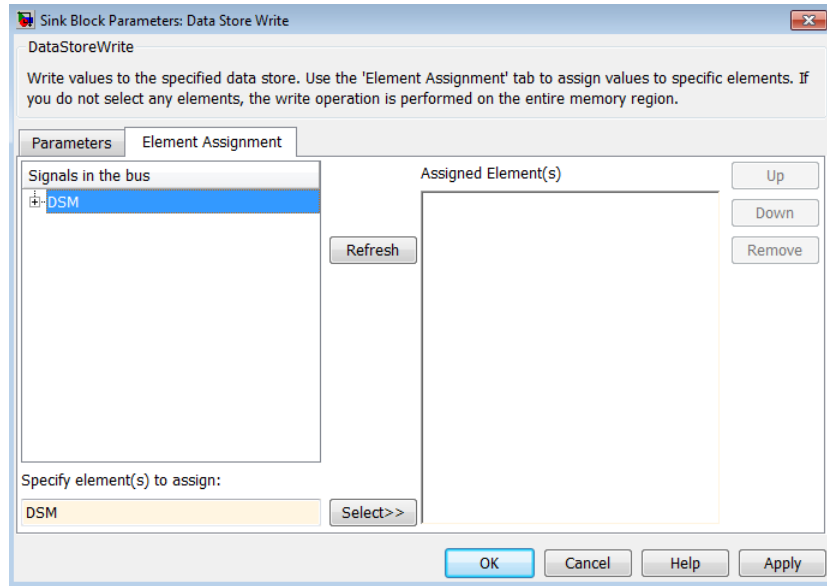
---

**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 30-21.

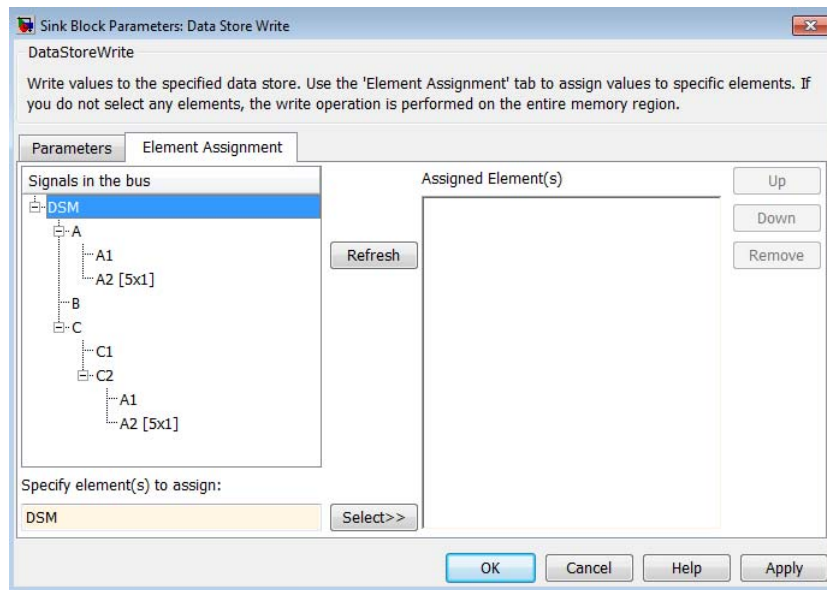
---

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`:

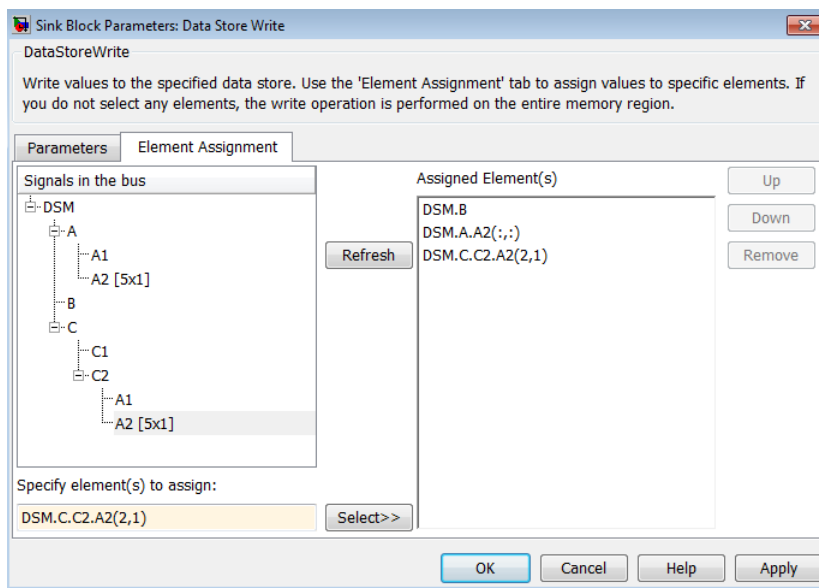


**2** Expand all the elements in the **Signals in the bus** list.



**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 30-19.

**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 30-16. 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**

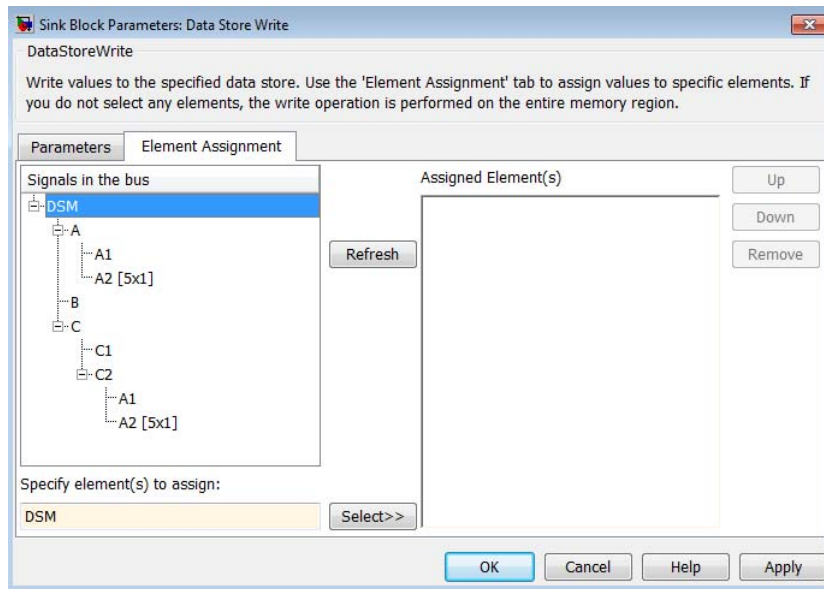
Use MATLAB matrix element syntax to specify specific elements. For details about specifying matrices in MATLAB, see “Creating and Concatenating Matrices”.

---

**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 30-16.



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 30-16.



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(gcf, '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” on page 30-22
“Local Data Store Example” on page 30-22
“Global Data Store Example” on page 30-23

### Overview

The following examples illustrate techniques for defining and accessing data stores. See “Ordering Data Store Access” on page 30-30 for techniques that control data store access over time, such as ensuring that a given data store is always written before it is read. See “Using Data Store Diagnostics” on page 30-33 for techniques you can use to help detect and correct potential data store errors without needing to run any simulations.

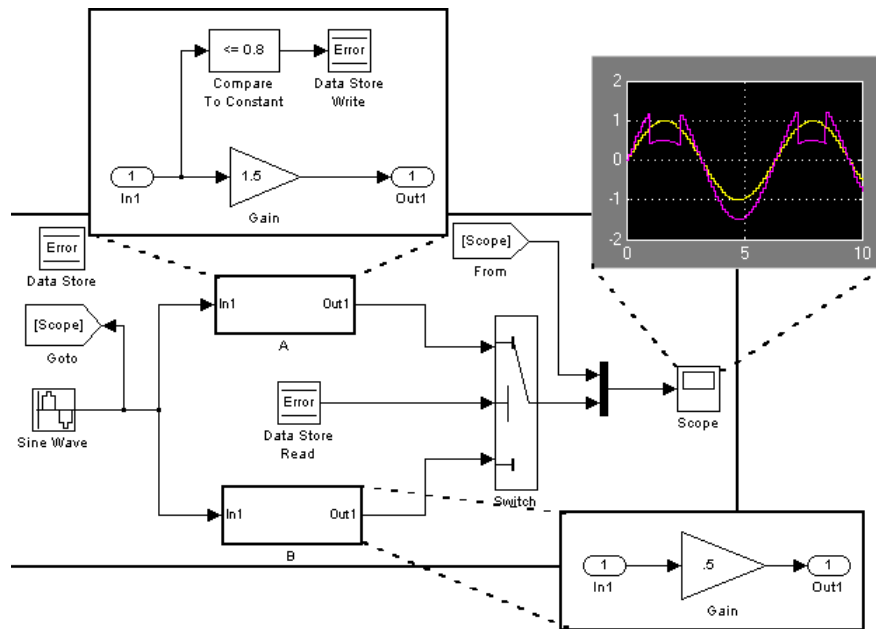
---

**Note** In addition to the following examples, see the `sldemo_mdref_dsm` demo, which shows how to use global data stores to share data among referenced models.

---

### Local Data Store Example

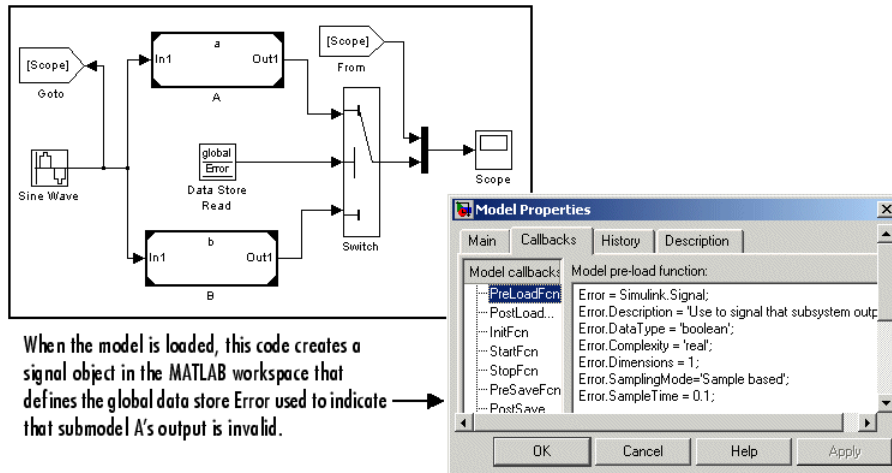
The following model illustrates creation and access of a local data store, which is visible only in a model or particular subsystem.



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.

## Logging Data Stores

### In this section...

“Logging Local and Global Data Store Values” on page 30-25

“Supported Data Types, Dimensions, and Complexity for Logging Data Stores” on page 30-25

“Data Store Logging Limitations” on page 30-26

“Logging Data Stores Created with a Data Store Memory Block” on page 30-26

“Logging Icon for the Data Store Memory Block” on page 30-27

“Logging Data Stores Created with a Simulink.Signal Object” on page 30-27

“Accessing Data Store Logging Data” on page 30-28

### Logging Local and Global Data Store Values

You can log the values of a local or global data store data variable for all the steps in a simulation. Two common uses of data store logging are for:

- Model debugging – view the order of all data store writes
- Confirming a model modification – use the logged data to establish a baseline for comparing results for identifying the impact of a model modification

To see an example of logging a global data store, run the `sldemo_mdref_dsm` demo.

### Supported Data Types, Dimensions, and Complexity for Logging Data Stores

You can log data stores that use the following data types:

- All built-in data types
- Enumerated data types
- Fixed-point data types

You can log data stores that use any dimension level or complexity.

## Data Store Logging Limitations

Limitations for using data store logging in a model are:

- To log data for a data store memory:
  - Simulate the top-level model in Normal mode.
  - For local data stores, the model containing the Data Store Memory block must be in model reference Normal mode.
  - Any block in a referenced model that writes to the data store memory must be executed in model reference Normal mode.
- If you set the **Configuration Parameters > Solver > Tasking mode for periodic sample times** parameter to `MultiTasking`, then you cannot log Data Store Memory blocks that use asynchronous sample times or hybrid sample times (that is, sample times resulting from when different data sources for the data store have different sample times).

For details about viewing information about sample times, see “How to View Sample Time Information” on page 4-9.

- You cannot log data stores that use custom data types.

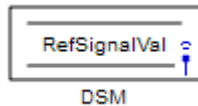
## Logging Data Stores Created with a Data Store Memory Block

To log a local data store that you create with a Data Store Memory block:

- 1 In the Block Parameters dialog box for the Data Store Memory block that you want to log, select the **Logging** pane.
- 2 Select the **Log signal data** check box.
- 3 Optionally, specify limits for the amount of data logged, using the **Minimum** and **Maximum** parameters.
- 4 Enable data store logging with the **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 “Defining Data Stores with Signal Objects” on page 30-12 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 “Defining Data Stores with Signal Objects” on page 30-12.
- 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 **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
<code>Simulink.SimulationData.BlockPath</code>	Represents a fully specified Simulink block path; use for capturing the full model reference hierarchy
<code>Simulink.SimulationData.Dataset</code>	Stores logged data elements and provides searching capabilities; use to group <code>Simulink.SimulationData.Element</code> objects in a single object
<code>Simulink.SimulationData.DataStoreMemory</code>	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_mdref_dsm` demo 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 Simulink1.SimulationData.BlockPath]  
    DSMWriters: [101x1 uint32]  
    Values: 101x1 timeseries]
```

To access an element by index, use the `Simulink.SimulationData.Dataset.getElement` method.

## Ordering Data Store Access

In this section...
“About Data Store Access Order” on page 30-30
“Ordering Access Using Function Call Subsystems” on page 30-30
“Ordering Access Using Block Priorities” on page 30-31

### About Data Store Access Order

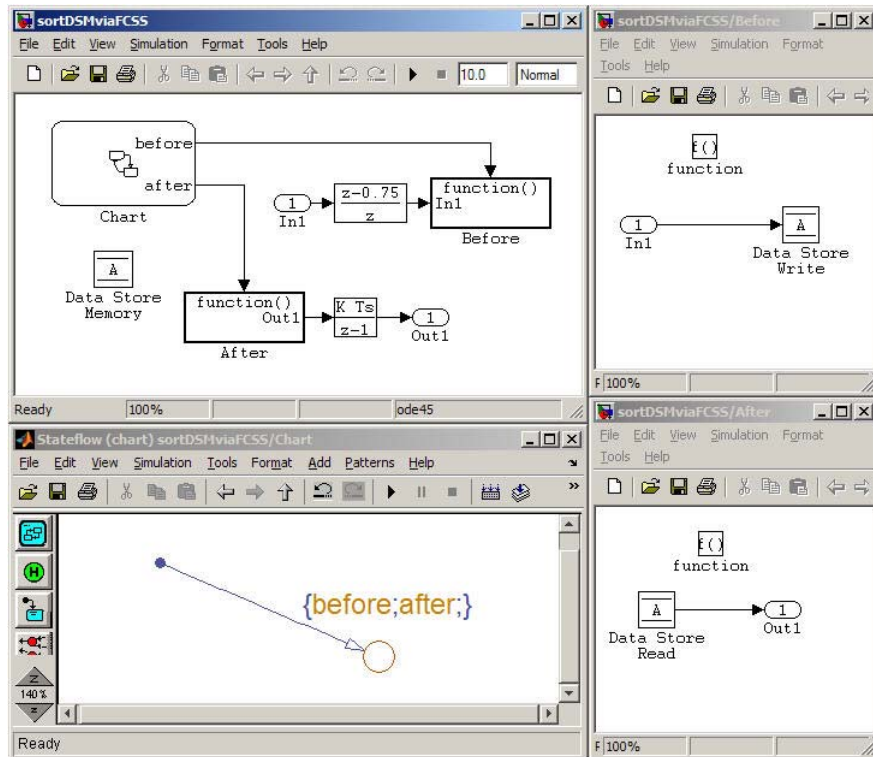
To obtain correct results from data stores, you must control the order of execution of the data store’s reads and writes. If a data store’s read occurs before its write, latency is introduced into the algorithm: the read obtains the value that was computed and stored in the previous time step, rather than the value computed and stored in the current time step.

Such latency may cause the system to behave other than as designed, and in some cases may destabilize the system. Even if these problems do not occur, an uncontrolled access order could change from one release of Simulink to the next.

This section describes several strategies for explicitly controlling the order of execution of a data store’s reads and writes. See “Using Data Store Diagnostics” on page 30-33 for techniques you can use to detect and correct potential data store errors without running simulations.

### Ordering Access Using Function Call Subsystems

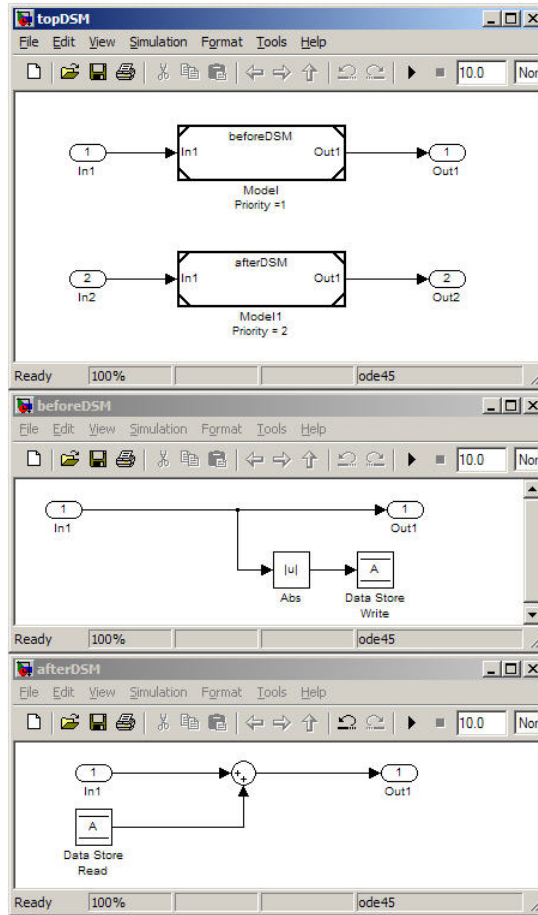
You can use function call subsystems to control the execution order of model components that access data stores. The next figure shows this technique:



The subsystem `Before` contains the Data Store Write, and the Stateflow chart calls that subsystem before it calls the subsystem `After`, which contains the Data Store Read.

## Ordering Access Using Block Priorities

You can embed data store reads and writes inside atomic subsystems or Model blocks whose priorities specify their relative execution order. The next figure shows this technique:



The Model block `beforeDSM` has a lower priority than `afterDSM`, so it is guaranteed to execute first. Since `beforeDSM` is atomic, all of its operations, including the Data Store Write, will execute prior to `afterDSM` and all of its operations, including the Data Store Read.

## Using Data Store Diagnostics

### In this section...

“About Data Store Diagnostics” on page 30-33

“Detecting Access Order Errors” on page 30-33

“Detecting Multitasking Access Errors” on page 30-36

“Detecting Duplicate Name Errors” on page 30-38

“Data Store Diagnostics in the Model Advisor” on page 30-40

### About Data Store Diagnostics

Simulink provides various run-time and compile-time diagnostics that you can use to help avoid problems with data stores. Diagnostics are available in the Configuration Parameters dialog box and the Data Store Memory block’s parameters dialog box. The Simulink Model Advisor provides support by listing cases where data store errors are more likely because diagnostics are disabled.

### Detecting Access Order Errors

You can use data store run-time diagnostics to detect unintended sequences of data store reads and writes that occur during simulation. You can apply these diagnostics to all data stores, or allow each Data Store Memory block to set its own value. The diagnostics are:

- **Detect read before write:** Detect when a data store is read from before written to within a given time step
- **Detect write after read:** Detect when a data store is written to after being read from within a given time step
- **Detect write after write:** Detect when a data store is written to multiple times within a given time step

These diagnostics appear in the **Configuration Parameters > Diagnostics > Data Validity > Data Store Memory Block** pane, where each can have one of the following values:

- `Disable all` — Disables this diagnostic for all data stores accessed by the model.
- `Enable all as warnings` — Displays the diagnostic as a warning in the MATLAB Command Window.
- `Enable all as errors` — Halts the simulation and displays the diagnostic in an error dialog box.
- `Use local settings` — Allow each Data Store Memory block to set its own value for this diagnostic (default).

The same diagnostics also appear in each Data Store Memory block 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 **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:

The image displays three windows from the MATLAB/Simulink environment:

- Top Window (dsmErrDiag):** A Simulink model diagram. It features a **Constant1** block with the value 12, a **Chart** block, a **Data Store Write** block (containing 'z'), a **Data Store Memory** block (containing 'z'), a **Display1** block, and an **Out3** block (containing '1'). Arrows indicate data flow from Constant1 to Data Store Write, from Chart to Display1, and from Data Store Memory to Out3.
- Middle Window (Stateflow chart dsmErrDiag/Chart):** A Stateflow chart showing a state transition. The state contains the code: 
$$\{y = 2*Z+A[0];$$
$$Z--; A--;\}$$
- Bottom Window (Simulation Diagnostics: dsmErrDiag):** A diagnostic window showing a block error. The message reads: "Block error Chart Simulink 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".

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:

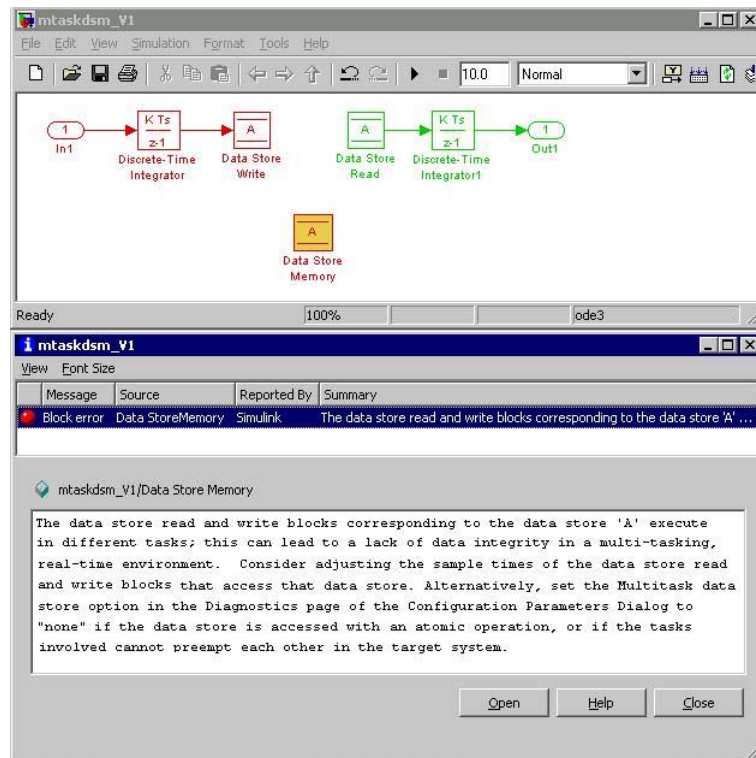
- 1 A task is writing to a data store.
- 2 A second task interrupts the first task.
- 3 The second task reads from that data store.

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 **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

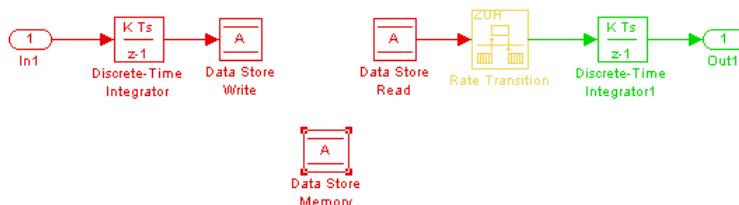


next figure illustrates a problem detected by setting **Multitask Data Store** to error:



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 more data store memories in different nested scopes have the same data store name. In this situation, the data store memory referenced by a data store read or write block at a low level may not be the intended store.

To prevent errors caused by duplicate data store names, set the compile-time diagnostic **Configuration Parameters > Diagnostics > Data Validity > Data Store Memory Block > Duplicate Data Store Names** to warning or error. By default, the value of the diagnostic is *none*, suppressing duplicate name detection. The next figure shows a problem detected by setting **Duplicate Data Store Names** to error:

The screenshot displays the MATLAB/Simulink environment with three windows:

- mtaskdsm\_V3**: The top-level model window. It shows a block diagram with an input 'In1' connected to a 'Discrete-Time Integrator' block (containing 'K Ts' and 'z-1'), which is connected to a 'Data Store Write' block (containing 'A'). Below this is a 'Data Store Memory' block (containing 'A'). To the right, a 'topSS' block (containing 'Out1') is connected to an output 'Out1'.
- mtaskdsm\_V3/topSS**: A subsystem window showing a 'Data Store Memory' block (containing 'A') connected to a 'bottomSS' block, which is connected to an output 'Out1'.
- mtaskdsm\_V3/topSS/bottomSS**: A subsystem window showing a 'Data Store Read' block (containing 'A') connected to a 'Discrete-Time Integrator' block (containing 'K Ts' and 'z-1'), which is connected to an output 'Out1'.

At the bottom, a diagnostic message window is open, displaying the following error:

Message	Source	Reported By	Summary
Block error	Data StoreMemory	Simulink	Data store memory tag 'A' is used for block 'mtaskdsm_V3/topSS/Dat...

The message text reads: "Data store memory tag 'A' is used for block '['mtaskdsm\\_V3/topSS/Data Store Memory'](#)' and block '['mtaskdsm\\_V3/Data Store Memory'](#)'." Buttons for "Open", "Help", and "Close" are visible at the bottom of the message window.

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-178B, “Software Considerations in Airborne Systems and Equipment Certification,” Section 6.3.3b.



# Managing Signals

---

- Chapter 31, “Working with Signals”
- Chapter 32, “Using Composite Signals”
- Chapter 33, “Working with Variable-Size Signals”





# Working with Signals

---

- “Signal Basics” on page 31-2
- “Signal Types” on page 31-8
- “Virtual Signals” on page 31-11
- “Signal Values” on page 31-15
- “Signal Names and Labels” on page 31-19
- “Signal Label Propagation” on page 31-24
- “Signal Dimensions” on page 31-34
- “Determining Output Signal Dimensions” on page 31-36
- “Displaying Signal Sources and Destinations” on page 31-41
- “Signal Ranges” on page 31-45
- “Initializing Signals and Discrete States” on page 31-52
- “Working with Test Points” on page 31-59
- “Displaying Signal Attributes” on page 31-63
- “Working with Signal Groups” on page 31-68

## Signal Basics

In this section...
“About Signals” on page 31-2
“Creating Signals” on page 31-3
“Signal Line Styles” on page 31-4
“Signal Properties” on page 31-5
“Testing Signals” on page 31-6

### 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

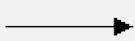

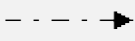
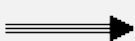
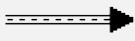


Create a signal by adding a source block to your model. For example, you can create a signal that varies sinusoidally with time, by dragging an instance of the Sine block from the Simulink Sources library into your model. See “Sources” for information about blocks that create signals in a model.

You can also use the Signal & Scope Manager to create signals in your model, without using blocks. See “Signal and Scope Manager” on page 15-25 for more information.

## Signal Line Styles

A Simulink model can include many different types of signals. For details, see “Signal Types” on page 31-8.

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 <b>Wide nonscalar lines</b> option, Simulink uses a thick, solid line to represent nonscalar signals. For information about line display options, see “Displaying Signal Attributes” on page 31-63.
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 31-67 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.

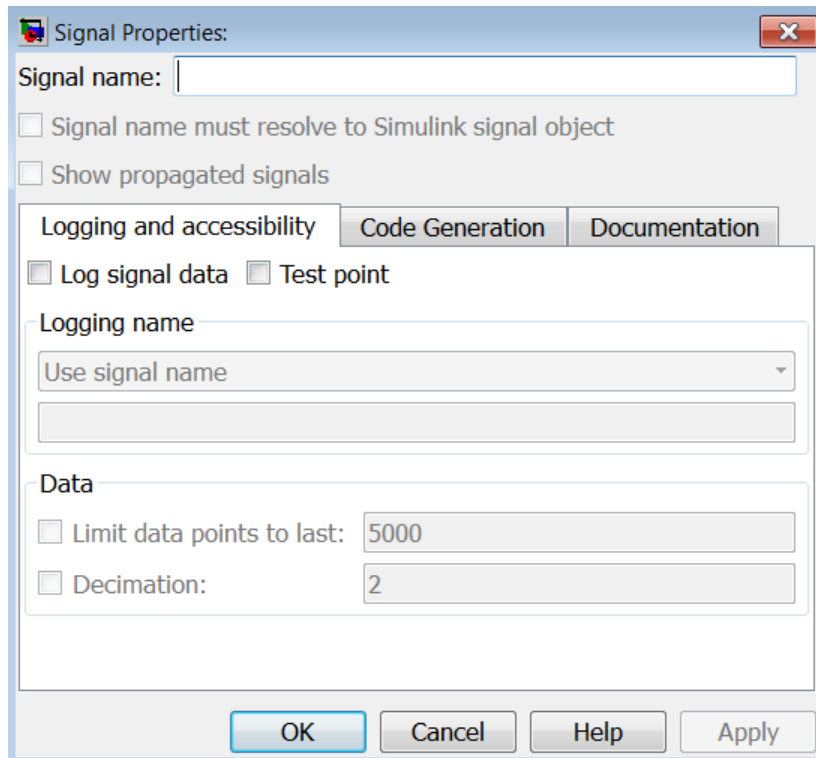
## Signal Properties

### 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 **Signal Properties**.



For details, see “Signal Properties Dialog Box”.

### **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 **Format > Port/Signals Displays** menus to include in the model layout information about signal attributes, such as:

- Port data types
- Design ranges
- Signal dimensions
- Signal resolution

For details, see “Displaying Signal Attributes” on page 31-63.

### **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 to Source** or **Highlight to Destination**.

For details, see “Displaying Signal Sources and Destinations” on page 31-41.

### **Testing Signals**

You can perform the following kinds of tests on signals:

- “Minimum and Maximum Values” on page 31-6
- “Connection Validation” on page 31-7

### **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 31-45.

### **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 output 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 Model Editor, select **Edit > 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 “Working with Signal Groups” on page 31-68.

## Signal Types

In this section...
“Summary of Signal Types” on page 31-8
“Control Signals” on page 31-9
“Composite (Bus) Signals” on page 31-9

### Summary of Signal Types

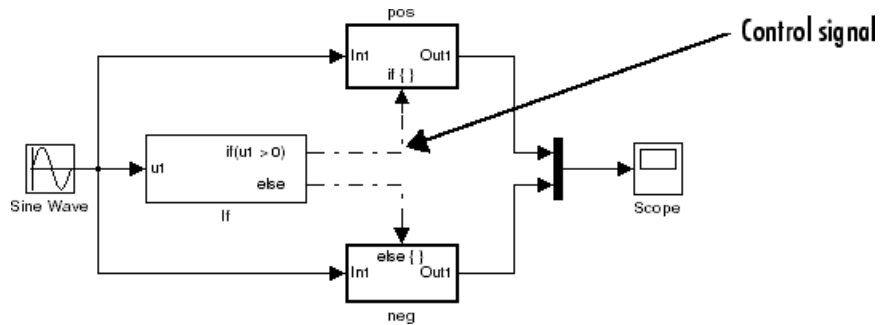
You can use many different kinds of signals in a model. The following table summarizes the signal types, and links to sections that describe each type in detail.

Signal Type	Description
Array of buses	An array whose elements are buses. See “Combining Buses into an Array of Buses” on page 32-75.
Bus (Composite)	A Simulink composite signal made up of other signals, optionally including other bus signals. See “Composite (Bus) Signals” on page 31-9.
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 31-9.
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 31-11.
Variable-Size	Signal whose size (the number of elements in a dimension), in addition to its values, can change during a model simulation. See Chapter 33, “Working with Variable-Size Signals”.
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 31-11.



## 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.



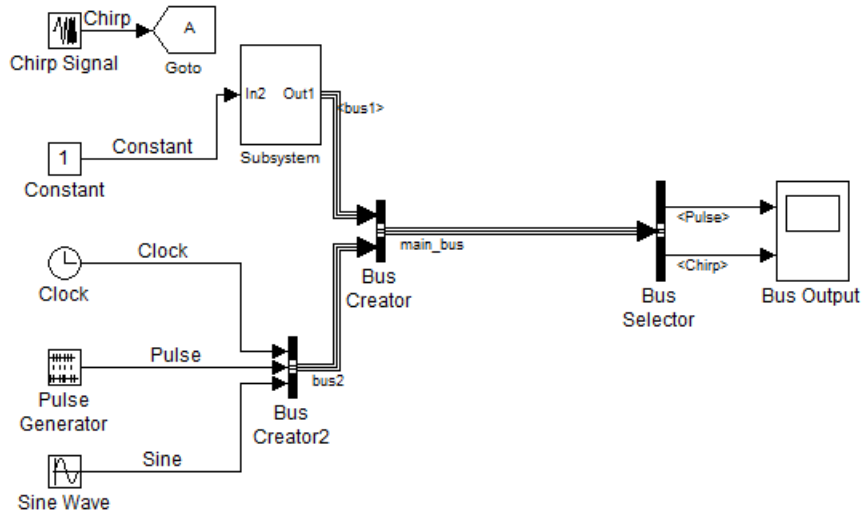
## Composite (Bus) Signals

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 the `busdemo` demo and simulate the model, the `bus1`, `bus2`, and `main_bus` signals are bus signals. These virtual bus signals use the triple line style.



### Bus Signal Demonstration



For details, see Chapter 32, “Using Composite Signals”.

# Virtual Signals

In this section...
“About Virtual Signals” on page 31-11
“Mux Signals” on page 31-11

## 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 32-3.

## 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 Chapter 32, “Using Composite Signals”. Although you can use a Mux block to create a composite signal in some cases, MathWorks discourages this practice. See “Avoiding Mux/Bus Mixtures” on page 32-93 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

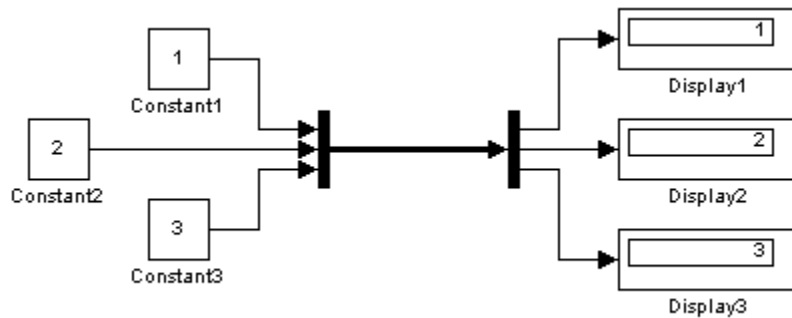
Extract and output the values in a mux (virtual vector) signal

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 **Format > Port/Signal Displays > Wide Nonscalar Lines** option enabled. See “Displaying Signal Attributes” on page 31-63 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 the Demux block documentation.

---

**Note** MathWorks discourages using Mux and Demux blocks to create and access buses under any circumstances. See “Avoiding Mux/Bus Mixtures” on page 32-93 for details.

---

# Signal Values

**In this section...**

“Signal Data Types” on page 31-15

“Signal Dimensions, Size, and Width” on page 31-15

“Complex Signals” on page 31-16

“Initializing Signal Values” on page 31-16

“Viewing Signal Values” on page 31-17

“Displaying Signal Values in Model Diagrams” on page 31-17

“Exporting Signal Data” on page 31-18

## 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 “Working with Data Types” on page 27-2 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 31-34.

## 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 in [Blocks — Alphabetical List](#) in the online Simulink reference.

## 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 Output, 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 “Initializing Signals and Discrete States” on page 31-52.

## 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 “About Scope Blocks, Signal Viewers, Signal Logging, and Test Points” on page 15-2. For detailed information about:

- Blocks that you can use to display signals in a model, see “Sinks” in the Simulink block reference
- Signal viewers, see “Signal Viewer Tasks” on page 15-6
- The Signal & Scope Manager, see “Signal and Scope Manager” on page 15-25
- Test points, which are signals that Simulink guarantees to be observable when using a Floating Scope block in a model, see “Working with Test Points” on page 31-59.

## 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 31-17
- “Display Signal Value After Simulation” on page 31-18

### 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 Model Editor, select **View > Port Value Labels**.
- 2** From the submenu, select either **Show When Hovering** or **Show When Clicked**.

**3** To change display options, use the **Options** submenu.

For details, see “Displaying Port Values” on page 20-29.

### **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 Port Value**.

### **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 29-4.

# Signal Names and Labels

In this section...
“Signal Names” on page 31-19
“Signal Labels” on page 31-22

## 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 31-22).

## 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 “Exporting Signal Data Using Signal Logging” on page 29-19.) 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 29-55.
- 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 31-20
- “Assign a Name in the Signal Properties Dialog Box” on page 31-20
- “Assign a name from the MATLAB Command Window” on page 31-21

### **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 multibranch 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 **Signal 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.

For more information, see “Signal Properties Dialog Box”.

### **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(gcf, '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** property.

### **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** property.

To delete a label without deleting the signal name, click near the edge of the label to select its surrounding box, then press Delete. The label disappears, but the signal continues to have its name.

### 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 31-19 .

### 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 Choose **Format > Font**.

**3** Select a font from the **Set 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 31-24.

## Signal Label Propagation

### In this section...

“About Signal Label Propagation” on page 31-24

“Propagated Signal Label Format” on page 31-24

“Blocks That Support Signal Label Propagation” on page 31-25

“Display Propagated Signal Labels” on page 31-26

“How Simulink Propagates Signal Labels” on page 31-27

### About Signal Label Propagation

For output signals of the blocks listed in “Blocks That Support Signal Label Propagation” on page 31-25, you can have Simulink create a propagated signal label.

For details about how to display propagated signal labels, see “Display Propagated Signal Labels” on page 31-26.

For details about results of signal label propagation processing, see “How Simulink Propagates Signal Labels” on page 31-27.

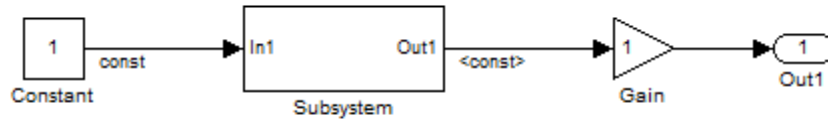
### Propagated Signal Label Format

When you enable the display of signal label propagation:

- 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 31-27.

## 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 31-26.

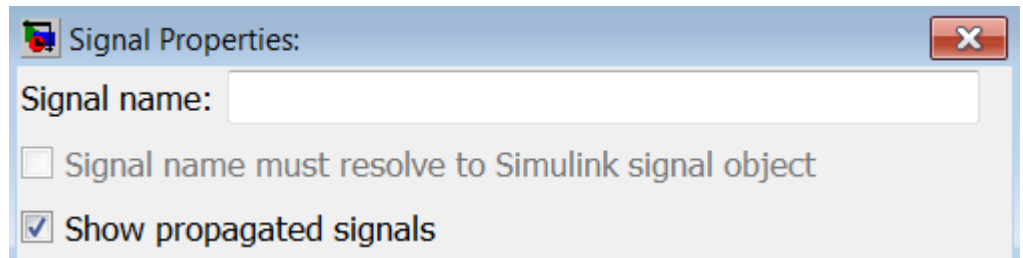
## Display Propagated Signal Labels

To display a propagated signal label:

- 1 Set **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 31-25.

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 31-31
- “Processing for Variants and Configurable Subsystems” on page 31-33

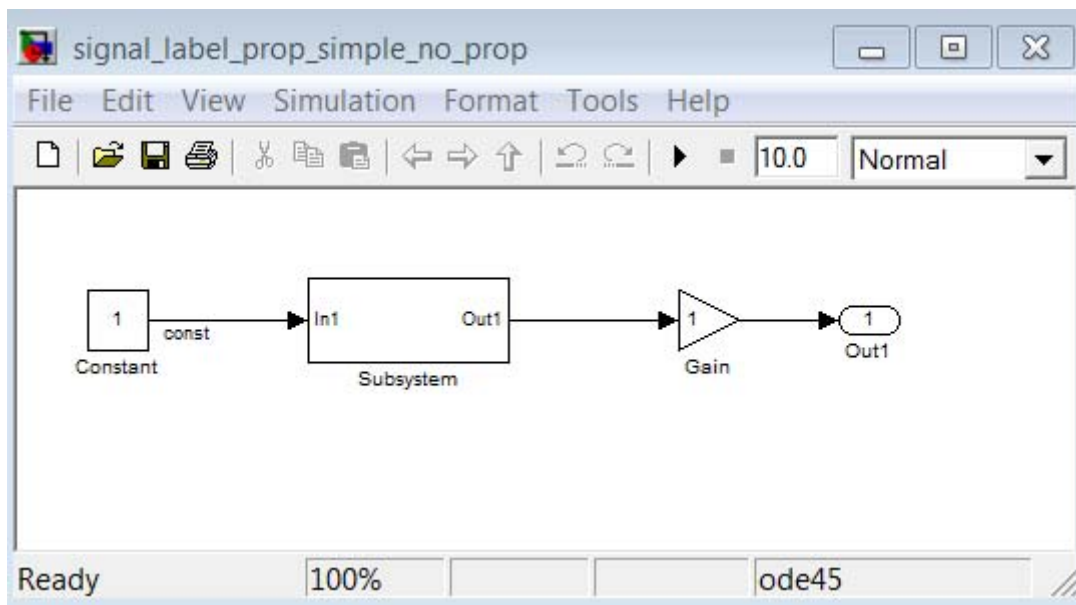
## General Signal Label Propagation Processing

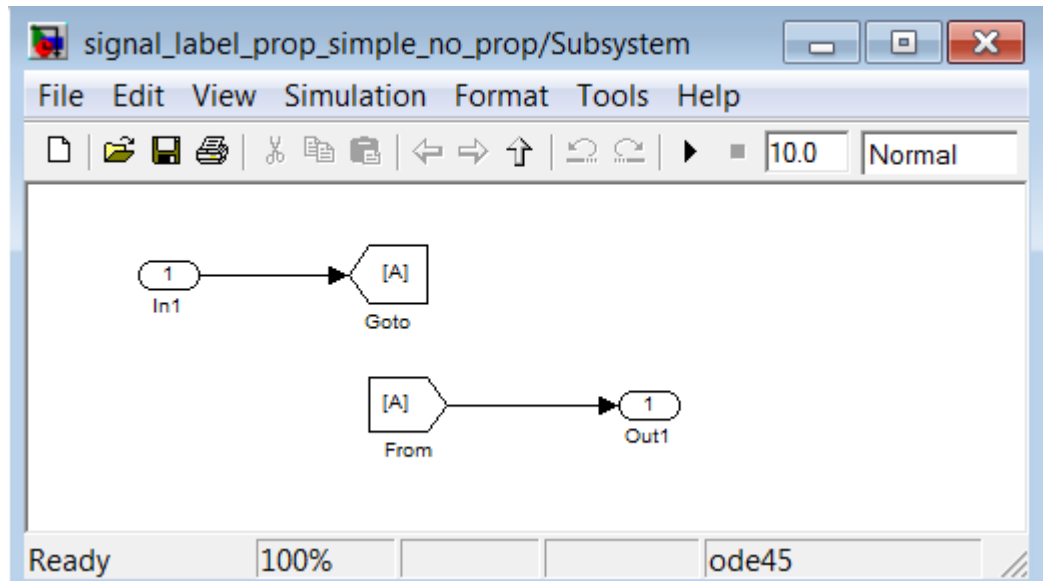
In general, when you enable signal label propagation for an output signal of a block (for example, BlockA), Simulink performs the following processing to find the source signal name to propagate:

- 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.

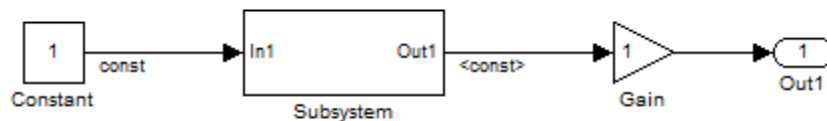
For example, in the following model, suppose that you enable signal label propagation for the output signal for the Subsystem block (that is, the signal connected to the Out1 port).



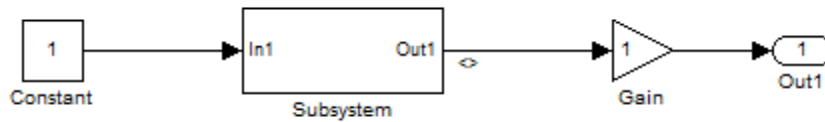


Simulink checks inside the subsystem, checks upstream from the From and GoTo blocks (which support signal label propagation and do not have a name), and then checks farther upstream, to the Constant block, which does not support signal label propagation.

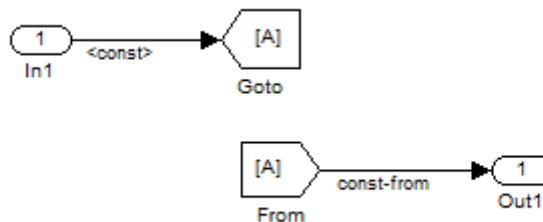
Simulink uses the signal name of the Constant block output signal, `const`. The propagated signal label for the Subsystem output signal is `<const>`.



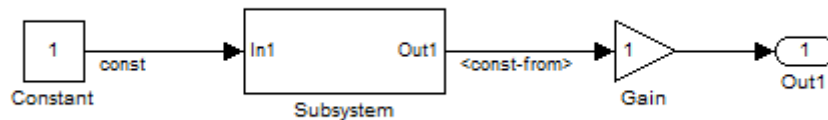
If the output signal from the Constant block did not have a signal name, then the propagated signal label would be an empty set of angle brackets (`<>`).



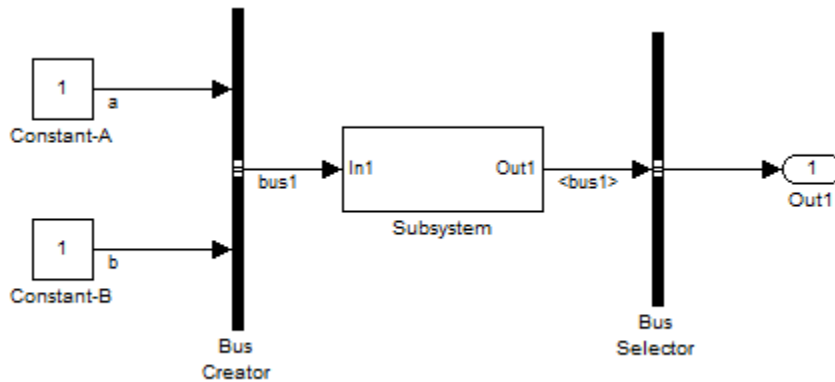
Suppose that in the Subsystem block you enable signal label propagation for the output signal from the In1 block, and you use the Signal Properties dialog box to specify the signal name `const-from` for the output signal of the From block, as shown below.



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).



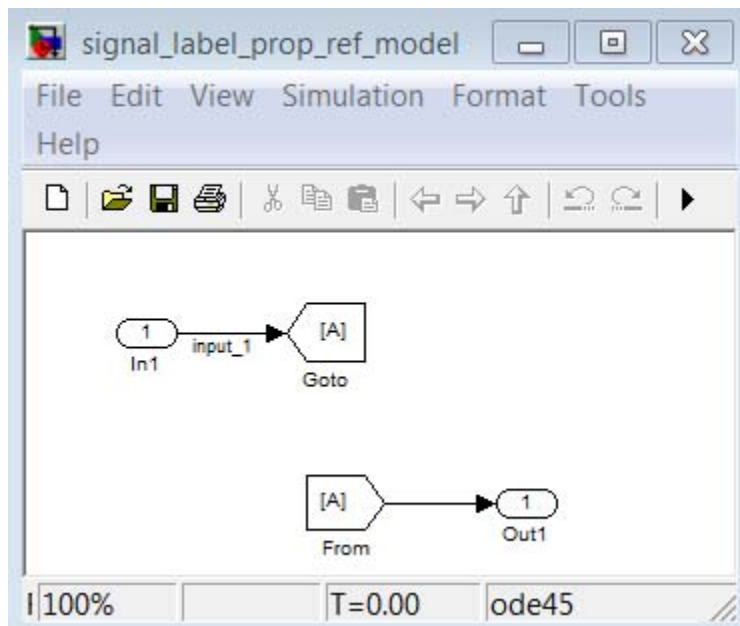
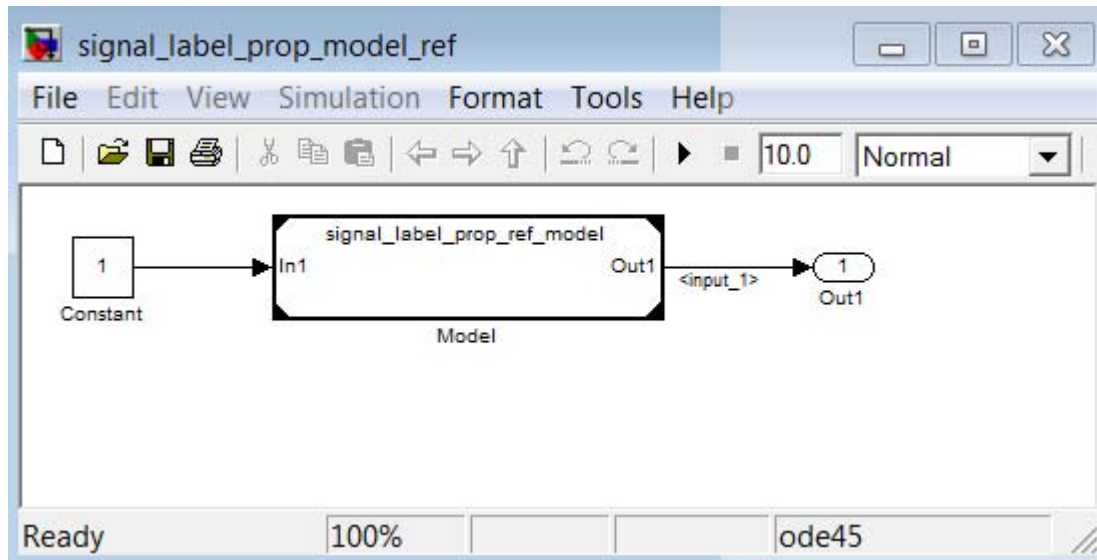
## Processing for Referenced Models

To enable signal label propagation for referenced models, in addition to the steps described in “Display Propagated Signal Labels” on page 31-26, enable the **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 `signal_label_prop_model_ref.mdl` 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.





## **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” on page 31-34

“Simulink Blocks that Support Multidimensional Signals” on page 31-35

### 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” in the MATLAB Getting Started documentation 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 description in Blocks — Alphabetical List in the online Simulink reference. See “Determining Output Signal Dimensions” on page 31-36 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 Chapter 33, “Working with Variable-Size Signals”.

---

## 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 window, and from the **Help** menu, point to **Block Support Table**, and then select **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 **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.

## Determining Output Signal Dimensions

### In this section...

“About Signal Dimensions” on page 31-36

“Determining the Output Dimensions of Source Blocks” on page 31-36

“Determining the Output Dimensions of Nonsource Blocks” on page 31-37

“Signal and Parameter Dimension Rules” on page 31-37

“Scalar Expansion of Inputs and Parameters” on page 31-38

### 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 the “Sources” table in the online Simulink block reference for a complete listing of Simulink source blocks. The output dimensions of a source block are the same as those of its output value parameters if the block’s **Interpret vector parameters as 1-D** parameter is off (that is, not selected in the block parameter dialog box). If the **Interpret vector parameters as 1-D** parameter is on, the output dimensions equal the output value parameter dimensions unless the parameter dimensions are N-by-1 or 1-by-N. In the latter case, the block outputs a vector signal of width N.

As an example of how a source block’s output value parameter(s) and **Interpret vector parameters as 1-D** parameter determine the dimensionality of its output, consider the Constant block. This block outputs a constant signal equal to its **Constant value** parameter. The following table illustrates how the dimensionality of the **Constant value** parameter and the setting of the **Interpret vector parameters as 1-D** parameter determine the dimensionality of the block’s output.

Constant Value	Interpret vector parameters as 1-D	Output
scalar	off	one-element array
scalar	on	one-element array
1-by-N matrix	off	1-by-N matrix
1-by-N matrix	on	N-element vector
N-by-1 matrix	off	N-by-1 matrix
N-by-1 matrix	on	N-element vector
M-by-N matrix	off	M-by-N matrix
M-by-N matrix	on	M-by-N matrix

Simulink source blocks allow you to specify the dimensions of the signals that they output. You can therefore use them to introduce signals of various dimensions into your model.

## Determining the Output Dimensions of Nonsource Blocks

If a block has inputs, the dimensions of its outputs are, after scalar expansion, the same as those of its inputs. (All inputs must have the same dimensions, as discussed in “Signal and Parameter Dimension Rules” on page 31-37).

## 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 31-39) 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 31-39) 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**

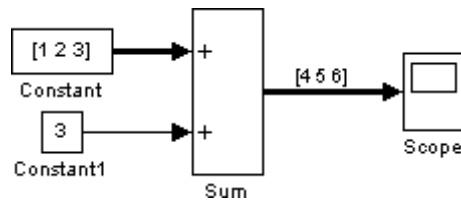
*Scalar expansion* is the conversion of a scalar value into a nonscalar array of the same dimensions. Many Simulink blocks support scalar expansion of

inputs and parameters. Block descriptions in the *Simulink Reference* indicate whether Simulink applies scalar expansion to a block's inputs and parameters.

### Scalar Expansion of Inputs

Scalar expansion of inputs refers to the expansion of scalar inputs to match the dimensions of other nonscalar inputs or nonscalar parameters. When the input to a block is a mix of scalar and nonscalar signals, Simulink expands the scalar inputs into nonscalar signals having the same dimensions as the other nonscalar inputs. The elements of an expanded signal equal the value of the scalar from which the signal was expanded.

The following model illustrates scalar expansion of inputs. This model adds scalar and vector inputs. The input from block Constant1 is scalar expanded to match the size of the vector input from the Constant block. The input is expanded to the vector [3 3 3].

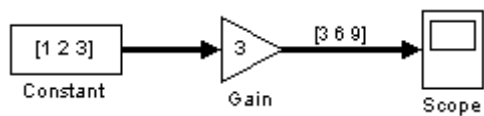


When a block's output is a function of a parameter and the parameter is nonscalar, Simulink expands a scalar input to match the dimensions of the parameter. For example, Simulink expands a scalar input to a Gain block to match the dimensions of a nonscalar gain parameter.

### Scalar Expansion of Parameters

If a block has a nonscalar input and a corresponding parameter is a scalar, Simulink expands the scalar parameter to have the same number of elements as the input. Each element of the expanded parameter equals the value of the original scalar. Simulink then applies each element of the expanded parameter to the corresponding input element.

This example shows that a scalar parameter (the Gain) is expanded to a vector of identically valued elements to match the size of the block input, a three-element vector.





## Displaying Signal Sources and Destinations

### In this section...

“About Signal Highlighting” on page 31-41

“Highlighting Signal Sources” on page 31-41

“Highlighting Signal Destinations” on page 31-42

“Removing Highlighting” on page 31-43

“Resolving Incomplete Highlighting to Library Blocks” on page 31-43

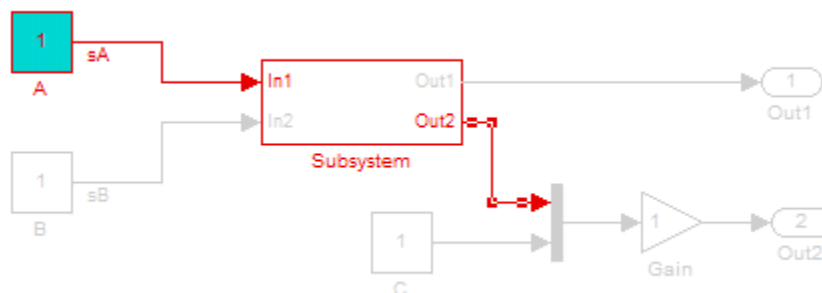
### About Signal Highlighting

You can highlight a signal and its source or destination block(s), then remove the highlighting once it has served its purpose. Signal highlighting crosses subsystem boundaries, allowing you to trace a signal across multiple subsystem levels. Highlighting does not cross the boundary into or out of a referenced model. If a signal is composite, all source or destination blocks are highlighted. (See Chapter 32, “Using Composite Signals”.)

### Highlighting Signal Sources

To display the source block(s) of a signal, choose the **Highlight to Source** option from the context menu for the signal. This option highlights:

- All branches of the signal anywhere in the model
- All virtual blocks through which the signal passes
- The nonvirtual block(s) that write the value of the signal

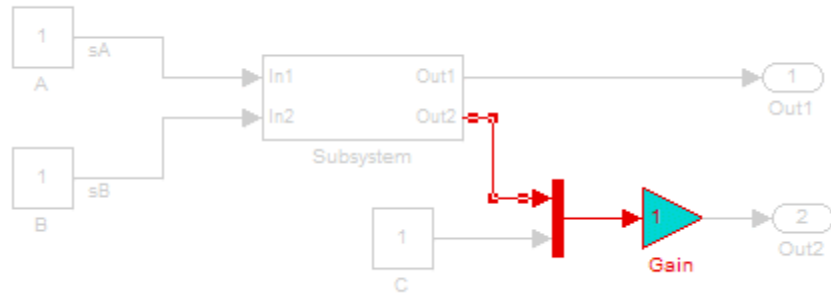


## Highlighting Signal Destinations

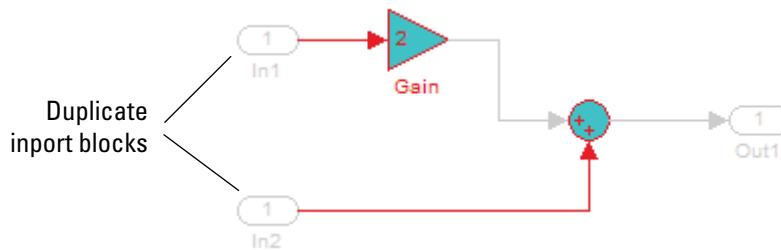
To display the destination blocks of a signal, choose the **Highlight to Destination** option from the context menu for the signal. This option highlights:

- All branches of the signal anywhere in the model
- All virtual blocks through which the signal passes
- The nonvirtual block(s) that read the value of the signal
- The signal and destination block for all blocks that are duplicates of the inport block for the line that you select

In this example, the selected signal highlights the Gain block as the destination block.



In the next example, selecting the signal from In2 and choosing the **Highlight to Destination** option highlights the signal and destination block for In2 and In1, because In1 and In2 are duplicate inport blocks.



## Removing Highlighting

To remove all highlighting, choose **Remove Highlighting** from the model's context menu, or choose **View > Remove Highlighting**.

## Resolving Incomplete Highlighting to Library Blocks

If the path from a source block or to a destination block includes an unresolved reference to a library block, the highlighting options highlight the path from or to the library block, respectively. To display the complete path, first update

the diagram (for example, by pressing **Ctrl+D**). The update of the diagram resolves all library references and displays the complete path to a destination block or from a source block.

## Signal Ranges

In this section...
“About Signal Ranges” on page 31-45
“Blocks That Allow Signal Range Specification” on page 31-45
“Specifying Ranges for Signals” on page 31-46
“Checking for Signal Range Errors” on page 31-47

### 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

See “Blocks — Alphabetical List” in the *Simulink Reference* for more information about these blocks and their parameters.

## Specifying Ranges for Signals

In general, use the **Output minimum** and **Output maximum** parameters that appear on a block parameter dialog box to specify a range of valid values for the block output signal. Exceptions include the Data Store Memory, Inport, Outport, and Signal Specification blocks, for which you use their **Minimum** and **Maximum** parameters to specify a signal range. See “Blocks That Allow Signal Range Specification” on page 31-45 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 31-38).

---

**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  $(\text{sqrt}(a^2+b^2))$

## 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 31-46) and the block data type. That is, Simulink performs the following check:

$$\text{DataTypeMin} \quad \text{MinValue} \quad \text{VALUE} \quad \text{MaxValue} \quad \text{DataTypeMax}$$

where

- **DataTypeMin** is the minimum value representable by the block data type.
- **MinValue** is the minimum value the block should output, specified by, e.g., **Output minimum**.
- **VALUE** is the signal value that the block outputs.
- **MaxValue** is the maximum value the block should output, specified by, e.g., **Output maximum**.
- **DataTypeMax** is the maximum value representable by the block data type.

---

**Note** It is possible to overspecify how a block handles signals that exceed particular ranges. For example, you can specify values (other than the default values) for both signal range parameters and enable the **Saturate on integer overflow** parameter. In this case, Simulink displays a warning message that advises you to disable the **Saturate on integer overflow** parameter.

---

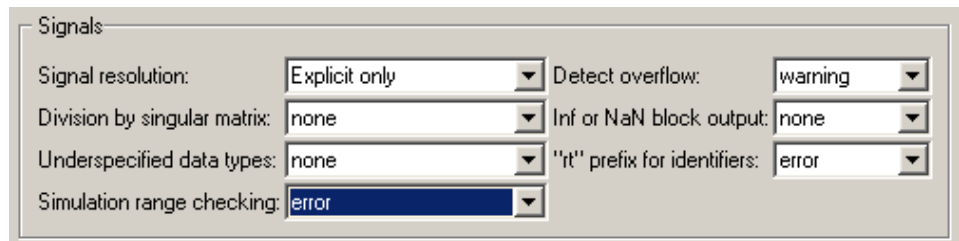
## Enabling Simulation Range Checking

To enable the **Simulation range checking** diagnostic:

- 1 In your model window, select **Simulation > Configuration Parameters**.

Simulink displays the Configuration Parameters dialog box.

- 2 In the **Select** tree on the left side of the Configuration Parameters dialog box, click the **Diagnostics > Data Validity** category. On the right side under **Signals**, set the **Simulation range checking** diagnostic to error or warning.



- 3 Click **OK** to apply your changes and close the Configuration Parameters dialog box.

See “Simulation range checking” in the *Simulink Graphical User Interface* documentation for more information.

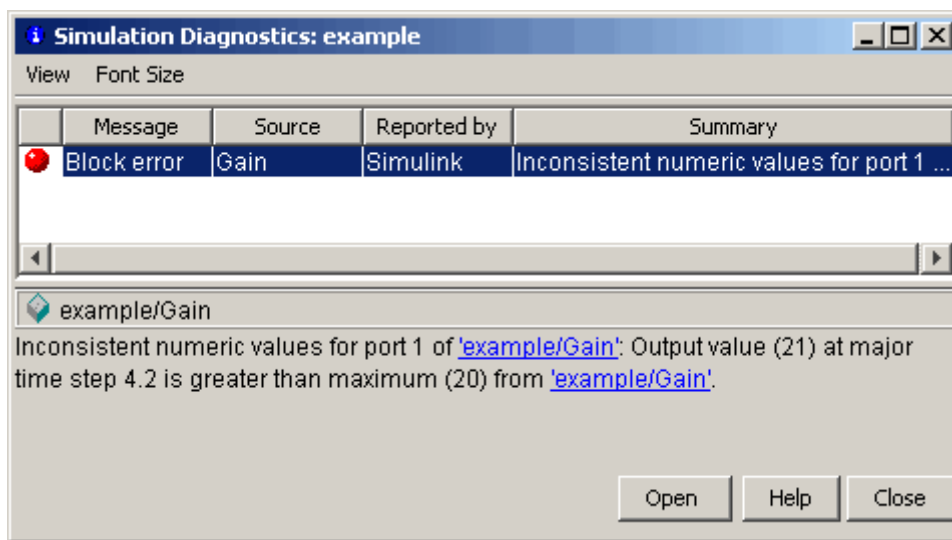
## Simulating Models with Simulation Range Checking

To check for signal range errors or warnings:



- 1 Enable the **Simulation range checking** diagnostic for your model (see “Enabling Simulation Range Checking” on page 31-48).
- 2 In your model window, select **Simulation > Start** to simulate the model.

Simulink simulates your model and performs signal range checking. If a signal exceeds its specified range when the **Simulation range checking** diagnostic specifies error, Simulink stops the simulation and displays an error message:



Otherwise, if a signal exceeds its specified range when the **Simulation range checking** diagnostic specifies warning, Simulink displays a warning message in the MATLAB Command Window:

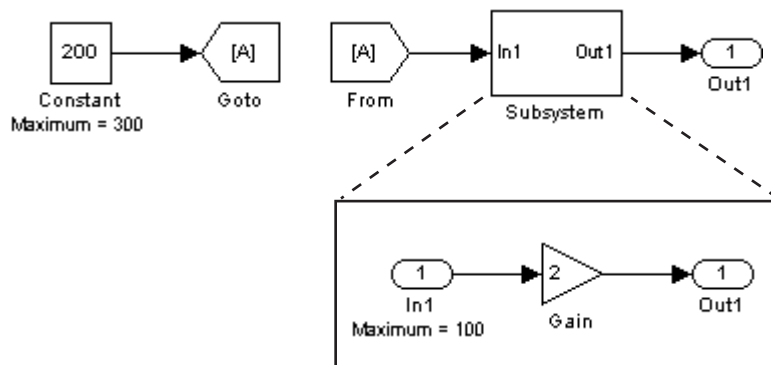
```
Warning: Inconsistent numeric values for port 1
of 'example/Gain': Output value (21) at major
time step 4.2 is greater than maximum (20) from
'example/Gain'.
```

Each message identifies the block whose output signal exceeds its specified range, and the time step at which this violation occurs.

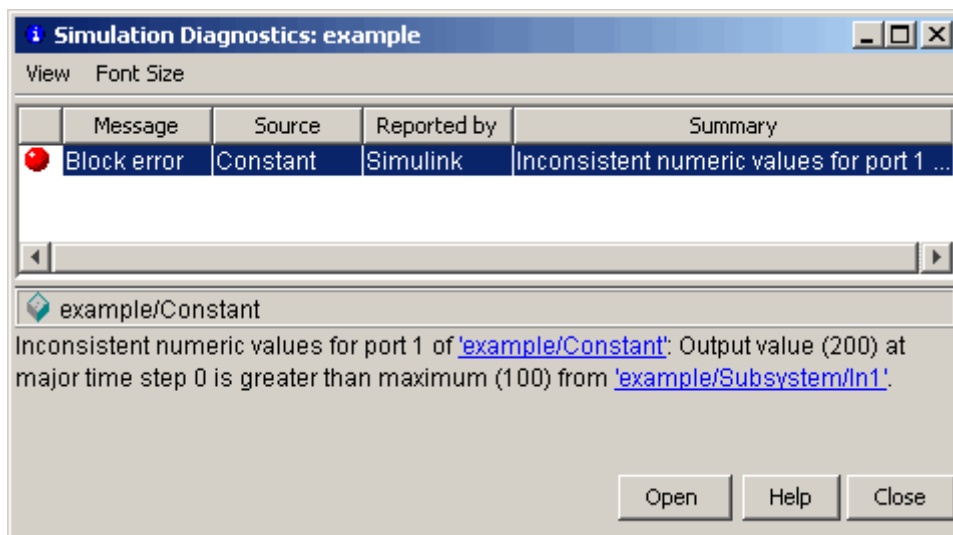
### Signal Range Propagation for Virtual Blocks

Some virtual blocks (see “Virtual Blocks” on page 20-2) 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:



## Initializing Signals and Discrete States

### In this section...

“About Initialization” on page 31-52

“Using Block Parameters to Initialize Signals and Discrete States” on page 31-53

“Using Signal Objects to Initialize Signals and Discrete States” on page 31-53

“Using Signal Objects to Tune Initial Values” on page 31-54

“Example: Using a Signal Object to Initialize a Subsystem Output” on page 31-56

“Initialization Behavior Summary for Signal Objects” on page 31-57

### About Initialization

---

**Note** For information about initializing bus signals, see “Specifying Initial Conditions for Bus Signals” on page 32-63.

---

Simulink allows you to specify the initial values of signals and discrete states, i.e., the values of the signals and discrete states at the **Start time** of the simulation. You can use signal objects to specify the initial values of any signal or discrete state in a model. In addition, for some blocks, e.g., Outport, Data Store Memory, or Memory, you can use either a signal object or a block parameter or both to specify the initial value of a block state or output. In such cases, Simulink checks to ensure that the values specified by the signal object and the parameter are consistent.

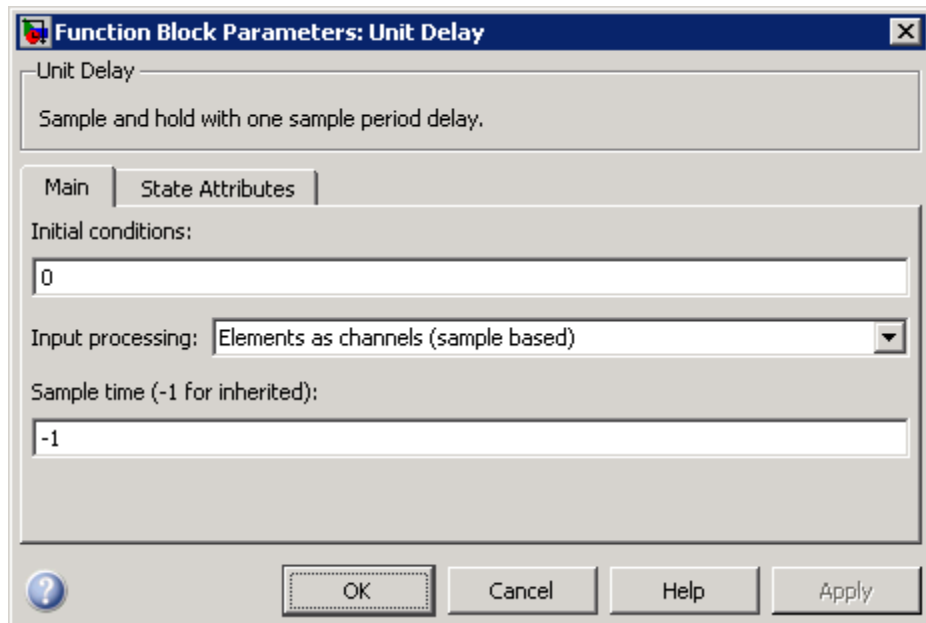
When you specify a signal object for signal or discrete state initialization, or a variable as the value of a block parameter, Simulink resolves the name that you specify to an appropriate object or variable, as described in “Resolving Symbols” on page 3-76.

A given signal can be associated with at most one signal object under any circumstances. The signal can refer to the object more than once, but every

reference must resolve to exactly the same object. A different signal object that has exactly the same properties will not meet the requirement for uniqueness. A compile-time error occurs if a model associates more than one signal object with any signal. For more information, see `Simulink.Signal` and the Merge block.

## Using Block Parameters to Initialize Signals and Discrete States

For blocks that have an initial value or initial condition parameter, you can use that parameter to initialize a signal. For example, the following Block Parameters dialog box initializes the signal for a Unit Delay block with an initial condition of 0.



## Using Signal Objects to Initialize Signals and Discrete States

To use a signal object to specify an initial value:

- 1 Create the signal object in the MATLAB workspace, as explained in “Working with Data Objects” on page 27-37.

The name of the signal object must be the same as the name of the signal or discrete state that the object is initializing.

---

**Note** Consider also setting the **Signal name must resolve to Simulink signal object** option in the Signal Properties dialog box. This setting ensures consistency between signal objects in the MATLAB workspace and the signals that appear in your model.

---

- 2 Set the signal object’s storage class to a value other than 'Auto' or 'SimulinkGlobal'.
- 3 Set the signal object’s `Initial` value property to the initial value of the signal or state. For details on what you can specify, see the description of `Simulink.Signal`.

If you can also use a block parameter to set the initial value of the signal or state, you should set the parameter either to null (`[]`) or to the same value as the initial value of the signal object. If you set the parameter value to null, Simulink uses the value specified by the signal object to initialize the signal or state. If you set the parameter to any other value, Simulink compares the parameter value to the signal object value and displays an error if they differ.

## Using Signal Objects to Tune Initial Values

Simulink allows you to use signal objects as an alternative to parameter objects (see `Simulink.Parameter` class in the Simulink online reference) to tune the initial values of block outputs and states that can be specified via a tunable parameter. To use a signal object to tune an initial value, create a signal object with the same name as the signal or state and set the signal object’s initial value to an expression that includes a variable defined in the MATLAB workspace. You can then tune the initial value by changing the value of the corresponding workspace variable during the simulation.

For example, suppose you want to tune the initial value of a Memory block state named `M1`. To do this, you might create a signal object named

M1, set its storage class to 'ExportedGlobal', set its initial value to K (`M1.InitialValue='K'`), where K is a workspace variable in the MATLAB workspace, and set the corresponding initial condition parameter of the Memory block to [] to avoid consistency errors. You could then change the initial value of the Memory block's state any time during the simulation by changing the value of K at the MATLAB command line and updating the block diagram (e.g., by typing **Ctrl+D**).

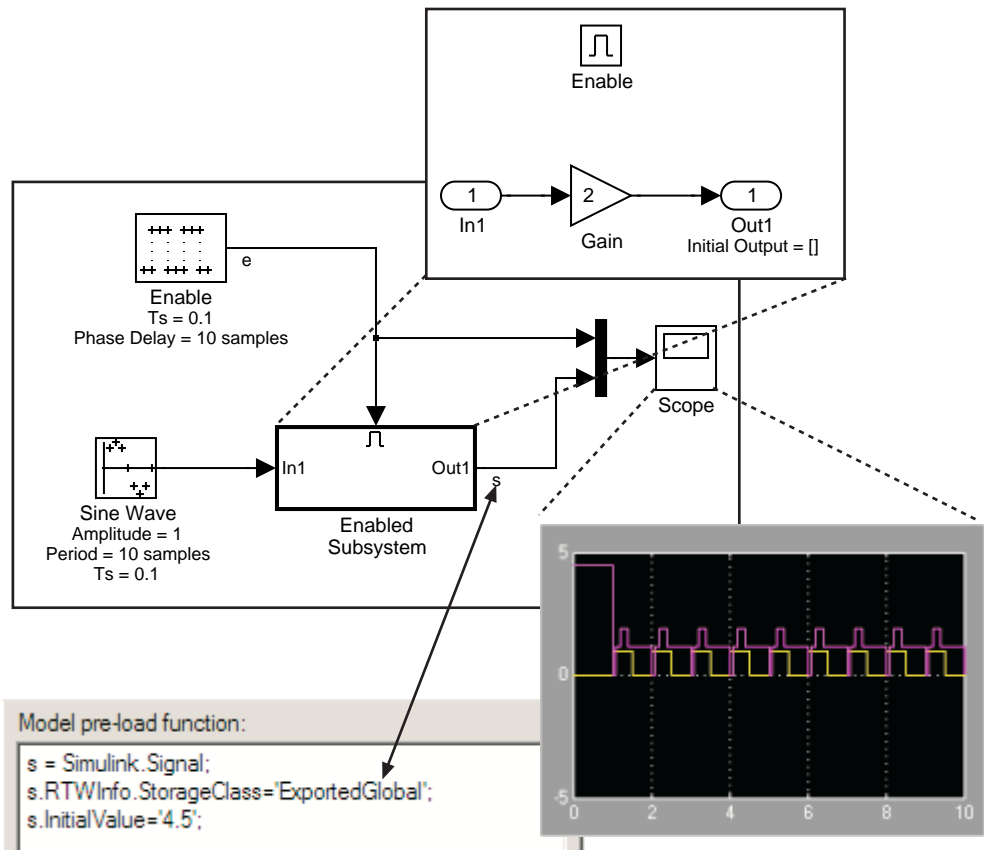
---

**Note** To be tunable via a signal object, a signal or state's corresponding initial condition parameter must be tunable, e.g., the inline parameter optimization for the model containing the signal or state must be off or the parameter must be declared tunable in the Model Parameter Configuration dialog box. For more information, see "Tunable Parameters" on page 2-9 and "Using Tunable Parameters" on page 21-13.

---

## 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.



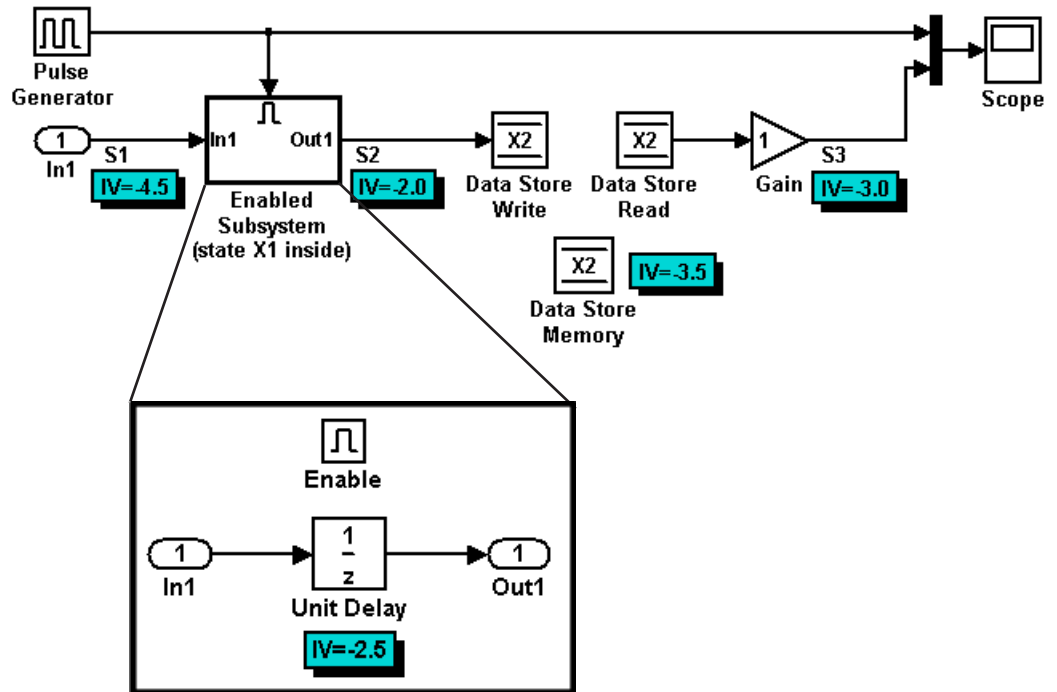
Signal `s` is initialized to 4.5. To avoid a consistency error, the initial value of the enabled subsystem's Output block must be `[]` or 4.5.

If you need a signal object and its initial value setting to persist across Simulink sessions, see "Creating Persistent Data Objects" on page 27-47.



## 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	<ul style="list-style-type: none"> <li>• Initialized to S1.InitialValue.</li> <li>• If you use the <b>Data Import/Export</b> 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.</li> </ul>
X1	Unit Delay block — Block with a discrete	<ul style="list-style-type: none"> <li>• Initialized to X1.InitialValue.</li> <li>• Simulink checks whether X1.InitialValue matches the initial condition specified for the block and displays an error if a mismatch occurs.</li> </ul>

Signal or Discrete State	Description	Behavior
	state that has an initial condition	<ul style="list-style-type: none"> <li>• At first write, the output equals <code>X1.InitialValue</code> and the state equals <code>S1</code>.</li> <li>• At each time step after the first write, the output equals the state and the state is updated to equal <code>S1</code>.</li> <li>• 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 <b>States when enabling</b> is set to <b>reset</b>.</li> </ul>
X2	Data Store Memory block	<ul style="list-style-type: none"> <li>• Data type work (DWork) vector initialized to <code>X2.InitialValue</code>. For information on work vectors, see "Using Work Vectors" in Writing S-Functions.</li> <li>• Simulink checks whether <code>X2.InitialValue</code> matches the initial condition specified for the block, and displays an error if a mismatch occurs.</li> <li>• Data Store Write blocks overwrite the value.</li> </ul>
S2	Output of an enabled subsystem	<ul style="list-style-type: none"> <li>• Initialized to <code>S2.InitialValue</code> or the value of the Output block. If multiple initial values are specified for the same signal, all initial values must be the same.</li> <li>• The first write occurs when the subsystem is enabled. The block feeding the subsystem output sets the value.</li> <li>• The initial value is also used as a reset value if the subsystem's Enable block parameter <b>States when enabling</b> or Output block parameter <b>Output when disabled</b> is set to <b>reset</b>.</li> </ul>
S3	Persistent signals	<ul style="list-style-type: none"> <li>• Initialized to <code>S3.InitialValue</code>.</li> <li>• The output value is reset by the block at each time step.</li> <li>• Affects code generation only. For simulation, setting the initial value for <code>S3</code> is irrelevant because the values are overwritten at the model's simulation start time.</li> </ul>

## Working with Test Points

### In this section...

“What Is a Test Point?” on page 31-59

“Designating a Signal as a Test Point” on page 31-59

“Displaying Test Point Indicators” on page 31-61

### What Is a Test Point?

A *test point* is a signal that Simulink guarantees to be observable when using a Floating Scope block in a model. Simulink allows you to designate any signal in a model as a test point.

Designating a signal as a test point exempts the signal from model optimizations, such as signal storage reuse (see “Signal storage reuse”) and block reduction (see “Implement logic signals as Boolean data (vs. double)”). These optimizations render signals inaccessible and hence unobservable during simulation.

Signals designated as test points will not have algebraic loops minimized, even if **Minimize algebraic loop occurrences** is selected (for more information about algebraic loops, see “Algebraic Loops” on page 2-40).

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” in the Simulink Coder documentation.

Marking a signal as a test point has no impact on signal logging during simulation. For information about logging signals, see “Exporting Signal Data Using Signal Logging” on page 29-19.

### 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**.

See “Signal Properties Dialog Box” for more information about specifying signal properties.

### **Test Points in Referenced Models that Use Library Blocks**

Simulink might not log all signals configured for signal logging in a referenced model, if *both* of these conditions exist:

- The referenced model sets the **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, use *one* of the following two approaches:

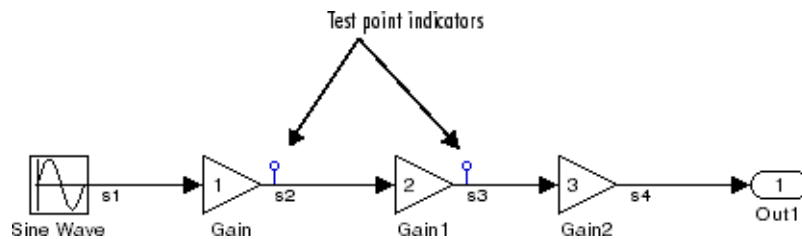
- Set the **Signal logging format** parameter to Dataset. See “Benefits of Using the Dataset Format for Signal Logging” on page 29-35.
- If you need to use the ModelDataLogs format, update the referenced model:
  - 1 Open the referenced model.

- 2 Perform an update diagram on the referenced model (for example, by pressing **Ctrl+D**).
- 3 Save the referenced model.

Also, when a referenced model uses a library, if 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, then all test pointed signals in a referenced model might not be available for display. To ensure the display of all test pointed signals, update the referenced model, as described above.

## Displaying Test Point Indicators

By default, Simulink displays an indicator on each signal whose **Signal Properties > Test point** option is enabled. For example, in the following model signals s2 and s3 are test points:

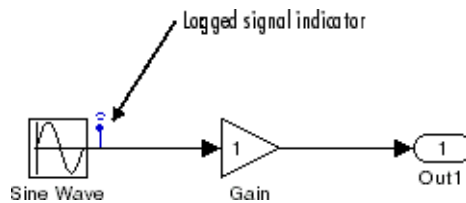


---

**Note** Simulink does not display an indicator on a signal that is specified as a test point by a `Simulink.Signal` object, because such a specification is external to the graphical model.

---

A signal that is a test point can also be logged. See Chapter 29, “Importing and Exporting Simulation Data” for information about signal logging. The appearance of the indicator changes to indicate signals for which logging is also enabled.



To turn display of test point indicators on or off, select or clear **Port/Signal Displays > Testpoint/Logging Indicators** from the Simulink **Format** menu.

## Displaying Signal Attributes

### In this section...

“Port/Signal Displays Menu” on page 31-63

“Port Data Types” on page 31-64

“Design Ranges” on page 31-64

“Signal Dimensions” on page 31-65

“Signal Resolution Indicators” on page 31-66

“Wide Nonscalar Lines” on page 31-67

### Port/Signal Displays Menu

The **Format >Port/Signal Displays** submenu of the model window offers the following options for displaying signal properties on the block diagram:

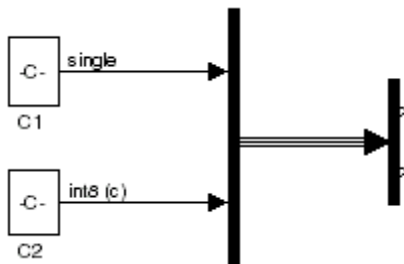
- Linearization Indicators
- Port Data Types (See “Port Data Types” on page 31-64)
- Design Ranges (See “Design Ranges” on page 31-64)
- Signal Dimensions (See “Signal Dimensions” on page 31-65)
- Storage Class
- Testpoint/Logging Indicators
- Signal Resolution Indicators (See “Signal Resolution Indicators” on page 31-66)
- Viewer Indicators
- Wide Nonscalar Lines (See “Wide Nonscalar Lines” on page 31-67)

In addition, you can display sample time information. If you first select **Format > Sample Time Display**, a submenu provides the choices of **Colors**, **Annotations** and **All**. The **Colors** option allows the block diagram signal lines and blocks to be color-coded based on the sample time types and relative rates. The **Annotations** option provides black codes on the signal lines which indicate the type of sample time. **All** causes both the colors and the

annotations to display. All of these options cause a Sample Time Legend to appear. The legend contains a description of the type of sample time and the sample time rate. If **Colors** is turned 'on', color codes also appear in the legend. The same is true if **Annotations** are turned 'on'.

### Port Data Types

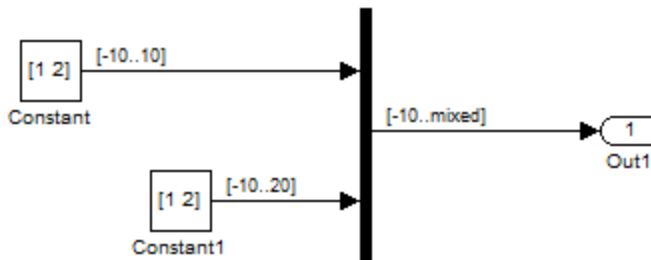
Displays the data type of a signal next to the output port that emits the signal.



The notation (c) following the data type of a signal indicates that the signal is complex.

### 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.



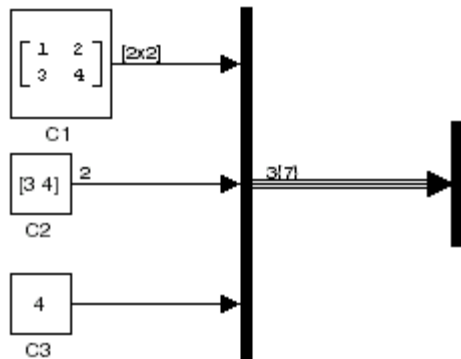


Ranges are displayed in the format [min..max]. In the above example, the design range at the output port of the Mux block is displayed as [-10..mixed], because the two signals the Mux block combines have the same design minimum but different design maximums.

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  $[N_1 \times N_2]$  where  $N_i$  is the size of the  $i$ th dimension of the signal. If the line represents a bus carrying signals of the same data type, Simulink displays  $N\{M\}$  where  $N$  is the number of signals carried by the bus and  $M$  is the total number of signal elements carried by the bus. If the bus carries signals of different data types, Simulink displays only the total number of signal elements  $\{M\}$ .

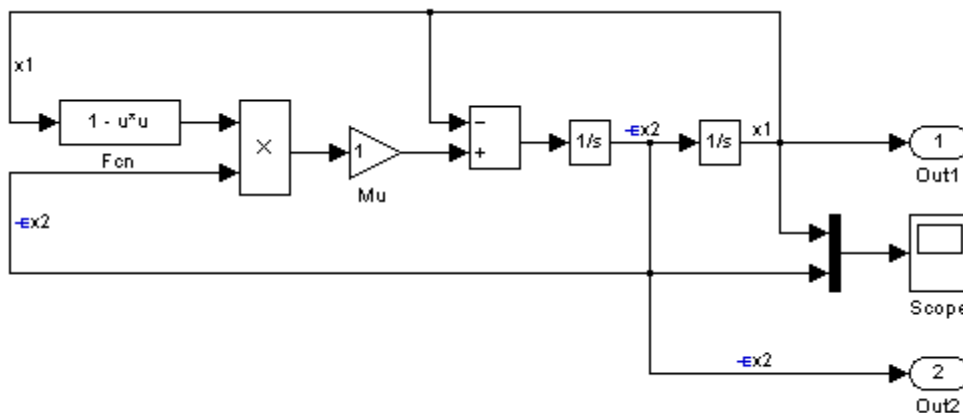
## Signal Resolution Indicators

The Simulink Editor by default graphically indicates signals that must resolve to signal objects. For any labeled signal whose **Signal name must resolve to signal object** property is enabled, a signal resolution icon appears to the left of the signal name. The icon looks like this:



A signal resolution icon indicates only that a signal's **Signal name must resolve to signal object** property is enabled. The icon does not indicate whether the signal is actually resolved, and does not appear on a signal that is implicitly resolved without its **Signal name must resolve to signal object** property being enabled.

Where multiple labels exist, each label displays a signal resolution icon. No icon appears on an unlabeled branch. In the next figure, signal  $x_2$  must resolve to a signal object, so a signal resolution icon appears to the left of the signal name in each label:



Copyright 2004 The MathWorks, Inc.

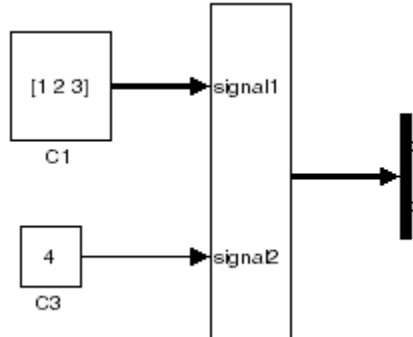
To suppress the display of signal resolution icons, in the model window deselect **Format > Port/Signal Displays > Signal Resolution Indicators**, which is selected by default. To restore signal resolution icons, reselect **Signal Resolution Indicators**. Individual signals cannot be set to show or

hide signal resolution indicators independently of the setting for the whole model. For additional information, see:

- “Resolving Symbols” on page 3-76
- “Initializing Signals and Discrete States” on page 31-52
- Simulink.Signal

## Wide Nonscalar Lines

Draws lines that carry vector or matrix signals wider than lines that carry scalar signals.



See Chapter 32, “Using Composite Signals” for more information about vector and matrix signals.

## Working with Signal Groups

### In this section...

“About Signal Groups” on page 31-68

“Signal Builder Window” on page 31-68

“Creating Signal Group Sets” on page 31-74

“Editing Waveforms” on page 31-102

“Signal Builder Time Range” on page 31-108

“Exporting Signal Group Data” on page 31-109

“Printing, Exporting, and Copying Waveforms” on page 31-109

“Simulating with Signal Groups” on page 31-110

“Simulation Options Dialog Box” on page 31-111

### About Signal Groups

The Signal Builder block displays and allows you to create or edit interchangeable groups of signal sources and quickly switch the groups into and out of a model.

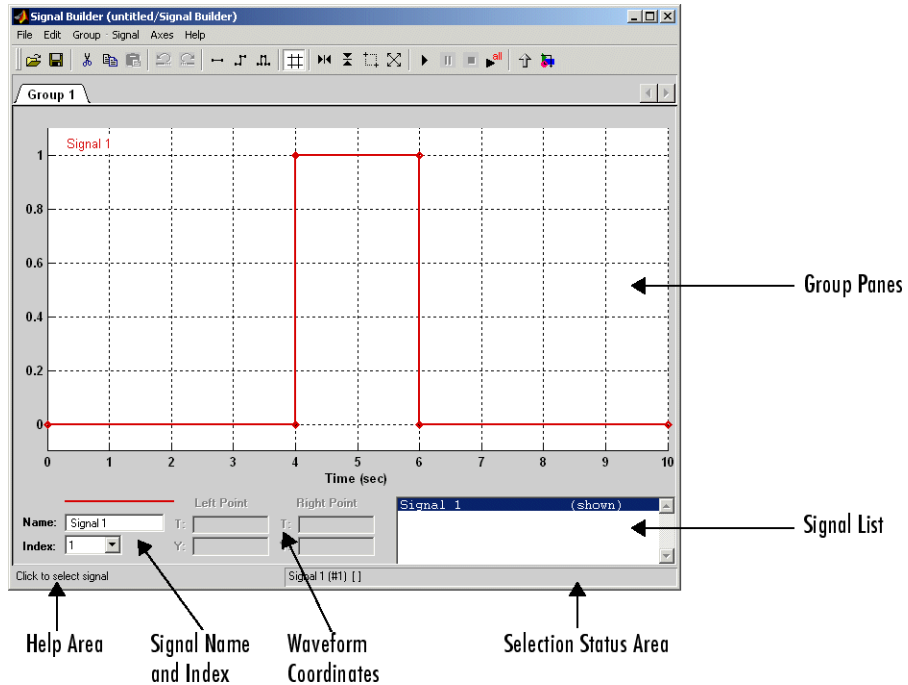
Signal groups can greatly facilitate testing a model, especially when you use them with conjunction with Simulink Assertion blocks and the Model Coverage Tool from the Simulink Verification and Validation. For a description of the Model Coverage Tool, see the “Simulink Verification and Validation User’s Guide” ).

Model Configuration Parameter **Solver** pane settings can affect the Signal Builder block output. See “Solvers” on page 2-22 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 on the pane tab. Only one pane is visible at a time. To display a group that is not visible, select the tab that shows its name. The block outputs the group of signals whose pane is currently visible. Each pane occupies a tab in the Signal Builder block dialog box.

### **Signal Axes**

The signals appear on separate axes that share a common time range (see “Signal Builder Time Range” on page 31-108). 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 31-71) 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 31-102).

### **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 31-74).

### **Index**

Index of the currently selected signal. The index indicates the output port at which the signal appears. An index of 1 indicates the topmost output port, 2 indicates the second port from the top, and so on. You can change the index of a signal by editing this field (see “Changing a Signal Index” on page 31-74).

### **Help Area**

Displays context-sensitive tips on using Signal Builder window features.

## Editing Signal Groups

The Signal Builder window allows you to create, rename, move, and delete signal groups from the set of groups represented by a Signal Builder block.

**Creating and Deleting Signal Groups.** To create a signal group, copy an existing signal group and then modify it to suit your needs. To copy an existing signal group, select its tab and then select **Copy** from the Signal Builder **Group** menu. To delete a group, select its tab and then select **Delete** from the **Group** menu.

**Renaming Signal Groups.** To rename a signal group, select the group tab and then select **Rename** from the Signal Builder **Group** menu. A dialog box appears. Edit the existing name in the dialog box or enter a new name. Click **OK**.

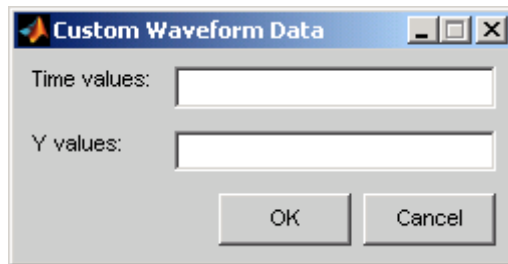
**Moving Signal Groups.** To reposition a group in the stack of group panes, select the pane and then select **Move Right** from the Signal Builder **Group** menu to move the group lower in the stack or **Move Left** to move the pane higher in the stack.

## Editing Signals

The Signal Builder window allows you to create, cut and paste, hide, and delete signals from signal groups.

**Creating Signals.** To create a signal in the currently selected signal group, select **New** from the Signal Builder **Signal** menu. A menu of waveforms appears. The menu includes a set of standard waveforms (**Constant**, **Step**, and so on) and a **Custom** waveform option. Select one of the waveforms. If you select a standard waveform, the Signal Builder adds a signal with that waveform to the currently selected group.

If you select **Custom**, a custom waveform dialog box appears.



The dialog box allows you to add a custom piecewise linear waveform to the groups defined by the Signal Builder block. Enter the custom waveform time coordinates in the **Time values** field and the corresponding signal amplitudes in the **Y values** field. The entries in either field can be any MATLAB expression that evaluates to a vector. The resulting vectors must be of equal length. Click **OK**. The Signal Builder adds a signal having the specified shape to the currently selected group.

**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 31-70).

## Creating Signal Group Sets

You can create signal groups in the Signal Builder block by:

- “Creating Signal Group Sets Manually” on page 31-75
- “Importing Signal Group Sets” on page 31-76

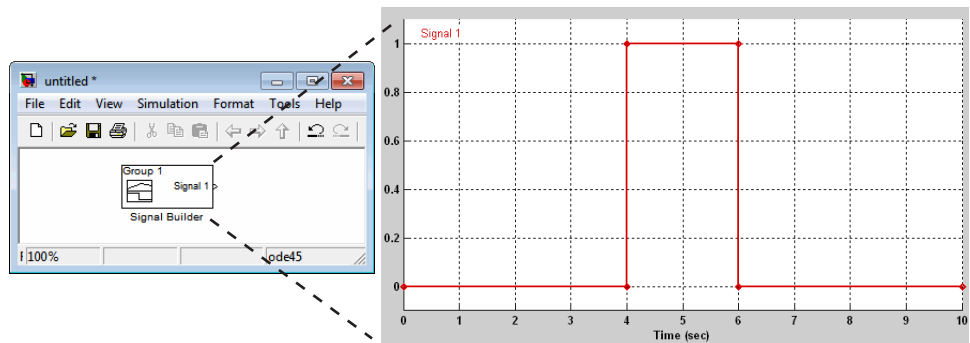
You can also use the `signalbuilder` function to populate the Signal Builder block.

## Creating Signal Group Sets Manually

This topic describes how to create signal group sets manually. If you have signal data files, such as those from test cases, consider importing this data as described in “Importing Signal Group Sets” on page 31-76.

To create an interchangeable set of signal groups:

- 1 Drag an instance of the Signal Builder block from the Simulink Sources library and drop it into your model.



By default, the block represents a single signal group containing a single signal source that outputs a square wave pulse.

- 2 Use the block signal editor (see “Signal Builder Window” on page 31-68) 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 31-110 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 31-76 for a description of the data formats that the Signal Builder block accepts. The procedures in the following topics use the file `matlabroot\help\toolbox\simulink\ug\examples\signals\3Grp_3Sig.xls`.

See “Basic Simulation Workflow” in the *Simulink Getting Started Guide* for a description of the Signal Builder block in a simulation workflow.

**Importing Signal Groups from Existing Data Sets.** You might have existing signal data sets that you want to enter into the Signal Builder block. The **File > Import from File** command on the Signal Builder window starts the Import File dialog box. This dialog box is modal, which means that focus cannot change to another MATLAB window while the dialog box is running. If you want to see changes in the Signal Builder window after you import data, do one of the following:

- Close the Import File dialog box.
- Set up the Import File dialog box and Signal Builder window side by side.

---

**Note** You cannot undo the results of importing a signal data file. In addition, you cannot undo the last action performed before opening the Import File dialog box. When you close the Import File dialog box, the **Undo last edit** and **Redo last edit** buttons on the Signal Builder window are grayed out. These buttons are grayed out regardless of whether you imported a data file.

---

The Import File dialog box accepts the following appropriately formatted file types:

- Microsoft Excel (.xls, .xlsx)
- Comma-separated value (CSV) text files (.csv)
- MAT-files (.mat)

You can import your data set file only if it is appropriately formatted.

For Microsoft Excel spreadsheets:

- The Signal Builder block interprets the first row as signal name. If you do not specify a signal name, the Signal Builder block assigns a default one with the format `Imported_Signal #`, where # increments with each additional unnamed signal.
- The Signal Builder block interprets the first column as time. In this column, the time values must increase.
- The Signal Builder block interprets the remaining columns as signals.
- If there are multiple sheets:
  - Each sheet must have the same number of signals (columns).
  - Each sheet must have the same set of signal names (if any).
  - Each column on each sheet must have the same number of rows.
- Signal Builder block interprets each worksheet as a signal group.
- Linux and Mac OS X platforms support only Microsoft Excel 97–2003 Workbook (\*.xls) formats.

This example contains an acceptably formatted Microsoft Excel spreadsheet. It has three worksheets named Group1, Group2, and Group3, representing three signal groups.

Time must be first column

1	Time	DC In	Trigger	AC In
2		0	1	2
3		1	2	3
4		2	3	4
5		3	4	5
6		4	5	6
7		5	6	7
8		6	7	8
9		7	8	9
10		8	9	10
11		9	10	11
12		10	11	12
13		11	12	13
14		12	13	14
15		13	14	15
16		14	15	16
17		15	16	17
18				

Signal names (optional)

Worksheets - equivalent to signal group

For CSV text files:

- Each file contains only numbers. Do not name signals in a CSV file.
- The Signal Builder block interprets the first column as time. In this column, the time values must increase.
- The Signal Builder block interprets the remaining columns as signals.
- Each column must have the same number of entries.
- The Signal Builder block interprets each file as one signal group.

- The Signal Builder block assigns a default signal name to each signal with the format `Imported_Signal #`, where # increments with each additional signal.

This example contains an acceptably formatted CSV file. The contents represent one signal group.

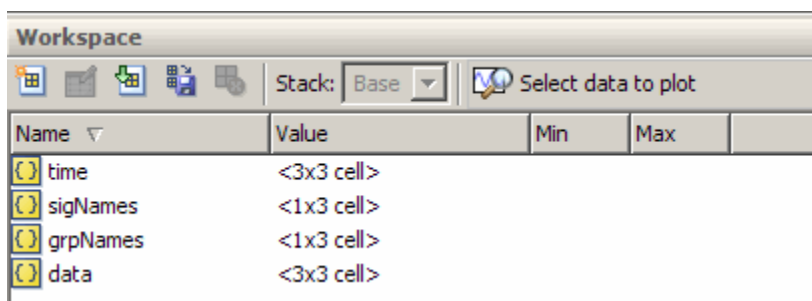
```
0,0,0,5,0
1,0,1,5,0
2,0,1,5,0
3,0,1,5,0
4,5,1,5,0
5,5,1,5,0
6,5,1,5,0
7,0,1,5,0
8,0,1,5,1
9,0,1,5,1
10,0,1,5,0
```

For MAT-files:

- The Signal Builder block supports logged data from the `Simulink.ModelDataLogs` object and interprets this data as a single group.
- The Signal Builder block supports data store logging that the `Simulink.SimulationData.Dataset` object represents and interprets this data as a single group.
- The Signal Builder block supports Simulink output saved as a structure with time.
- The Signal Builder block supports the Signal Builder data format. This format is a group of cell arrays that must be labeled:
  - `time`
  - `data`
  - `sigName`
  - `groupName``sigName` and `groupName` are optional.
- Signal Builder block does not support:

- Simulink output as only a structure
- Simulink output as only an array

This example contains an acceptably logged MATLAB workspace. Use the MATLAB workspace **Save** command to save the variables to a MAT-file. Import this file to the Signal Builder block.

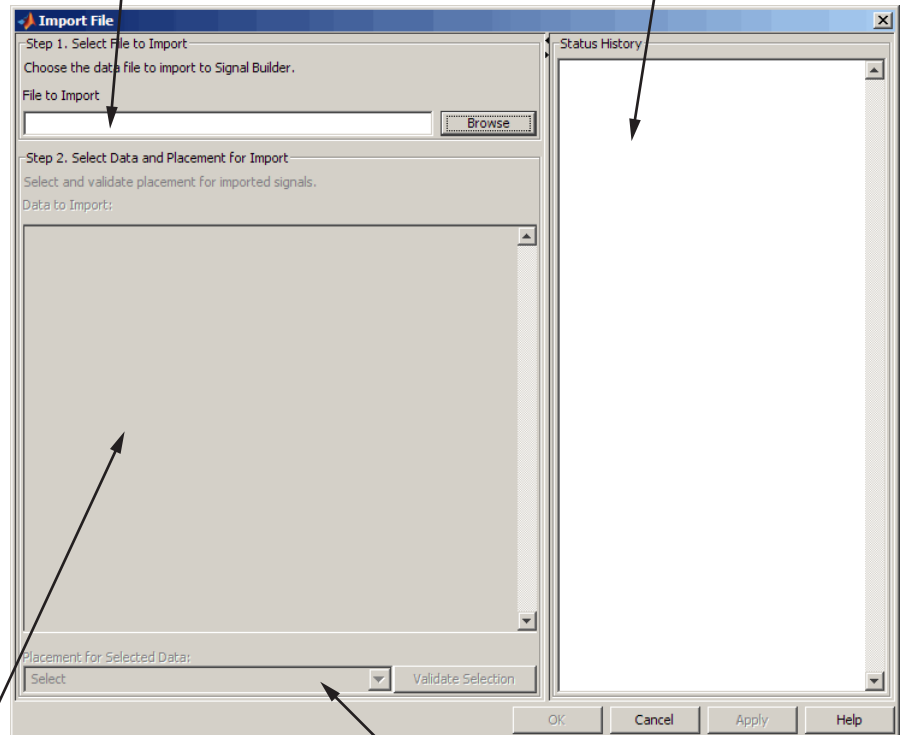


**Signal Builder Block Import File Dialog Box.** The Signal Builder Import File dialog box allows you to import existing signal data files into the Signal Builder block.



Signal data file to import

Repository of data import status messages



Tree view of signal data file contents

Drop-down list of import actions for signal data

**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.

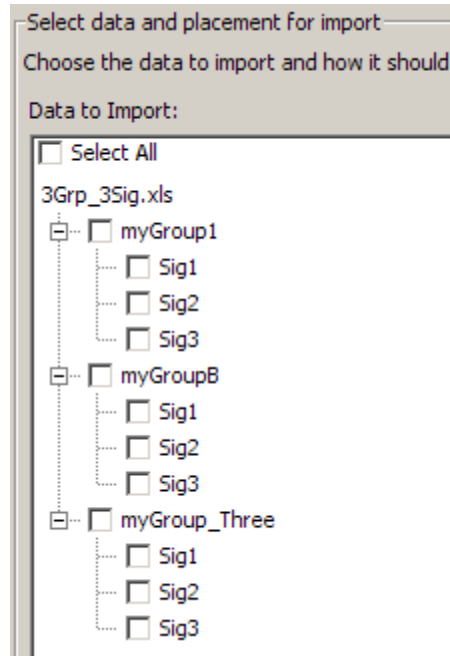
---

**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:

```
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. 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

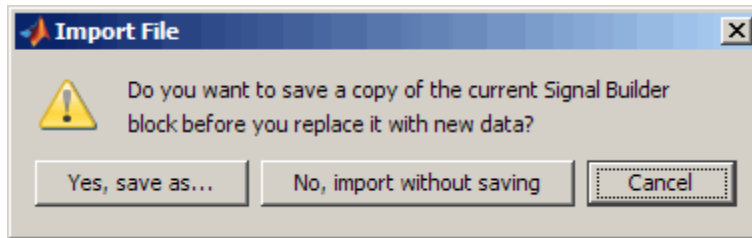
(Names may have been renamed for uniqueness.)

.....

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.

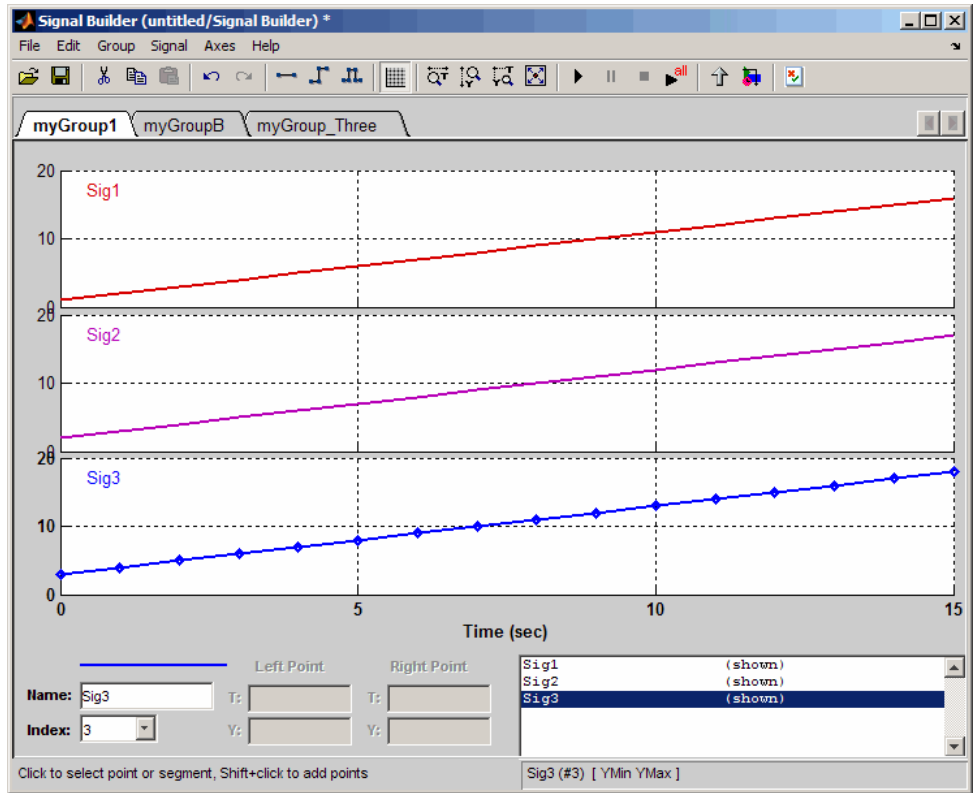


- 10 Click a button, as follows:

<b>To...</b>	<b>Click...</b>
<p>Save the contents of the Signal Builder block before replacing it with the new signal data.</p> <hr/> <p><b>Note</b> 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.</p> <hr/>	<b>Yes, save as</b>
<p>Replace the contents of the Signal Builder block without saving them first.</p>	<b>No, import without saving</b>
<p>Stop the replacement process.</p>	<b>Cancel</b>

For this example, select **No, import without saving** to replace the contents of the Signal Builder block.

- 11** The Signal Builder block updates with the new signal data. Click **OK** to close the Import File dialog box and inspect the Signal Builder block.



- 12** Click **OK**.
- 13** Inspect the updated Signal Builder window to confirm that your signal data is intact.
- 14** Close the Signal Builder window and save and close the model. For example, save the model as `signalbuilder1.mdl`.

**Appending Selected Signals to All Existing Signal Groups.** You can import signals from a signal data file and append selected signals to the end of all existing signal groups. If the signal names to be appended are not unique, the software renames them by incrementing each name by 1 or higher until it is a unique signal name. For example, if the block and data file contain signals named `thermostat`, the software renames the imported signal to `thermostat1` upon appending. If you add another signal named `thermostat`, the software names that latest version `thermostat2`.

This topic uses `signalbuilder1.mdl` from the procedure in “Replacing All Signal Data with Selected Data” on page 31-81.

**1** In the MATLAB Command Window, type `signalbuilder1.mdl`.

**2** Double-click the Signal Builder block.

The Signal Builder window appears.

**3** In the Signal Builder window, select **File > Import from File**.

The Import File dialog box appears.

**4** In the **File to Import** field, enter a signal data file name or click **Browse**.

The file browser is displayed.

**5** If you select the file browser, navigate to and select a signal data file. For example, select `3Grp_3Sig.xls`.

---

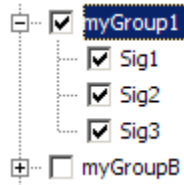
**Note** If you try to import an improperly formatted signal data file, an error message pops up. When you click to dismiss this window, the **Status History** pane displays an error message. For example:

```
File 'signals.mat' format does not  
comply with Signal Builder required format.  
There is no 'time' parameter defined.  
.....
```

---

The **Data to Import** pane contains the signal data from the file. Click the expander to display all the signals.

- 6 Select the signals you want to import. In this example, there are three groups, myGroup1, myGroupB, and myGroup\_Three. Select all the signals in myGroup1.



- 7 From the **Placement for Selected Data** list, select the action to take on the signal data. For example, select Append selected signals to all groups.

The **Confirm Selection** button is activated. Validate your signal selection before the Signal Builder block performs the specified action. If the signal data selection is not appropriate, **Confirm Selection** remains grayed out. For example, **Confirm Selection** remains grayed out if the number of signals you select is not the same as the number of signals in the Signal Builder group that you want to replace.

- 8 Click the **Confirm Selection** button.

If the requested action is a valid one, the Status History pane displays messages to indicate the state. For example:

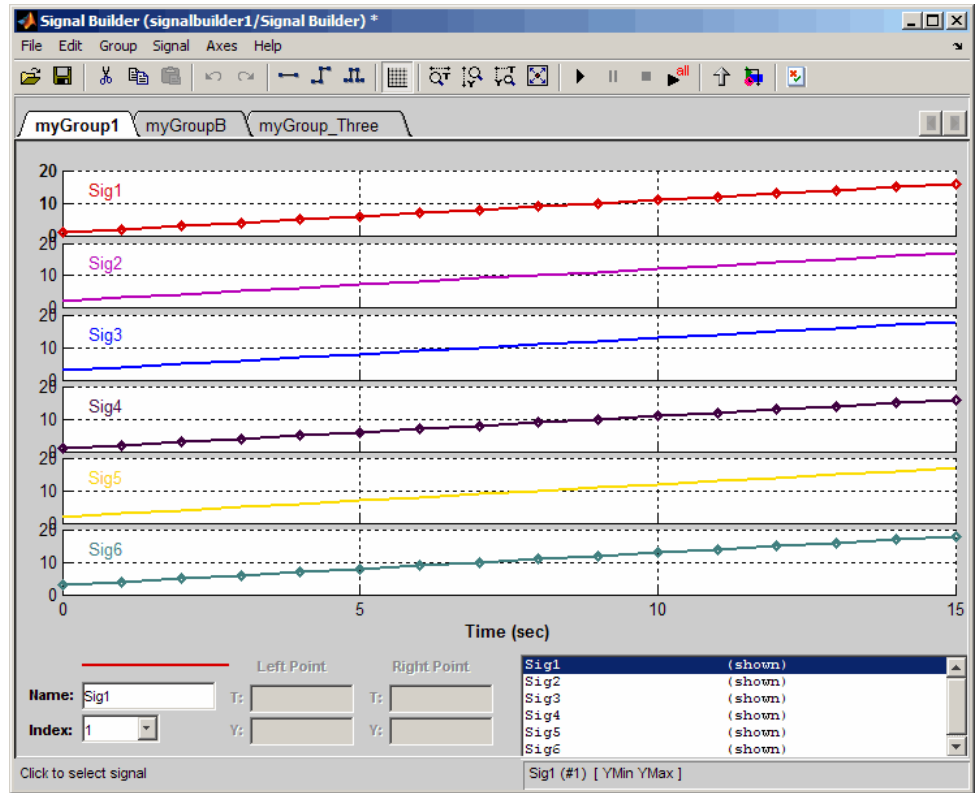


```
3 signal(s) will be appended to each group.  
Selected signal name(s):  
Before:  
  Sig1  
  Sig2  
  Sig3  
  
After:  
  Sig4  
  Sig5  
  Sig6  
  
Signal name(s) in the block:  
Before:  
  Sig1  
  Sig2  
  Sig3  
  
After:  
  Sig1  
  Sig2  
  Sig3  
  Sig4  
  Sig5  
  Sig6  
  
(Names may have been renamed for uniqueness.)  
.....
```

The confirmation also enables the **OK** and **Apply** buttons.

Observe the **Before** and **After** headings for the signals. These sections indicate the names of the block and imported data signals before and after the append action.

- 9 If you are satisfied with the status message, click **Apply** to append the selected signals to all the signal groups in the Signal Builder block.
- 10 The Signal Builder block updates with the new signal data. Click **OK** to close the Import File dialog box and inspect the Signal Builder block.



- 11 Click **OK**.
- 12 Inspect the updated Signal Builder window to confirm that your signal data is intact. Notice that the software has renamed the signals Sig1, Sig2, and Sig3 from the signal data file to Sig4, Sig5, and Sig6 in the Signal Builder block.
- 13 Close the Signal Builder window and save and close the model. For example, save the model as `signalbuilder2.mdl`.

**Appending Selected Signals to Sequential Existing Signal Groups.**

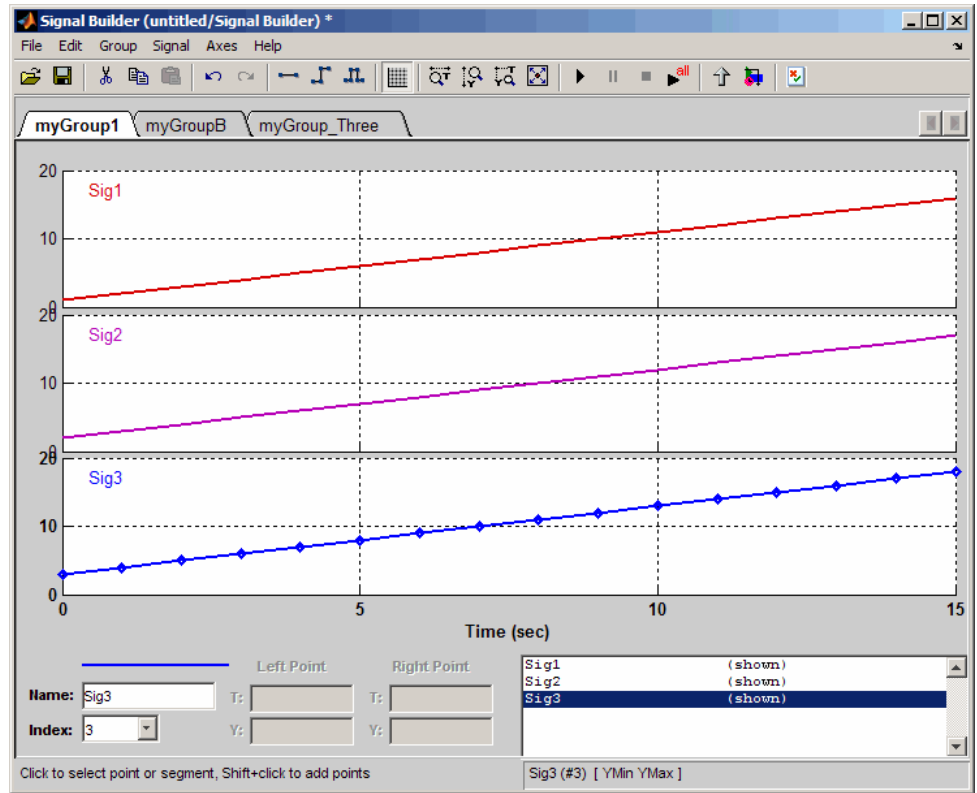
You can append signals, in the order in which they are selected, to the end of sequential signal groups. This statement means that you select the same number of signals as there are signal groups, and sequentially append each signal to a different group. The software renames each appended signal to the name of the last appended signal.

This topic uses `signalbuilder1.mdl` from the procedure in “Replacing All Signal Data with Selected Data” on page 31-81.

- 1** In the MATLAB Command Window, type `signalbuilder1.mdl`.
- 2** Double-click the Signal Builder block.

The Signal Builder window appears.

- 3** Note how many groups exist in the Signal Builder block. For example, this Signal Builder block has three groups, `myGroup1`, `myGroupB`, and `myGroup_Three`.



4 Double-click the block.

The Import File dialog box appears.

5 In the **File to Import** field, enter a signal data file name or click **Browse**.

The file browser appears.

6 If you select the file browser, navigate to and select a signal data file. For example, select 3Grp\_3Sig.xls.

---

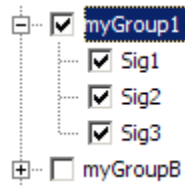
**Note** If you try to import an improperly formatted signal data file, an error message popup window. When you click to dismiss this window, the **Status History** pane displays an error message. For example:

```
File 'signals.mat' format does not
comply with Signal Builder required format.
There is no 'time' parameter defined.
.....
```

---

The **Data to Import** pane contains the signal data from the file. Click the expander to display all the signals.

- 7 Select the signals you want to import. In this example, there are three groups, myGroup1, myGroupB, and myGroup\_Three. Select all the signals in myGroup1.



- 8 From the **Placement for Selected Data** list, select the action to take on the signal data. For example, select **Append selected signals to different groups (in order)**.

The **Confirm Selection** button is activated. Validate your signal selection before the Signal Builder block performs the specified action.

- 9 Click the **Confirm Selection** button.

If the requested action is a valid one, the Status History pane displays messages to indicate the state. For example:

1 signal will be appended to each group.

Selected signal names:

Before:

Sig1

Sig2

Sig3

Selected unique signal name:

After:

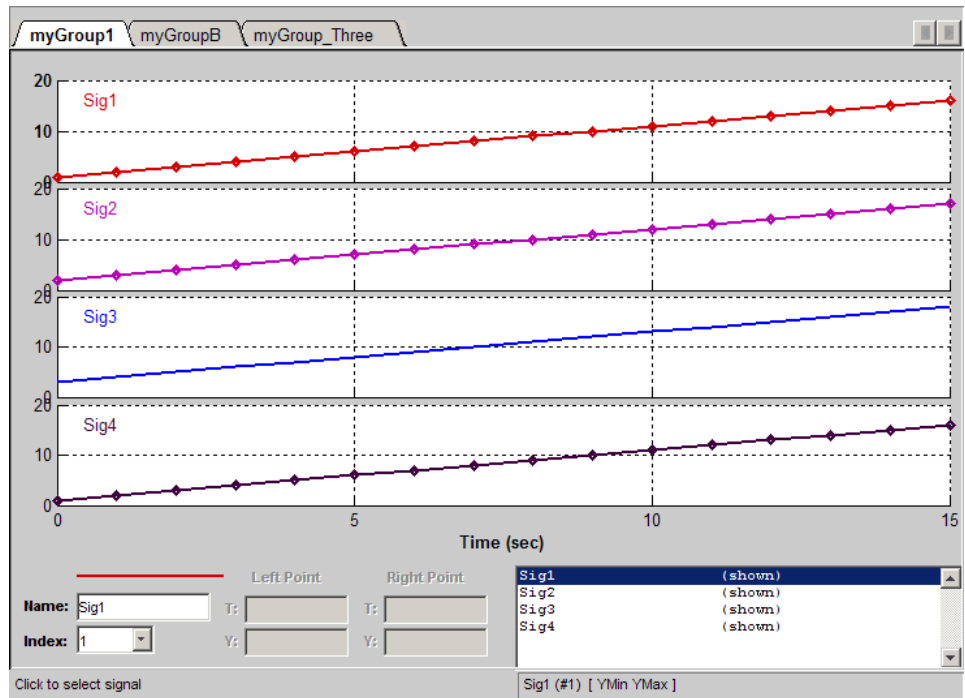
Sig4

The confirmation also enables the **OK** and **Apply** buttons.

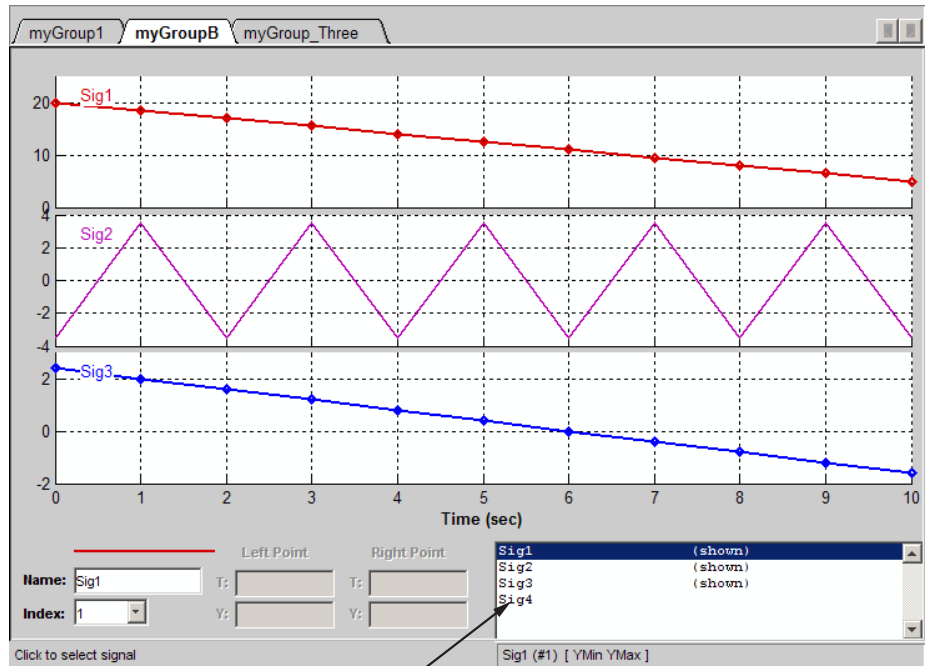
- 10** If you are satisfied with the status message, click **Apply** to append the signals.

The Signal Builder block updates with the new signal data. Click **OK** to close the Import File dialog box and inspect the three groups of the Signal Builder block.

The topmost signal group, myGroup1, shows all signals by default, including the new Sig4.



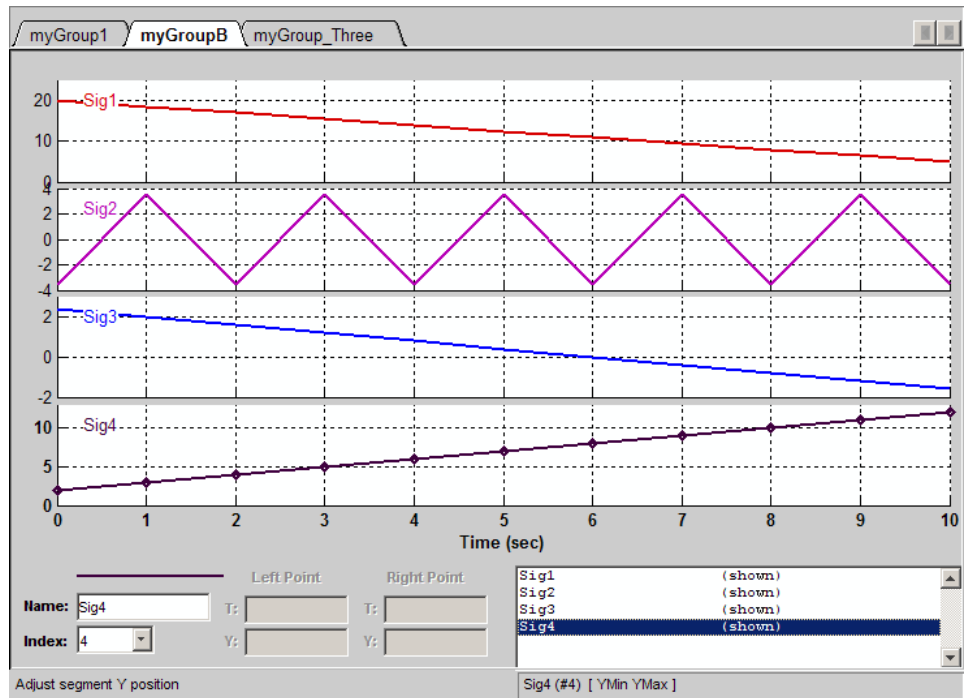
- 11** Click another tab, for example, myGroupB. Notice that Sig4 exists for the group, hidden by default.



Sig4 appears in signal list, but does not appear in group pane

- 12** To show Sig4 on this tab, double-click Sig4 in the Selection Status area of the tab. The graph is updated to reflect Sig4.





- 13** Close the Signal Builder window and save and close the model. For example, save the model as `signalbuilder3.mdl`.

**Appending Signal Groups to Existing Groups.** You can append one or more signal groups to the end of the list of existing signal groups. If the block already has a signal group with the same name as the one you are adding, the software increments the group name by 1 or higher until it is unique before adding it. For example, if the block and data file contain groups named `MyGroup1`, the software renames the imported group to `MyGroup2` upon appending. If you add another group named `MyGroup1`, the software names that latest version `MyGroup3`.

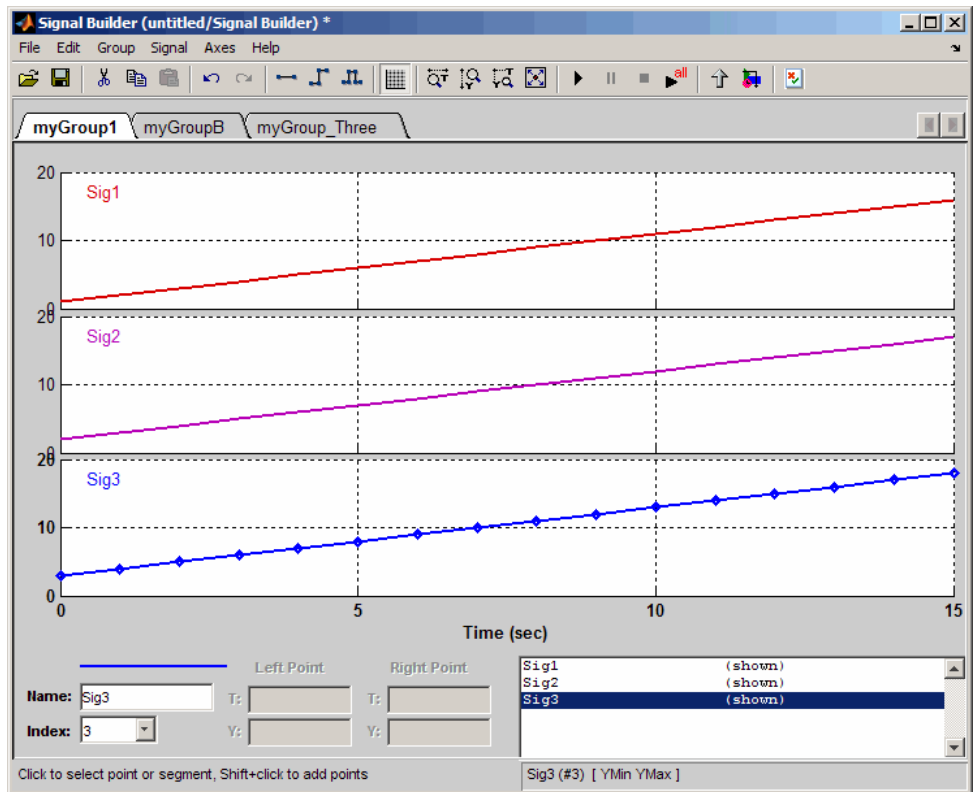
This topic uses `signalbuilder1.mdl` from the procedure in “Replacing All Signal Data with Selected Data” on page 31-81.

- 1** In the MATLAB Command Window, type `signalbuilder1.mdl`.

- 2** Double-click the Signal Builder block.

The Signal Builder window appears.

- 3** Note how many groups exist in the Signal Builder block, and how many signals exist in each group. The Signal Builder block requires that all groups have the same number of signals. For example, this Signal Builder block has three groups, myGroup1, myGroupB, and myGroup\_Three. Three signals exist in each group.



- 4** Double-click the block.

The Import File dialog box appears.

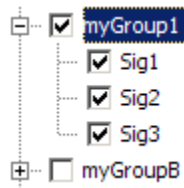
- 5 In the **File to Import** text field, enter a signal data file name or click **Browse**.

The file browser appears.

- 6 If you select the file browser, navigate to and select a signal data file. For example, select 3Grp\_3Sig.xls.

The **Data to Import** pane contains the signal data from the file. Click the expander to display all the signals.

- 7 Evaluate the number of signals in the groups of this data file. If the number of signals in each group equals the number of signals in the groups that exist in the block, you can append one of these groups to the block.
- 8 Select the group you want to import. In this example, there are three groups, myGroup1, myGroupB, and myGroup\_Three. Select myGroup1.



- 9 From the **Placement for Selected Data** list, select the action to take on the signal group. For example, select **Append groups**.

The **Confirm Selection** button is activated. Validate your signal selection before the Signal Builder block performs the specified action.

- 10 Click the **Confirm Selection** button.

If the requested action is a valid one, the Status History pane displays messages to indicate the state. For example:

1 group(s) (each with 3 signal(s)),  
will be appended to the existing block.

Selected group name(s):

Before:

myGroup1

After:

myGroup2

Signal name(s) in selected group(s):

Before:

Sig1

Sig2

Sig3

Signal name(s) in the block:

Before:

Sig1

Sig2

Sig3

After:

Sig1

Sig2

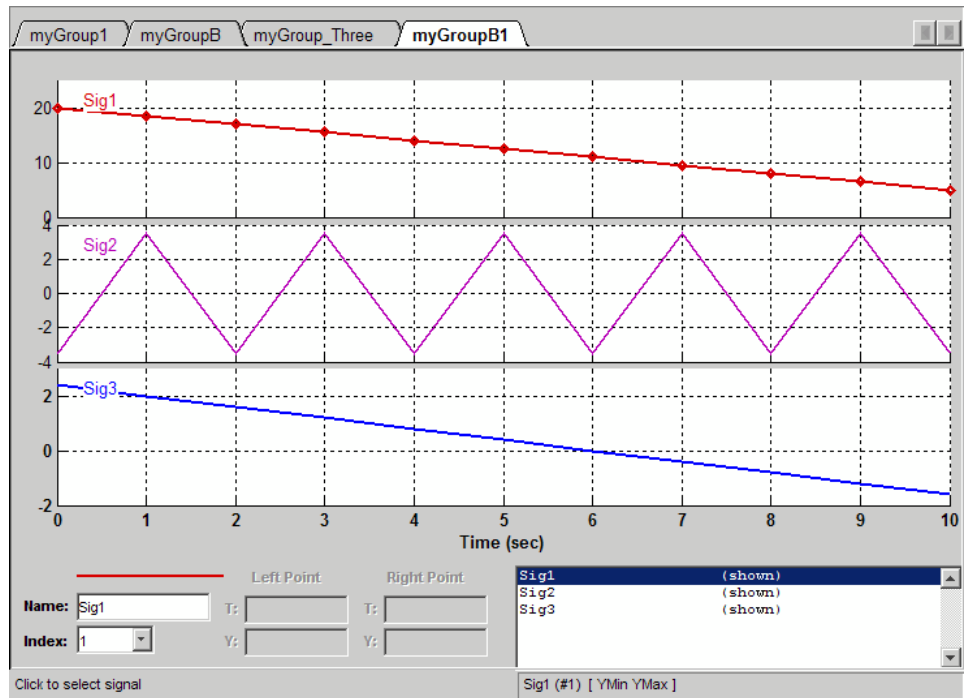
Sig3

The confirmation also enables the **OK** and **Apply** buttons.

- 11** If you are satisfied with the status message, click **Apply** to append the signals.

The Signal Builder block updates with the new signal data. Click **OK** to close the Import File dialog box and inspect the groups of the Signal Builder block.

Notice the addition of the new signal group as the last tab. Because there is already a signal group named myGroupB, the software automatically increments the new signal group name by 1.



- 12** Close the Signal Builder window and save and close the model. For example, save the model as `signalbuilder4.mdl`.

### Appending Signals with the Same Name to Existing Signal Groups.

If you append a signal whose name is the same as a signal that exists in the Signal Builder block, the software increments the name of the appended signal by 1. The software repeats incrementing until the appended signal name is unique. For example:

- 1** Assume your Signal Builder block has a signal group, `myGroup1`, with the signals `Sig1`, `Sig2`, and `Sig3`.
- 2** Append a signal named `Sig1` to `myGroup1`.
- 3** Observe that the software increments `Sig1` to `Sig4` before appending it to `myGroup1`.

**Appending a Group of Signals with Different Signal Names.** If you append a signal group whose signal names differ from those that exist in the Signal Builder block, the software changes the names of the existing signals to be the same as the appended signals. For example,

- 1 Assume your Signal Builder block has a signal group, myGroup1, with the signals Sig1, Sig2, and Sig3.
- 2 Append a signal group named myGroup2 whose signal names are SigA, SigB, and SigC.
- 3 Observe that the software:
  - Appends myGroup2.
  - Renames the signals in myGroup1 to be the same as those in myGroup2.

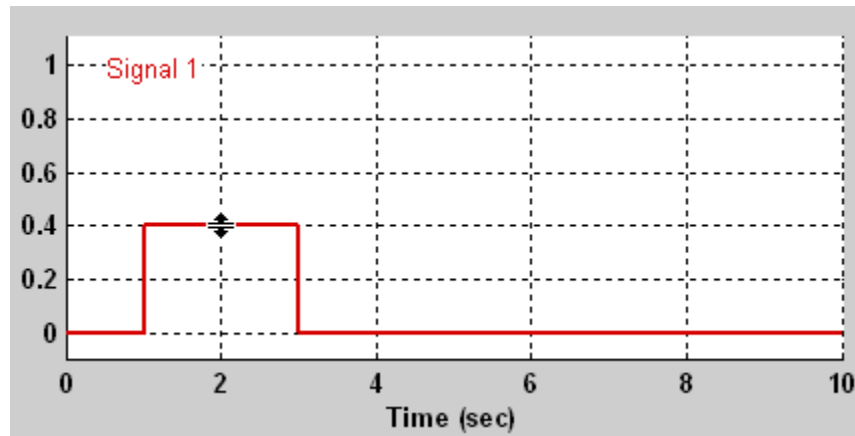
### Editing Waveforms

The Signal Builder window allows you to change the shape, color, and line style and thickness of the waveforms output by a group.

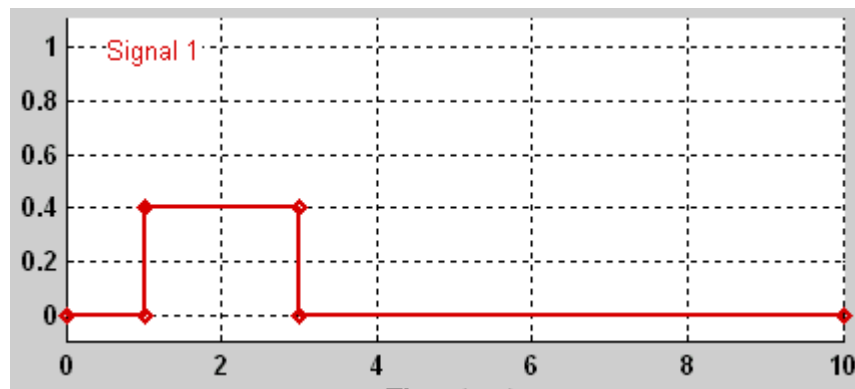
### Reshaping a Waveform

The Signal Builder window allows you to change the waveform by selecting and dragging its line segments and points with the mouse or arrow keys or by editing the coordinates of segments or points.

**Selecting a Waveform.** To select a waveform, left-click the mouse on any point on the waveform.



The Signal Builder displays the waveform points to indicate that the waveform is selected.

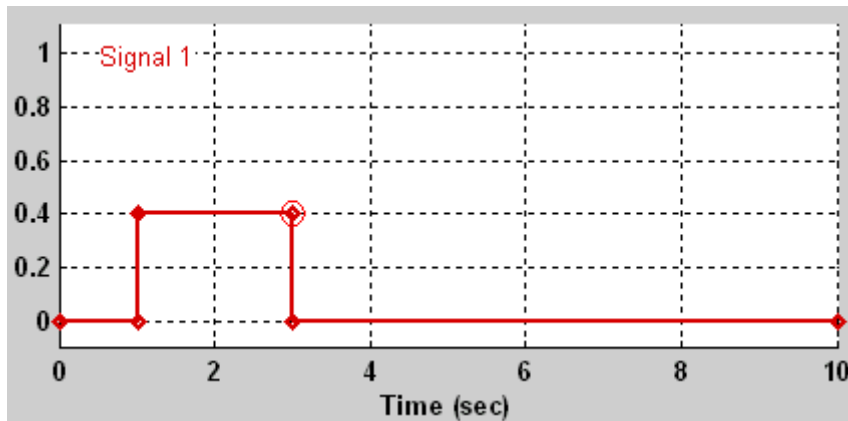


To deselect a waveform, left-click any point on the waveform axis that is not on the waveform itself or press the **Esc** key.

**Selecting Points.** To select a point of a waveform, first select the waveform. Then position the mouse cursor over the point. The cursor changes shape to indicate that it is over a point.



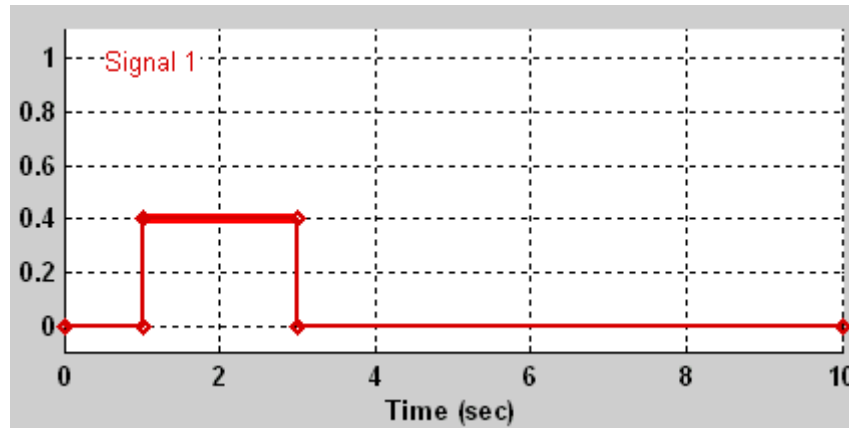
Left-click the point with the mouse. The Signal Builder draws a circle around the point to indicate your selection.



To deselect the point, press the **Esc** key.



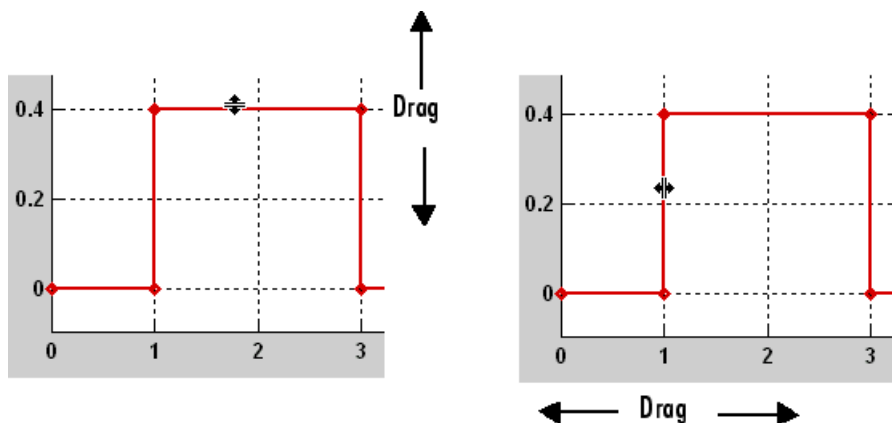
**Selecting Segments.** To select a line segment, first select the waveform that contains it. Then left-click the segment. The Signal Builder thickens the segment to indicate that it is selected.



To deselect the segment, press the **Esc** key.

**Moving Waveforms.** To move a waveform, select it and use the arrow keys on your keyboard to move the waveform in the desired direction. Each key stroke moves the waveform to the next location on the snap grid (see “Snap Grid” on page 31-106) 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**.

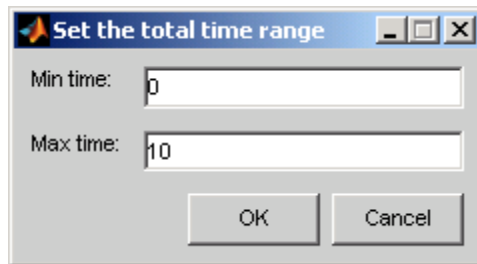
## Signal Builder Time Range

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 31-108).

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 31-111 for more information).

## Changing a Signal Builder Time Range

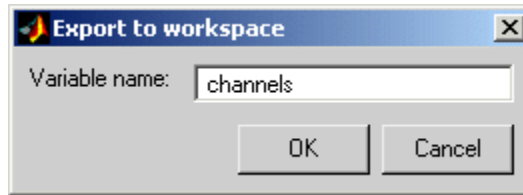
To change the time range, select **Change Time Range** from the Signal Builder **Axes** menu. A dialog box appears.



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 31-110).

If you want to capture inputs and outputs that the **Run all** command generates, consider using the SystemTest™ software.

## Activating a Signal Group

During a simulation, a Signal Builder block always outputs the active signal group. The active signal group is the group selected in the Signal Builder window for that block, if the dialog box is open. Otherwise, the active group is the group that was selected when the dialog box was last closed. To activate a group, open the group Signal Builder window and select the group.

## Running Different Signal Groups in Succession

The Signal Builder toolbar includes the standard Simulink buttons for running a simulation. This facilitates running several different signal groups in succession. For example, you can open the dialog box, select a group, run a simulation, select another group, run a simulation, etc., all from the Signal Builder window.

## Running All Signal Groups

To run all the signal groups defined by a Signal Builder block, open the block dialog box and click the **Run all** button



from the Signal Builder toolbar. The **Run all** command runs a series of simulations, one for each signal group defined by the block. If you installed Simulink Verification and Validation on your system and are using the Model Coverage Tool, the **Run all** command configures the tool to collect and save coverage data for each simulation in the MATLAB workspace and display a

report of the combined coverage results at the end of the last simulation. This allows you to quickly determine how well a set of signal groups tests your model.

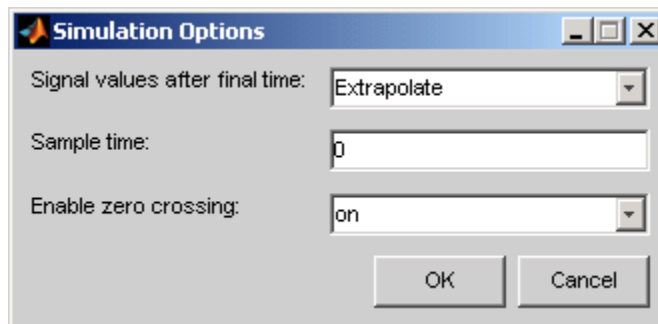
---

**Note** To stop a series of simulations started by the **Run all** command, enter **Ctrl+C** at the MATLAB command line.

---

## Simulation Options Dialog Box

The **Simulation Options** dialog box allows you to specify simulation options pertaining to the Signal Builder. To display the dialog box, select **Simulation Options** from the **File** menu of the Signal Builder window. The dialog box appears.



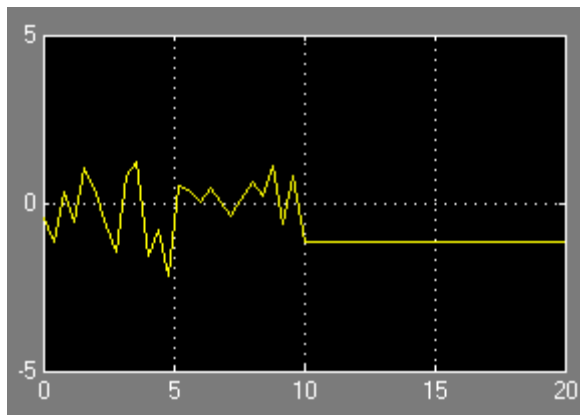
The dialog box allows you to specify the following options.

### Signal values after final time

The setting of this control determines the output of the Signal Builder block if a simulation runs longer than the period defined by the block. The options are

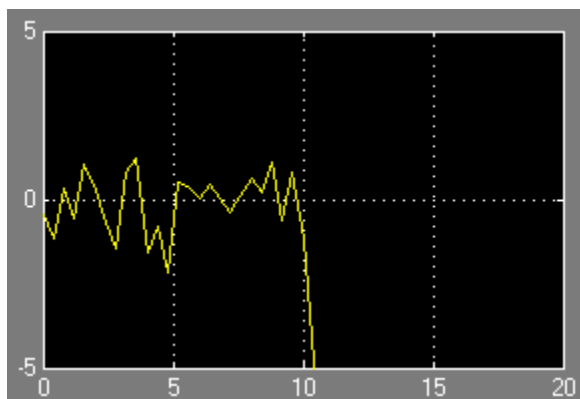
- Hold final value

Selecting this option causes the Signal Builder block to output the last defined value of each signal in the currently active group for the remainder of the simulation.



- Extrapolate

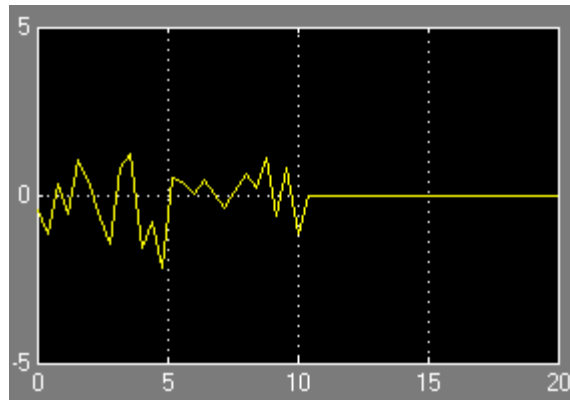
Selecting this option causes the Signal Builder block to output values extrapolated from the last defined value of each signal in the currently active group for the remainder of the simulation.



- Set to zero

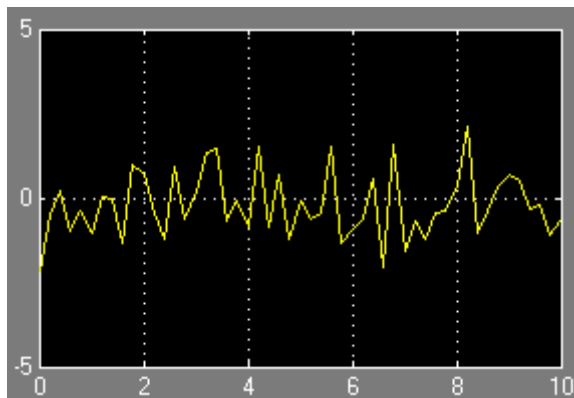


Selecting this option causes the Signal Builder block to output zero for the remainder of the simulation.

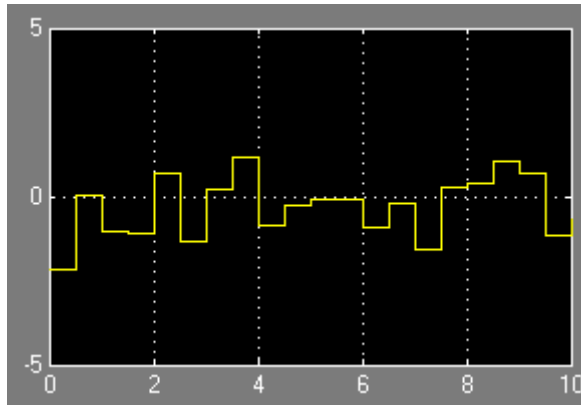


### Sample time

Determines whether the Signal Builder block outputs a continuous (the default) or a discrete signal. If you want the block to output a continuous signal, enter 0 in this field. For example, the following display shows the output of a Signal Builder block set to output a continuous Gaussian waveform over a period of 10 seconds.



If you want the block to output a discrete signal, enter the sample time of the signal in this field. The following example shows the output of a Signal Builder block set to emit a discrete Gaussian waveform having a 0.5 second sample time.



### **Enable zero crossing**

Specifies whether the Signal Builder block detects zero-crossing events (enabled by default). For more information, see “Zero-Crossing Detection” on page 2-24.

# Using Composite Signals

---

- “About Composite Signals” on page 32-2
- “Creating and Accessing a Bus” on page 32-10
- “Nesting Buses” on page 32-12
- “Bus-Capable Blocks” on page 32-14
- “Using Bus Objects” on page 32-15
- “Using the Bus Editor” on page 32-18
- “Filtering Displayed Bus Objects” on page 32-42
- “Customizing Bus Object Import and Export” on page 32-49
- “Using the Bus Object API” on page 32-55
- “Virtual and Nonvirtual Buses” on page 32-56
- “Connecting Buses to Inports and Outports” on page 32-59
- “Specifying Initial Conditions for Bus Signals” on page 32-63
- “Combining Buses into an Array of Buses” on page 32-75
- “Buses and Libraries” on page 32-92
- “Avoiding Mux/Bus Mixtures” on page 32-93
- “Buses in Generated Code” on page 32-103
- “Composite Signal Limitations” on page 32-104

## About Composite Signals

### In this section...

“Composite Signal Terminology” on page 32-2

“Types of Simulink Buses” on page 32-3

“View Information about Buses” on page 32-3

“Buses and Muxes” on page 32-8

“Bus Objects” on page 32-8

“Bus Code” on page 32-9

### 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 32-14, “Connecting Buses to Inports and Outports” on page 32-59, and “Composite Signal Limitations” on page 32-104 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 31-11 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 32-56 for more information.

## View Information about Buses

To view information about buses, use one of the following approaches:

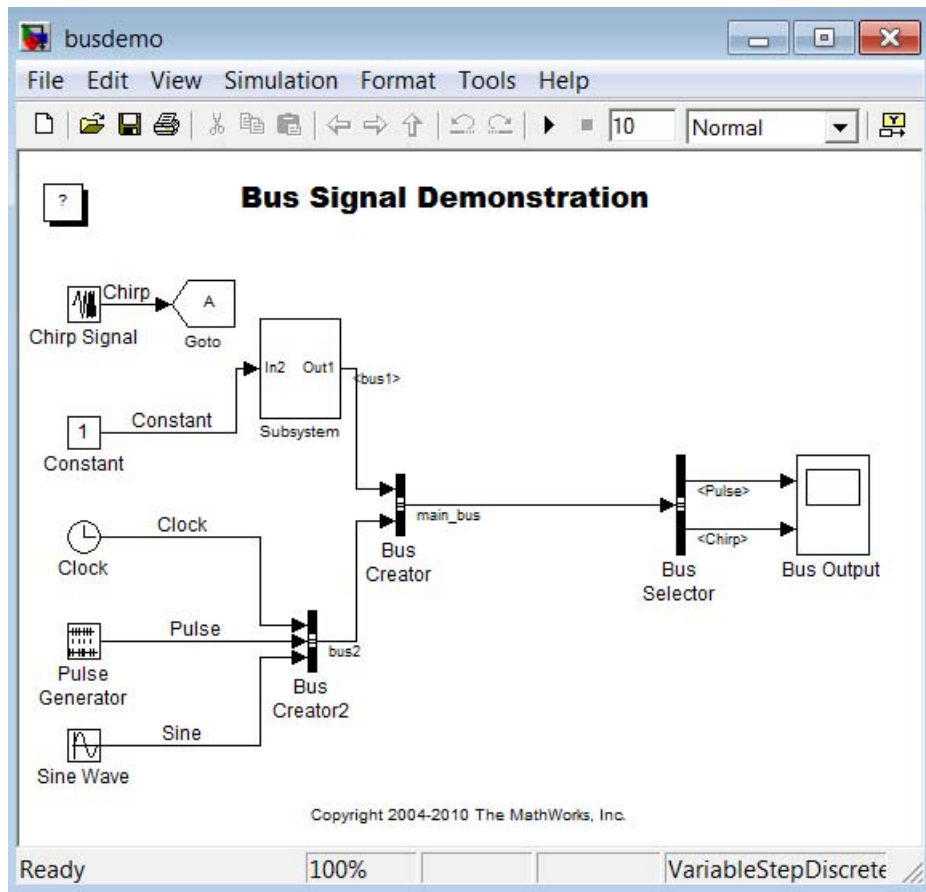
- Use the Signal Hierarchy Viewer to interactively display bus hierarchy (for bus signals)
- From the MATLAB command line, display the type and hierarchy of a bus signal in a compiled model. For details, see “CompiledBusType and SignalHierarchy Parameters” on page 32-6.

## Signal Hierarchy Viewer

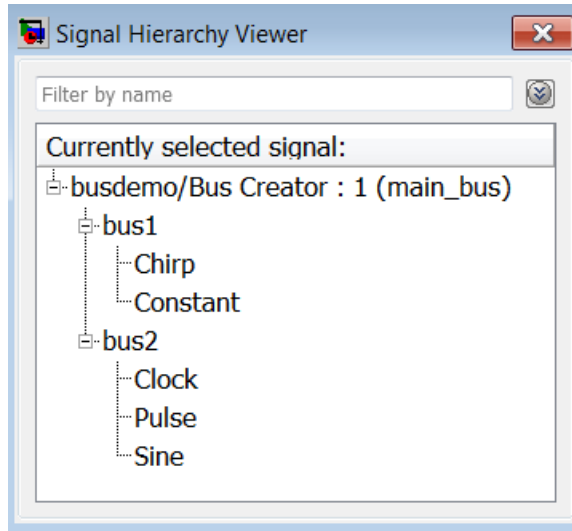
Use the Signal Hierarchy Viewer to interactively display information about a signal. For a bus signal, the Signal Hierarchy Viewer displays the bus hierarchy.

- 1 Right-click a signal line.
- 2 Select the **Signal Hierarchy** option. The Signal Hierarchy Viewer dialog box appears.

For example, open the busdemo demo.



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.

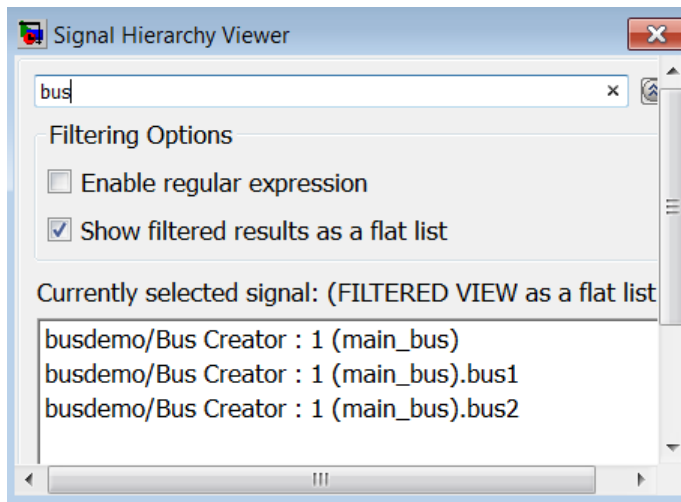
**1** Select **View > Signal Hierarchy**.

**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:

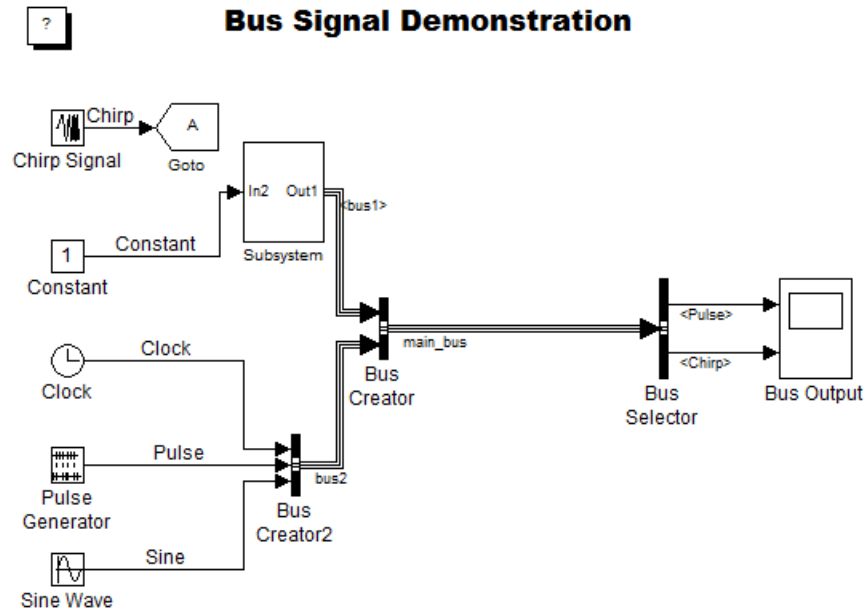
- `CompiledBusType` — For a compiled model, returns information about whether the signal connected to a port is a bus, and if so, whether the signal is a virtual or nonvirtual bus.
- `SignalHierarchy` — If the signal is a bus, returns the name and hierarchy of the signals in the bus.

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 demo, 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 31-11. 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 “Avoiding Mux/Bus Mixtures” on page 32-93 for details.

Another way for a mux/bus mixture to occur is when a virtual bus signal is treated as a mux, such as a bus signal that inputs directly to a Gain block. To detect such mixtures, in the **Configuration Parameters > Diagnostics > Connectivity** pane, set the **Bus signal treated as vector** diagnostic to warning or error.

## Bus Objects

A bus can have an associated *bus object*, which can both provide and validate bus properties. A bus object is an instance of class `Simulink.Bus` that is defined in the base workspace. The object defines the structure of the bus and the properties of its elements, such as nesting, data type, and size. Bus objects are optional for virtual buses and required for nonvirtual buses. See “Using Bus Objects” on page 32-15 for more information. You can create bus objects programmatically or by using the Simulink Bus Editor, which facilitates bus object creation and management. See “Using the Bus Editor” on page 32-18 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.

## Creating and Accessing a Bus

The Signal Routing library provides three blocks that you can use for implementing buses:

### **Bus Creator**

Create a bus that contains specified elements

### **Bus Assignment**

Replace specified bus elements

### **Bus Selector**

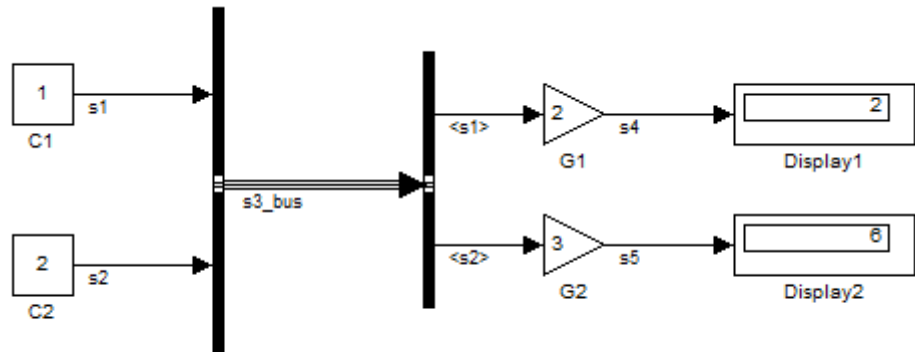
Select elements from a bus

Each of these blocks is virtual or nonvirtual depending on whether the bus that it processes is virtual or nonvirtual. The Simulink software chooses the block type, and changes it automatically if the bus type changes.

To create and access a bus signal that has default properties:

- 1** Clone a Bus Creator and Bus Selector block from the Signal Routing library.
- 2** Connect the Bus Creator, Bus Selector, and other blocks as needed to implement the desired bus.

The next figure shows two signals (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 (s13\_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 31-4 for more about the graphical appearance of signals. You can also display other signal characteristics graphically, as described under “Displaying Signal Attributes” on page 31-63.

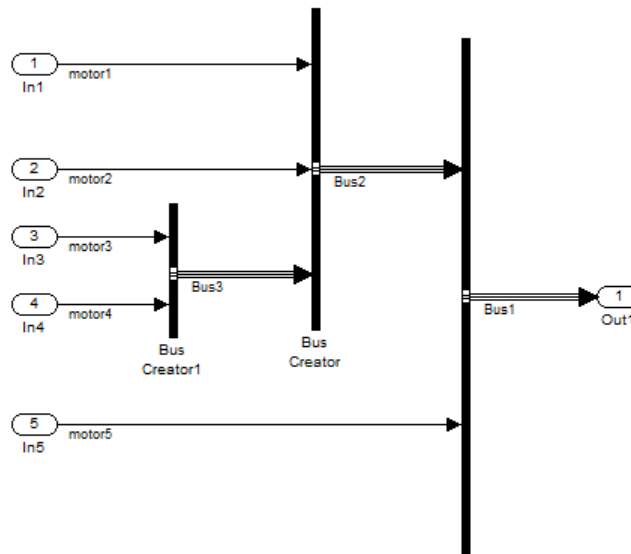
Simulink automatically labels the output signals of the Bus Selector block to reflect the name of the selected bus elements (for example, in the above model, s1 and s2).

For more information about creating and accessing buses, see the reference documentation for the Bus Creator, Bus Selector, and Bus Assignment blocks.

## Nesting 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 Source** or **Highlight to Destination** from the signal's Context menu. (See "Displaying Signal Sources and Destinations" on page 31-41 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 the specific block in *Blocks-Alphabetical List* for more information.

You can sometimes connect a virtual bus to a block that is not bus-capable without generating an error, but such a connection intermixes buses and muxes, which MathWorks discourages. See “Avoiding Mux/Bus Mixtures” on page 32-93 for details.



## Using Bus Objects

In this section...
“About Bus Objects” on page 32-15
“Bus Object Capabilities” on page 32-16
“Associating Bus Objects with Simulink Blocks” on page 32-16

### 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 32-16.

When a bus object governs a signal output by a block, the signal is a bus that has exactly the properties specified by the object. When a bus object governs a signal input by a block, the signal must be a bus that has exactly the properties specified by the object; any variance causes an error.

A bus object can also specify properties that were not defined by constituent signals, but were left to be inherited. A property specification in a bus object can either validate or provide the corresponding property in the bus. If the bus specifies a different property, an error occurs. If the bus does not specify the property, but leaves it to be inherited, the bus inherits the property from the bus object. Note again that such inheritance never includes signal values.

You can use the Simulink Bus Editor to create and manage bus objects, as described in “Using the Bus Editor” on page 32-18, or you can use the Simulink API, as described in “Using the Bus Object API” on page 32-55. 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`.

---

## Using the Bus Editor

### In this section...

- “Introduction” on page 32-18
- “Opening the Bus Editor” on page 32-19
- “Displaying Bus Objects” on page 32-21
- “Creating Bus Objects” on page 32-23
- “Creating Bus Elements” on page 32-26
- “Nesting Bus Definitions” on page 32-29
- “Changing Bus Entities” on page 32-33
- “Exporting Bus Objects” on page 32-39
- “Importing Bus Objects” on page 32-40
- “Closing the Bus Editor” on page 32-41

### Introduction

The Simulink Bus Editor is a tool similar to the Model Explorer, but is customized for use with bus objects. You can use the Simulink Bus Editor to:

- Create new bus objects and elements
- Navigate, change, and nest bus objects
- Import existing bus objects from a MATLAB code file or MAT-file
- Export bus objects to a MATLAB code file or MAT-file

For a description of bus objects and their use, see “Using Bus Objects” on page 32-15.

### Base Workspace Bus Objects

All bus objects exist in the MATLAB base workspace. Bus Editor actions take effect in the base workspace immediately, and can be used by Simulink models as soon as each action is complete. The Bus Editor does not have a workspace of its own: it acts only on the base workspace. Bus Editor actions

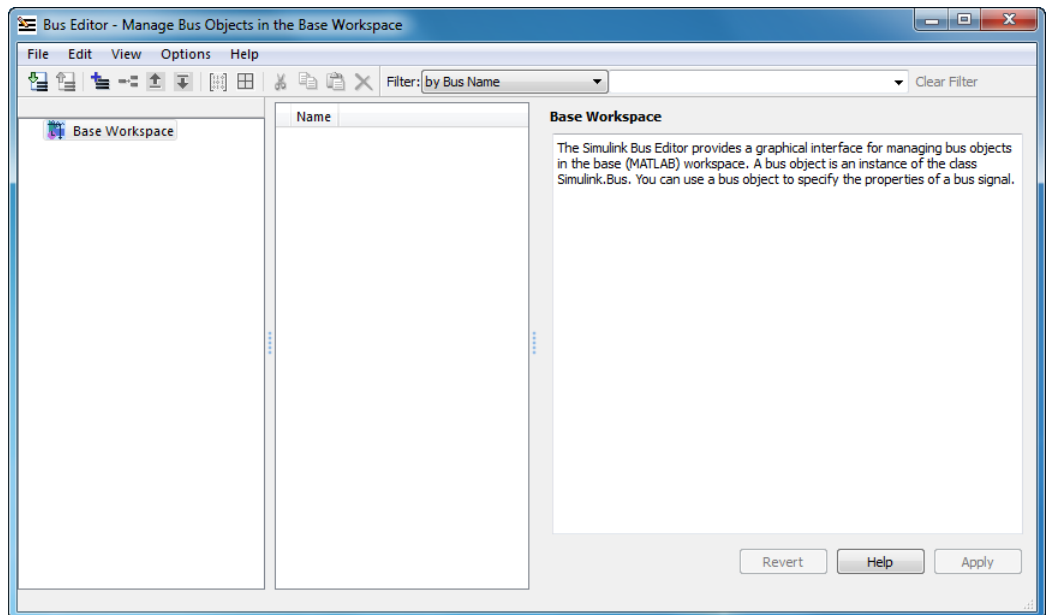
do not directly affect bus object definitions in saved MATLAB code files or MAT-files. To save changed bus object definitions, export them from the base workspace into MATLAB code files or MAT-files, as described in “Exporting Bus Objects” on page 32-39.

## Opening the Bus Editor

You can open the Bus Editor in any of these ways:









- Select **Bus Editor** from the model editor’s **Tools** menu.
- Click the **Launch Bus Editor** button on a bus object’s dialog box in the Model Explorer.
- Enter `buseditor` at the command line of the MATLAB software.

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 GUI shortcuts for Cut, Copy, Paste, and Delete. The Toolbar Tip for each icon describes the command, and the menu entry for each command shows any shortcut. The icons for commands that are specific to the Bus Editor are:

Command	Icon	Description
<b>Import</b>		Import the contents of a MATLAB code file or MAT-file into the base workspace.
<b>Export</b>		Export all bus objects and elements to a MATLAB code file or MAT-file.
<b>Create</b>		Create a new bus object in the base workspace.
<b>Insert</b>		Add a bus element below the currently selected bus entity.
<b>Move Up</b>		Move the selected element up in the list of a bus object's elements.
<b>Move Down</b>		Move the selected element down in the list of bus object elements.
<b>Create/Edit a Simulink.Parameter object</b>		Create or edit a Simulink.Parameter object for the selected bus object.
<b>Create a MATLAB structure</b>		Create a MATLAB structure for the selected bus object.

You can use toolbar icons and keyboard shortcuts instead of menu commands whenever you prefer.

## Displaying Bus Objects

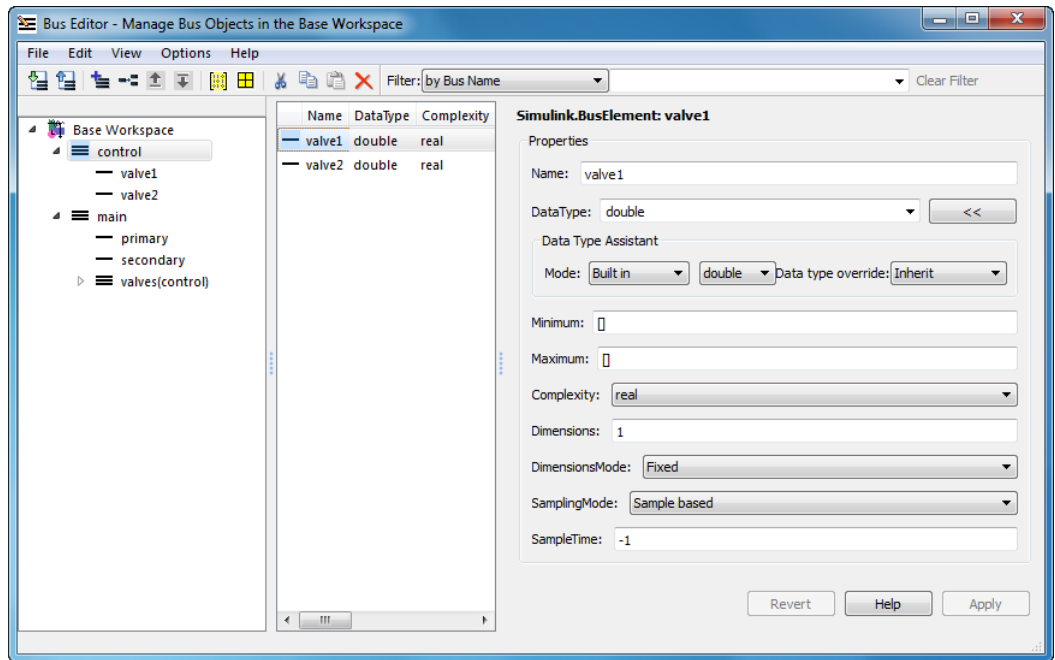
The Bus Editor is similar to the Model Explorer (which can display bus objects but cannot edit them) and uses the same three panes to display bus objects:

- **Hierarchy pane** (left) — Displays the bus objects defined in the base workspace
- **Contents pane** (center) — Displays the elements of the bus object selected in the Hierarchy pane
- **Dialog pane** (right) — Displays for editing the current selection in the Contents or Hierarchy pane

Items that appear in the Hierarchy pane or the Contents pane have Context menus that provide immediate access to the capabilities most likely to be useful with that item. The contents of an item's Context menu depend on the item and the current state within the Bus Editor. All Context menu options are also available from the menu bar and/or the toolbar. Right-click any item in the Hierarchy or Contents pane to see its Context menu.

### Hierarchy Pane

If no bus objects exist in the base workspace, the Hierarchy pane shows only **Base Workspace**, which is the root of the hierarchy of bus objects. The Bus Editor then looks as shown in the previous figure. As you create or import bus objects, they appear in the Hierarchy Pane as nodes subordinate to **Base Workspace**. The bus objects appear in alphabetical order. The next figure shows the Bus Editor with two bus objects, `control` and `main`, defined in the base workspace:



The Hierarchy pane displays each bus object as an expandable node. The root of the node displays the name of the bus object, and (if the bus contains any elements) a button for expanding and collapsing the node. Expanding a bus node displays named subnodes that represent the bus’s top-level elements. In the preceding figure, both bus objects are fully expanded , and control is selected.

### Contents Pane

Selecting any top-level bus object in the Hierarchy Pane displays the object’s elements in the Contents pane. In the previous figure, the elements of bus object control, valve1 and valve2, appear. Each element’s properties appear to the right of the element’s name. These properties are editable, and you can edit the properties of multiple elements in one operation, as described in “Editing in the Contents Pane” on page 32-34.



## 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 32-36.

## Filter Boxes

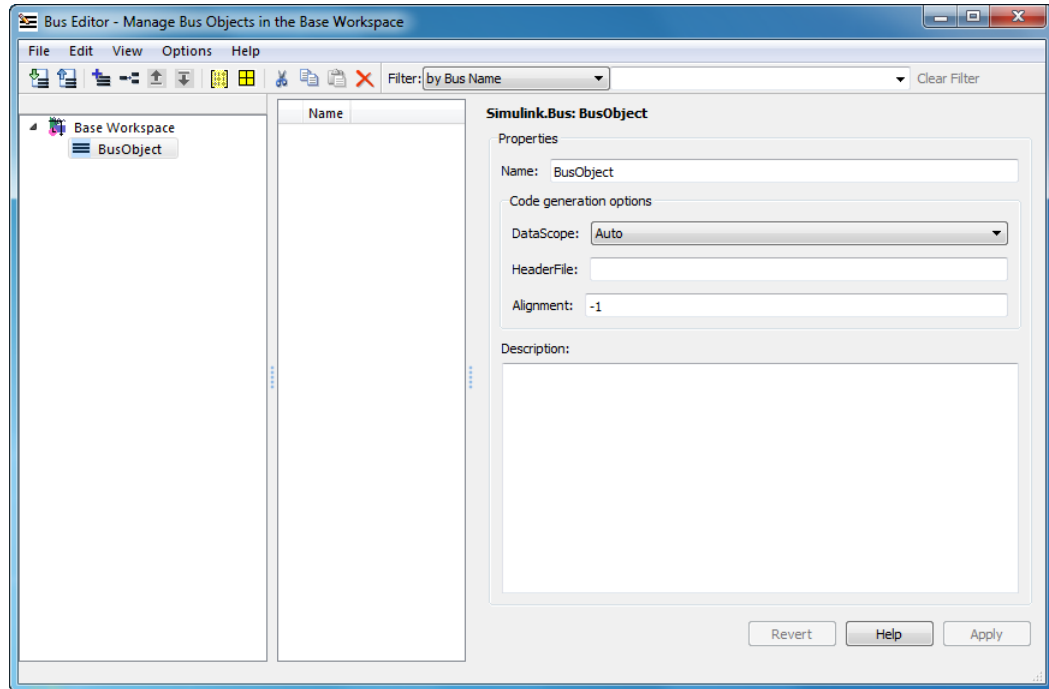
By default, the Bus Editor displays all bus objects that exist in the base workspace. Where a model contains large numbers of bus objects, seeing them all at the same time can be inconvenient. To facilitate working efficiently with large collections of bus objects, you can use the **Filter** boxes, to the right of the iconic tools in the toolbar, to show a selected subset of bus objects. See “Filtering Displayed Bus Objects” on page 32-42 for details.

## Creating Bus Objects

To use the Bus Editor to create a new bus object in the base workspace:

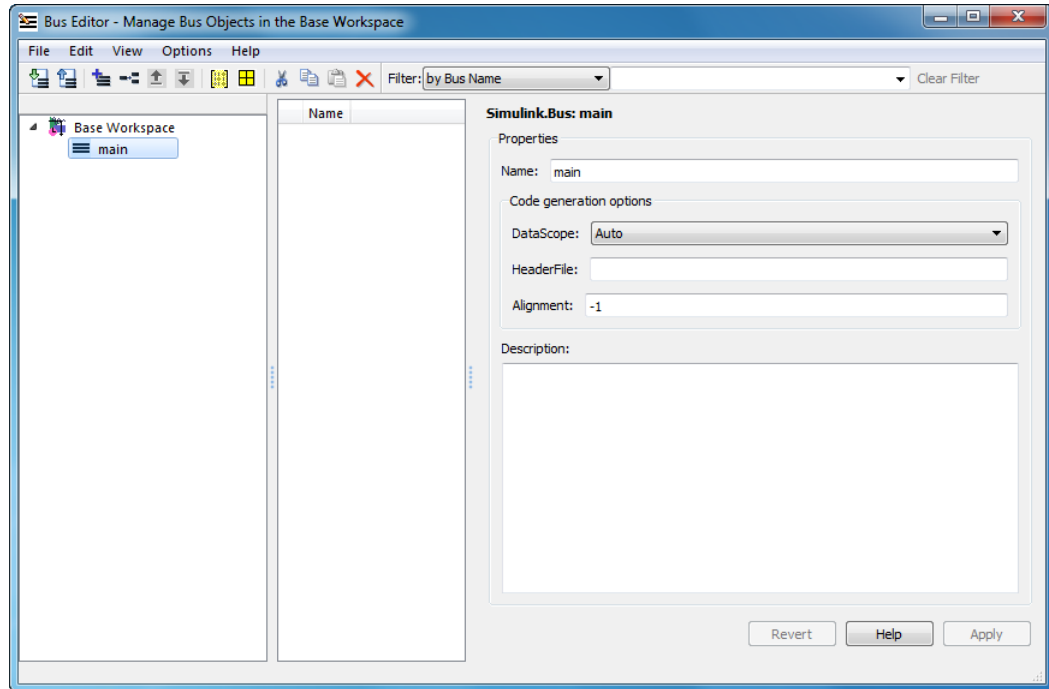
- 1 Choose **File > Add Bus**.

A new bus object with a default name and properties is created immediately in the base workspace. The object appears in the Hierarchy pane, and its default properties appear in the Dialog pane:

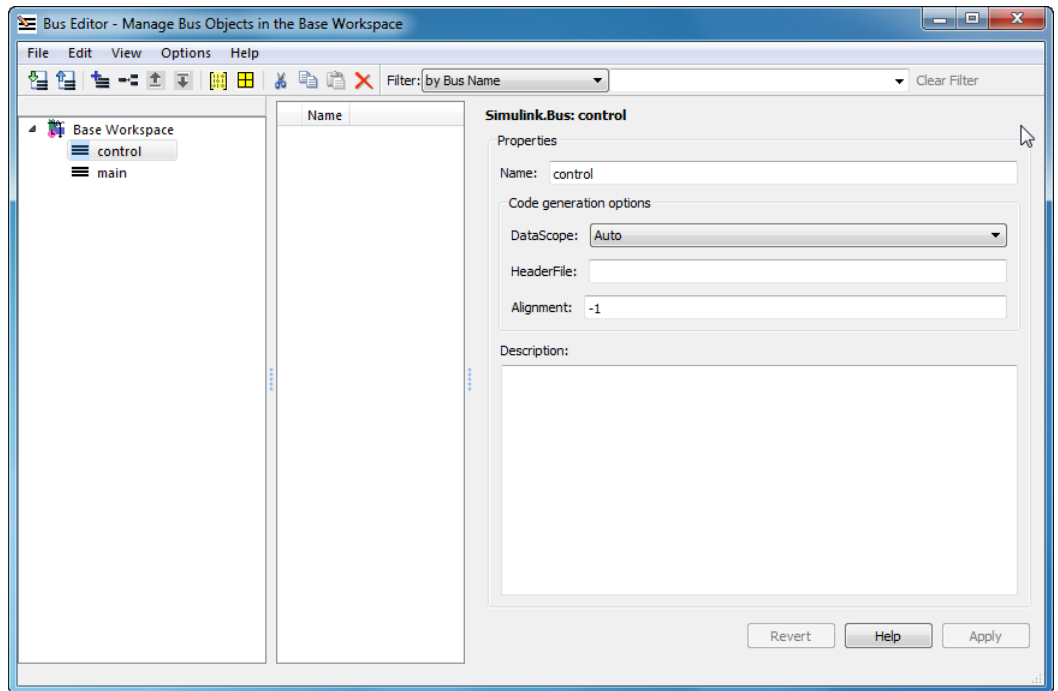


- 2 To specify the bus object name and other properties, in the Dialog pane:
  - a Specify the **Name** of the of the new bus object (or you can retain the default name). The name must be unique in the base workspace. See “Choosing a Signal Name” on page 31-19 for guidelines for signal names.
  - b Optionally, 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:



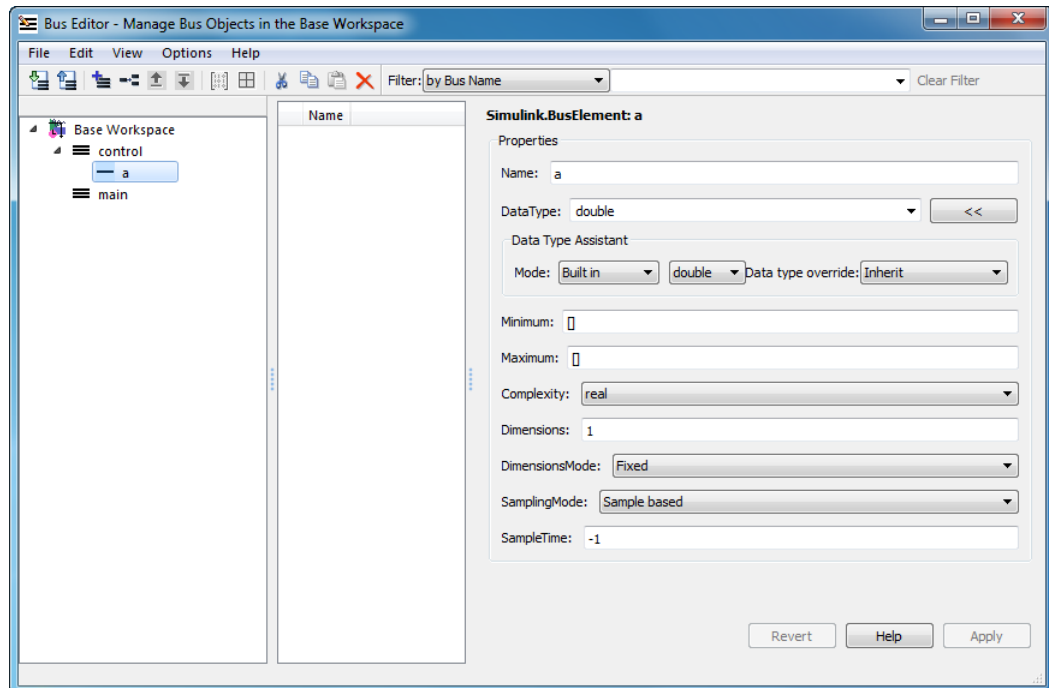
You can also use capabilities outside the Bus Editor to create new bus objects. Such objects do not appear in the Bus Editor until the next time its window is selected.

### Creating Bus Elements

Every bus element belongs to a specific bus. To create a new bus element:

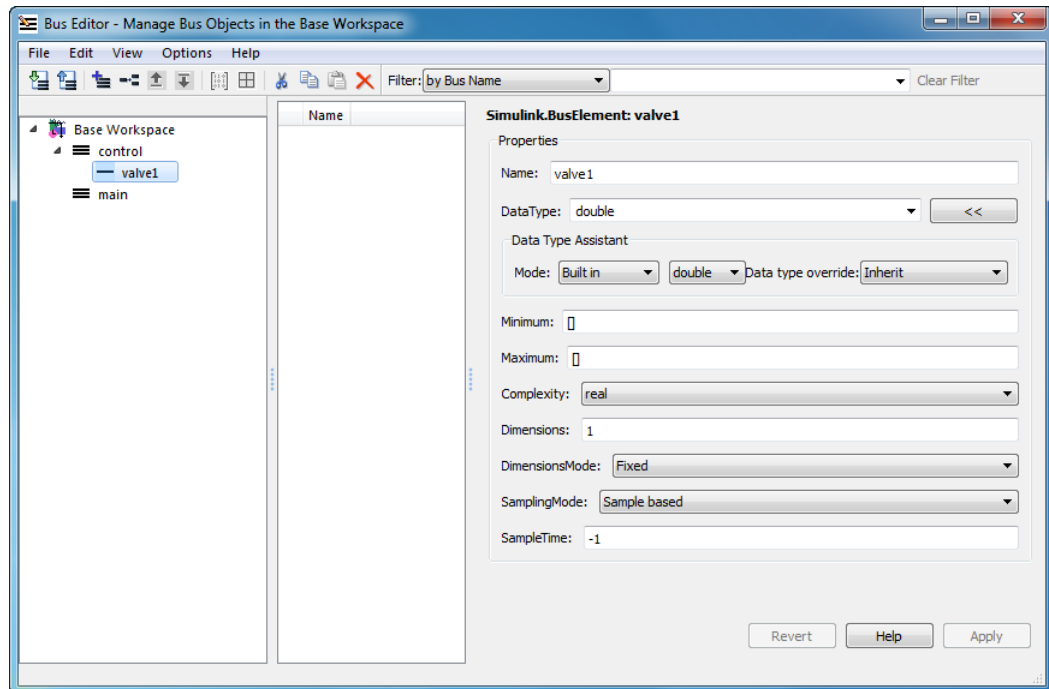
- 1 In the Hierarchy pane, select the entity below which to create the new element. The entity can be a bus or a bus element. The new element will belong to the selected bus object, or to the bus object that contains the selected element. The previous figure shows the `control` bus object selected.
- 2 Choose **File > Add/Insert BusElement**.

A new bus element with a default name and properties is created immediately in the applicable bus object. The object appears in the Hierarchy pane immediately below the previously selected entity, and its default properties appear in the Dialog pane:

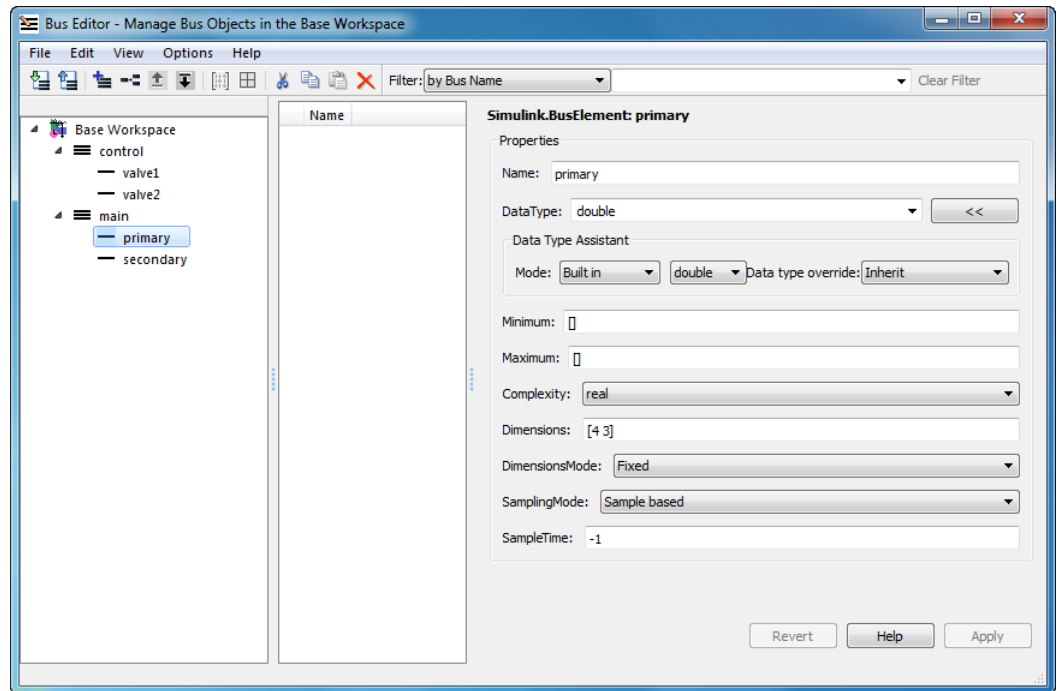


- 3 To specify the bus element name and other properties, in the Dialog pane:
  - a Specify the **Name** of the of the new bus element (or you can retain the default name). The name must be unique among the elements of the bus object. See “Signal Names” on page 31-19 for guidelines for signal names.
  - 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.

## Nesting Bus Definitions

As described in “Nesting Buses” on page 32-12, any signal in a bus can be another bus, which can in turn contain subordinate buses, and so on to any depth. Describing nested buses with bus objects requires nesting the bus definitions that the objects provide.

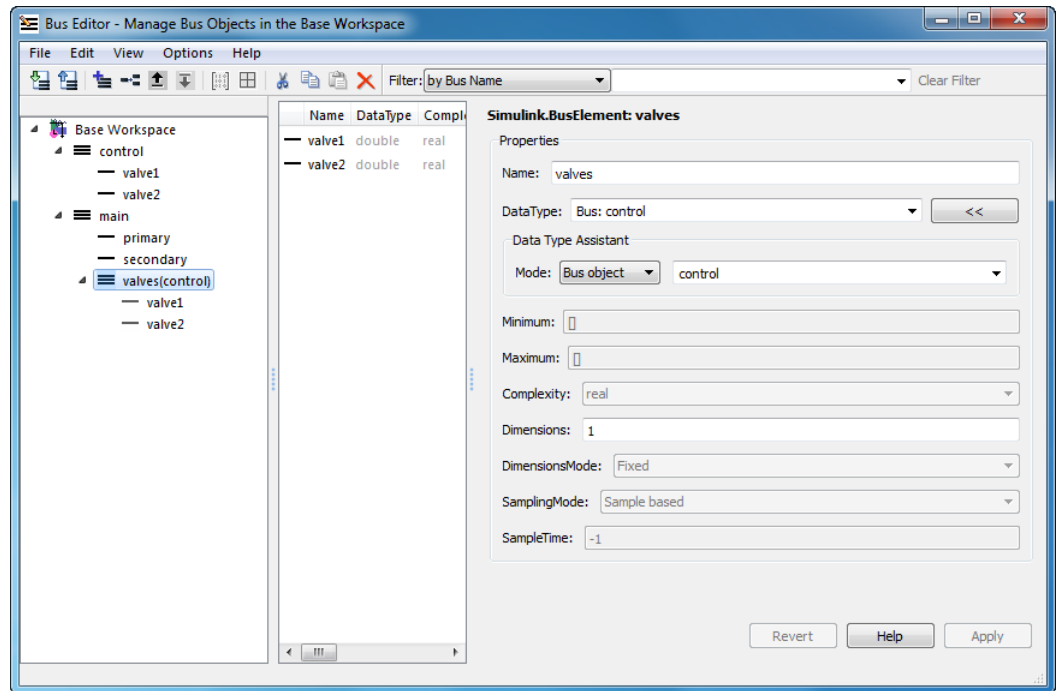
Every bus object inherently defines a data type whose properties are those specified by the object. To nest one bus definition in another, you assign to an element of one bus object a data type that is defined by another bus object. The element then represents a nested bus whose structure is given by the bus object that provides its data type.

A data type defined by a bus object is called a *bus type*. Nesting buses by assigning bus types to elements, rather than by subordinating the bus objects that define the types, allows the same bus definition to be used conveniently in multiple contexts without unwanted interactions. To specify that an element of a bus object represents a nested bus definition:

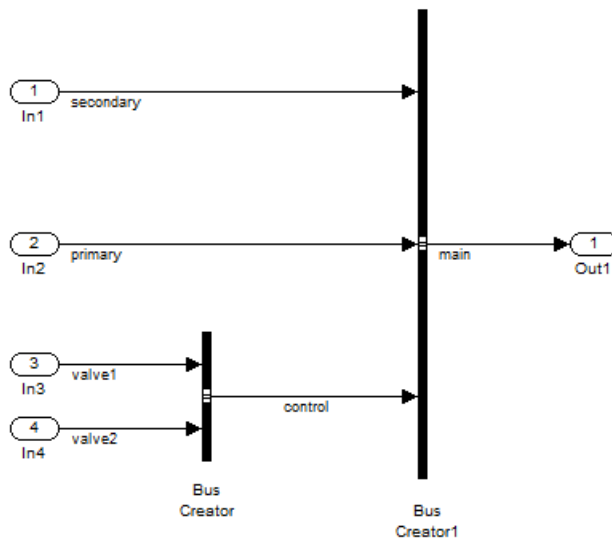
- 1** Create a bus element to represent the nested bus definition, in the appropriate position under the containing bus object, and give the element the desired name. (You can also use an existing element.)
- 2** Use the Dialog pane to set the data type of the element to the name of a bus object. The Data Type Assistant shows the names of all available bus types. (You can also specify a nonexistent bus type and define the object later.)

In the preceding figure, if you add to bus object `main` a third element named `valves`, set the data type of `valves` to be `control` (the name of the other defined bus object) and expand the new element `valves`, the Bus Editor looks like this:





The bus object main shown in the Bus Editor now defines the same structure used by the bus signal main in the next figure:



The distinction between a bus object and the bus type that it defines can be useful for initially understanding how nested bus objects work and how the Bus Editor handles them. In other contexts, the distinction is mostly an implementation detail, and describing bus objects themselves as being nested is more convenient. The rest of this chapter follows that convention.

You can nest a bus object in as many different bus objects as desired, and as many times in the same bus object as desired. You can nest bus objects to any depth, but you cannot define a circular structure by directly or indirectly nesting a bus object within itself.

If you try to define a circular structure, the Bus Editor posts a warning and sets the data type of the element that would have completed the cycle to **double**. Click **OK** to dismiss the Notice and continue using the editor.

You can use the Hierarchy pane to explore nested bus objects by expanding the objects, but you cannot change any property of a bus object anywhere that it appears in nested form. To change the properties of a nested bus object, you must change the source object, which is accessible at the top level in the Hierarchy pane. You can jump from a nested bus object to its source

object by selecting the nested object and choosing **Go to 'element'** from its Context menu.

## Changing Bus Entities

You can use the Bus Editor to change and delete existing bus objects and elements at any time. All three panes allow you to change the entities that they display. Changes that create, reorder, or delete entities take effect immediately in the base workspace. Changes to properties take effect when you apply them, or can be canceled, leaving the properties unchanged. The Bus Editor does not provide an Undo capability.

The Bus Editor provides comprehensive GUI capabilities for changing bus entities. You can Cut, Copy, and Paste within and between panes in any way that has a legal result. The Hierarchy and Dialog panes provide a Context menu for the current selection. Pasting a Copied entity always creates a copy, as distinct from a pointer to the original. The Bus Editor automatically changes names when needed to avoid duplication.

Changes made outside the bus editor can affect the information on display within it. Any change to an existing bus object or bus element is visible immediately in the editor. Any change that creates or deletes a bus object becomes visible in the bus editor next time its window is selected.

## Editing in the Hierarchy pane

You can select the root node **Base Workspace** and perform various operations, like export, cut, copy, paste, and delete. The operation simultaneously affects all bus objects displayed in the Hierarchy pane, but does not affect any that are invisible because a filter is in effect. See “Filtering Displayed Bus Objects” on page 32-42 for details.

As you use the Bus Editor, the Hierarchy pane automatically reorders the bus objects it displays to maintain alphabetical order. This behavior cannot be changed. However, the elements under a bus object can appear in any order. To change that order, cut and paste elements as needed, or move elements up and down as follows:

- 1 Select the element to be moved.

**2** Choose **Edit > Move Element Up** or **Edit > Move Element Down**.

You cannot Paste one bus object under another to create a nested bus object specification. To specify a nested bus, you must change the data type of a bus element to be the type of an existing bus object, as described in “Nesting Buses” on page 32-12.

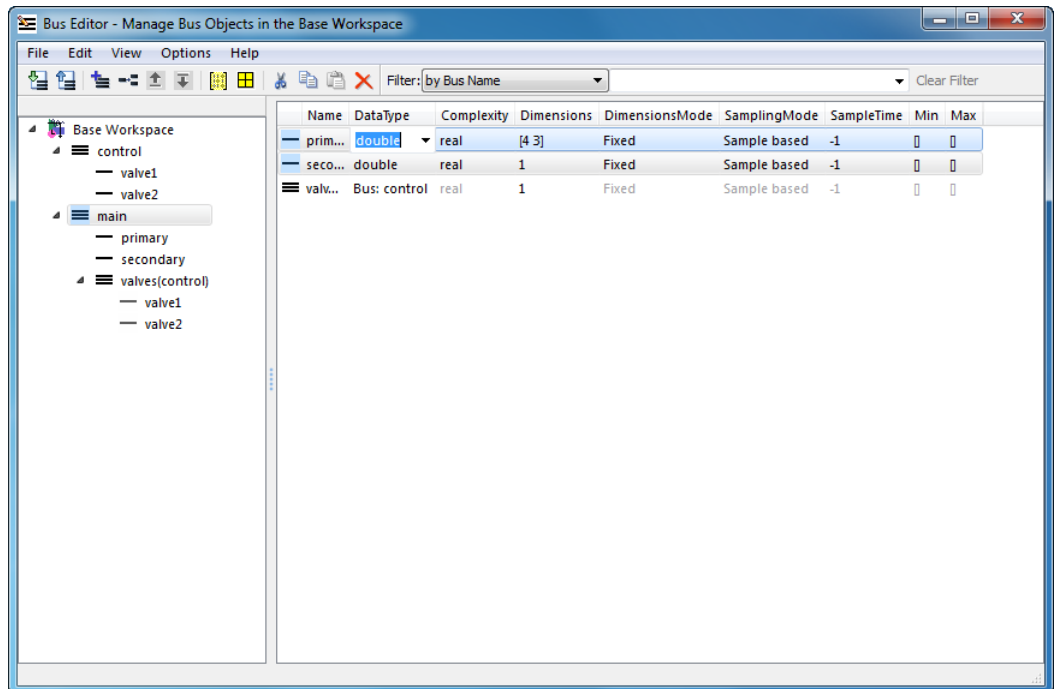
### **Editing in the Contents Pane**

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.

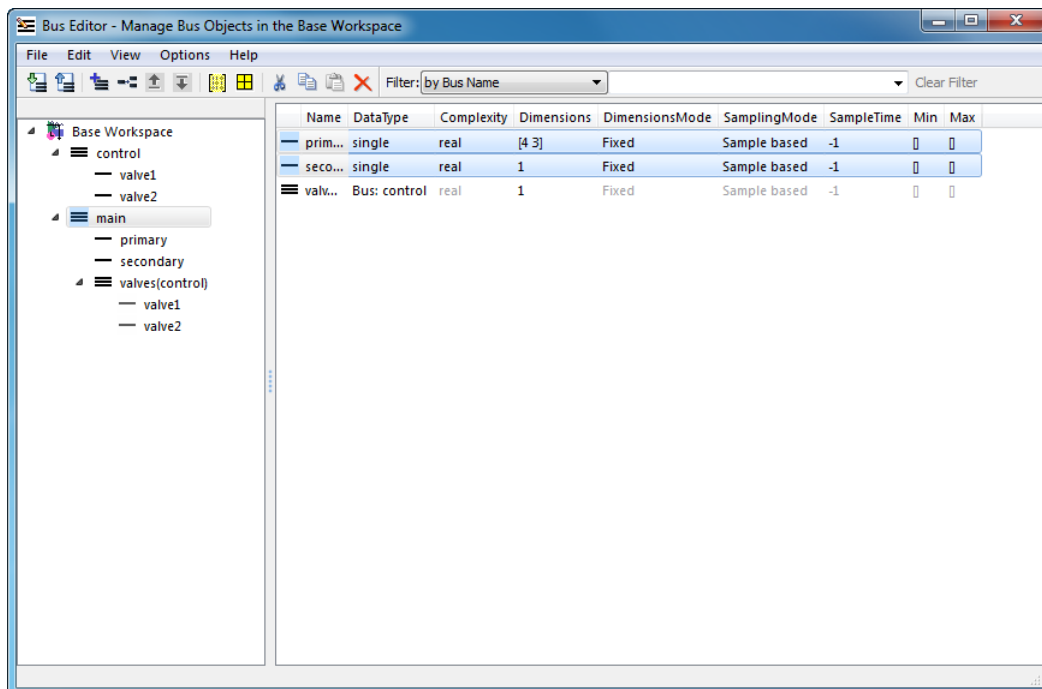
Choose **View > Dialog View** to hide the Dialog pane to provide more room to display properties in the Contents pane. Choose the command again to redisplay the Dialog pane.

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 **Data Type** property selected for editing in the second element:

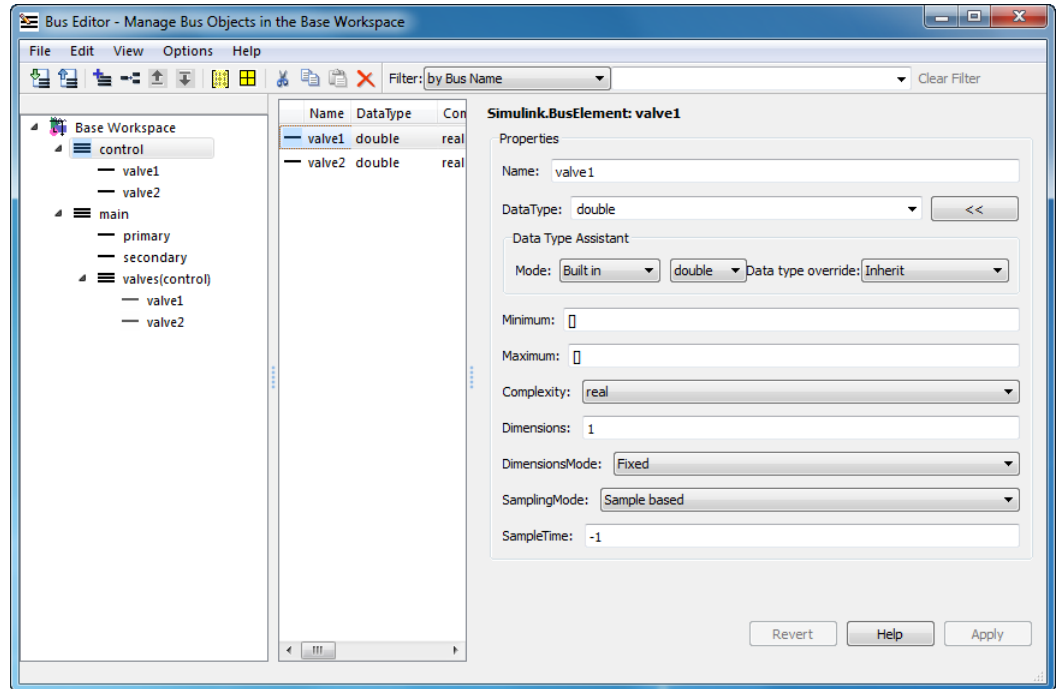


If you change the value of **Data Type** to **single** and press Return, the value changes for both elements. The effect is the same no matter which element you edit in a multiple selection:

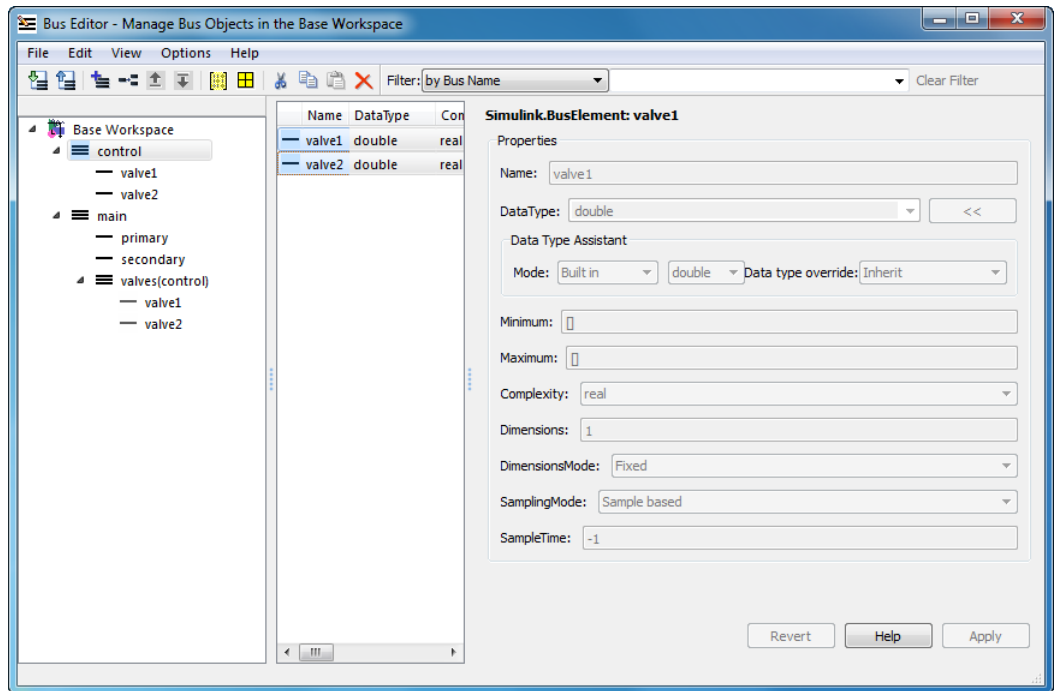


### Editing in the Dialog Pane

When a bus object is selected in the Hierarchy pane, or a bus object or element is selected in the Contents pane, the properties of the selected item appear in the Dialog pane. In the next figure, `valve1` is selected in the Contents pane, so the Dialog pane shows its properties:



The properties shown in the Dialog pane are editable, and the pane includes the Data Type Assistant. Click **Apply** to save changes, or **Revert** to cancel them and restore the values that existed before any unapplied changes. You can edit only one element at a time in the Dialog pane. If multiple entities are selected in the Contents pane, all fields in the Dialog pane are grayed out:



If you use the Dialog pane to change any property of a bus entity, then navigate elsewhere without clicking either **Apply** or **Revert**, a query box appears by default. The query box asks whether to apply changes, ignore changes, or continue as if the navigation had not been tried. You can suppress this query for future operations by checking **Never ask me again** in the box, or by selecting **Options > Auto Apply/Ignore Dialog Changes**.

If you suppress the query, and thereafter navigate away from a change without clicking **Apply** or **Revert**, the Bus Editor automatically applies or discards changes, depending on which action you most recently chose in the box. You can re-enable the query box for future operations by deselecting **Options > Auto Apply/Ignore Dialog Changes**.



## Exporting Bus Objects

Like all base workspace objects, bus objects are not saved with a model that uses them, but exist separately in a MATLAB code file or MAT-file. You can use the Bus Editor to export some or all bus objects to either type of file.

- If you export bus objects to a MATLAB code file, the Bus Editor asks whether to store them in object format or cell format (the default). Specify the desired format.
- If exporting would overwrite an existing MATLAB code file or MAT-file, a confirmation dialog box appears. Confirm the export or cancel it and try a different filename.

To export all bus objects from the base workspace to a file:

- 1** Choose **File > Export to File**.

The Export dialog box appears.

- 2** Specify the desired name and format of the export file.
- 3** Click **Save**.

All bus objects, and nothing else, are exported to the specified file in the specified format.

To export only selected bus objects from the base workspace to a file:

- 1** Select a bus object in the Hierarchy pane, or one or more bus objects in the Contents pane.
- 2** Right-click to display the Context menu.
- 3** Choose **Export to File** to export only the selected bus objects, or **Export with Related Bus Objects to File** to also export any nested bus objects used by the selected objects.
- 4** Use the Export dialog box to export the selected bus object(s).

Clicking the **Export** icon in the toolbar is equivalent to choosing **File > Export**, which exports all bus objects whether or not any are selected.

### **Customizing Bus Object Export**

You can customize bus object export by providing a custom function that writes the exported objects to something other than the default destination, a MATLAB code file or MAT-file stored in the file system. For example, the exported bus objects could be saved as records in a corporate database. See “Customizing Bus Object Import and Export” on page 32-49 for details.

### **Importing Bus Objects**

You can use the Bus Editor to import the definitions in a MATLAB code file or MAT-file to the base workspace. Importing the file imports the complete contents of the file, not just any bus objects that it contains. If you import a file not exported by the Bus Editor, be careful that it does not contain unwanted definitions previously exported from the base workspace or created programmatically.

To import bus objects from a file to the base workspace:

- 1** Choose **File > Import into Base Workspace**.
- 2** Use the Open File dialog box to navigate to and import the desired file.

Before importing the file, the Bus Editor posts a warning that importing the file will overwrite any variable in the base workspace that has the same name as an entity in the file. Click **Yes** or **No** as appropriate. The imported bus objects appear immediately in the editor. You can also use capabilities outside the Bus Editor to import bus objects. Such objects do not appear in the Bus Editor until the next time its window becomes the current window.

### **Customizing Bus Object Import**

You can customize bus object import by providing a custom function that imports the objects from something other than the default source, a MATLAB code file or MAT-file stored in the file system. For example, the bus objects could be retrieved from records in a corporate database. See “Customizing Bus Object Import and Export” on page 32-49 for details.

## Closing the Bus Editor

To close the Bus Editor, choose **File > Close**. Closing the Bus Editor neither saves nor discards changes to bus objects, which remain unaffected in the base workspace. However, if you also close MATLAB without saving changes to bus objects, the changes will be lost. To save bus objects without saving other base workspace contents, use the techniques described in “Exporting Bus Objects” on page 32-39. You can also save bus objects using any MATLAB technique that saves the contents of the base workspace, but the resulting file will contain everything in the base workspace, not just bus objects.

You can configure the Bus Editor so that closing it posts a reminder to save bus objects. To enable the reminder, select **Options > Always Warn Before Closing**. When this option is selected and you try to close the Bus Editor, a reminder appears that asks whether the editor should save bus objects before closing. Click **Yes** to save bus objects and close, **No** to close without saving bus objects, or **Cancel** to dismiss the reminder and continue in the Bus Editor. You can disable the reminder by deselecting **Options > Always Warn Before Closing**.

## Filtering Displayed Bus Objects

### In this section...

“Filtering by Name” on page 32-43

“Filtering by Relationship” on page 32-44

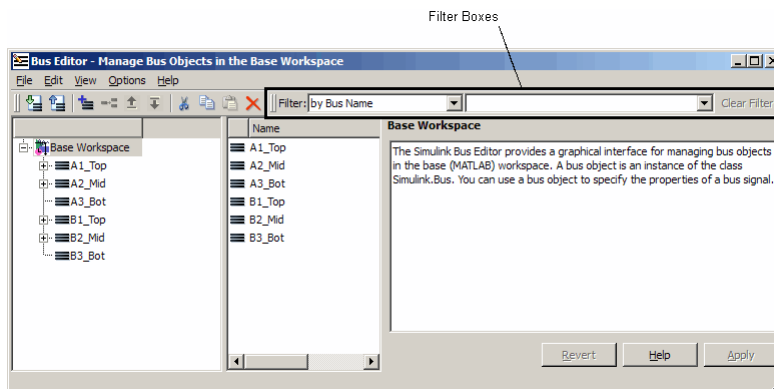
“Changing Filtered Objects” on page 32-47

“Clearing the Filter” on page 32-47

By default, the Bus Editor displays all bus objects that exist in the base workspace, always in alphabetical order. When a model contains large numbers of bus objects, seeing them all at the same time can be inconvenient. To facilitate working efficiently with large collections of bus objects, you can set the Bus Editor to display only bus objects that:

- Have names that match a given string or regular expression
- Have a specified relationship to a bus object specified by name

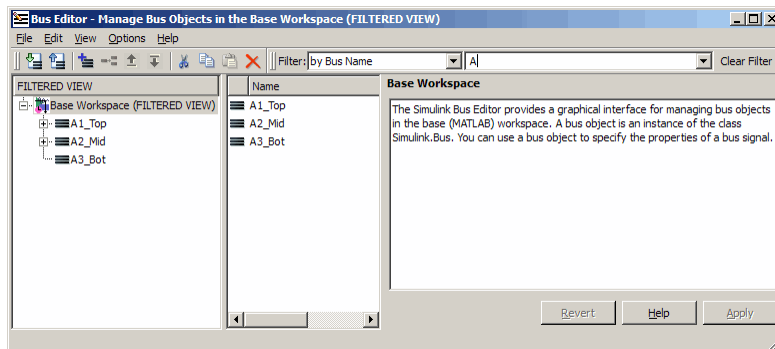
To set a filter, you specify values in the **Filter** boxes to the right of the tools in the toolbar. The left **Filter** box specifies the type of filtering. This box always appears, and is called the **Filter Type** box. Depending on the specified type of filtering, one or two boxes appear to the right of the **Filter Type** box. The next figure indicates the **Filter** boxes and shows that six bus objects exist in the Base Workspace:



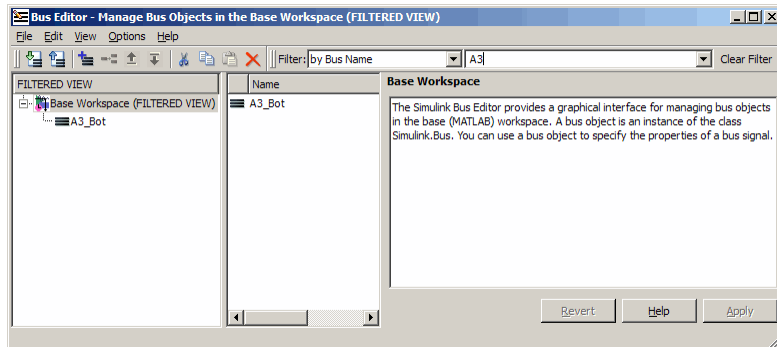
The bus objects shown form two disjoint hierarchies. A1\_Top is the parent of A2\_Mid, which is the parent of A3\_Bot. Similarly, B1\_Top > B2\_Mid > B3\_Bot. See “Nesting Buses” on page 32-12 for information about bus object hierarchies.

## Filtering by Name

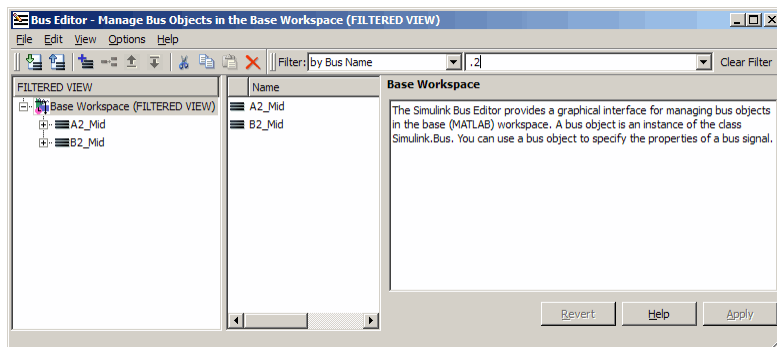
To filter bus objects by name, set the **Filter Type** box to by Bus Name (which is the default). The right **Filter** box is the **Object Name** box. Type any MATLAB regular expression (which can just be a string) into the **Object Name** box. As you type, the Bus Editor updates dynamically to show only bus objects whose names match the expression you have typed. The comparison is case-sensitive. For example, entering A displays:



Note that **FILTERED VIEW** appears in three locations, as shown in the preceding figure. This indicator appears whenever any filter is in effect. Entering the additional character 3 into the **Object Name** box displays:



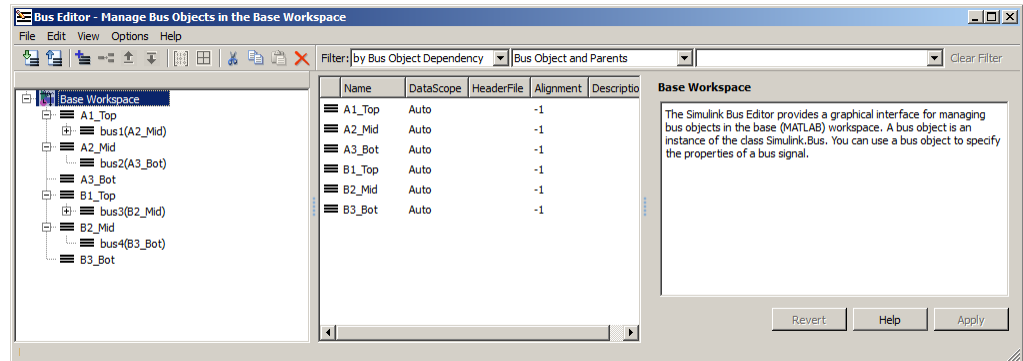
In a MATLAB regular expression, the metacharacter dot (.) matches any character, so entering .2 displays:



See “Regular Expressions” for complete information about MATLAB regular expression syntax.

### Filtering by Relationship

To filter bus objects by relationship, set the **Filter Type** box to by Bus Object Dependency. A third **Filter** box, called the **Relationship** box, appears between the **Filter Type** box and the **Object Name** box. You may have to widen the Bus Editor to see all three boxes:



In the **Relationship** box, select the type of relationship to display. The options are:

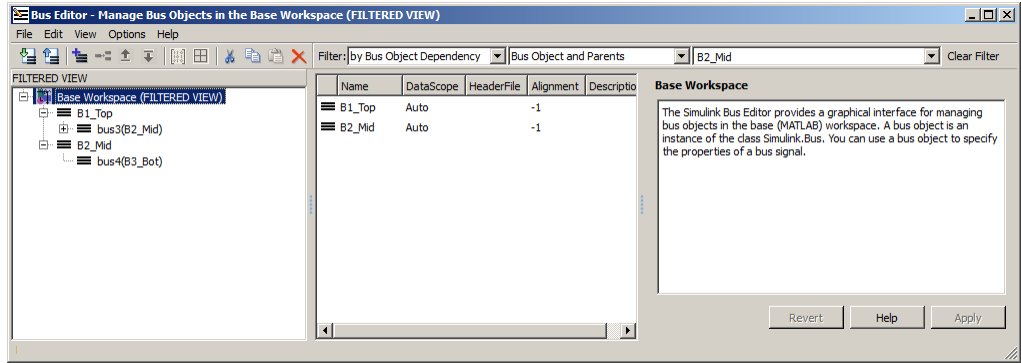
- **Bus Object and Parents** — Show a specified bus object and all superior bus objects in the hierarchy (default)
- **Bus Object and Dependents** — Show a specified bus object and all subordinate bus objects in the hierarchy
- **Bus Object and Related Objects** — Show a specified bus object and all superior and subordinate bus objects

In the **Object Name** box, specify a bus object by name. You can use the list to select any existing bus object name, or you can type a name. As you type, the editor:

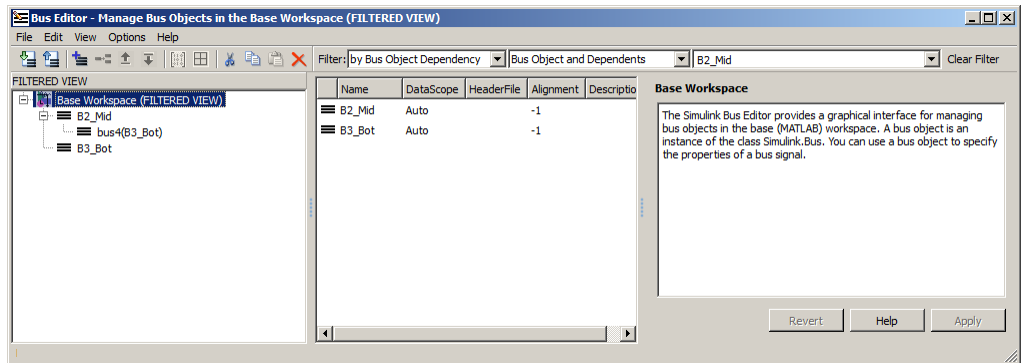
- Dynamically completes the field to indicate the first bus object that alphabetically matches what you have typed.
- Updates the display panes to show only that object and any objects that have the specified relationship to it.

When filtering by relationship, you must enter a string, not a regular expression, in the **Object Name** box. The match is case-sensitive. For example, assuming that A1\_Top is the parent of A2\_Mid, which is the parent of A3\_Bot (as previously described) if you enter B2 (or any leftmost substring that matches only B2\_Mid) in the **Object Name** box, the Bus Editor displays the following for each of the three choices of relationship type:

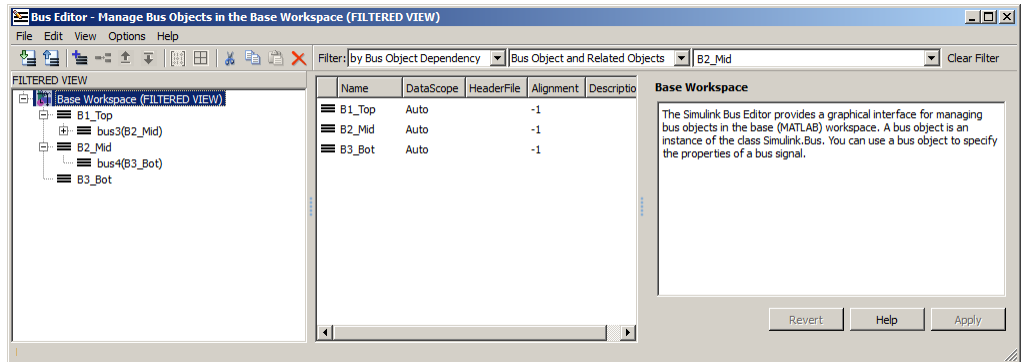
### Bus Object and Parents



## Bus Object and Dependents



## Bus Object and Related Objects





Note that **FILTERED VIEW** appears in each the preceding figures, as it does when any filter is in effect.

## Changing Filtered Objects

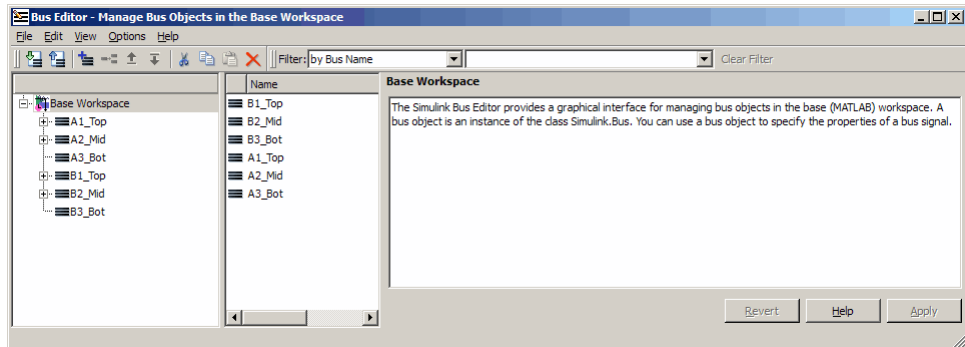
You can work with any bus object that is visible in a filtered display exactly as you could in an unfiltered display. If you change the name or dependency of an object so that it no longer passes the current filter, the object vanishes from the display. Conversely, if some activity outside the Bus Editor changes a filtered object so that it passes the current filter, the object immediately becomes visible.

A new bus object created within the Bus Editor with a filter in effect may or may not appear, depending on the filter. If you create a new bus object but do not see it in the editor, check the filter. The new object (whose name always begins with `BusObject`) may exist but be invisible. Bus objects created or imported using capabilities outside the Bus Editor are not visible until the Bus Editor window is next selected, regardless of whether a filter is in effect.

Operations performed on the root node **Base Workspace** in the Hierarchy pane, such as exporting bus objects, affect only visible objects. An object that is invisible because a filter is in effect is unaffected by the operation. If you want to export all existing bus objects, be sure to clear any filter that may be in effect before performing the export.

## Clearing the Filter

To clear any filter currently in effect, click the **Clear Filter** button at the right of the Filter subpane, or press the **F5** key. The subpane reverts to its default state, in which all bus objects appear:



If you jump from a nested bus object to its source object by selecting the nested object and choosing **Go to 'element'** from its Context menu, and the source object is invisible due to a filter, the Bus Editor automatically clears the filter and selects the source object. Jumping to an object that is already visible leaves the filter unchanged.

## Customizing Bus Object Import and Export

In this section...
“Prerequisites for Customization” on page 32-50
“Writing a Bus Object Import Function” on page 32-50
“Writing a Bus Object Export Function” on page 32-51
“Registering Customizations” on page 32-52
“Changing Customizations” on page 32-53

You can use the Bus Editor to import bus objects to the base workspace, as described in “Importing Bus Objects” on page 32-40, and to export bus objects from the base workspace, as described in “Exporting Bus Objects” on page 32-39. By default, the Bus Editor can import bus objects only from a MATLAB code file or MAT-file, and can export bus objects only to a MATLAB code file or MAT-file, with the files stored somewhere that is accessible using an ordinary **Open** or **Save** dialog.

Alternatively, you can customize the Bus Editor’s import and export commands by writing MATLAB functions that provide the desired capabilities, and registering these functions using the Simulink Customization Manager. When a custom bus object import or export function exists, and you use the Bus Editor to import or export bus objects, the editor calls the custom import or export function rather than using its default capabilities.

A customized import or export function can have any desired effect and use any available technique. For example, rather than storing bus objects in MATLAB code files or MAT-files in the file system, you could provide customized functions that store the objects as records in a corporate database, perhaps in a format that also meets other corporate data management requirements.

This section describes techniques for designing and implementing a custom bus object import or export function, and for using the Simulink Customization Manager to register such a custom function. The registration process establishes the custom import and export functions as callbacks for the Bus Editor **Import to Base Workspace** and **Export to File** commands, replacing the default capabilities of the editor.

Customizing the Bus Editor's import and export capabilities has no effect on any MATLAB or Simulink API function: it affects only the behavior of the Bus Editor. You can customize bus object import, export, or both. You can establish, change, and cancel import or export customization at any time. Canceling import or export customization restores the default Bus Editor capabilities for that operation without affecting the other.

## Prerequisites for Customization

To perform bus object import or export customization, you must understand:

- The MATLAB language and programming techniques that you will need. See *MATLAB Programming Fundamentals* and related MATLAB documentation for information about MATLAB programming.
- Simulink bus object syntax. See “About Bus Objects” on page 32-15, `Simulink.Bus`, `Simulink.BusElement`, and “Nesting Bus Definitions” on page 32-29.
- The proprietary format into which you will translate bus objects, and all techniques necessary to access the facility that stores the objects.
- Any platform-specific techniques needed to obtain data from the user, such as the name of the location in which to store or access bus objects.

The rest of the information that you will need, including all necessary information about the Simulink Customization Manager appears in this section. For complete information about the Customization Manager, see Chapter 34, “Customizing the Simulink User Interface”.

## Writing a Bus Object Import Function

A callback function that customizes bus import can use any MATLAB programming construct or technique. The function can take zero or more arguments, which can be anything that the function needs to perform its task. You can use functions, global variables, or any other MATLAB technique to provide argument values. The function can also poll the user for information, such as a designation of where to obtain bus object information. The general algorithm of a custom bus object import function is:

- 1 Obtain bus object information from the local repository.

- 2** Translate each bus object definition to a Simulink bus object.
- 3** Save each bus object to the MATLAB base workspace.

An example of the syntactic shell of an import callback function is:

```
function myImportCallback
disp('Custom import was called!');
```

Although this function does not import any bus objects, it is syntactically valid and could be registered with the Simulink Customization Manager. A real import function would somehow obtain a designation of where to obtain the bus object(s) to import; convert each one to a Simulink bus object; and store the object in the base workspace. The additional logic needed is enterprise-specific.

## Writing a Bus Object Export Function

A callback function that customizes bus export can use any MATLAB programming construct or technique. The function must take one argument, and can take zero or more additional arguments, which can be anything that the function needs to perform its task. When the Bus Editor calls the function, the value of the first argument is a cell array containing the names of all bus objects selected within the editor to be exported. You can use functions, global variables, or any other MATLAB technique to provide values for any additional arguments. The general algorithm of a customized export function is:

- 1** Iterate over the list of object names in the first argument.
- 2** Obtain the bus object corresponding to each name.
- 3** Translate the bus object to the proprietary syntax.
- 4** Save the translated bus object in the local repository.

An example of the syntactic shell of such an export callback function is:

```
function myExportCallback(selectedBusObjects)
disp('Custom export was called!');
for idx = 1:length(selectedBusObjects)
```

```
    disp([selectedBusObjects{idx} ' was selected for export.']);  
end
```

Although this function does not export any bus objects, it is syntactically valid and could be registered. It accepts a cell array of bus object names, iterates over them, and prints each name. A real export function would use each name to retrieve the corresponding bus object from the base workspace; convert the object to proprietary format; and store the converted object somewhere. The additional logic needed is enterprise-specific.

## Registering Customizations

To customize bus object import or export, you provide a *customization registration function* that inputs and configures the Customization Manager whenever you start the Simulink software or subsequently refresh Simulink customizations. The steps for using a customization registration function are:

- 1** Create a file named `sl_customization.m` to contain the customization registration function (or use an existing customization file).
- 2** At the top of the file, create a function named `sl_customization` that takes a single argument (or use the customization function in an existing file). When the function is invoked, the value of this argument will be the Customization Manager.
- 3** Configure the `sl_customization` function to set `importCallbackFcn` and `exportCallbackFcn` to be function handles that specify your customized bus object import and export functions.
- 4** If `sl_customization.m` is a new customization file, put it anywhere on the MATLAB search path. Two frequently-used locations are `matlabroot` and the current working directory; or you may want to extend the search path.

A simple example of a customization registration function is:

```
function sl_customization(cm)  
disp('My customization file was loaded.');
```

```
cm.BusEditorCustomizer.importCallbackFcn = @myImportCallBack;  
cm.BusEditorCustomizer.exportCallbackFcn = @(x)myExportCallBack(x);
```

When the Simulink software starts up, it traverses the MATLAB search path looking for files named `sl_customization.m`. The software loads each such file that it finds (not just the first file) and executes the `sl_customization` function at its top, establishing the customizations that the function specifies.

Executing the previous customization function will display a message (which an actual function probably would not) and establish that the Bus Editor uses a function named `myImportCallback()` to import bus objects, and a function named `myImportCallback(x)` to export bus objects.

The function corresponding to a handle that appears in a callback registration need not be defined when the registration occurs, but it must be defined when the Bus Editor later calls the function. The same latitude and requirement applies to any functions or global variables used to provide the values of any additional arguments.

Other functions can also exist in the `sl_customization.m` file. However, the Simulink software ignores files named `sl_customization.m` except when it starts up or refreshes customizations, so any changes to functions in the customization file will be ignored until one of those events occurs. By contrast, changes to other MATLAB code files on the MATLAB path take effect immediately.

## Changing Customizations

You can change the handles established in the `sl_customization` function by changing the function to specify the changed handles, saving the function, then refreshing customizations by executing:

```
sl_refresh_customizations
```

The Simulink software then traverses the MATLAB path and reloads all `sl_customization.m` files that it finds, executing the first function in each one, just as it did on Simulink startup.

You can revert to default import or export behavior by setting the appropriate `BusEditorCustomizer` element to `[]` in the `sl_customization` function, then refreshing customizations. Alternatively, you can eliminate both customizations in one operation by executing:

```
cm.BusEditorCustomizer.clear
```

where `cm` was previously set to a customization manager object (see “Registering Customizations” on page 32-52).

Changes to the import and export callback functions themselves, as distinct from changes to the handles that register them as customizations, take effect immediately unless they are in the `sl_customization.m` file itself, in which case they take effect next time you refresh customizations. Keeping the callback functions in separate files usually provides more flexible and modular results.



## Using the Bus Object API

The Simulink software provides all Bus Editor capabilities programmatically. Many of these capabilities, like importing and exporting MATLAB code files and MAT-files, are not specific to bus objects, and are described elsewhere in the MATLAB and Simulink documentation.

The classes that implement bus objects are:

`Simulink.Bus`

Specify the properties of a signal bus

`Simulink.BusElement`

Describe an element of a signal bus

The functions that create and save bus objects are:

`Simulink.Bus.createObject`

Create bus objects for blocks, optionally saving them in a MATLAB file in a specified format

`Simulink.Bus.cellToObject`

Convert a cell array containing bus information to bus objects in the base workspace

`Simulink.Bus.objectToCell`

Convert bus objects in the base workspace to a cell array containing bus information

`Simulink.Bus.save`

Export specified bus objects or all bus objects from the base workspace to a MATLAB file in a specified format

`Simulink.Bus.createMATLABStruct`

Create MATLAB structure with same hierarchy, names, and attributes as the bus signal

In addition, when you use `Simulink.SubSystem.convertToModelReference` to convert an atomic subsystem to a referenced model, you can save any bus objects created during the conversion to a MATLAB file.

## Virtual and Nonvirtual Buses

### In this section...

“Introduction” on page 32-56

“Creating Nonvirtual Buses” on page 32-56

“Nonvirtual Bus Sample Times” on page 32-57

“Automatic Bus Conversion” on page 32-58

“Explicit Bus Conversion” on page 32-58

### Introduction

A bus signal can be *virtual*, meaning that it is just a graphical convenience that has no functional effect, or *nonvirtual*, meaning that the signal occupies its own storage. During simulation, a block connected to a virtual bus reads inputs and writes outputs by accessing the memory allocated to the component signals. These signals are typically noncontiguous, and no intermediate memory exists. Simulation results and generated code are exactly the same as if the bus did not exist, which functionally it does not.

By contrast, a block connected to a nonvirtual bus reads inputs and writes outputs by accessing copies of the component signals. The copies are maintained in a contiguous area of memory allocated to the bus. Such a bus is represented by a structure in generated code, which can be helpful when tracing the correspondence between the model and the code.

Compared with nonvirtual buses, virtual buses reduce memory requirements because they do not require a separate contiguous storage block, and execute faster because they do not require copying data to and from that block. Not all blocks can accept buses. See “Bus-Capable Blocks” on page 32-14 for more about which blocks can handle which types of buses. Virtual buses are the default except where nonvirtual buses are explicitly required. See “Connecting Buses to Inports and Outports” on page 32-59 for more information.

### Creating Nonvirtual Buses

Bus signals do not specify whether they are virtual or nonvirtual; they inherit that specification from the block in which they originate. Every block that

creates or requires a nonvirtual bus must have an associated bus object. Those blocks are:

- Bus Creator
- Inport
- Outport

To specify that a bus is nonvirtual:

- 1** Associate the block with a bus object, as described in “Associating Bus Objects with Simulink Blocks” on page 32-16.
- 2** Open the **Block Parameters** dialog of the Bus Creator, Inport, or Outport block.
- 3** Set **Data type** to **Bus**: <object name> and replace <object name> with the bus object name.
- 4** Click **OK** or **Apply**.

The **Signal Attributes** parameter is applicable only to root Inport and Outport blocks, and does not appear in the parameters of a subsystem Inport or Outport block. In a root Outport block, setting **Signal Attributes** > **Output as nonvirtual bus in parent model** specifies that the bus emerging in the parent model is nonvirtual. The bus that is input to the root Outport can be virtual or nonvirtual.

## Nonvirtual Bus Sample Times

All signals in a nonvirtual bus must have the same sample time, even if the elements of the associated bus object specify inherited sample times. Any bus operation that would result in a nonvirtual bus that violates this requirement generates an error.

All buses and signals input to a Bus Creator block that outputs a nonvirtual bus must therefore have the same sample time. You can use a Rate Transition block to change the sample time of an individual signal, or of all signals in a bus, to allow the signal or bus to be included in a nonvirtual bus.

## Automatic Bus Conversion

When updating a diagram prior to simulation or code generation, the Simulink software automatically converts virtual buses to nonvirtual buses where the conversion is possible and prevents an error. For example, referenced models and Stateflow charts require any bus connected to them to be nonvirtual.

The conversion consists of inserting hidden Signal Conversion blocks into the model where needed.

The source block of any virtual bus that is converted to a nonvirtual bus, whether explicitly or automatically, must specify a bus object, as described in “Using Bus Objects” on page 32-15. 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.

## Connecting Buses to Inports and Outports

### In this section...

“Connecting Buses to Root Level Inports” on page 32-59

“Connecting Buses to Root Level Outports” on page 32-59

“Connecting Buses to Nonvirtual Inports” on page 32-59

“Connecting Buses to Model, Stateflow, and MATLAB Function Blocks” on page 32-61

“Connecting Multi-Rate Buses to Referenced Models” on page 32-62

### Connecting Buses to Root Level Inports

If you want a root level Inport of a model to produce a bus signal, in the Inport block parameters dialog box, set **Data type** to **Bus: <object name>** and replace <object name> with the name of the bus object name that defines the bus that the Inport produces. See “Using Bus Objects” on page 32-15 for more information.

### Connecting Buses to Root Level Outports

A root level Outport of a model can accept a virtual bus only if all elements of the bus have the same data type. The Outport block automatically unifies the bus to a vector having the same number of elements as the bus, and outputs that vector.

If you want a root level Outport of a model to accept a bus signal that contains mixed types, in the Outport block parameters dialog box, set **Data type** to **Bus: <object name>** and replace <object name> with the name of the bus object name that defines the bus that the Inport produces. If the bus signal is virtual, it will be converted to nonvirtual, as described in “Automatic Bus Conversion” on page 32-58. See “Using Bus Objects” on page 32-15 more information.

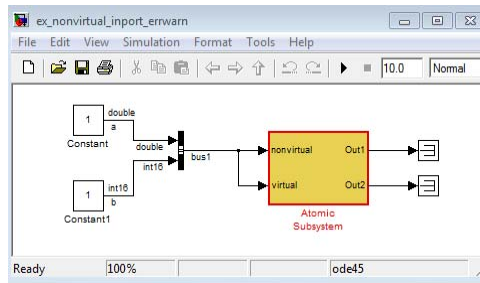
### Connecting Buses to Nonvirtual Inports

By default, an Inport block is a virtual block and accepts a bus as input. However, an Inport block is nonvirtual if it resides in a conditionally executed

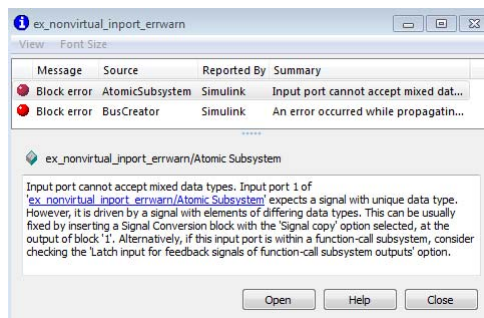
or atomic subsystem, or a referenced model, and it or any of its components is directly connected to an output of the subsystem or model. In such a case, the Inport block can accept a bus only if all elements of the bus have the same data type.

If the components are of differing data types, attempting to simulate the model causes the Simulink software to halt the simulation and display an error message. You can avoid this problem, without changing the semantics of your model, by inserting a Signal Conversion block between the Inport block and the Output block to which it was originally connected.

For example, the following model, which includes an atomic subsystem, does not simulate.

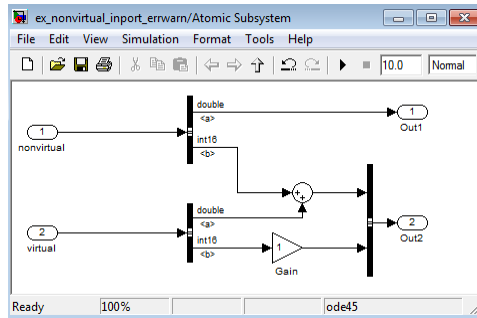


Starting the simulation generates the following error messages:

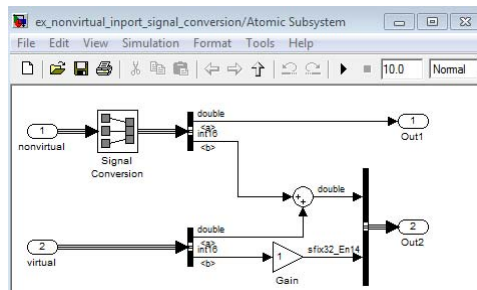


Opening the subsystem reveals that in this model, the Inport block labeled `nonvirtual` is nonvirtual because it resides in an atomic subsystem and one of its components (labeled `a`) is directly connected to one of the subsystem's

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.



## Connecting 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 32-58 for details.

## Connecting Multi-Rate Buses to Referenced Models

In a model that uses a fixed-rate solver, referenced models can input only single-rate buses. However, you can input the signals in a multi-rate bus to a referenced model by inserting blocks into the parent and referenced model as follows:

- 1 In the parent model:** Insert a Rate Transition block to convert the multi-rate bus to a single-rate bus. The Rate Transition block must specify a rate in its **Block Parameters > Output port sample time** field unless one of the following is true:
  - The **Configuration Parameters > Solver** pane specifies a rate:
    - **Periodic sample time constraint** is Specified
    - **Sample time properties** contains the specified rate.
  - The Inport that accepts the bus in the referenced model specifies a rate in its **Block Properties > Signal Attributes > Sample time** field.
- 2 In the referenced model:** Use a Bus Selector block to pick out signals of interest, and use Rate Transition blocks to convert the signals to the desired rates.



## Specifying Initial Conditions for Bus Signals

### In this section...

“Bus Signal Initialization” on page 32-63

“Creating Initial Condition (IC) Structures” on page 32-65

“Three Ways to Initialize Bus Signals Using Block Parameters” on page 32-70

“Setting Diagnostics to Support Bus Signal Initialization” on page 32-74

### Bus Signal Initialization

Bus signal initialization is a special kind of signal initialization. For general information about initializing signals, see “Initializing Signals and Discrete States” on page 31-52.

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.

<b>Task</b>	<b>Documentation</b>
Define an IC structure	“Creating Initial Condition (IC) Structures” on page 32-65
Use an IC structure to specify a nonzero initial condition.	“Three Ways to Initialize Bus Signals Using Block Parameters” on page 32-70
Set Configuration Parameters dialog box diagnostics	“Setting Diagnostics to Support Bus Signal Initialization” on page 32-74

## Creating Initial Condition (IC) Structures

You can create partial or full IC structures to represent initial values for a bus signal. Create an IC structure by either:

- Defining a MATLAB structure in the MATLAB base or Simulink model workspace
- Specifying an expression that evaluates to a structure for the initial condition parameter in the Block Parameters dialog box for a block that supports bus signal initialization

For information about defining MATLAB structures, see “Structures” 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.

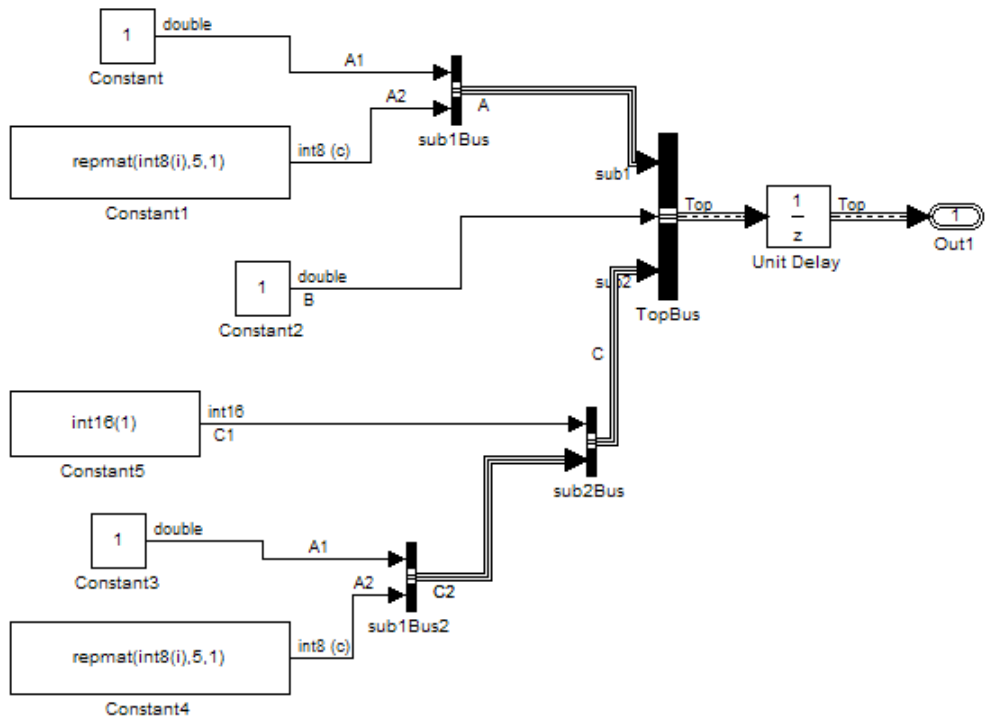
---

### **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, `basic_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 `basic_example` model.

The following table shows valid initial condition specifications.

Valid Syntax	Description
<code>K.A.A1 = 3</code>	Bus element <code>Top.A.A1</code> is double; the corresponding structure field is <code>3</code> , which is a double.
<code>K = struct('C',struct('C1',int16(4)))</code>	Matching data types can require you to cast types. Bus element <code>Top.C.C1</code> is <code>int16</code> . The corresponding structure field explicitly specifies <code>int16(4)</code> .
<code>K = struct('B',3,'A',struct('A1',4))</code>	Bus element <code>Top.B</code> and <code>Top.A</code> 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 `basic_example` model.

These three initial condition specifications are *not* valid:

Invalid Syntax	Reason the Syntax Is Invalid
<code>K.A.A2 = 3</code>	Value data type, dimension, and complexity do not match. <code>Top.A.A2</code> is an <code>int8</code> , but <code>K.A.A2</code> is a double; <code>Top.A.A2</code> is <code>5x1</code> , but <code>K.A.A2</code> is <code>1x1</code> ; <code>Top.A.A2</code> is complex, but <code>K.A.A2</code> is real.
<code>K.C.C2 = 3</code>	You cannot use a scalar to initialize IC substructures.
<code>K = struct('B',3,'X',4)</code>	You cannot specify fields that are not in the bus ( <code>X</code> 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**

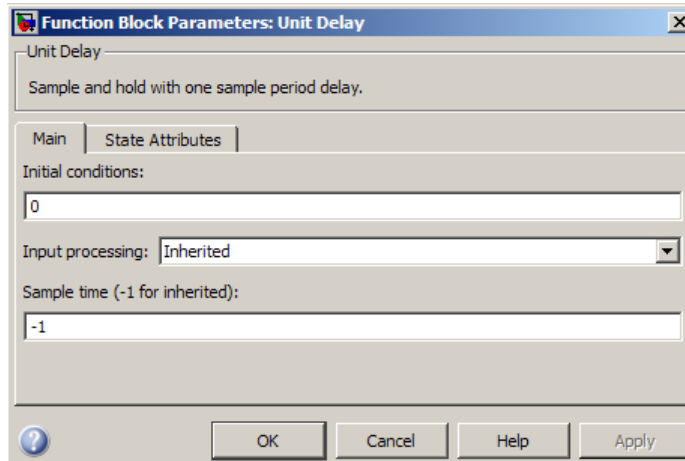
To detect when structure parameters are not consistent in shape (hierarchy and names) with the associated bus signal, in the Model Editor, use the **Tools > Model Advisor > By Product > Simulink** “Check for partial structure parameter usage with bus signals” check. This check identifies partial IC structures.

### **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 32-63).



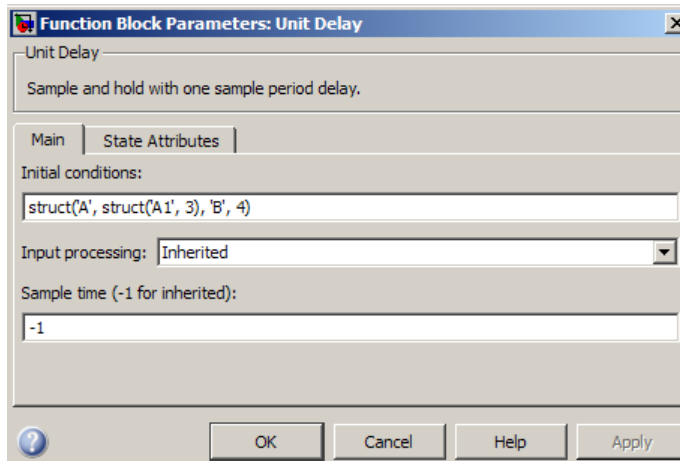
For example, the Block Parameters dialog box for the Unit Delay block has an **Initial conditions** parameter.



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:

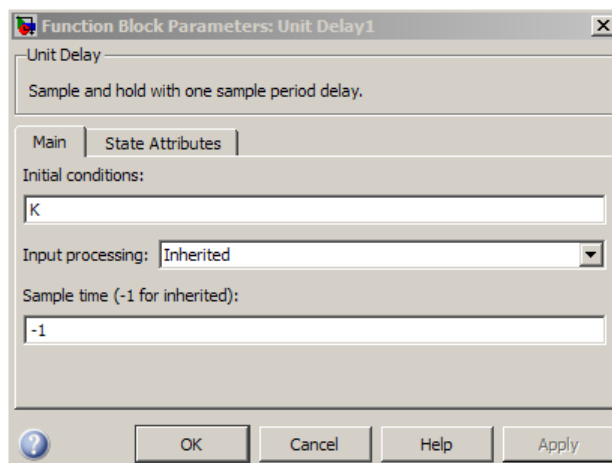


- A MATLAB variable that you define as an IC structure with the appropriate values.

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:

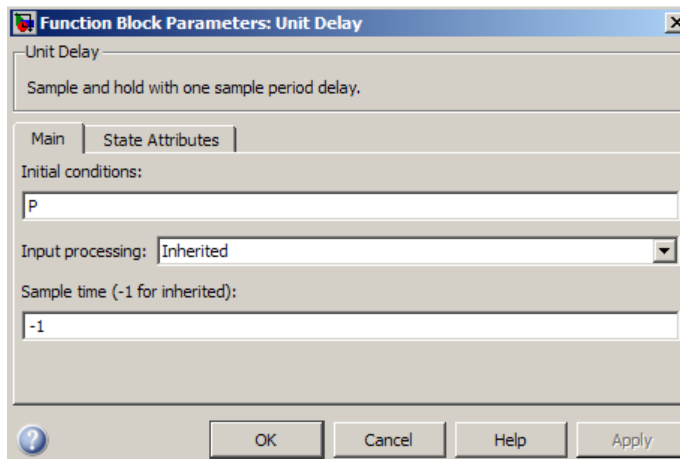


- A `Simulink.Parameter` object that uses an IC structure for the `Value` property

For example, you could define the partial structure `P` in the base workspace (reflecting the basic model discussed in the previous section):

```
P = Simulink.Parameter;
P.Datatype = 'Bus: Top';
P.Value = Simulink.Bus.createMATLABStruct('Top');
P.Value.A.A1 = 3;
P.Value.B = 5;
```

You can then specify the `P` structure as the **Initial conditions** parameter of the Unit Delay block:



All three approaches require that you define an IC structure (see “Creating Initial Condition (IC) Structures” on page 32-65). You cannot specify a nonzero scalar value or any other type of value other than 0, an IC structure, or `Simulink.Parameter` object to initialize a bus signal.

Defining an IC structure as a MATLAB variable, rather than specifying the IC structure directly in the block parameters dialog box offers several advantages, including:

- Reuse of the IC structure for multiple blocks

- Using the IC structure as a tunable parameter during simulation

You can tune the value of a `Simulink.Parameter` object during simulation.

### **Setting Diagnostics to Support Bus Signal Initialization**

To enable bus signal initialization, before you start a simulation, set the following two Configuration Parameter diagnostics as indicated:

- In the **Configuration Parameters > Diagnostics > Connectivity** pane, set “Mux blocks used to create bus signals” to `error`.
- **Configuration Parameters > Diagnostics > Data Validity** pane, set “Underspecified initialization detection” to `simplified`.

The documentation for these diagnostics explains how convert your model to handle error messages the diagnostics generate.

## Combining Buses into an Array of Buses

### In this section...

“What Is an Array of Buses?” on page 32-75

“Benefits of an Array of Buses” on page 32-77

“Blocks That Support Arrays of Buses” on page 32-78

“Array of Buses Limitations” on page 32-79

“Defining an Array of Buses” on page 32-81

“Using an Array of Buses in a Model” on page 32-84

“Generated Code for an Array of Buses” on page 32-87

“Converting a Model to Use an Array of Buses” on page 32-88

### What Is an Array of Buses?

An array of buses is an array whose elements are buses. Each element in an array of buses must be nonvirtual and must have the same bus type. (That is, each bus object has the same signal name, hierarchy, and attributes for its bus elements).

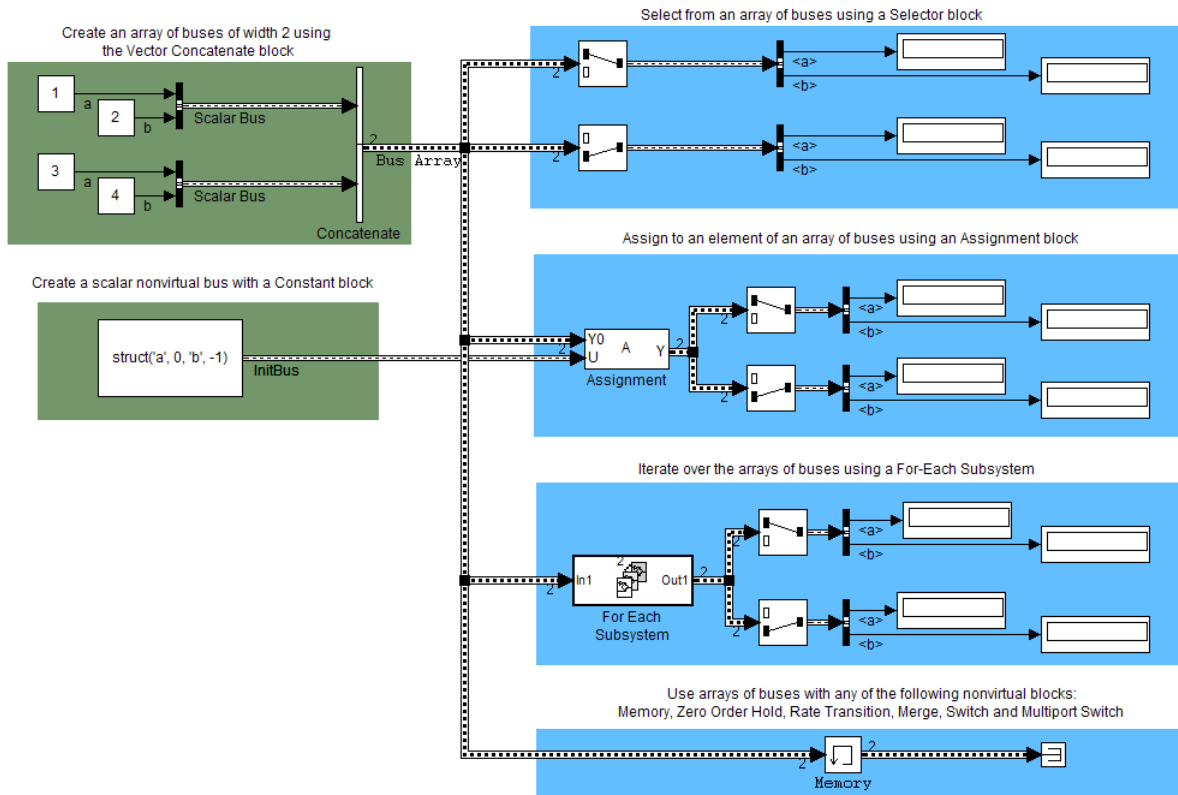
An example of using an array of buses is to model a multi-channel communication system. You can model all the channels using the same bus object, although each of channels could have a different value.

Using arrays of buses involves:

- Using a bus object as a data type (See “Specifying a Bus Object Data Type” on page 27-27.)
- Working with arrays (See “Matrices and Arrays”

To see an example of a model that uses an array of buses, open the `sldemo_bus_arrays` demo. In this demo, the nonvirtual bus input signals connect to a Concatenate block that creates an array of bus signals. When you update the diagram, the demo model looks like the following figure:

Modeling Arrays of Bus Signals



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 32-77
- “Blocks That Support Arrays of Buses” on page 32-78

- “Array of Buses Limitations” on page 32-79

For details about working with an array of buses, see:

- “Defining an Array of Buses” on page 32-81
- “Using an Array of Buses in a Model” on page 32-84
- “Generated Code for an Array of Buses” on page 32-87

For information about converting an existing model to use an array of buses, see “Converting a Model to Use an Array of Buses” on page 32-88.

## **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 20-2)
- 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 32-80.

### **Using Arrays of Buses with Bus-Related Blocks**

To select a signal within an array of buses, first use a Selector block to find the appropriate bus within the vector. Then use a Bus Selector block to select the signal.

To assign to a signal within an array of buses, first use a Bus Assignment block to assign to a bus element. Then 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 you cannot use a Bus Creator block to create array of buses output.

## **Array of Buses Limitations**

### **Bus Limitations**

The buses that you combine into an array must all:

- Be nonvirtual
- Have the same bus type (that is, same name, hierarchies, and attributes for the bus elements)
- Have no variable-size signals or frame-based signals

### **Structure Parameter Limitations**

The following limitations apply to using structure parameters with an array of buses.

You can use:

- 0 as an initial condition for an array of buses

- A scalar **struct** that represents the same hierarchy and names as the array of buses

You *cannot* use:

- Partial structures
- An array of structures
- A structure parameter for an array of buses that has an element that is an array of buses

For more information, see “Specifying Initial Conditions for Bus Signals” on page 32-63.

### 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 32-79.

Block	Block Parameters Limitations
Memory	<b>Initial condition</b> — 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	<ul style="list-style-type: none"> <li>• <b>Allow unequal port widths</b> — Clear this parameter.</li> <li>• <b>Number of inputs</b> — Set to a value of 2 or greater.</li> </ul>

Block	Block Parameters Limitations
	<ul style="list-style-type: none"> <li>• <b>Initial condition</b> — Only this parameter (which may be, but does not have to be, a structure) is scalar-expanded to match the dimensions of the array.</li> </ul>
Multiport Switch	<b>Number of data ports</b> — Set to a value of 2 or greater.
Signal Conversion	<b>Output</b> — Set to Signal copy.
Switch	<b>Threshold</b> — Specify a scalar threshold.

### Simulink Feature Limitations

You cannot:

- Log an array of buses signal
- Import data from or export data to an array of buses.

### Stateflow Limitations

Stateflow action language does not support arrays of buses.

## Defining an Array of Buses

For information about the kinds of buses that you can combine into an array of buses, see “Bus Limitations” on page 32-79.

### 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.

<b>Block</b>	<b>Bus Signal Input Requirement</b>	<b>Output</b>
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 <b>Concatenate dimension</b> parameter.

To use a Concatenate block to define an array of buses, see “How to Define an Array of Buses” on page 32-82.

---

**Note** Do not use a Mux block or a Bus Creator block to define an array of buses. Instead, use a Bus Creator block to create scalar bus signals.

---

### How to Define an Array of Buses

- 1 Define one bus object to use for all the bus signals that you want to combine into an array of buses. For information about defining bus objects, see “Creating Bus Objects” on page 32-23.

The `sldemo_bus_arrays` demo defines an `sldemo_bus_arrays_busobject` bus object, which the Bus Creator blocks use for the input bus signals (Scalar Bus) for the array of buses.

- 2 Add a Vector Concatenate or Matrix Concatenate block to the model and open the block parameters dialog box for the block.

The `sldemo_bus_arrays_busobject` demo uses a Vector Concatenate block, because the inputs are scalars.

- 3** Set the **Number of inputs** parameter to be the number of buses that you want to be in the array of buses.

The block icon displays the number of input ports that you specify.

- 4** Set the **Mode** parameter to match the type of the input bus data.

In the `sldemo_bus_arrays` demo, the input bus data is scalar, so the **Mode** setting is **Vector**.

- 5** If you use a Matrix Concatenation block, set the **Concatenate dimension** parameter to specify the output dimension along which to concatenate the input arrays. Enter one of the following values:

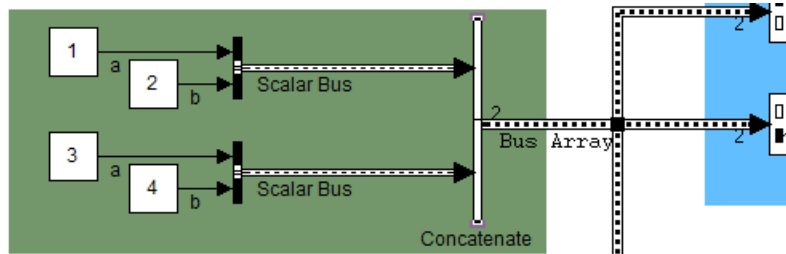
- 1 to concatenate input arrays vertically
- 2 to concatenate input arrays horizontally
- A higher dimension than 2, to perform multidimensional concatenation on the inputs

- 6** Connect the buses that you want to be in the array of buses to the Concatenate block.

### Signal Line Style for an Array of Buses

After you create an array of buses and update the diagram, the line style for the array of buses signal is a thicker version of the signal line style for a nonvirtual bus signal.

For example, in the `sldemo_bus_arrays` demo, the `Scalar Bus` signal is a nonvirtual bus signal, and the `Bus Array` output signal of the Concatenate block is an array of buses signal.



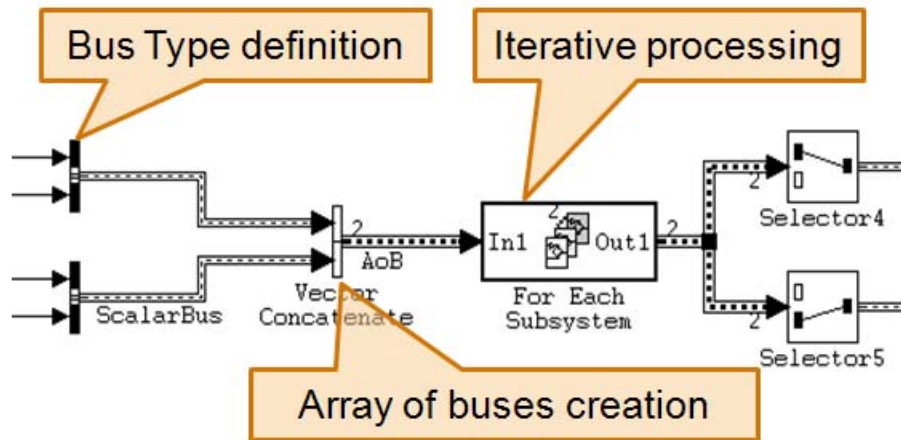
## Using an Array of Buses in a Model

### A General Workflow for Using an Array of Buses in a Model

Setting up a model to use an array of buses usually involves basic tasks similar to these:

- 1** Define the array of buses, as described in “Defining an Array of Buses” on page 32-81.
- 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 32-85.
- 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.



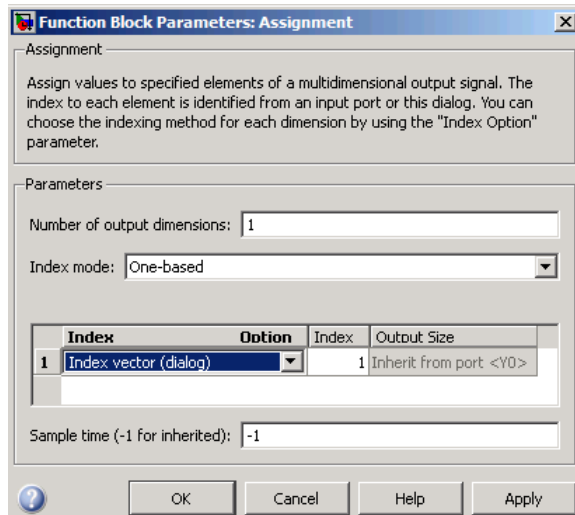
### Performing Iterative Processing with an Array of Buses

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` demo, the Assignment block assigns the value to the first element of the array of buses. The block parameters dialog box looks like the following graphic:



To assign bus elements within a bus signal, use the Bus Assignment block. The input for the Bus Assignment block must be a scalar bus signal.

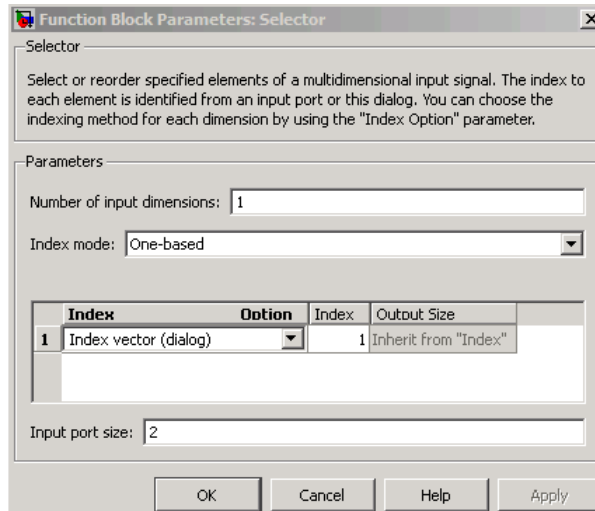
### Selecting Bus Elements from an Array of Buses

Use a Selector block to select elements of an array of buses. The input array of buses can be of any dimensionality.

The output bus signal of the Selector block is a selected or reordered set of elements from the input array of buses.

For example, the `sldemo_bus_arrays` demo uses Selector blocks to select elements from the array of buses signal that the Assignment and For Each Subsystem blocks outputs. The block parameters dialog box for the Selector block that selects the first element looks like the following graphic:





To select bus elements within a bus signal, use the Bus Selector block. The input for the Bus Selector block must be a scalar bus signal.

## Generated Code for an Array of Buses

When you generate code for a model that includes an array of buses, a `typedef` that represents the underlying bus type appears in the `*_types.h` file.

Code generation produces an array of C structures that you can integrate with legacy C code that uses arrays of structures. As necessary, code for bus variables (arrays) are generated in the following structures:

- Block IO
- States
- External inputs
- External outputs

Here is a simplified example of some generated code for an array of buses.

```
typedef struct {  
    real_T a;  
    real_T b;          /* Block signals (auto storage) */  
} BusObject;          typedef struct {  
                        BusObject ForEachSubsystem_IterInp_0[2];  
                        } BlockIO_aob1;
```

## Converting a Model to Use an Array of Buses

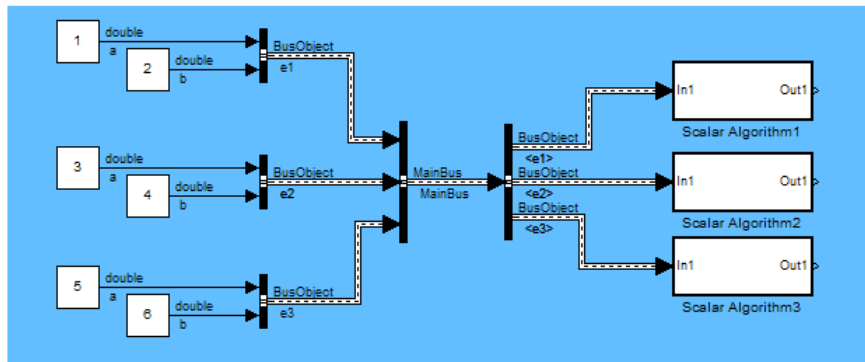
There are several reasons to convert a model to use an array of buses (see “Benefits of an Array of Buses” on page 32-77). For example:

- The model was developed before Simulink supported arrays of buses (introduced in R2010b), and the model contains many subsystems that perform the same kind of processing.
- The model that has grown in complexity.

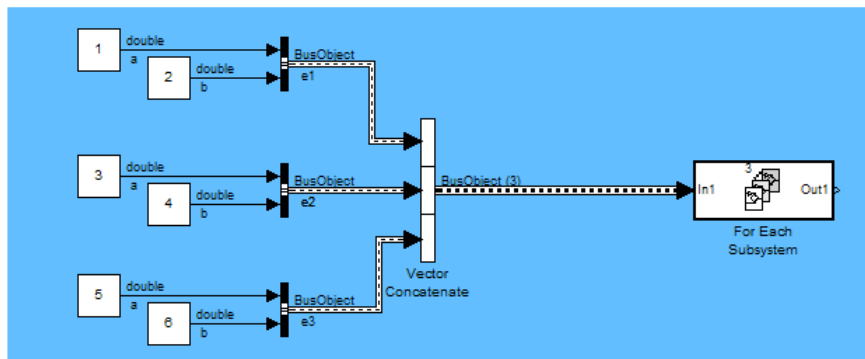
### General Workflow for Converting a Model to Use an Array of Buses

This section presents a general guide to converting a model that contains buses to a model that uses an array of buses. The method that you use depends on your model. For details about these techniques, see “Combining Buses into an Array of Buses” on page 32-75.

This workflow refers to a stylized example model. The example shows the original modeling pattern and a new modeling pattern that uses an array of buses.



Original modeling pattern



New modeling pattern

In the original modeling pattern:

- The target bus signal to be converted is named MainBus, and it has three elements, each of type BusObject.
- The ScalarAlgorithm1, ScalarAlgorithm2, and ScalarAlgorithm3 subsystems encapsulate the algorithms that operate on each of the bus elements. The subsystems all have the same content.
- A Bus Selector block picks out each element of MainBus to drive the subsystems.

The construction in the original modeling pattern is inefficient for two reasons:

- A copy of the subsystem that encapsulates the algorithm is made for each element of the bus that is to be processed.
- Adding another element to `MainBus` involves changing the bus object definition and the Bus Selector block, and adding a new subsystem. Each of these changes is a potential source of error.

To convert the original modeling pattern to use an array of buses:

- 1** Identify the target bus and associated algorithm that you want to convert. Typically, the target bus signal is a bus of buses, where each element bus signal is of the same type.
  - The bus that you convert must be a nonvirtual bus. You can convert a virtual bus to a nonvirtual bus if all elements of the target bus have the same sample time (or if the sample time is inherited).
  - The target bus cannot have variable-dimensioned and frame-based elements.
- 2** Use a Vector Concatenate or Matrix Concatenate block to convert the original bus of buses signal to an array of buses.

In the example, the new modeling pattern uses a Vector Concatenate block to replace the Bus Creator block that creates the `MainBus` signal. The output of the Vector Concatenate block is an array of buses, where the type of the bus signal is `BusObject`. The new model eliminates the wrapper bus signal (`MainBus`).

- 3** Replace all identical copies of the algorithm subsystem with a single For-Each subsystem that encapsulates the scalar algorithm. Connect the array of buses signal to the For-Each subsystem.

The new model eliminates the Bus Selector blocks that separate out the elements of the `MainBus` signal in the original model.

- 4** Configure the For Each Subsystem block to iterate over the input array of buses signal and concatenate the output bus signal.

For limitations, see the For Each Subsystem block documentation; for example, the scalar algorithm within the For-Each subsystem cannot have continuous states.

## Buses and Libraries

When you define a library block, the block can input, process, and output buses just as an ordinary subsystem can. MathWorks recommends not using Bus Selector blocks in library blocks, because such use complicates changing the library blocks and increases the likelihood of errors. When a Bus Selector block appears in a library block, the following considerations and recommendations apply:

- You cannot change a Bus Selector block directly within a library. To change the Bus Selector block, copy the library block that uses it to a model, edit the Bus Selector block within the context of the model, then copy the changed library block back to the library.
- The Inport that feeds the Bus Selector block should have an associated bus object, as described in “Using Bus Objects” on page 32-15. This bus object must be stored in a MATLAB code file or MAT-file, and imported into the base workspace of any model that subsequently uses the library block.
- Any model that uses the library block containing the Bus Selector should set **Configuration Parameters > Connectivity > Element name mismatch** to error. This setting minimizes the possibility of consistency errors at the interface to the library block.

See Chapter 25, “Working with Block Libraries” for information about creating block libraries and copying library blocks to and from them.

## Avoiding Mux/Bus Mixtures

### In this section...

“Introduction” on page 32-93

“Using Diagnostics for Mux/Bus Mixtures” on page 32-94

“Using the Model Advisor for Mux/Bus Mixtures” on page 32-98

“Correcting Buses Used as Muxes” on page 32-99

“Bus to Vector Block Compatibility Issues” on page 32-101

“Avoiding Mux/Bus Mixtures When Developing Models” on page 32-102

### 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 31-11 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 32-94 and “Using the Model Advisor for Mux/Bus Mixtures” on page 32-98 for details.

Another way for a mux/bus mixture to occur is when a virtual bus signal is treated as a mux, such as a bus signal that inputs directly to a Gain block. To detect such mixtures, in the **Configuration Parameters > Diagnostics > Connectivity** pane, set the **Bus signal treated as vector** diagnostic to warning or error.

---

**Note** Do not confuse muxes used as bus elements, which is legal and causes no problems, with mux/bus mixtures. A mux/bus mixture occurs only when some blocks treat a signal as a mux, while other blocks treat that same signal as a bus.

---

## Using Diagnostics for Mux/Bus Mixtures

The **Configuration Parameters > Diagnostics > Connectivity** pane provides the following diagnostics to detect mux/bus mixtures.

Diagnostic	Description
Mux blocks used to create bus signals	Detect and correct muxes that are used as buses
Bus signal treated as vector	Detect and correct buses that are used as muxes (vectors)
Non-bus signals treated as bus signals	Detect when Simulink implicitly converts a non-bus signal to a bus signal

You can use these diagnostics as described in this section, or you can use the Model Advisor to perform the some of these checks and also to obtain advice about corrections, as described in “Consulting the Model Advisor” on page 3-81. For complete information about the **Connectivity** pane, see “Connectivity Diagnostics Overview”.

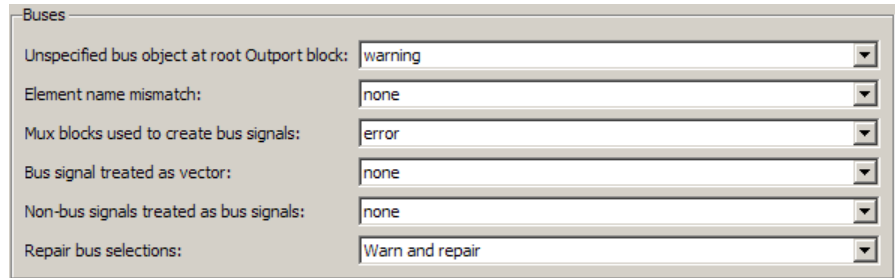
### Mux blocks used to create bus signals

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.



Option	Value
Unspecified bus object at root Output block:	warning
Element name mismatch:	none
Mux blocks used to create bus signals:	error
Bus signal treated as vector:	none
Non-bus signals treated as bus signals:	none
Repair bus selections:	Warn and repair

### 3 Click **OK** or **Apply**.

### 4 Build the model.

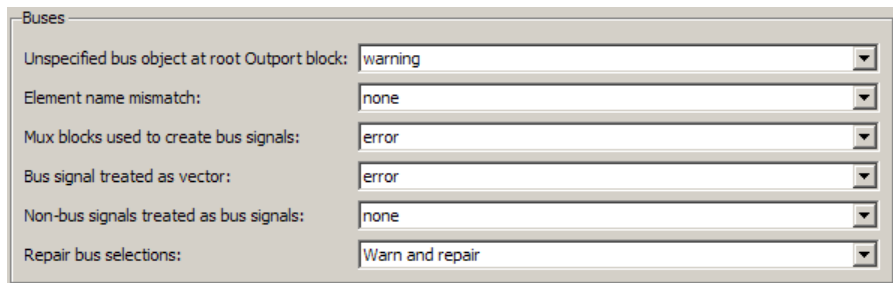
### 5 Replace blocks as needed to correct any cases of Mux blocks used to create buses. You can use the `slreplace_mux` function to replace all such Mux blocks in a single operation.

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 32-94.
- 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 32-99.

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:

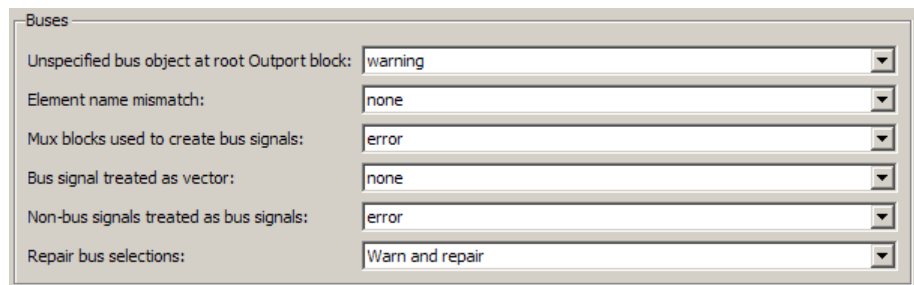
Value of <code>StrictBusMsg</code> (API)	Mux blocks used to create bus signals (GUI)	Bus signal treated as vector (GUI)
None	none	none
Warning	warning	none

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 32-94.
- 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.



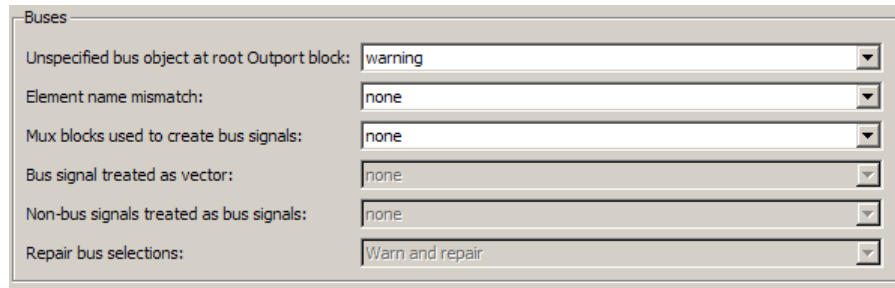
- 4 Click **OK** or **Apply**.
- 5 Build the model.
- 6 Correct the model where needed as described under “Correcting Buses Used as Muxes” on page 32-99.

For complete information about this option, see the reference documentation for “Non-bus signals treated as bus signals”.

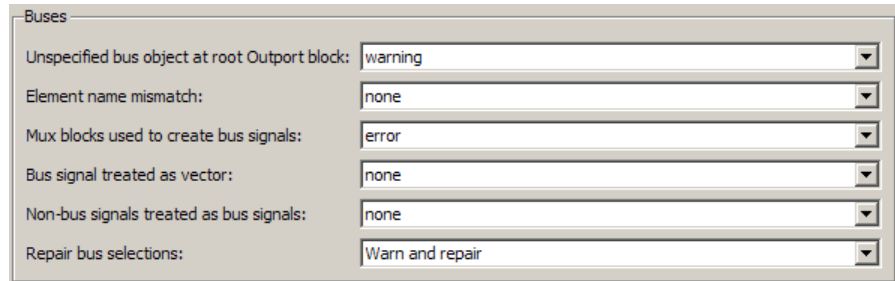
## Using the Model Advisor for Mux/Bus Mixtures

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 `s1replace_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 32-99 to correct any errors discovered by the check.

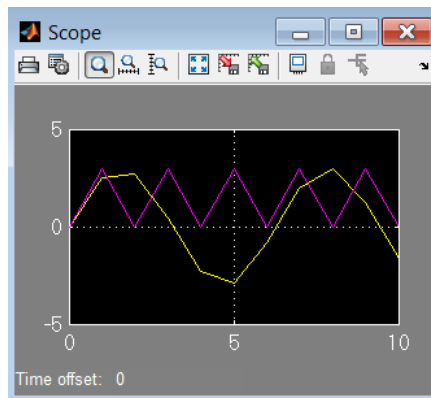
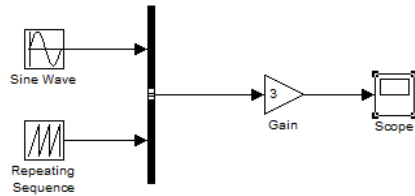
Instructions for using the Model Advisor appear in "Consulting the Model Advisor" on page 3-81.

## Correcting Buses Used as Muxes

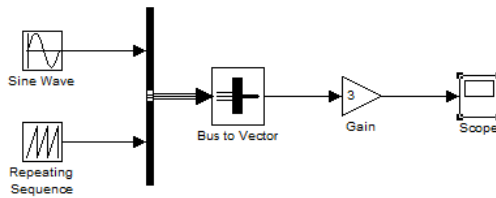
When you discover a bus signal used as a mux, one answer is to reorganize the model by replacing blocks so that the mixture no longer occurs. Where that is undesirable or unfeasible, the Simulink software provides two capabilities to address the problem:

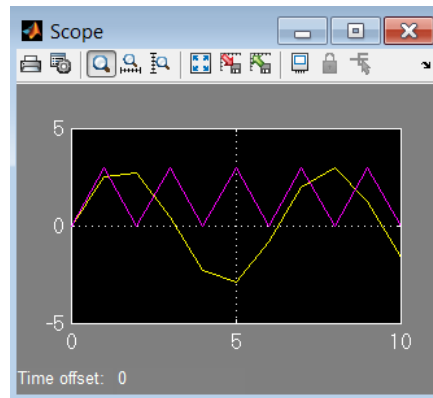
- The Bus to Vector block (Signal Attributes library), which you can insert into any bus used implicitly as a mux to explicitly convert the bus to a mux (vector).
- The `Simulink.BlockDiagram.addBusToVector` function, which automatically inserts Bus to Vector blocks wherever needed.

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

The various techniques for defining buses are essentially equivalent for simulation, but the techniques used can make a significant difference in the efficiency, size, and readability of generated code. For example, a nonvirtual bus appears as a structure in generated code, and only one copy exists of any algorithm that uses the bus. A virtual bus does not appear as a structure or any other coherent unit in generated code, and a separate copy of any algorithm that manipulates the bus exists for each element. Using buses properly results in efficient code and visually clean models. If you intend to generate production code for a model that uses buses, see “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 “Exporting Signal Data Using Signal Logging” on page 29-19.
- 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” on page 33-2
- “Simulink Models Using Variable-Size Signals” on page 33-6
- “S-Functions Using Variable-Size Signals” on page 33-19
- “Simulink Block Support for Variable-Size Signals” on page 33-22
- “Variable-Size Signal Limitations” on page 33-25

## Variable-Size Signal Basics

### In this section...

“About Variable-Size Signals” on page 33-2

“Creating Variable-Size Signals” on page 33-2

“How Variable-Size Signals Propagate” on page 33-3

“Empty Signals” on page 33-4

“Subsystem Initialization of Variable-Size Signals” on page 33-4

### 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 31-2 in the *Simulink User’s Guide*.

A Simulink variable-size signal is a signal whose size (the number of elements in a dimension), in addition to its values, can change during a model simulation. However, during a simulation, the number of dimensions cannot change. This capability allows you to model systems with varying resources, constraints, and environments.

### Creating Variable-Size Signals

You can create variable-size signals in your Simulink model by using:

- Switch or Multiport Switch blocks with different input ports having fixed-size signals with different sizes. The output is a variable-size signal.
- A selector block and the Starting and ending indices (port) indexing option. The index port signal can specify different subregions of the input data signal which produce an output signal of variable size as the simulation progresses.
- The S-function block with the output port configured for a variable-size signal. The output includes not only the values but also the dimension of the signal.

## How Variable-Size Signals Propagate

In the Simulink environment, variable-size signals can change their size during model execution in one of two ways:

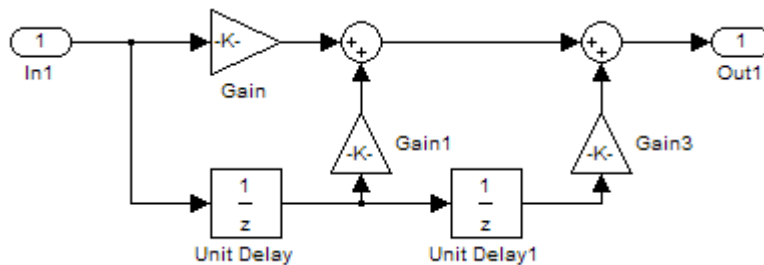
- **At every step of model execution.**

Various blocks in the model modify the sizes of the signals during execution of the output method.

- **Only during initialization of conditionally executed subsystems.**

Size changes occur during distinct mode-switching events in subsystems such as Action, Enable, and Function-Call subsystems.

You can see the key difference by considering a Discrete 2-Tap Filter block with states.



### Discrete 2-Tap Filter

Assume that the input signal dimension to this filter changes from 4 to 1 during simulation. It is ambiguous when and how the states of the Unit Delay blocks should adapt from 4 to 1 to continue processing the input. To ensure consistency, both Unit Delay blocks must change their state behavior synchronously. To prevent ambiguity, Simulink generally disallows blocks whose number of states depends on input signal sizes in contexts where signal sizes change at any point during execution.

In contrast, consider the same Discrete 2-Tap Filter block in a Function-Call subsystem. Assume that this subsystem is using the second way to propagate variable-size signals. In this case, the size of the input signal changes from 4 to 1 only at the initialization of the subsystem. At initialization, the subsystem resets all of its states (including the states of the two Unit Delay

blocks) to their initial values. Resetting the subsystem ensures no ambiguity on the assignment of states to the input signal of the filter.

“Demo of Mode-Dependent Variable-Size Signals” on page 33-13 shows how you can use the two ways of propagating variable-size signals in a complementary fashion to model complex systems.

## Empty Signals

An empty signal is a signal with a length of 0. For example, signals with size [0], [0x3], [2x0], and [2x0x3] are all empty signals. Simulink allows empty signals with variable-size signals and supports most element-wise operations. However, Simulink does not support empty signals for blocks that modify signal dimensions. Unsupported blocks include Reshape, Permute, and Sum along a specified dimension.

## Subsystem Initialization of Variable-Size Signals

The initial signal size from an Output 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 <b>Initial output</b> 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 Output 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 Output block is set to maximum size.
- When its parent subsystem repropagates signal sizes, the values of the subsystem variable-size output signals are also reset to their initial output parameter values.

## Simulink Models Using Variable-Size Signals

In this section...
“Demo of Variable-Size Signal Generation and Operations” on page 33-6
“Demo of Variable-Size Signal Length Adaptation” on page 33-10
“Demo of Mode-Dependent Variable-Size Signals” on page 33-13

### Demo of Variable-Size Signal Generation and Operations

This demo model shows how to create a variable-size signal from multiple fixed-size signals and from a single data signal. It also shows some of the operations you can apply to variable-size signals.

For a complete list of blocks that support variable-size signals, see “Simulink Block Support for Variable-Size Signals” on page 33-22.

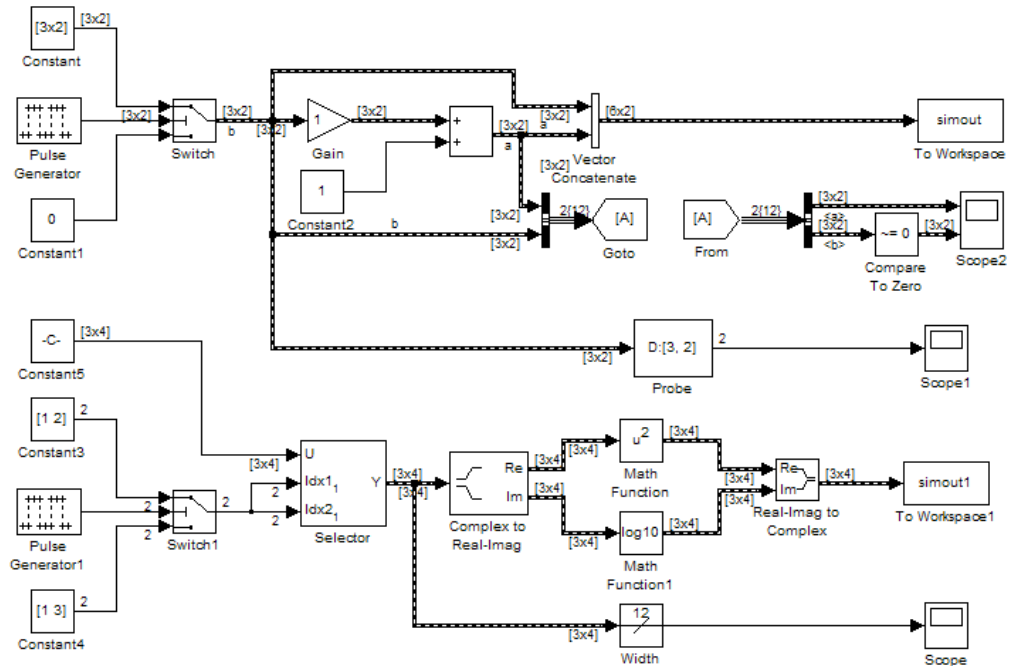
**1** In the MATLAB Command Window, type

```
sldemo_varsize_basic
```

**2** From the **Format** menu, point to **Port/Signal Displays**, and then click **Signal Dimensions**. Run a simulation or press Ctrl-D.

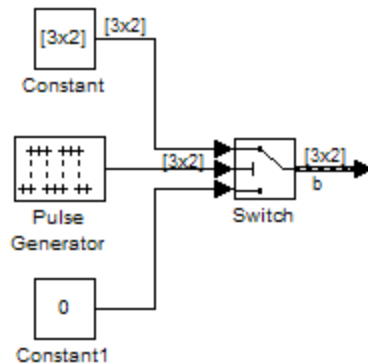
The Simulink editor displays the signal dimensions and line styles. See “Signal Basics” on page 31-2 for an interpretation of signal line styles.





### Creating a Variable-Size Signal from Fixed-Size Signals

One way to create a variable-size signal is to use the Switch block. The input signals to the Switch block can differ in their number of dimensions and in their size.



Output from the Switch block is a 2-D variable-size signal with a maximum size of 3x2. When you select the **Allow different data input sizes** parameter on the Switch block, Simulink does not expand the scalar value from the Constant1 block.

### Saving Variable-Size Signal Data

You could add a To Workspace block to the output from the Switch block. Since the model already has a To Workspace block, the second To Workspace block would save data to a signal array named `simout2`. The `values` field logs the actual signal values. If logged signal data is smaller than the maximum size, values are padded with NaNs or appropriate values. To obtain these signal values, type:

```
simout2.signals.values
```

```
ans(:,:,1) =
```

```
    1    -1  
   -2     2  
   -3     3
```

```
ans(:,:,2) =
```

```
    1    -1  
   -2     2  
   -3     3
```

```
ans(:,:,3) =
```

```
    0    NaN  
   NaN    NaN  
   NaN    NaN
```

The `valueDimensions` field logs the dimensions of a variable-size signal. To obtain the dimensions, type:

```
simout2.signals.valueDimensions
```

The signal dimensions for the first three time steps are shown.

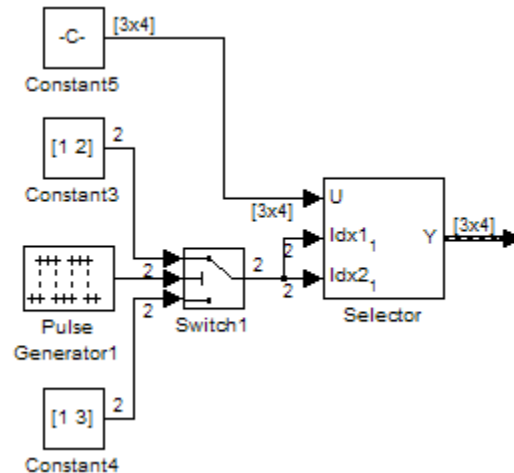
ans =

```

3     2
3     2
1     1
    
```

### Creating a Variable-Size Signal from a Single Data Signal

The data signal (Constant5) is a 3x4 matrix. The Pulse Generator represents a control signal that selects a starting and ending index value ( [1 2] or [1 3] ). The Selector block then uses the index values to select different parts of the data signal at each time step and output a variable-size signal.



### Viewing Changes in Signal Size

The output from the Selector block is either a 2x2 or 3x3 matrix. Because the maximum dimension for a variable-size signal is the 3x4 matrix from the data signal, the logged output signals are padded with NaNs.

Use the Probe or Width blocks to inspect the current dimensions and width of a variable-size signal. In addition, you can display variable-size signals

on Scope blocks and save variable-size signals to the workspace using the To Workspace block.

### Processing Variable-Size Signals

The remainder of the model demonstrates various operations that are possible with variable-size signals. Operations include using the Gain block, the Sum block, the Math Function block, the Matrix Concatenate block. You can connect variable-size signals with the From, Goto, Bus Assignment, Bus Creator, and Bus Selector blocks.

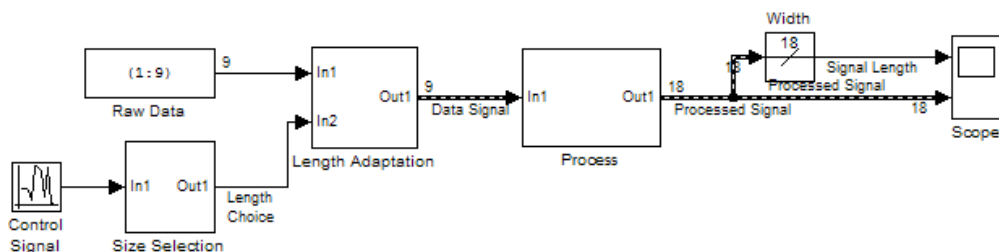
### Demo of Variable-Size Signal Length Adaptation

This demo model corresponds to a hypothetical system where the model adapts the length of a signal over time. Length adaptation is based on the value of a control signal. When the control signal falls within one of three predefined ranges, the fixed-size raw data signal changes to a variable-size data signal.

The variable-size signal connects to a processing block, where blocks that support variable-size signals operate on it. 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 33-22.

To open the demo model, in the MATLAB® Command Window, type:

```
sldemo_varsize_dataLengthAdapt
```



## Creating a Variable-Size Signal by Adapting the Length of a Data Signal

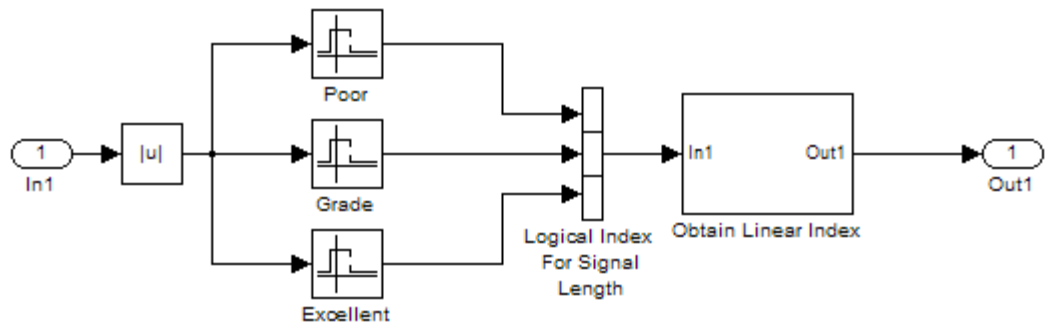
This model generates a data signal and converts the signal to a variable-size signal. The size of the signal depends on the value of a control signal. The raw data signal is a column vector with values from 1 to 9.

```
[1:9].'
```

```
ans =
```

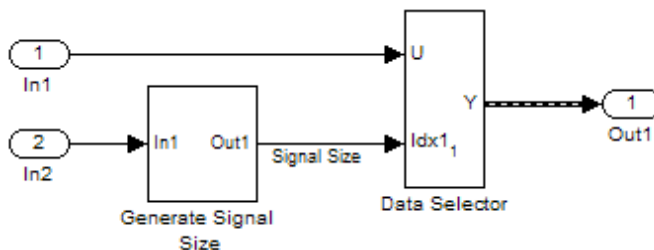
```
1
2
3
4
5
6
7
8
9
```

The Size Selection subsystem determines the quality of the data signal and outputs a quality value ( 1, 2, or 3). This value helps to select the length of the data signal in the Length Adaptation subsystem.



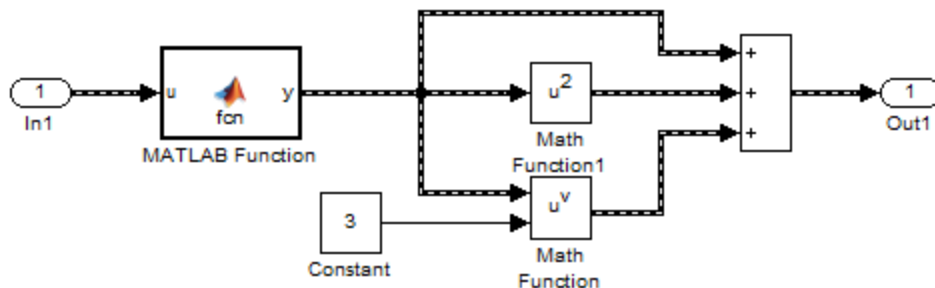
In the Length Adaptation subsystem, the Signal Size subsystem generates an index based on the quality value from the Size Selection subsystem (In2). The

Data Selector block uses the starting and ending indices to adapt the length of the data signal (In1) and output a variable-size signal.



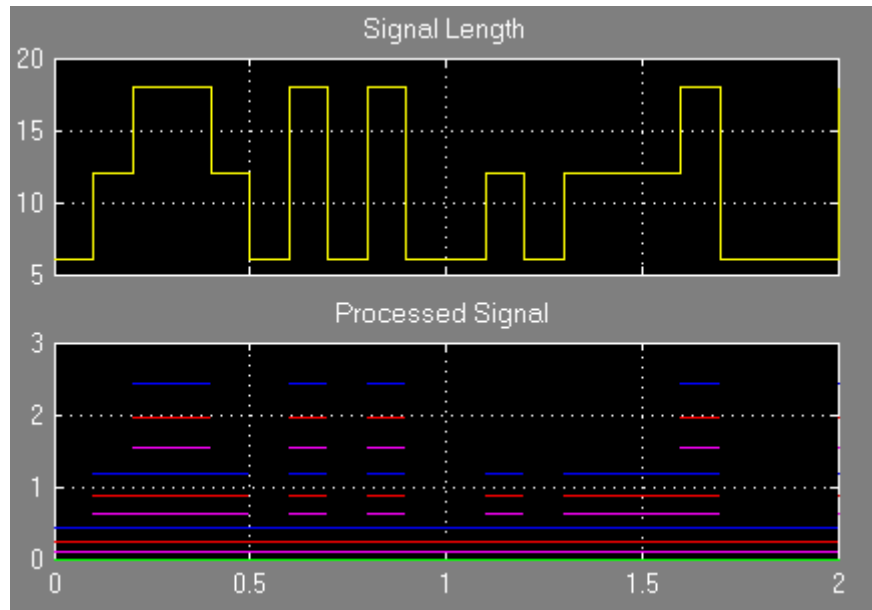
### Processing a Variable-Size Signal

The center section of the model processes the variable-size signal. The MATLAB Function block adds zeros between the data values in a way that is similar to upsampling a signal. The dimension of the signal changes from 9 to 18. The Math Function blocks demonstrate various manipulations you can do with variable-size signals.



### Visualizing a Variable-Size Signal

The right section of the model determines the signal width (size) and uses a scope to visualize the width and the processed data signal.



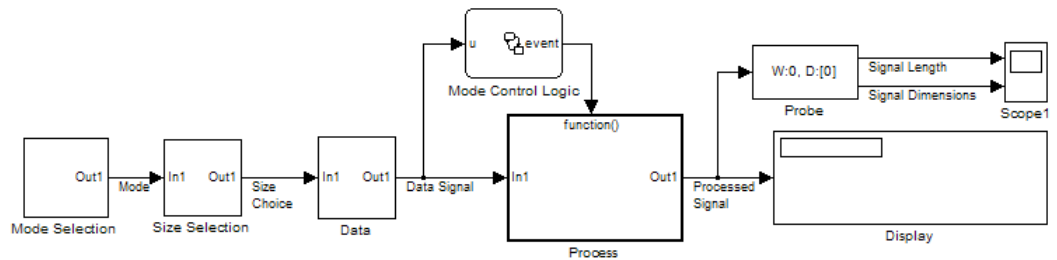
## Demo of Mode-Dependent Variable-Size Signals

This demo model represents a system that has three operation modes. For each mode, the data signal to process has a different size.

The Process subsystem in this model receives a variable-size signal where the size of the signal depends on the operation mode of the system. For each mode change, the Stateflow chart, Mode Control Logic, detects when the data signal size changes. It then generates a function call to reset the blocks in the Process subsystem.

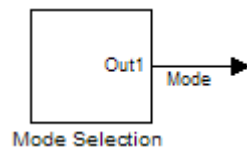
To open the model, In the MATLAB Command Window, type:

```
sldemo_varsize_multimode
```

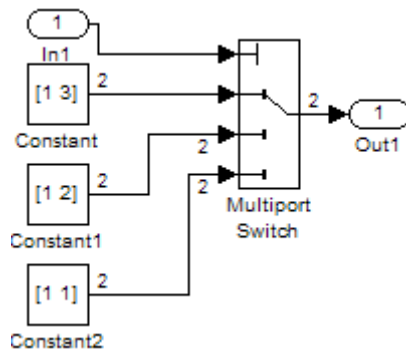


### Creating a Variable-Size Signal Based on Mode

The Mode Selection subsystem determines the mode for processing a data signal and outputs a mode value ( 1, 2, or 3). This value helps to select the length of the data signal using the Size Selection and Data subsystems.

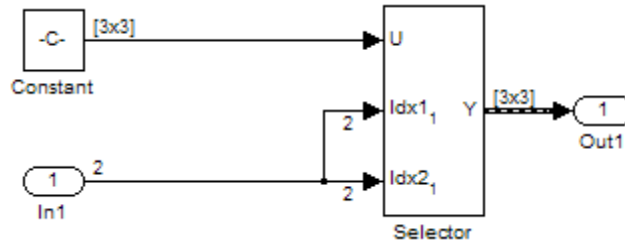


The Size Selection subsystem creates an index value from the mode value. In this example, the index values are [1 3], [1 2], and [1 1].



The Data subsystem takes a data signal (Constant block) and selects part of the data signal dependent on the mode. The output is a variable-size signal with a matrix size of 3x3, 2x2, and 1x1.





The dimensions of the raw data signal (Constant block) is a  $3 \times 3$ . 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  $3 \times 3$  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

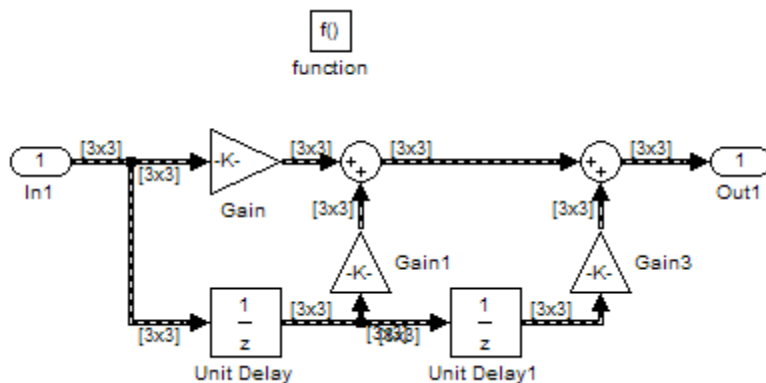
```

```
ans(:,:,3) =
    1     4     7
    2     5     8
    3     6     9
```

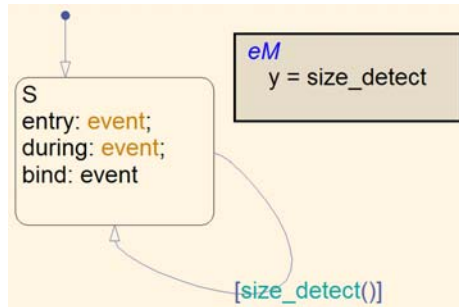
### Processing a Variable-Size Signal with a Conditionally Executed Subsystem

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 33-3.

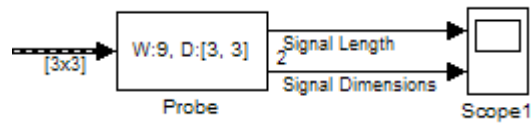


The Stateflow chart determines if there is a change in the size of the signal. The function `size_detect` calculates the width of the variable-size signal at each time step, and compares the current width to the previous width. If there is a change in signal size, the chart outputs a function-call output event that resets and repropagates the signal sizes within the Process subsystem.

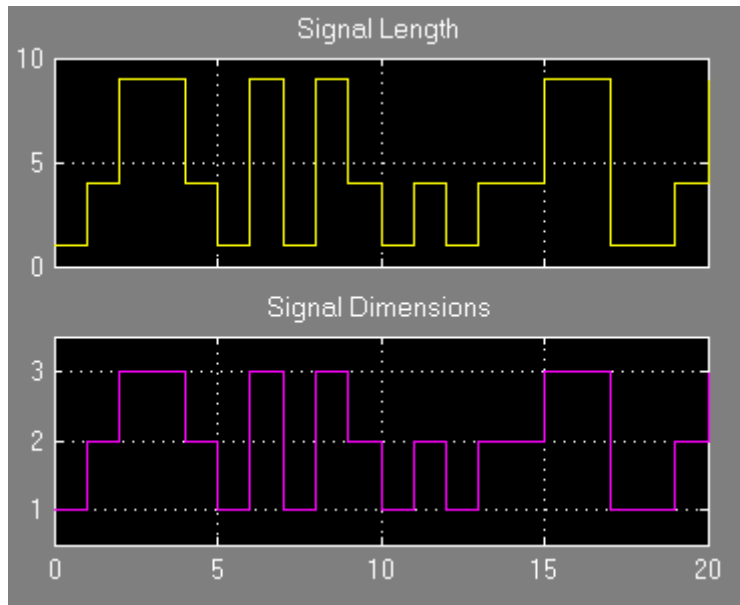


### Visualizing Data

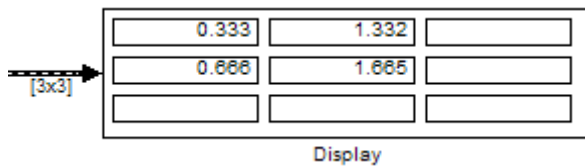
Use the Probe block to visualize signal size and signal dimension.



Since the signals are  $n \times n$  matrices, the signal dimension lines overlap in the Scope display.



You can use a Display block and the Simulink Debugger to visualize signal values at each time step.



## S-Functions Using Variable-Size Signals

### In this section...

“Demo of Level-2 MATLAB S-Function with Variable-Size Signals” on page 33-19

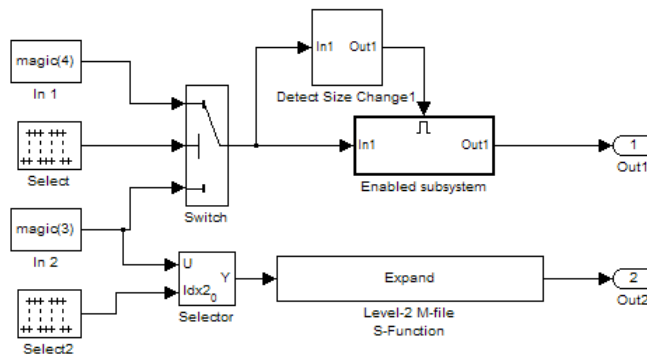
“Demo of C S-Function with Variable-Size Signals” on page 33-20

### Demo of Level-2 MATLAB S-Function with Variable-Size Signals

Both Level-2 MATLAB S-Functions and C S-Functions support variable-size signals when you set the **DimensionMode** for the output port to **Variable**. You also need to consider the current dimension of the input and output signals in the input and output update methods.

To open this demo model, in the MATLAB Command Window, type:

```
msfcndemo_varsize
```



```
matlabroot\toolbox\simulink\simdemos\simfeatures\msfcn_varsize_expand.m
```

```
matlabroot\toolbox\simulink\simdemos\simfeatures\tlc_dmsfcn_varsize_expand.tlc
```

```
matlabroot\toolbox\simulink\simdemos\simfeatures\msfcn_varsize_holdStatesUntilReset.m
```

```
matlabroot\toolbox\simulink\simdemos\simfeatures\tlc_dmsfcn_varsize_holdStatesUntilReset.tlc
```

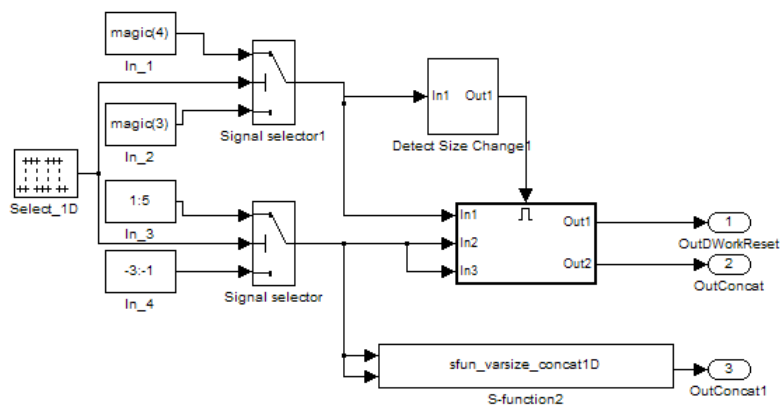
The Enabled subsystem includes a Level-2 MATLAB S-Function which demonstrates how to implement a block that holds its states until reset. Because this block contains states and delays the input signal, the input size can change only when a reset occurs.

The Expand block is a Level-2 MATLAB S-Function that takes a scalar input and outputs a vector of length indicated by its input value. The output is by  $1:n$  where  $n$  is the input value.

## Demo of C S-Function with Variable-Size Signals

To open this demo model, in the MATLAB Command Window, type:

```
sfcn_demo_varsize
```



```
matlabroot\toolbox\simulink\simdemos\simfeatures\src\sfun_varsize_concat1D.c
```

```
matlabroot\toolbox\simulink\simdemos\simfeatures\tlc_tlc_sfun_varsize_concat1D.tlc
```

```
matlabroot\toolbox\simulink\simdemos\simfeatures\src\sfun_varsize_holdStatesUntilReset.c
```

```
matlabroot\toolbox\simulink\simdemos\simfeatures\tlc_tlc_sfun_varsize_holdStatesUntilReset.tlc
```

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” on page 33-22
“Conditionally Executed Subsystem Blocks” on page 33-22
“Switching Blocks” on page 33-23

### 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 From the **Help** menu, select **Block Support Table > Simulink**.

An X in the **Variable-Size Support** column indicates support for that block.

---

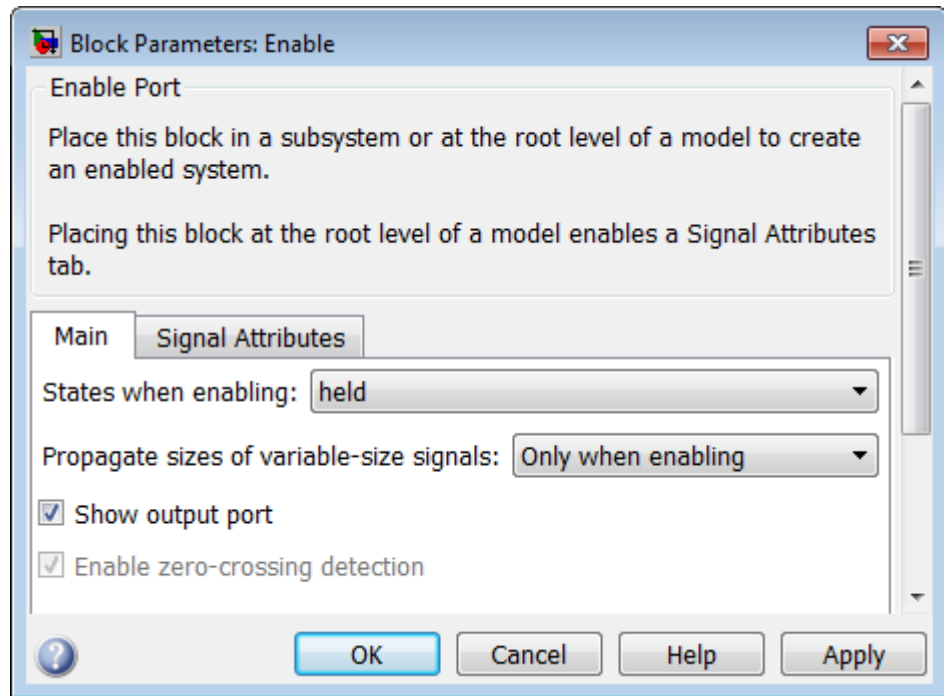
**Tip** You can also view the table by entering `showblockdatatypetable` at the command prompt.

---

### 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 execution**, **Only when execution is resumed (Action Port)**, and **Only when enabling (Enable and Trigger or Function-Call)**.

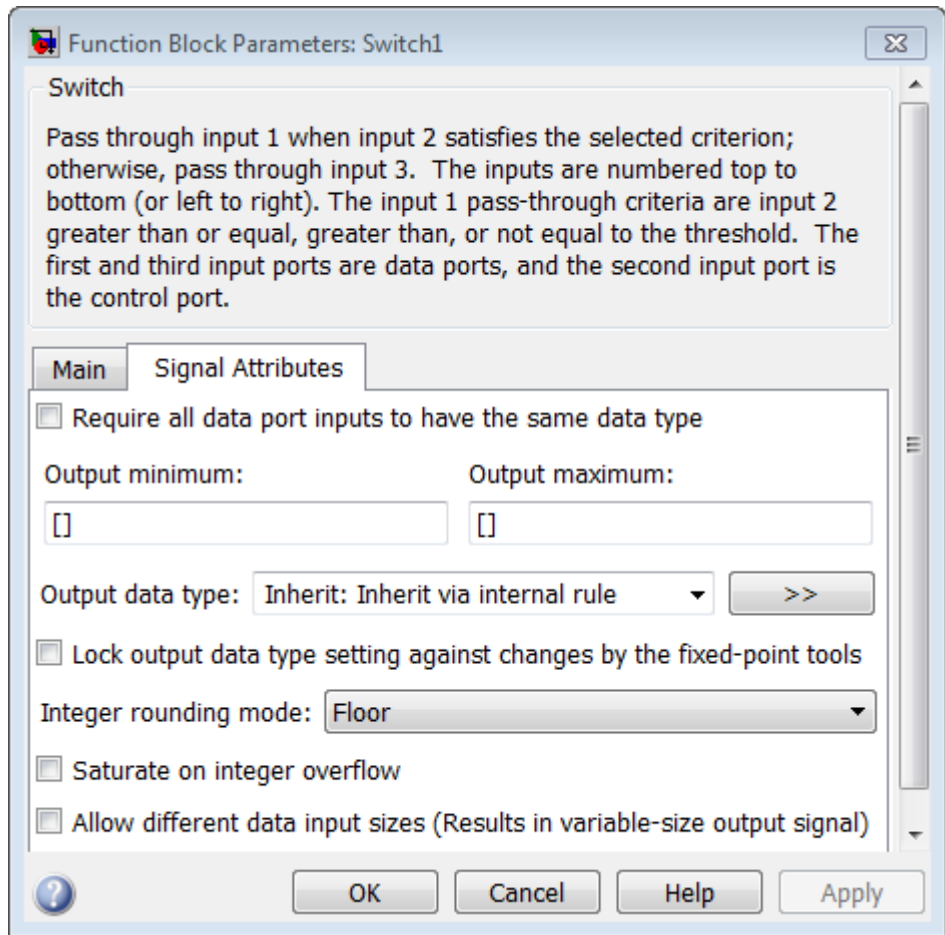




- Action Port
- Enable
- Trigger — **Trigger type** set to function-call

## 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 <code>Structure</code> or <code>Structure With Time</code> format for logging variable-size signals.
Right-click signal logging does not support variable-size signals.	Use a <code>To Workspace</code> block (with <code>Structure</code> or <code>Structure With Time</code> format) or a root <code>Output</code> 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 <code>Frame Conversion</code> 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.	—

<b>Limitation</b>	<b>Workaround</b>
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

---

- Chapter 34, “Customizing the Simulink User Interface”
- Chapter 35, “PrintFrame Editor”



# Customizing the Simulink User Interface

---

- “Adding Items to Model Editor Menus” on page 34-2
- “Disabling and Hiding Model Editor Menu Items” on page 34-13
- “Disabling and Hiding Dialog Box Controls” on page 34-15
- “Customizing the Library Browser” on page 34-21
- “Registering Customizations” on page 34-24

## Adding Items to Model Editor Menus

In this section...
“About Adding Items to the Model Editor Menus” on page 34-2
“Code Example” on page 34-2
“Defining Menu Items” on page 34-4
“Registering Menu Customizations” on page 34-9
“Callback Info Object” on page 34-10
“Debugging Custom Menu Callbacks” on page 34-10
“About Menu Tags” on page 34-10

### About Adding Items to the Model Editor Menus

You can add commands and submenus to the end of the Simulink model editor menus. Adding an item to the end of a Model Editor menu entails performing the following tasks:

- For each item, create a function, called a *schema function*, that defines the item (see “Defining Menu Items” on page 34-4).
- Register the menu customizations with the Simulink customization manager at startup, e.g., in an `sl_customization.m` file on the MATLAB path (see “Registering Menu Customizations” on page 34-9).
- Create callback functions that implement the commands triggered by the items that you add to the menus.

---

**Note** You can use the procedures described in the following sections to customize the Stateflow Chart Editor menu.

---

### Code Example

The following `sl_customization.m` file adds four items to the editor’s **Tools** menu.



```
function sl_customization(cm)

    %% Register custom menu function.
    cm.addCustomMenuFcn('Simulink:ToolsMenu', @getMyMenuItems);
end

%% Define the custom menu function.
function schemaFcns = getMyMenuItems(callbackInfo)
    schemaFcns = {@getItem1,...
                 @getItem2,...
                 {@getItem3,3}... %% Pass 3 as user data to getItem3.
                 @getItem4};
end

%% Define the schema function for first menu item.
function schema = getItem1(callbackInfo)
    schema = sl_action_schema;
    schema.label = 'Item One';
    schema.userdata = 'item one';
    schema.callback = @myCallback1;
end

function myCallback1(callbackInfo)
    disp(['Callback for item ' callbackInfo.userdata ' was called']);
end

function schema = getItem2(callbackInfo)
    % Make a submenu label 'Item Two' with
    % the menu item above three times.
    schema = sl_container_schema;
    schema.label = 'Item Two';
    schema.childrenFcns = {@getItem1, @getItem1, @getItem1};
end

function schema = getItem3(callbackInfo)
    % Create a menu item whose label is
    % 'Item Three: 3', with the 3 being passed
    % from getMyItems above.

    schema = sl_action_schema;
```

```
        schema.label = ['Item Three: ' num2str(callbackInfo.userdata)];
    end

function myToggleCallback(callbackInfo)
    if strcmp(get_param(gcs, 'ScreenColor'), 'red') == 0
        set_param(gcs, 'ScreenColor', 'red');
    else
        set_param(gcs, 'ScreenColor', 'white');
    end
end

end

%% Define the schema function for a toggle menu item.
function schema = getItem4(callbackInfo)
    schema = sl_toggle_schema;
    schema.label = 'Red Screen';
    if strcmp(get_param(gcs, 'ScreenColor'), 'red') == 1
        schema.checked = 'checked';
    else
        schema.checked = 'unchecked';
    end
    schema.callback = @myToggleCallback;
end
```

## Defining Menu Items

You define a menu item by creating a function that returns an object, called a *schema* object, that specifies the information needed to create the menu item. The menu item that you define may trigger a custom action or display a custom submenu. See the following sections for more information.

- “Defining Menu Items That Trigger Custom Commands” on page 34-4
- “Defining Custom Submenus” on page 34-7

### Defining Menu Items That Trigger Custom Commands

To define an item that triggers a custom command, your schema function must accept a callback info object (see “Callback Info Object” on page 34-10) and create and return an action schema object (see “Action Schema Object” on page 34-5) that specifies the item’s label and a function, called a *callback*,

to be invoked when the user selects the item. For example, the following schema function defines a menu item that displays a message when selected by the user.

```
function schema = getItem1(callbackInfo)

    %% Create an instance of an action schema.
    schema = sl_action_schema;

    %% Specify the menu item's label.
    schema.label = 'My Item 1';

    %% Specify the menu item's callback function.
    schema.callback = @myCallback1;

end

function myCallback1(callbackInfo)
    disp(['Callback for item ' callbackInfo.userdata
         ' was called']);
end
```

**Action Schema Object.** This object specifies information about menu items that trigger commands that you define, including the label that appears on the menu item and the function to be invoked when the user selects the menu item. Use the function `sl_action_schema` to create instances of this object in your schema functions. Its properties include

- **tag**  
Optional string that identifies this action, for example, so that it can be referenced by a filter function.
- **label**  
String specifying the label that appears on a menu item that triggers this action.
- **state**  
String that specifies the state of this action. Valid values are 'Enabled' (the default), 'Disabled', and 'Hidden'.

- `statustip`

String specifying text to appear in the editor's status bar when the user selects the menu item that triggers this action.

- `userdata`

Data that you specify. May be of any type.

- `accelerator`

String specifying a keyboard shortcut that a user may use to trigger this action. The string must be of the form `'Ctrl+K'`, where *K* is the shortcut key. For example, `'Ctrl+T'` specifies that the user may invoke this action by holding down the **Ctrl** key and pressing the **T** key.

- `callback`

String specifying a MATLAB expression to be evaluated or a handle to a function to be invoked when a user selects the menu item that triggers this action. This function must accept one argument: a callback info object.

**Toggle Schema Object.** This object specifies information about a menu item that toggles some object on or off. Use the function `sl_toggle_schema` to create instances of this object in your schema functions. Its properties include

- `tag`

Optional string that identifies this toggle action, for example, so that it can be referenced by a filter function.

- `label`

String specifying the label that appears on a menu item that triggers this toggle action.

- `checked`

This property must be set to one of the following values:

`'checked'` Menu item displays a check mark.

`'unchecked'` Menu item does not display a check mark.

- `state`

String that specifies the state of this toggle action. Valid values are 'Enabled' (the default), 'Disabled', and 'Hidden'.

- **statustip**

String specifying text to appear in the editor's status bar when the user selects the menu item that triggers this toggle action.

- **userdata**

Data that you specify. May be of any type.

- **accelerator**

String specifying a keyboard shortcut that a user may use to trigger this action. The string must be of the form 'Ctrl+K', where *K* is the shortcut key. For example, 'Ctrl+T' specifies that the user may invoke this action by holding down the **Ctrl** key and pressing the **T** key.

- **callback**

String specifying a MATLAB expression to be evaluated or a handle to a function to be invoked when a user selects the menu item that triggers this action. This function must accept one argument: a callback info object.

## Defining Custom Submenus

To define a submenu, create a schema function that accepts a callback info object and returns a container schema object (see “Container Schema Object” on page 34-7) that specifies the schemas that define the items on the submenu. For example, the following schema function defines a submenu that contains three instances of the menu item defined in the example in “Defining Menu Items That Trigger Custom Commands” on page 34-4.

```
function schema = getItem2( callbackInfo )
    schema = sl_container_schema;
    schema.label = 'Item Two';
    schema.childrenFcns = {@getItem1, @getItem1, @getItem1};
end
```

**Container Schema Object.** A container schema object specifies a submenu's label and its contents. Use the function `sl_container_schema` to create instances of this object in your schema functions. Properties of the object include

- `tag`  
Optional string that identifies this submenu.
- `label`  
String specifying the submenu's label.
- `state`  
String that specifies the state of this submenu. Valid values are 'Enabled' (the default), 'Disabled', and 'Hidden'.
- `statustip`  
String specifying text to appear in the editor's status bar when the user selects this submenu.
- `userdata`  
Data that you specify. May be of any type.
- `childrenFcns`  
Cell array that specifies the contents of the submenu. Each entry in the cell array can be
  - a pointer to a schema function that defines an item on the submenu (see “Defining Menu Items” on page 34-4)
  - 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 34-10) passed to the schema function
  - 'separator', which causes a separator to appear between the item defined by the preceding entry in the cell array and the item defined in the following entry. This case is ignored for this entry, e.g., 'SEPARATOR' and 'Separator' are valid entries. A separator is also suppressed if it would appear at the beginning or end of the submenu and combines separators that would appear successively (e.g., as a result of an item being hidden) into a single separator.

For example, the following cell array specifies two submenu entries:

```
{@getItem1, 'separator', {@getItem2, 1}}
```

In this example, a 1 is passed to `getItem2` via a callback info object.

- `generateFcn`

Pointer to a function that returns a cell array defining the contents of the submenu. The cell array must have the same format as that specified for the container schema objects `childrenFcns` property.

---

**Note** The `generateFcn` property takes precedence over the `childrenFcns` property. If you set both, the `childrenFcns` property is ignored and the cell array returned by the `generateFcn` is used to create the submenu.

---

## Registering Menu Customizations

You must register custom items to be included on a Simulink menu with the customization manager. Use the `sl_customization.m` file for a Simulink installation (see “Registering Customizations” on page 34-24) to perform this task. In particular, for each menu that you want to customize, your system’s `sl_customization` function must invoke the customization manager’s `addCustomMenuFcn` method (see “Customization Manager” on page 34-24). Each invocation should pass the tag of the menu (see “About Menu Tags” on page 34-10) to be customized and a custom menu function that specifies the items to be added to the menu (see “Creating the Custom Menu Function” on page 34-9). For example, the following `sl_customization` function adds custom items to the Simulink Tools menu.

```
function sl_customization(cm)
    %% Register custom menu function.
    cm.addCustomMenuFcn('Simulink:ToolsMenu', @getMyItems);
```

## Creating the Custom Menu Function

The custom menu function returns a list of schema functions that define custom items that you want to appear on the model editor menus (see “Defining Menu Items” on page 34-4).

Your custom menu function should accept a callback info object (see “Callback Info Object” on page 34-10) and return a cell array that lists the schema functions. Each element of the cell array can be either a handle to a schema function or a two-element cell array whose first element is a handle to a

schema function and whose second element is user-defined data to be passed to the schema function. For example, the following custom menu function returns a cell array that lists three schema functions.

```
function schemas = getMyItems(callbackInfo)
    schemas = {@getItem1, ...
              @getItem2, ...
              {@getItem3,3} }; % Pass 3 as userdata to getItem3.
end
```

## Callback Info Object

Instances of these objects are passed to menu customization functions. Properties of these objects include

- `uiObject`

Handle to the owner of the menu for which this is the callback. The owner can be the Simulink editor or the Stateflow editor.

- `model`

Handle to the model being displayed in the editor window.

- `userdata`

User data. The value of this field can be any type of data.

## Debugging Custom Menu Callbacks

On systems using the Microsoft Windows operating system, selecting a custom menu item whose callback contains a breakpoint can cause the mouse to become unresponsive or the menu to remain open and on top of other windows. To fix these problems, use the MATLAB code debugger keyboard commands to continue execution of the callback.

## About Menu Tags

A menu tag is a string that identifies a Simulink Model Editor or Stateflow Chart Editor menu bar or menu. You need to know a menu's tag to add



custom items to it (see “Registering Menu Customizations” on page 34-9). You can configure the editor to display all (see “Displaying Menu Tags” on page 34-11) but the following tags:

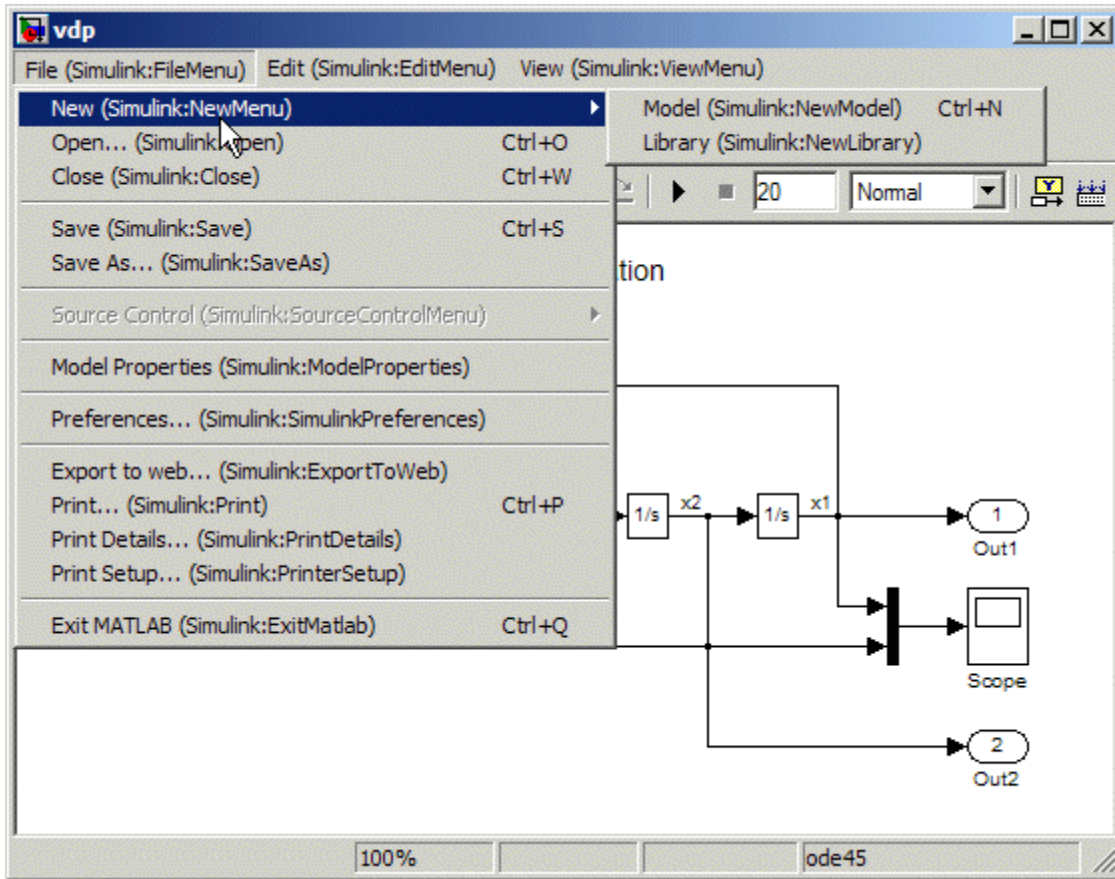
Tag	Usage
Simulink:MenuBar	Add menus to Model Editor’s menu bar.
Simulink:ContextMenu	Add items to the end of Model Editor’s context menu.
Simulink:PreContextMenu	Add items to the beginning of Model Editor’s context menu.
Stateflow:MenuBar	Add menus to Chart Editor’s menu bar.
Stateflow:ContextMenu	Add items to the end of Chart Editor’s context menu.
Stateflow:PreContextMenu	Add items to the beginning of Chart Editor’s context menu.

### Displaying Menu Tags

You can configure the Simulink software (and the Stateflow product) to display the tag for a menu item next to the item’s label, allowing you to determine at a glance the tag for a menu. To configure the editor to display menu tags, set the customization manager’s `showWidgetIdAsToolTip` property to `true`, e.g., by entering the following commands at the command line:

```
cm = sl_customization_manager;
cm.showWidgetIdAsToolTip=true;
```

The tag of each menu item appears next to the item's label on the menu:



To turn off tag display, enter the following command at the command line:

```
cm.showWidgetIdAsToolTip=false;
```

---

**Note** Some menu items may not work while menu tag display is enabled. To ensure that all items work, turn off menu tag display before using the menus.

---

## Disabling and Hiding Model Editor Menu Items

### In this section...

“About Disabling and Hiding Model Editor Menu Items” on page 34-13

“Example: Disabling the New Model Command on the Simulink Editor’s File Menu” on page 34-13

“Creating a Filter Function” on page 34-13

“Registering a Filter Function” on page 34-14

### 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 34-13).
- Register the filter function with the customization manager (see “Registering a Filter Function” on page 34-14).

For more information on Model Editor menu items, see:

### Example: Disabling the New Model Command on the Simulink Editor’s File Menu

```
function sl_customization(cm)
    cm.addCustomFilterFcn('Simulink:NewModel',@myFilter);
end

function state = myFilter(callbackInfo)
    state = 'Disabled';
end
```

### Creating a Filter Function

Your filter function must accept a callback info object and return a string that specifies the state that you want to assign to the menu item. Valid states are

- 'Hidden'
- 'Disabled'
- 'Enabled'

Your filter function may have to compete with other filter functions and with Simulink itself to assign a state to an item. Who succeeds depends on the strength of the state that each assigns to the item. 'Hidden' is the strongest state. If any filter function or Simulink assigns 'Hidden' to the item, it is hidden. 'Enabled' is the weakest state. For an item to be enabled, all filter functions and the Simulink or Stateflow products must assign 'Enabled' to the item. The 'Disabled' state is of middling strength. It overrides 'Enabled' but is itself overridden by 'Hidden'. For example, if any filter function or Simulink or Stateflow assigns 'Disabled' to a menu item and none assigns 'Hidden' to the item, the item is disabled.

---

**Note** The Simulink software does not allow you to filter some menu items, for example, the **Exit MATLAB** item on the Simulink **File** menu. An error message is displayed if you attempt to filter a menu item that you are not allowed to filter.

---

### Registering a Filter Function

Use the customization manager's `addCustomFilterFcn` method to register a filter function. The `addCustomFilterFcn` method takes two arguments: a tag that identifies the menu or menu item to be filtered (see “Displaying Menu Tags” on page 34-11) and a pointer to the filter function itself. For example, the following code registers a filter function for the **New Model** item on the Simulink **File** menu.

```
function sl_customization(cm)
    cm.addCustomFilterFcn('Simulink:NewModel',@myFilter);
end
```

## Disabling and Hiding Dialog Box Controls

### In this section...

“About Disabling and Hiding Controls” on page 34-15

“Example: Disabling a Button on a Simulink Dialog Box” on page 34-16

“Writing Control Customization Callback Functions” on page 34-17

“Dialog Box Methods” on page 34-17

“Dialog Box and Widget IDs” on page 34-18

“Registering Control Customization Callback Functions” on page 34-19

### 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 34-18), and position the mouse over a widget. If a widget ID appears, the dialog box is customizable.

Once you have determined that a dialog box or class of dialog boxes is customizable, you must write 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 “Writing Control Customization Callback Functions” on page 34-17) and registering the callback functions via an object called the customization manager (see “Registering Control Customization Callback Functions” on page 34-19). Simulink then invokes

the callback functions to disable or hide the controls whenever a user opens the dialog boxes.

For more information on Dialog Box controls, see:

### **Example: Disabling a Button on a Simulink Dialog Box**

The following `sl_customization.m` file disables the **Build** button on the **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

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 34-24).
- 3 Open the `sldemo_engine` demo model, for example, by entering the command `sldemo_engine` at the command line.

## Writing Control Customization Callback Functions

A callback function for disabling or hiding controls on a dialog box should accept one argument: a handle to the dialog box object that contains the controls you want to disable or hide. The dialog box object provides methods that the callback function can use to disable or hide the controls that the dialog box contains.

The dialog box object also provides access to objects containing information about the current model. Your callback function can use these objects to determine whether to disable or hide controls. For example, the following callback function uses these objects to disable the **Build** button on the **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)`

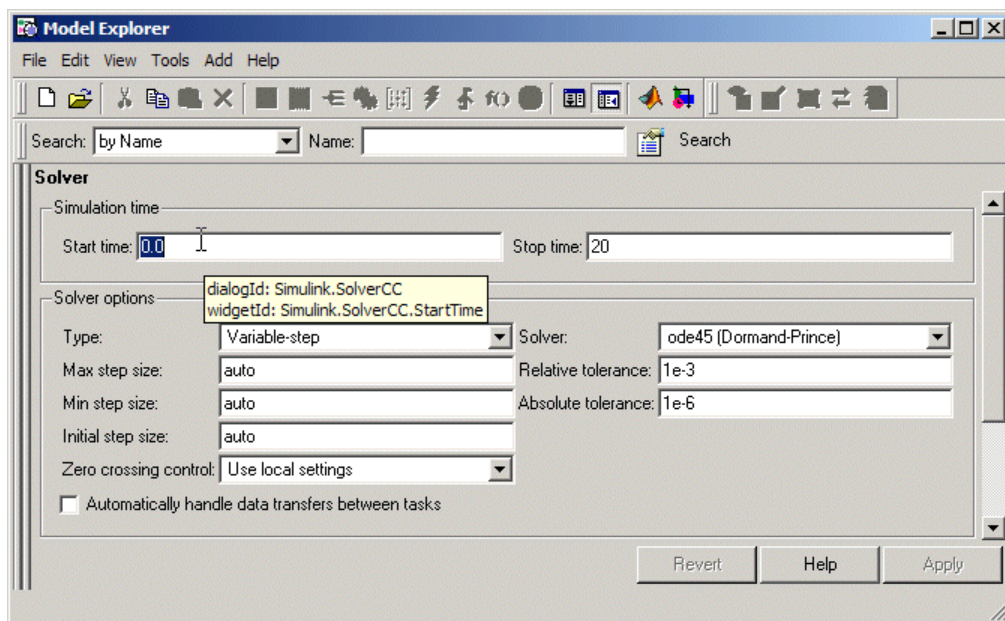
where `widgetIDs` is a cell array of widget identifiers (see “Dialog Box and Widget IDs” on page 34-18) that specify the widgets to be disabled or hidden.

## Dialog Box and Widget IDs

Dialog box and widget IDs are strings that identify a control on a Simulink dialog box. To determine the dialog box and widget ID for a particular control, execute the following code at the command line:

```
cm = sl_customization_manager;
cm.showWidgetIdAsToolTip = true
```

Then, open the dialog box that contains the control and move the mouse cursor over the control to display a tooltip listing the dialog box and the widget IDs for the control. For example, moving the cursor over the **Start time** field on the **Solver** pane of the Configuration Parameters dialog box reveals that the dialog box ID for the **Solver** pane is `Simulink.SolverCC` and the widget ID for the **Start time** field is `Simulink.SolverCC.StartTime`.





---

**Note** The tooltip displays “not customizable” for controls that are not customizable.

---

## Registering Control Customization Callback Functions

To register control customization callback functions for a particular installation of the Simulink product, include code in the installation’s `sl_customization.m` file (see “Registering Customizations” on page 34-24) that invokes the customization manager’s `addDlgPreOpenFcn` on the callbacks.

The `addDlgPreOpenFcn` takes two arguments. The first argument is a dialog box ID (see “Dialog Box and Widget IDs” on page 34-18) and the second is a pointer to the callback function to be registered. Invoking this method causes the registered function to be invoked for each dialog box of the type specified by the dialog box ID. The function is invoked before the dialog box is opened, allowing the function to perform the customizations before they become visible to the user.

The following example registers a callback that disables the **Build** button on the **Code Generation** pane of the Configuration Parameters dialog box (see “Writing Control Customization Callback Functions” on page 34-17).

```
function sl_customization(cm)

    % Disable for standalone Configuration Parameters dialog box.
    cm.addDlgPreOpenFcn('Simulink.ConfigSet',@disableRTWBuildButton)

    % Disable for Configuration Parameters dialog box that appears in
    % the Model Explorer
    cm.addDlgPreOpenFcn('Simulink.RTWCC',@disableRTWBuildButton)

end
```

---

**Note** Registering a customization callback causes the Simulink software to invoke the callback for every instance of the class of dialog boxes specified by the method's dialog box ID argument. This allows you to use a single callback to disable or hide a control for an entire class of dialog boxes. In particular, you can use a single callback to disable or hide the control for a parameter that is common to most built-in blocks. This is because most built-in block dialog boxes are instances of the same dialog box super class.

---

## Customizing the Library Browser

### In this section...

“Reordering Libraries” on page 34-21

“Disabling and Hiding Libraries” on page 34-21

“Customizing the Library Browser’s Menu” on page 34-22

### Reordering Libraries

The order in which a library appears in the Library Browser is determined by its name and its sort priority. Libraries appear in the Library Browser’s tree view in ascending order of priority, with all blocks having the same priority sorted alphabetically. The Simulink library has a sort priority of -1 by default; all other libraries, a sort priority of 0. This guarantees that the Simulink library is by default the first library displayed in the Library Browser. You can reorder libraries by changing their sort priorities. To change library sort priorities, insert a line of code of the following form in an `sl_customization.m` file (see “Registering Customizations” on page 34-24) on the MATLAB path:

```
cm.LibraryBrowserCustomizer.applyOrder( {'LIBNAME1', PRIORITY1, ...
                                         'LIBNAME2', 'PRIORITY2, ...
                                         .
                                         .
                                         'LIBNAMEN', PRIORITYN} );
```

where `LIBNAMEN` is the name of the library or its `.mdl` file and `PRIORITYn` is an integer indicating the library’s sort priority. For example, the following code moves the Simulink Extras library to the top of the Library Browser’s tree view.

```
cm.LibraryBrowserCustomizer.applyOrder( {'Simulink Extras', -2} );
```

### Disabling and Hiding Libraries

To disable or hide libraries, sublibraries, or library blocks, insert code of the following form in an `sl_customization.m` file (see “Registering Customizations” on page 34-24) on the MATLAB path:

```
cm.LibraryBrowserCustomizer.applyFilter( {'PATH1', 'STATE1', ...
                                           'PATH2', 'STATE2', ...
                                           .
                                           .
                                           'PATHN', 'STATEN'} );
```

where PATH<sub>n</sub> is the path of the library, sublibrary, or block to be disabled or hidden and 'STATEN' is 'Disabled' or 'Hidden'. For example, the following code hides the Simulink Sources sublibrary and disables the Sinks sublibrary.

```
cm.LibraryBrowserCustomizer.applyFilter({'Simulink/Sources','Hidden'});
cm.LibraryBrowserCustomizer.applyFilter({'Simulink/Sinks','Disabled'});
```

## Customizing the Library Browser's Menu

You can perform the same kinds of customizations to the Library Browser's menu as you can to the model and Stateflow editor menus. Simply use the corresponding Library Browser menu tags to perform the customizations.

- LibraryBrowser:FileMenu
- LibraryBrowser>EditMenu
- LibraryBrowser:ViewMenu
- LibraryBrowser:HelpMenu

For example, the following code adds a menu item to the Library Browser's file menu:

```
%Menu customization:
% Add items to the Library Browser File menu
cm.addCustomMenuFcn('LibraryBrowser:FileMenu',@getMyMenuItems)

%% Define the custom menu function.
function schemaFcns = getMyMenuItems(callbackInfo)
schemaFcns = {@myBasic};
end

%% Define the schema function for first menu item.
function schema = myBasic(callbackInfo)
disp('1');
```

```
schema = sl_action_schema;  
schema.label = 'Display 1';  
schema.userdata = 'item one';  
schema.tag = 'LibraryBrowser:ItemOne';  
end
```

## Registering Customizations

### In this section...

“About Registering User Interface Customizations” on page 34-24

“Customization Manager” on page 34-24

### 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 34-24). Your instance of the `sl_customization` function should use these methods to register customizations specific to your application. For more information, see the following sections on performing customizations.

- “Adding Items to Model Editor Menus” on page 34-2
- “Disabling and Hiding Model Editor Menu Items” on page 34-13
- “Disabling and Hiding Dialog Box Controls” on page 34-15

The `sl_customization.m` file is read when the Simulink software starts. If you subsequently change the `sl_customization.m` file, you must restart the Simulink software or enter the following command at the command line to effect the changes:

```
sl_refresh_customizations
```

### Customization Manager

The customization manager includes the following methods:

- `addCustomMenuFcn(stdMenuTag, menuSpecsFcn)`

Adds the menus specified by `menuSpecsFcn` to the end of the standard Simulink menu specified by `stdMenuTag`. The `stdMenuTag` argument is a string that specifies the menu to be customized. For example, the `stdMenuTag` for the Simulink editor's **Tools** menu is `'Simulink:ToolsMenu'` (see “Displaying Menu Tags” on page 34-11 for more information). The `menuSpecsFcn` argument is a handle to a function that returns a list of functions that specify the items to be added to the specified menu. See “Adding Items to Model Editor Menus” on page 34-2 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 34-11 for more information). The `filterFcn` argument is a pointer to a function that hides or disables the specified menu item. See “Disabling and Hiding Model Editor Menu Items” on page 34-13 for more information.





# PrintFrame Editor

---

- “PrintFrame Editor Overview” on page 35-2
- “Designing the Print Frame” on page 35-8
- “Specifying the Print Frame Page Setup” on page 35-9
- “Creating Borders (Rows and Cells)” on page 35-11
- “Adding Information to Cells” on page 35-14
- “Changing Information in Cells” on page 35-18
- “Saving and Opening Print Frames” on page 35-22
- “Printing Block Diagrams with Print Frames” on page 35-23
- “Example” on page 35-26

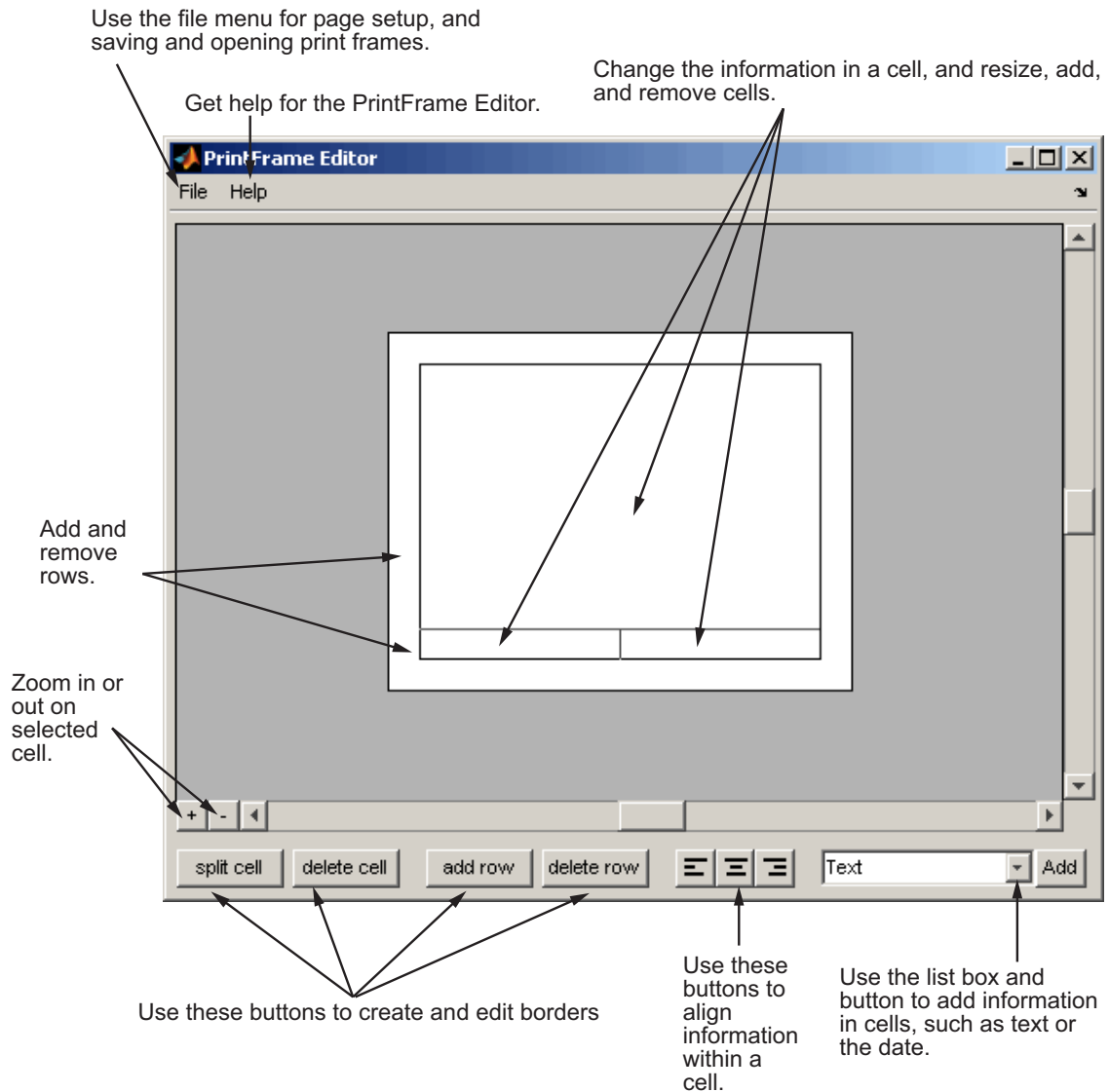
## PrintFrame Editor Overview

In this section...
“About the Print Frame Editor” on page 35-2
“What PrintFrames Are” on page 35-3
“Starting the PrintFrame Editor” on page 35-6
“Getting Help for the PrintFrame Editor” on page 35-7
“Closing the PrintFrame Editor” on page 35-7
“Print Frame Process” on page 35-7

### 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.

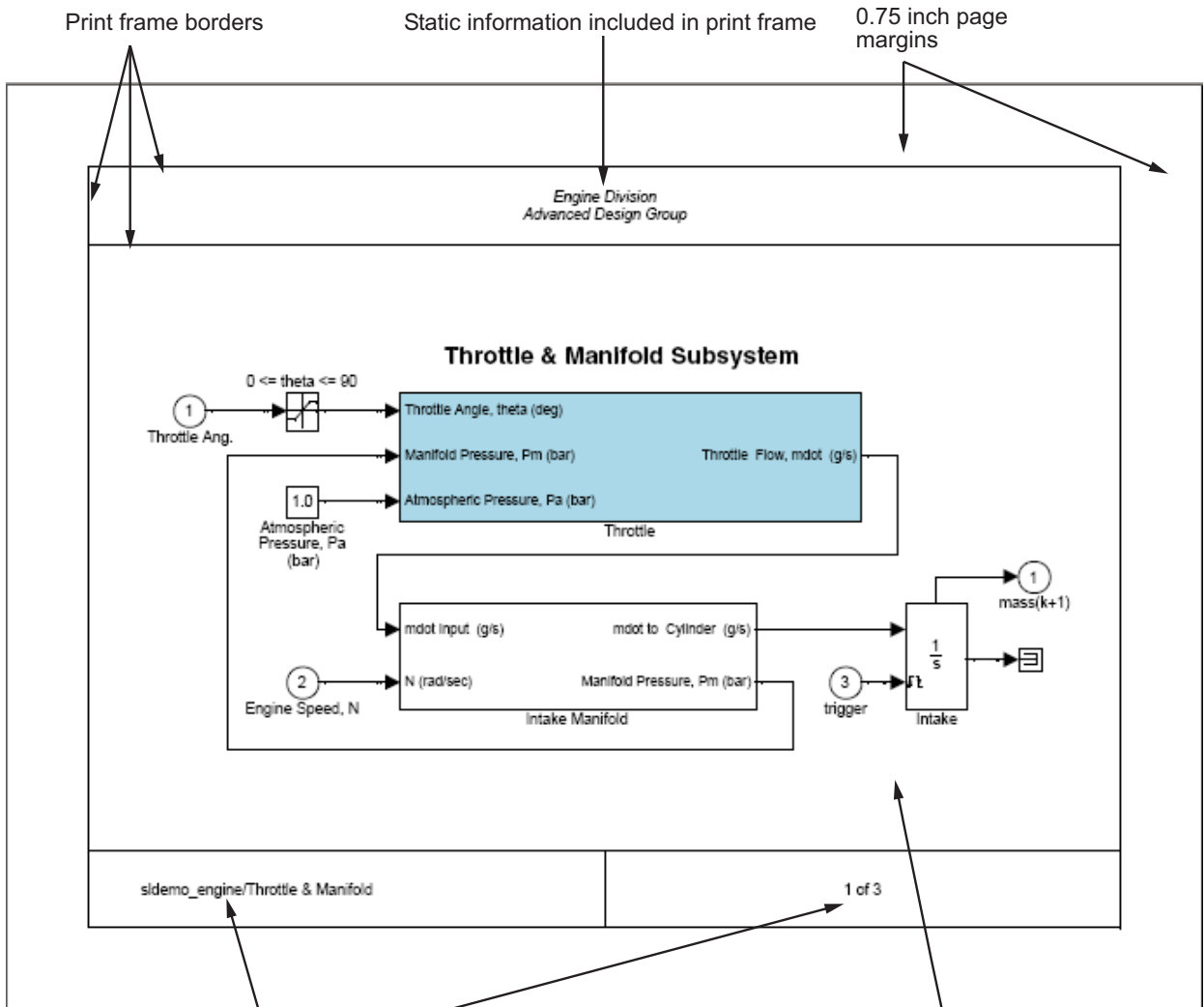


## What PrintFrames Are

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.



Variable information included in print frame

Simulink block diagram

See the "Example" on page 35-26 for specific instructions to create this print frame.

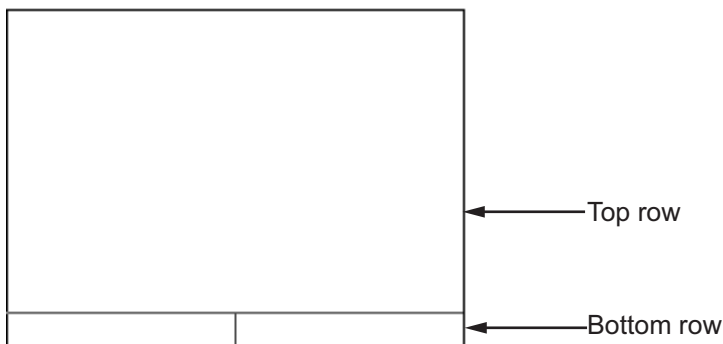
## Starting the PrintFrame Editor

Type `frameedit` at the MATLAB prompt. The **PrintFrame Editor** window appears. The **PrintFrame Editor** window opens with the default print frame.

You can use `frameedit filename` to open the **PrintFrame Editor** window with the specified 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.

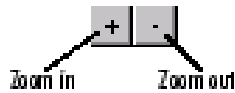
## Zooming In and Out

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.

## Getting Help for the PrintFrame Editor

Select **PrintFrame Editor Help** from the **Help** menu in the PrintFrame Editor window to access this online help.

## Closing the PrintFrame Editor

To close the **PrintFrame Editor** window, click the close box in the upper right corner, or select **Close** from the **File** menu.

## Print Frame Process

These are the basic steps for creating and using print frames:

- “Designing the Print Frame” on page 35-8
- “Specifying the Print Frame Page Setup” on page 35-9
- “Creating Borders (Rows and Cells)” on page 35-11
- “Adding Information to Cells” on page 35-14
- “Changing Information in Cells” on page 35-18
- “Saving and Opening Print Frames” on page 35-22
- “Printing Block Diagrams with Print Frames” on page 35-23

See also the “Example” on page 35-26.

## Designing the Print Frame

In this section...
“Before You Begin” on page 35-8
“Variable and Static Information” on page 35-8
“Single Use or Multiple Use Print Frames” on page 35-8

### Before You Begin

Before you create a print frame using the PrintFrame Editor, consider the type of information you want to include in it and how you want the information to appear. You might want to make a sketch of how you want the print frame to look, and note the wording you want to use.

### Variable and Static Information

In a print frame, you can include variable and static information. Variable information is automatically supplied at the time of printing, for example, the date the block diagram is being printed. Static information always prints exactly as you entered it, for example, the name and address of your organization.

### Single Use or Multiple Use Print Frames

You can design a print frame for one particular block diagram, or you can design a more generic print frame for printing with different block diagrams.



## Specifying the Print Frame Page Setup

After you have an idea of the design of your print frame, specify the page setup for the print frame.

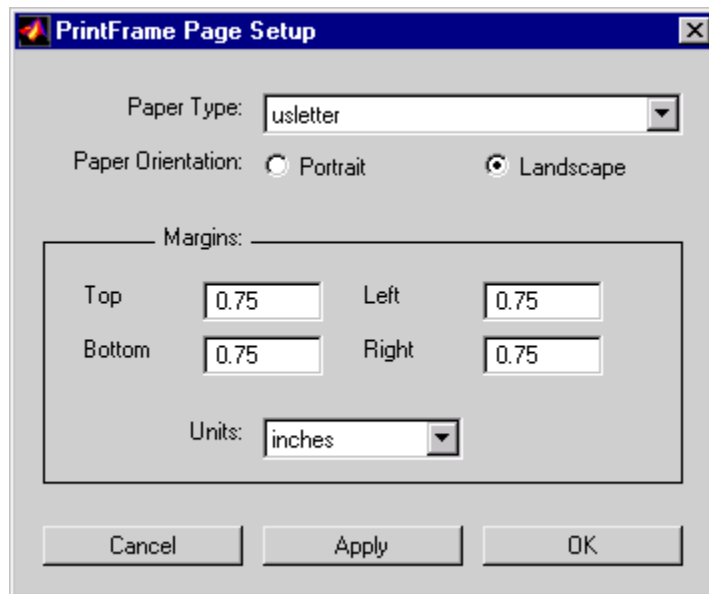
---

**Note** Always begin creating a new print frame with **PrintFrame Page Setup**. If, instead, you begin by creating borders and adding information, and then later change the page setup, you might have to correct the borders and placement of the information. For example, if you add information to cells and then change the page setup paper orientation from landscape to portrait, the information you added might not fit in the cells, given the new orientation.

---

- 1 In the **PrintFrame Editor** window, select **Page Setup** from the **File** menu.

The **PrintFrame Page Setup** dialog box appears.



- 2 In the dialog box, specify:

- **Paper Type** – for example, usletter
  - **Paper Orientation** – portrait or landscape
  - **Margins** for the print frame and the **Units** in which to specify the margins
- 3** Click **Apply** to see the effects of the changes you made. Then click **OK** to close the dialog box.

## Creating Borders (Rows and Cells)

### In this section...

- “First Steps” on page 35-11
- “Adding and Removing Rows” on page 35-11
- “Adding and Removing Cells” on page 35-12
- “Resizing Rows and Cells” on page 35-12
- “Print Frame Size” on page 35-12

### First Steps

Once you have set up the page, use the PrintFrame Editor to specify borders (cells) in which the block diagram and information will be placed.

---

**Important** Always specify the PrintFrame page setup before creating borders and adding information (see “Specifying the Print Frame Page Setup” on page 35-9). Otherwise, you might have to correct the borders and placement of the information. For example, if you add information to cells and then change the paper orientation from landscape to portrait, the information you added might not fit in the cells, given the new orientation.

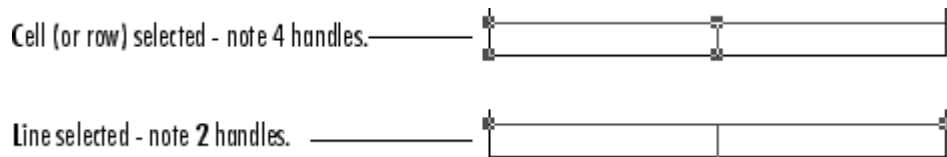
---

### Adding and Removing Rows

You can add and remove rows in a print frame.

- 1 Click within an existing row to select it. If a row consists of multiple cells, click in any of the cells in the row to select that row.

When a row is selected, handles appear on all four corners. If handles appear on only two corners, you clicked on and only selected the line, not the row.



- 2 Click the **add row** button to create a new row.

The new row appears above the row you selected.

- 3 To remove a row, select the row and click the **delete row** button.

## Adding and Removing Cells

You can create multiple cells within a row.

- 1 Select the row in which you want multiple cells.
- 2 Click the **split cell** button.

The row splits into two cells. If the row already consists of more than one cell, the selected cell splits into two cells.

- 3 To remove a cell, select the cell and click the **delete cell** button.

## Resizing Rows and Cells

You can change the dimensions of a row or cell.

- 1 Click on the line you want to move.

A handle appears on both ends of the line.

- 2 Drag the line to the new location.

For example, to make a row taller, click on the top line that forms the row. Then drag the line up and the height of the row increases.

## Print Frame Size

Note that the overall size of the print frame is based on the options you specify using the page setup feature. Therefore, when you change the dimensions

of one row or cell, the dimensions of the row or cell next to it change in an inverse direction. For example, if you drag the top line of a row to make it taller, the row above it becomes shorter by the same amount.

To change the overall dimensions of the print frame, use the page setup feature. See “Specifying the Print Frame Page Setup” on page 35-9.

## Adding Information to Cells

### In this section...

“Procedure for Adding Information to Cells” on page 35-14

“Text Information” on page 35-15

“Variable Information” on page 35-15

“Multiple Entries in a Cell” on page 35-16

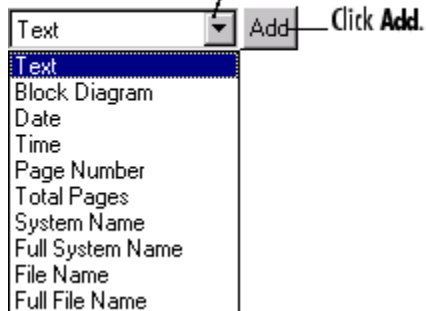
### Procedure for Adding Information to Cells

Use the following steps to add information to cells.

- 1 Select the cell where you want to add information.
- 2 From the list box, select the type of information you want to add.
- 3 Click the **Add** button.

An edit box containing that information appears in the cell. (The edit boxes for your platform might look slightly different from those in the figure below.)

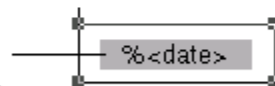
Select an item from the list.



For **Text**, an empty edit box appears.



For variable information, the variable's name appears in the edit box. In this example, the variable information is **Date**.



- 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.

---

## Changing Information in Cells

### In this section...

“Aligning the Information in a Cell” on page 35-18

“Editing Text Strings” on page 35-18

“Removing and Copying Entries” on page 35-19

“Changing the Font Characteristics” on page 35-20

### Aligning the Information in a Cell

To align the information within a cell:

- 1 Click within the cell to select it.
- 2 Click on one of the **Align** buttons for left, center, or right alignment.



The information aligns within the cell.

Alignment does not apply to the cell that contains the `%<blockdiagram>` entry. The block diagram is automatically scaled and centered to fit in that cell at the time of printing.

### Editing Text Strings

You can change text you typed in a cell:

- 1 Double-click the information you want to edit.

An edit box appears around all of the information in that cell.

- 2 Click at the start of the text you want to change and drag to the end of the text to be changed.

This highlights the text.

- 3 Type the replacement text.

It automatically replaces the highlighted text.

- 4 Click anywhere outside of the edit box to end editing mode.

---

**Note** Be careful not to edit the text of a variable entry, because then the variable information will not print. For example, if you accidentally remove the % from the %<page> entry, the text <page> will print instead of the actual page number.

---

## Removing and Copying Entries

You can cut, copy, paste, or delete an entry:

- 1 Double-click the information you want to remove or copy.

An edit box appears around all of the information in that cell.

- 2 Click at the start of the entry you want to edit and drag to the end of that entry. This highlights the entry.

For variable information, be sure to include the entire string, for example, %<page>.

Note that for computers running the Microsoft Windows operating system, you can select all of the entries in a cell by right-clicking the information and choosing **Select All** from the pop-up menu.

- 3 Use the standard editing techniques for your platform to cut, copy, or delete the highlighted information.
  - For computers running the Microsoft Windows operating system, right-click in the edit box and select **Cut**, **Copy**, or **Delete** from the pop-up menu.
  - For UNIX based systems, highlighting the information automatically copies it to the clipboard. If you want to remove it, press the **Delete** key.

If you make a mistake, use your platform's standard undo technique. For example, for computers running the Microsoft Windows operating system, right-click in the edit box and select **Undo** from the pop-up menu.

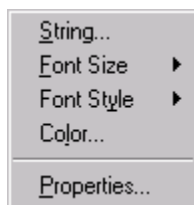
- 4** If you cut or copied the information to the clipboard and want to paste it, double-click the entry where you want to paste it and position the cursor at the new location in that edit box. Then use the standard paste technique for your platform.
  - For computers running the Microsoft Windows operating system, right-click at the new location and select **Paste** from the pop-up menu.
  - For UNIX based systems, click at the new location and then click the middle mouse button.
- 5** Click somewhere outside of the edit box to end editing mode.

## Changing the Font Characteristics

You can change the font characteristics for the information in any cell. Specifically, you can specify the font size, style, color, and family.

- 1** Right-click the information in the cell.

The information in the cell is selected and the pop-up menu for changing font characteristics appears.



If this pop-up menu does not appear, it is because you were in edit mode. To get the font pop-up menu, click somewhere outside of the edit box surrounding the information and then right-click.

- 2** Select an item from the pop-up menu. Choose **Properties** if you want to change the font family or if you want to change multiple characteristics at once.

Note that you can also select **String** from the pop-up menu, which allows you to edit the text string.

- 3** Select the new font characteristic(s) for that cell. For example, for **Font Size**, select the new size from its pop-up menu.

Note that changing the font characteristics for the %<blockdiagram> entry is not relevant and does nothing.

## Saving and Opening Print Frames

In this section...
“Saving a Print Frame” on page 35-22
“Opening a Print Frame” on page 35-22

### Saving a Print Frame

You must save a print frame to print a block diagram with that print frame. To save a print frame:

- 1 Select **Save As** from the **File** menu.

The **Save As** dialog box appears.

- 2 Type a name for the print frame in the **File name** edit box.

- 3 Click the **Save** button.

The print frame is saved as a figure file, which has the `.fig` extension. A figure file is a binary file used for print frames.

### Opening a Print Frame

You can open a saved print frame in the PrintFrame Editor, make changes to it, and save it under the same or a different name. To open an existing print frame:

- 1 Select **Open** from the **File** menu.

- 2 Select the print frame you want to open.

All print frames are figure files.

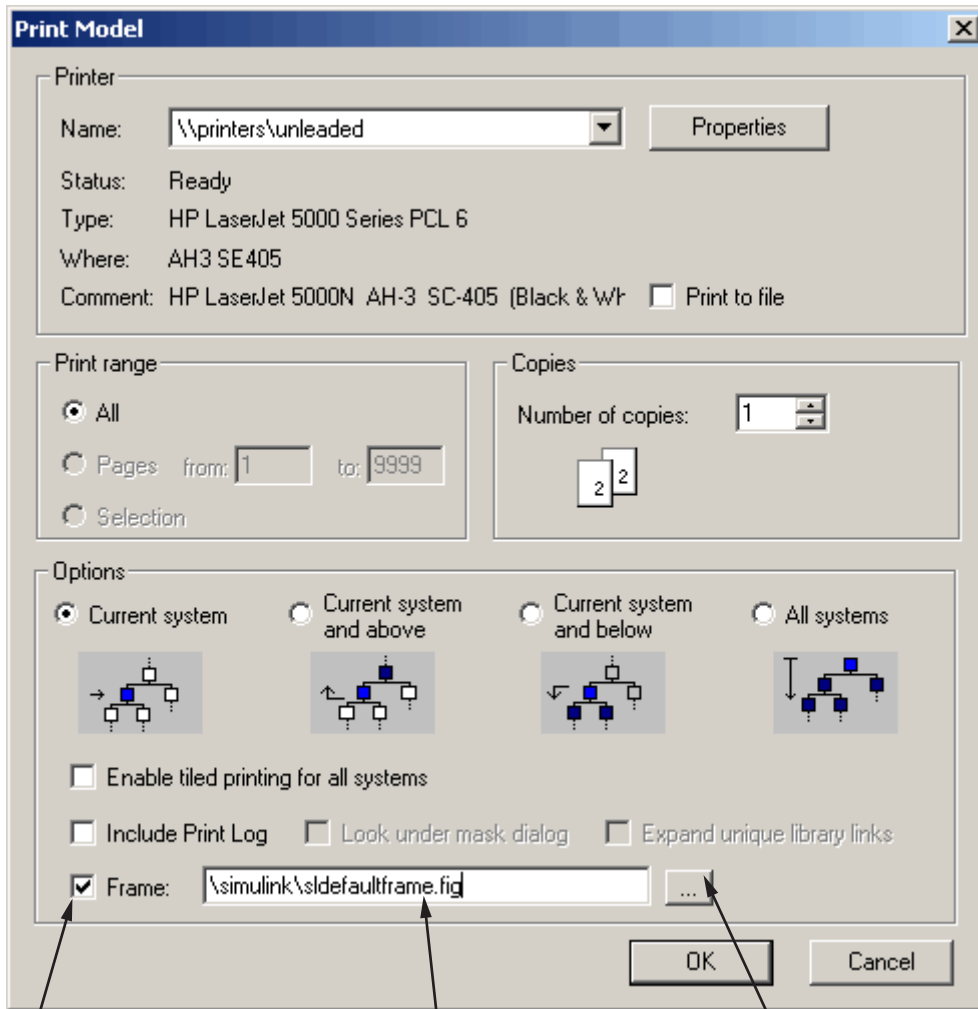
Alternatively, you can open a print frame from the MATLAB prompt. Type `frameedit filename` and the PrintFrame Editor opens with the print frame file you specified.

## Printing Block Diagrams with Print Frames

When using the Simulink software or Stateflow product, you can print a block diagram with the print frame.

- 1 Select **Print** from the **File** menu.

The **Print Model** dialog box appears. The dialog box shown below is for computers running the Microsoft Windows operating system. The dialog box for your platform might look slightly different.



Check this box to print the block diagram with a print frame.

Type the path and filename of the print frame you want the block diagram to print with,

or click the ... button and then select the print frame file.

In the **Print Model** dialog box:

- 1 Select the **Frame** check box.



- 2 Supply the 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.

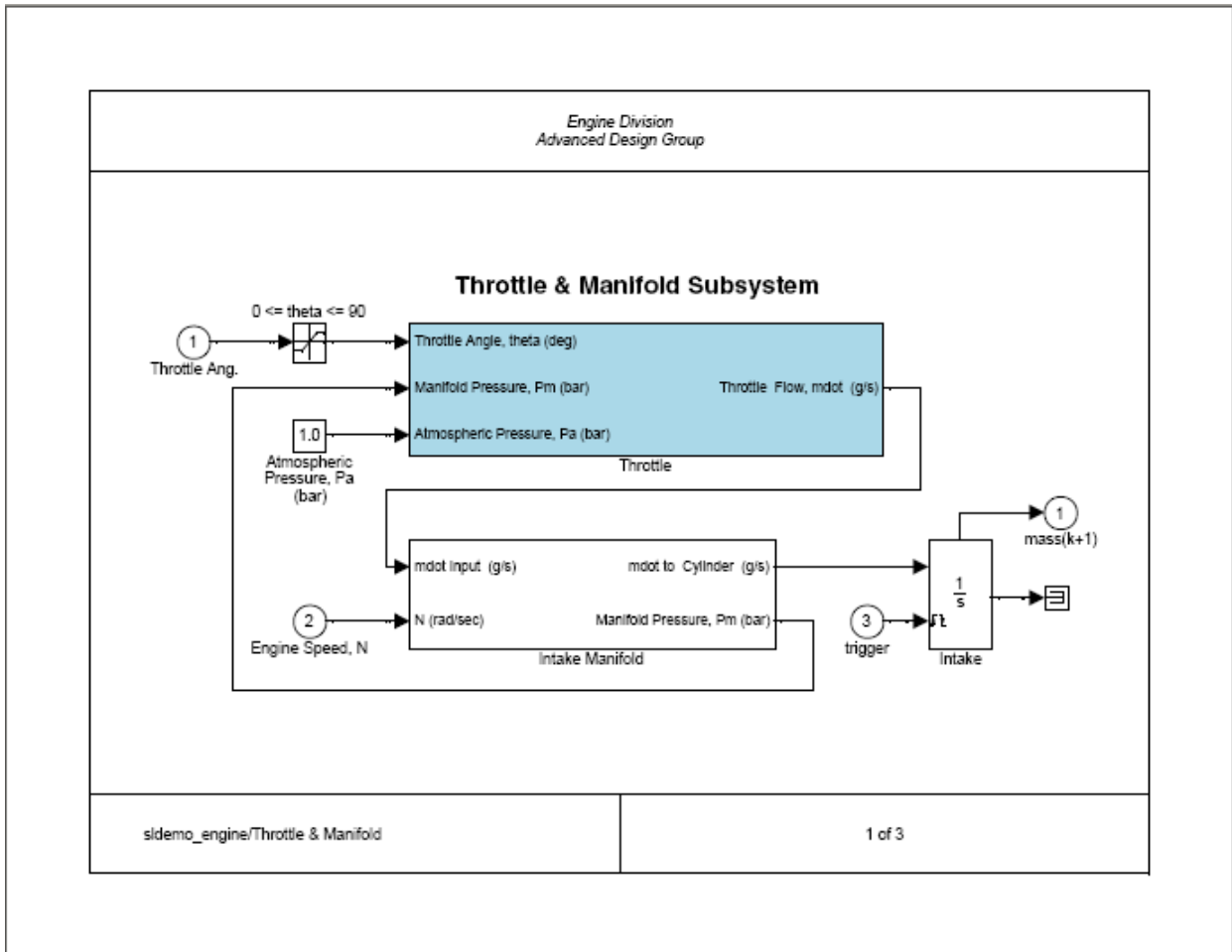
See also the example, "Print the Block Diagram with the Print Frame" on page 35-30.

## Example

<b>In this section...</b>
“About the Example” on page 35-26
“Create the Print Frame” on page 35-27
“Print the Block Diagram with the Print Frame” on page 35-30

### About the Example

This example uses a Simulink software demo engine model. It involves two parts — first creating a print frame, and then printing the engine model with that print frame. The result looks similar to the figure below.



## Create the Print Frame

**1** At the MATLAB prompt, type `frameedit`.

The **PrintFrame Editor** window appears.

**2** Set up the page:

- a** Select **Page Setup** from the **File** menu.

The **PrintFrame Page Setup** dialog box opens.

- b** For **Paper Type**, select a size that is appropriate for your printer.
- c** For this example, keep the **Paper Orientation** as **Landscape** and the **Margins** set to **0.75 inches**.
- d** Click the **OK** button.

The dialog box closes. The print frame you see in the **PrintFrame Editor** window will reflect your changes.

- 3** Add the information entries `%<blockdiagram>`, `%<fullsystem>`, and `%<page>`.
  - a** Click within the upper row in the print frame.
  - b** From the bottom right list box, select **Block Diagram**, then click **Add**. The `%<blockdiagram>` appears in the row.
  - c** Click within the lower left cell in the print frame.
  - d** From the bottom right list box, select **Full System Name**, then click **Add**. The `%<fullsystem>` appears in the cell.
  - e** Click within the lower right cell in the print frame.
  - f** From the bottom right list box, select **Page Number**, then click **Add**. The `%<page>` appears in the cell.

- 4** Add a row at the top.

- a** Click within the upper row in the print frame, the row that contains the `%<blockdiagram>` entry.

Be sure that handles appear on all four corners of the row.

- b** Click the **add row** button.

A new row appears at the top, above the row you selected.

- 5** Make the new row shorter.

- a** Click on the horizontal line that separates the top row (the row you just added) from the row beneath it (the row containing the `%<blockdiagram>` entry).

Be sure that only two handles appear, one at each end of the line. If you see four handles in either row, click directly on the horizontal line and the other two handles disappear.

- b** Drag the line up until the top row is about the same height as the row at the bottom of the print frame.

**6** Add information in the top row.

- a** Click anywhere within the top row (the row you just added).
- b** Select **Text** from the information list box.
- c** Click the **Add** button.

An edit box appears in the cell.

- d** Type **Engine Division**, press the **Enter** key to advance the cursor to the next line, and then type **Advanced Design Group**.

Click the zoom in button if you need to magnify the entry.

- e** Click outside of the edit box to end editing mode.

**7** In the left cell of the bottom row, align the information on the left.

- a** Click the zoom out button if you need to.
- b** Click within the left cell of the bottom row to select it.
- c** Click the left alignment button.

The entry moves to the left.

**8** Make the information in the top row appear in italics.

- a** Right-click on the entry in the row.
- b** Select **Font Style** from the pop-up menu.

If the pop-up menu for font properties does not appear, you are in editing mode. Click outside of the edit box to end editing mode and then right-click the text to access the pop-up menu.

- c** From the **Font Style** pop-up menu, select **italic**.

The entry in the cell appears in italics and the information will appear in italics when the print frame is printed with a Simulink diagram.

- 9 Add the total number of pages to the right cell in the bottom row.
  - a Click within the cell to select it.
  - b Add the total pages entry: select **Total Pages** from the information list box and click the **Add** button.

The %<npages> entry appears after the %<page> entry. If you need to, zoom in to see the entry.

- c Add the text **of** after the page number entry. Click the cursor after the %<page> entry, and then type **of** (type a space before and after the word).

The information in the cell now is: %<page> of %<npages>.

- 10 Save the print frame: select **Save As** from the **File** menu. In the **Save Frame** dialog box, type engdiv1 for the **File name**. Click the **Save** button.

The print frame is saved as a figure file.

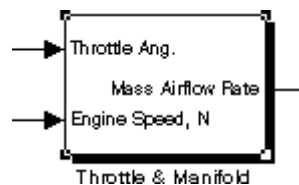
- 11 You can close the **PrintFrame Editor** window by clicking the close box.

## Print the Block Diagram with the Print Frame

- 1 To view the Simulink engine model, type `sldemo_engine` at the MATLAB prompt.

The engine model appears in a Simulink window.

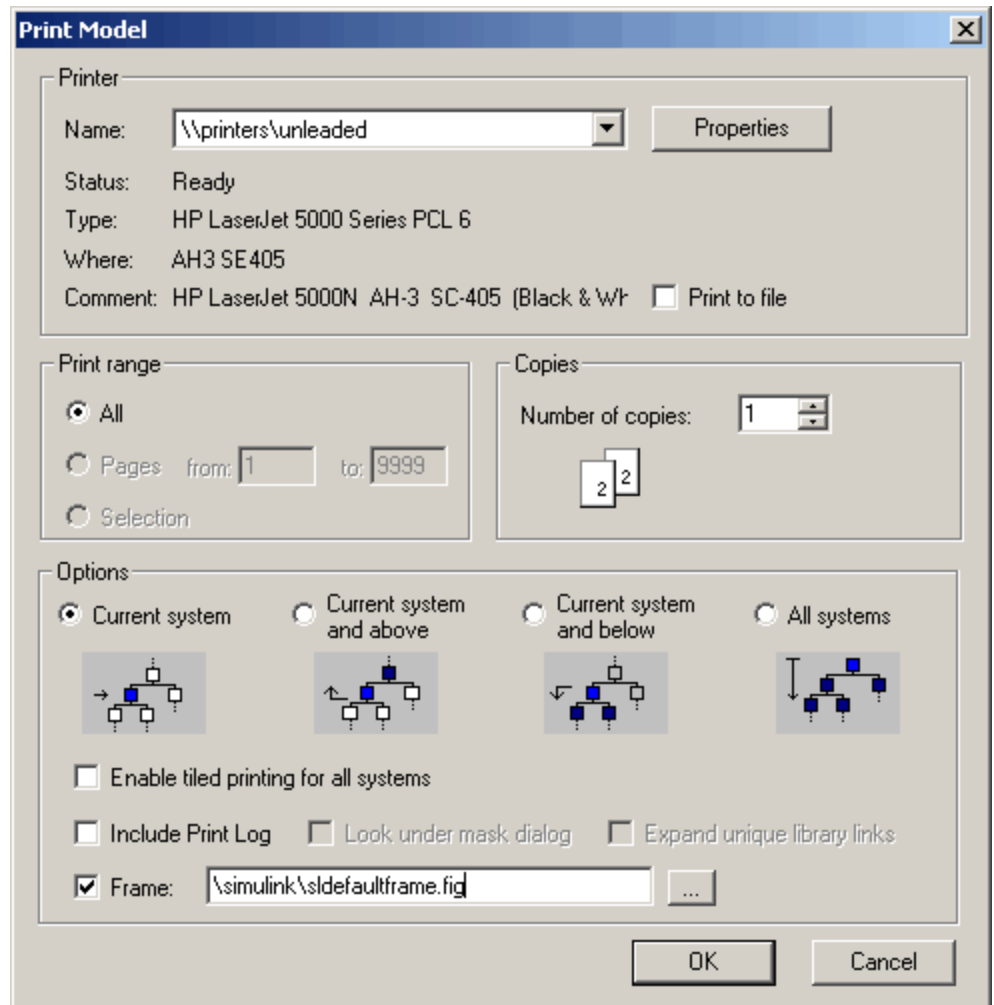
- 2 Double-click the Throttle & Manifold block.



The Throttle & Manifold subsystem opens in a new window.

- 3 In the **Throttle & Manifold** window, select **Print** from the **File** menu.

The **Print Model** dialog box opens with the default settings as shown here.



- 4 In the **Print Model** dialog box, set the page orientation to landscape. This example uses the techniques for computers running the Microsoft Windows

operating system. Use the methods for your own platform to change the page orientation for printing.

- a** Click the **Properties** button.

The **Document Properties** dialog box opens.

- b** Go to the **Page Setup** tab.
- c** For **Orientation**, select **Landscape**.
- d** Click **OK**.

The **Document Properties** dialog box closes.

- 5** In the **Print Model** dialog box, under **Options**, select **Current system and below**.

This specifies that the Throttle & Manifold block diagram and its subsystems will print.

- 6** Check the **Frame** check box.
- 7** Specify the print frame to use.
  - a** Click the ... button.
  - b** In the **Frame File Selection** dialog box, find the file name of the print frame you just created, `engdiv1.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 `engdiv1` print frame, but note that their variable information in the print frame is different.



# Running Models on Target Hardware

---

- Chapter 36, “About the Run on Target Hardware Feature”
- Chapter 37, “Work with BeagleBoard Hardware”
- Chapter 38, “Work with LEGO MINDSTORMS NXT Hardware”



# About the Run on Target Hardware Feature

---

*Run on Target Hardware* is a feature of the Simulink product that runs a Simulink model on *target hardware*, such as LEGO® MINDSTORMS® NXT or BeagleBoard hardware. 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
- Demos

For detailed information about using the Target Installer with your hardware, see:

“Install Target for Use with BeagleBoard Hardware” on page 37-2

“Install Target for Use with LEGO MINDSTORMS NXT Hardware” on page 38-2

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.

For specific information about any of the features or menu items described in this section, see:

- Chapter 37, “Work with BeagleBoard Hardware”
- Chapter 38, “Work with LEGO MINDSTORMS NXT Hardware”

# Work with BeagleBoard Hardware

---

- “Install Target for Use with BeagleBoard Hardware” on page 37-2
- “Replace the Firmware on the BeagleBoard Hardware” on page 37-9
- “Open a Serial Command Line Session with the BeagleBoard Hardware” on page 37-24
- “Connect the BeagleBoard Hardware to a Network and Configure IP Settings” on page 37-29
- “Get the IP Address of the BeagleBoard Hardware” on page 37-33
- “Open the Block Library for BeagleBoard Hardware” on page 37-36
- “Run a Model on BeagleBoard Hardware” on page 37-38
- “Tune Parameters and Monitor Data in a Model Running on BeagleBoard Hardware” on page 37-41
- “Detect and Fix Task Overruns on BeagleBoard Hardware” on page 37-45

## Install Target for Use with 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 a Model on BeagleBoard Hardware” on page 37-38.

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**.
- Demos

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.

---

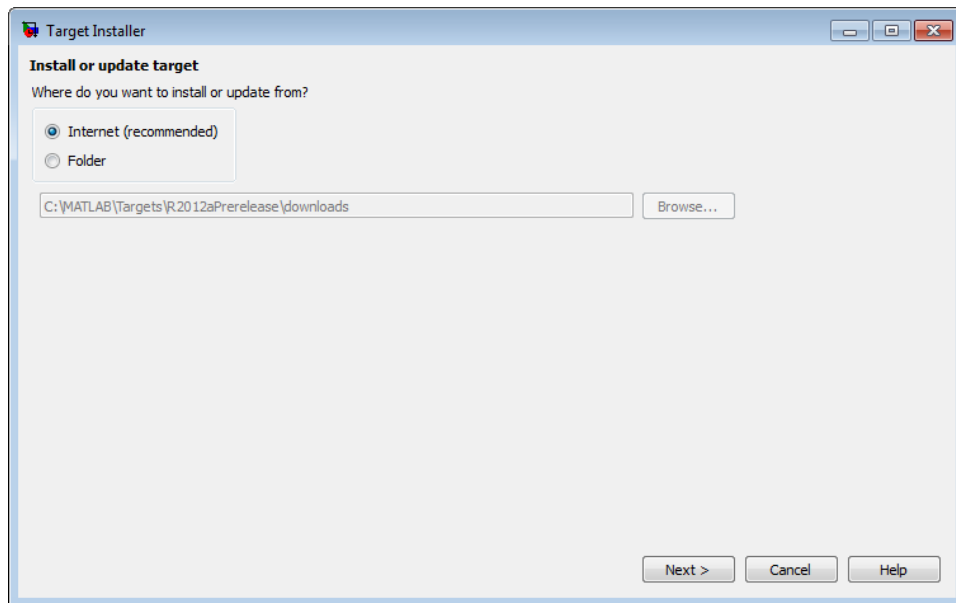
**Internet:** This option is selected by default. Target Installer downloads and install the support package and third-party software from the Internet.

**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.

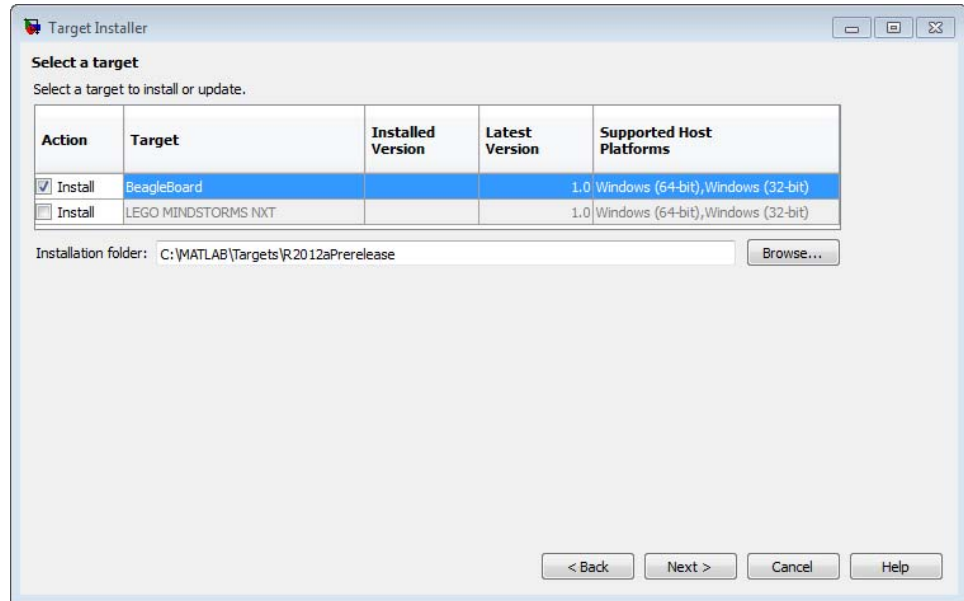
To locate the support package in a folder, search for a filename that begins with `rtt_beagleboard` and ends with `.zip`. For example:  
`rtt_beagleboard_r2012a_v1_0.zip`



- 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.





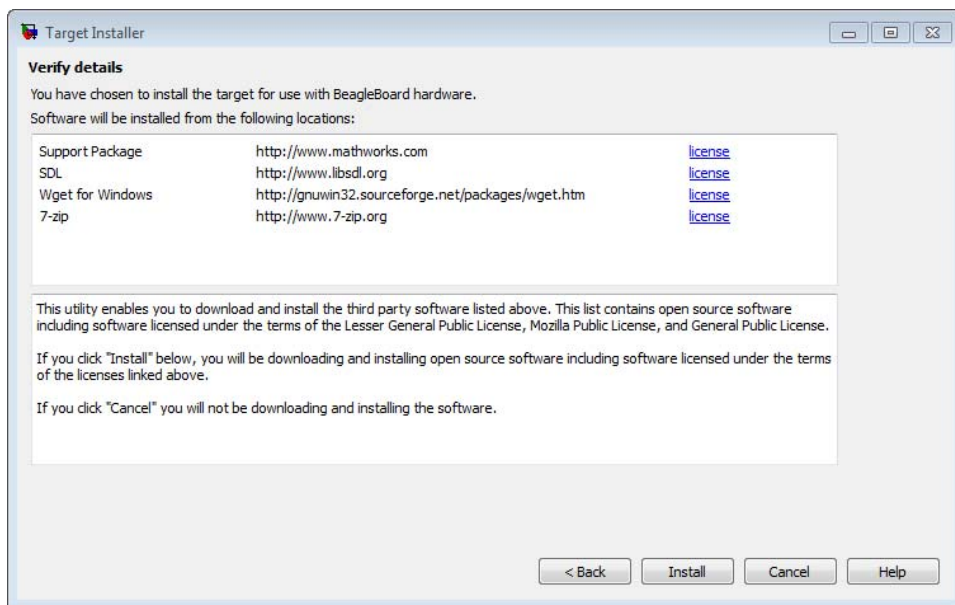
---

**Note** You must have write privileges for the Installation folder.

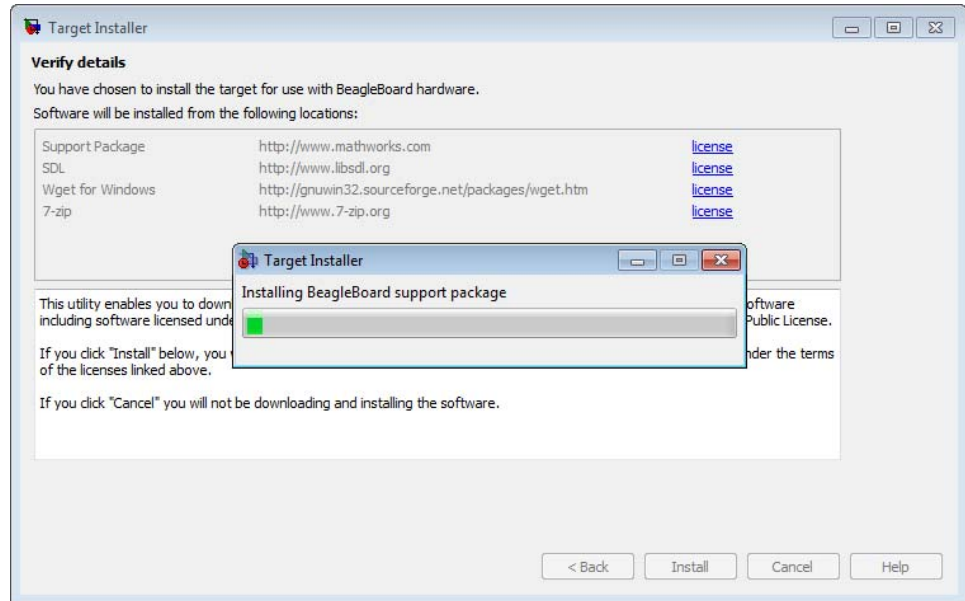
---

- 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**.

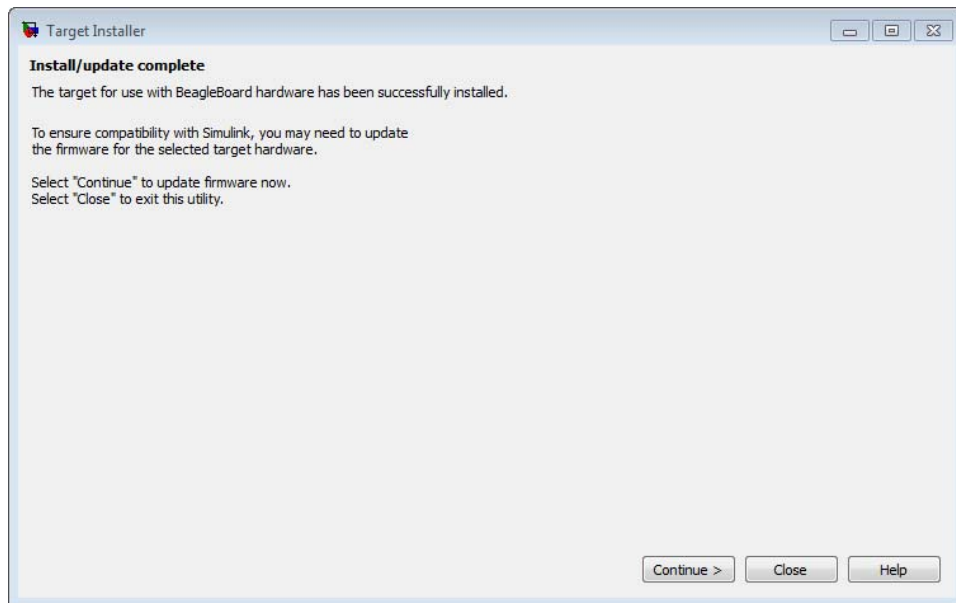


Target Installer displays a progress bar while it downloads and installs the third-party software.



**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 the Firmware on the BeagleBoard Hardware” on page 37-9.



## Replace the Firmware on the 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 Target for Use with BeagleBoard Hardware” on page 37-2.

After replacing the firmware, you can run a Simulink model on the BeagleBoard hardware, as described in “Run a Model on BeagleBoard Hardware” on page 37-38.

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 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.

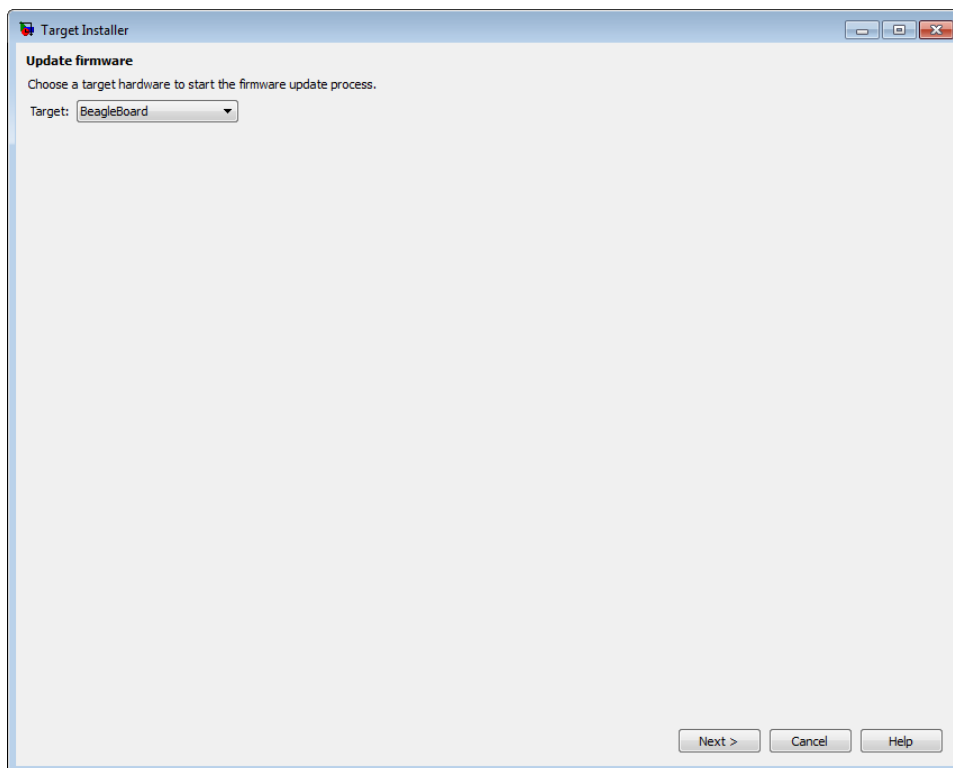
---

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 >**.

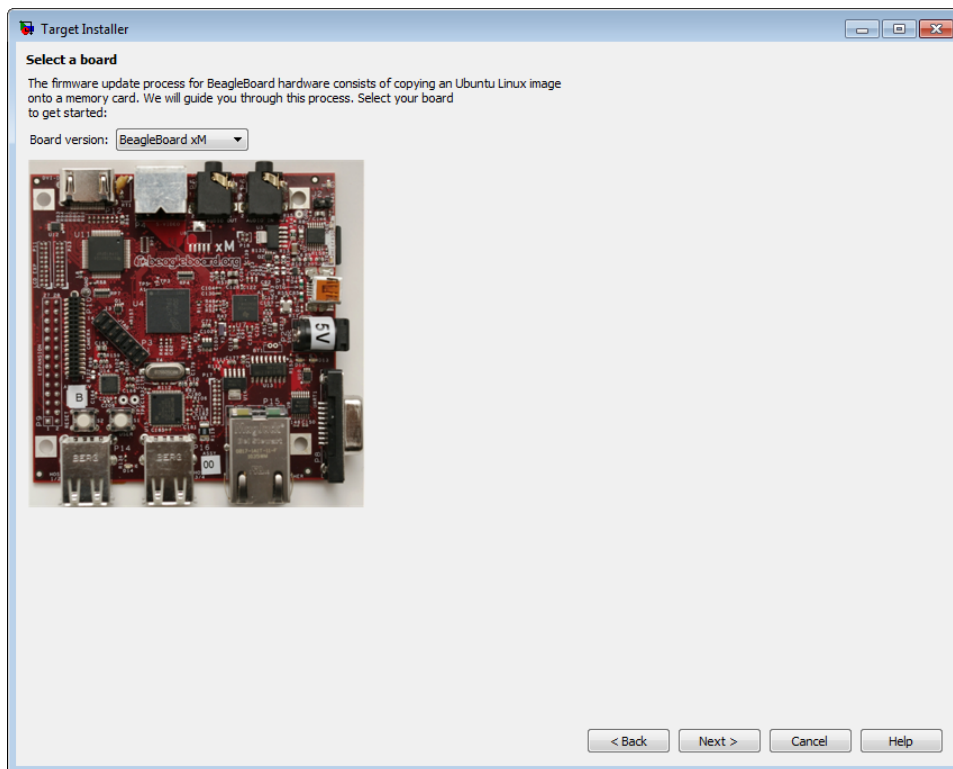


**3** Choose your board version and click **Next >**. This action enables the Target Installer to display instructions that are specific to your hardware.

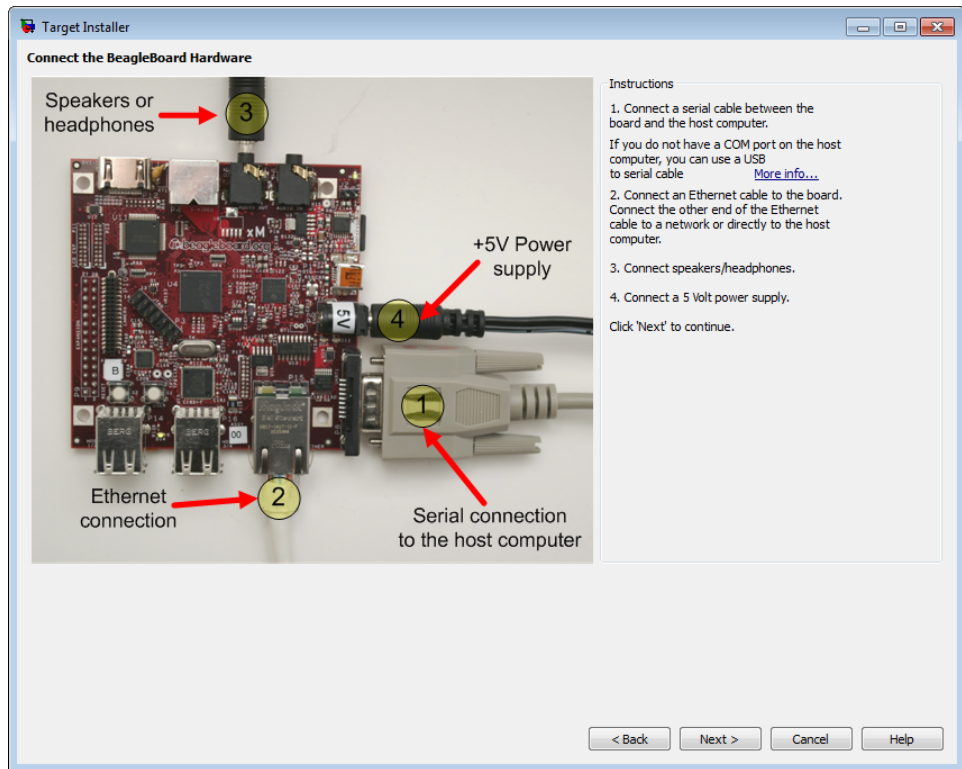
---

**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.

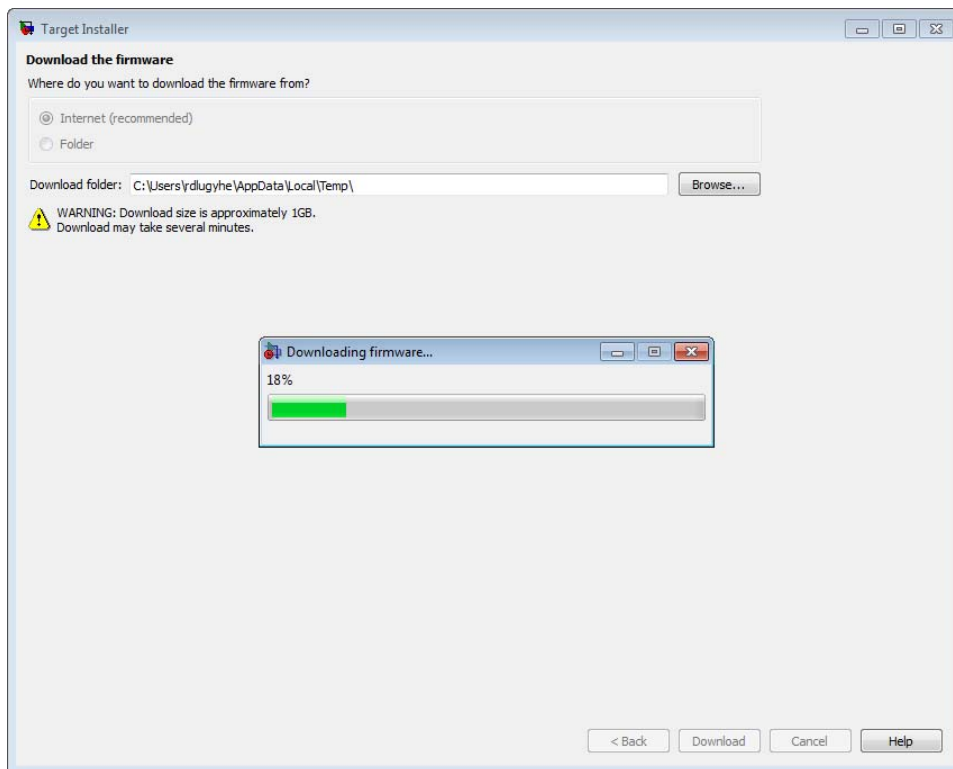
**Folder:** When you click **Download**, Target Installer checks the **Download folder** for a valid firmware image:

- 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.

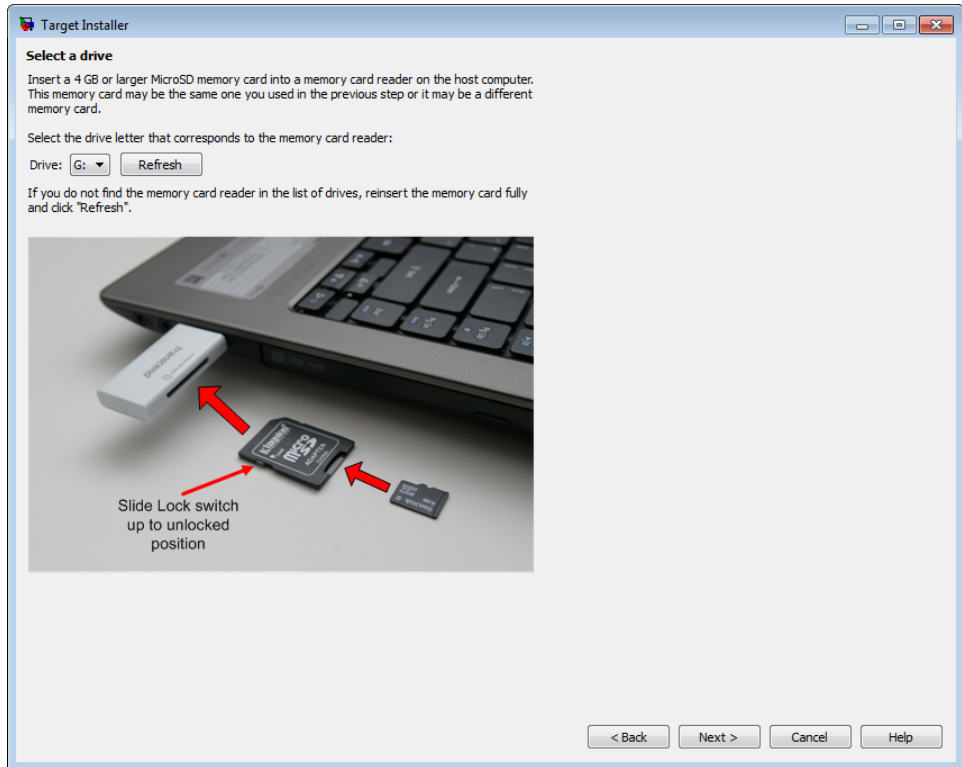
You must have write privileges for the download folder. If you use the default download folder, having write privileges is typically not an issue. If you change to a new download folder for which you do not have write permissions, such as a shared folder on a network, the Target Installer generates an 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.

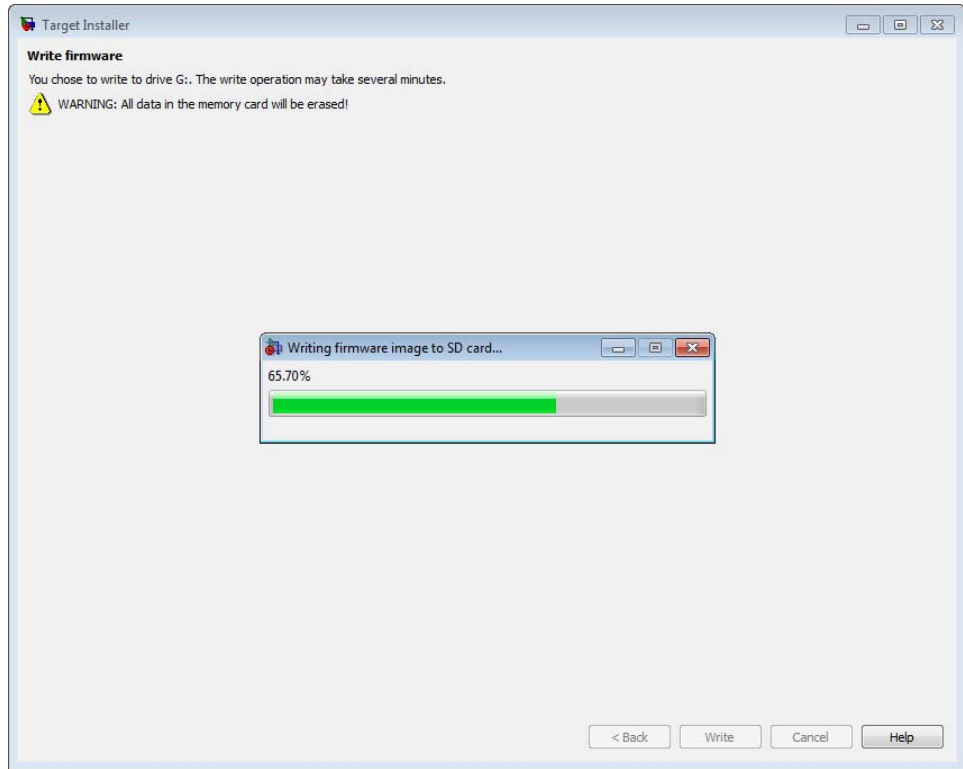
To locate the firmware image in a folder, search for a filename that begins with `beagleboard_ubuntu`. For example: `beagleboard_ubuntu_11_04_r4_12_08_2011.img.7z`



- 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**.

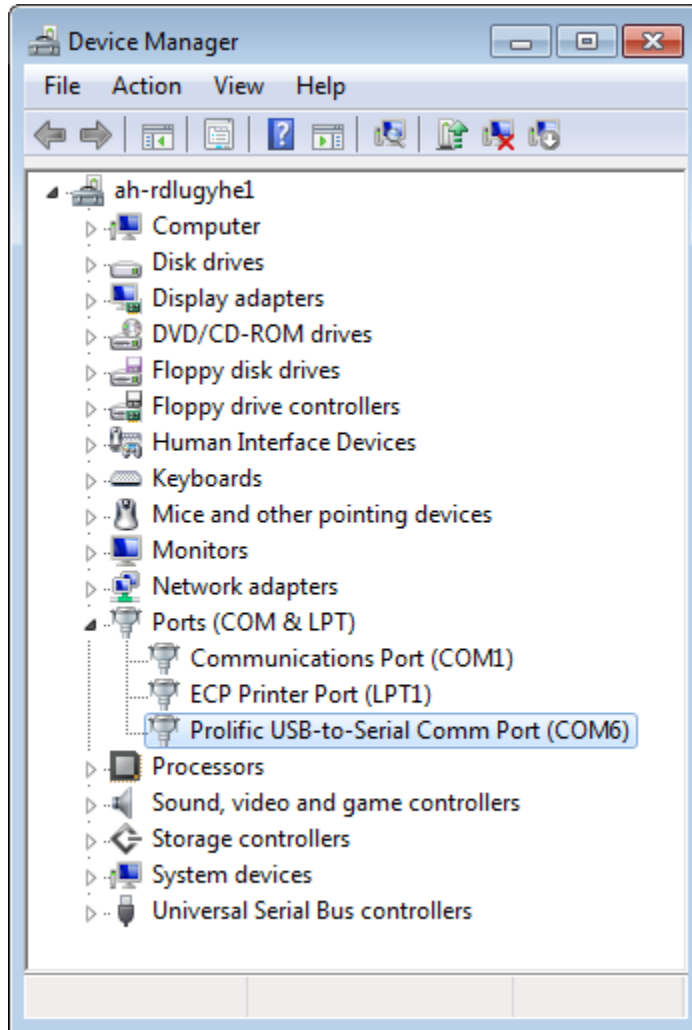


- 8 Click **Write**. Target Installer overwrites all previous data on the memory card with the firmware. This process takes several minutes to complete.



- 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.

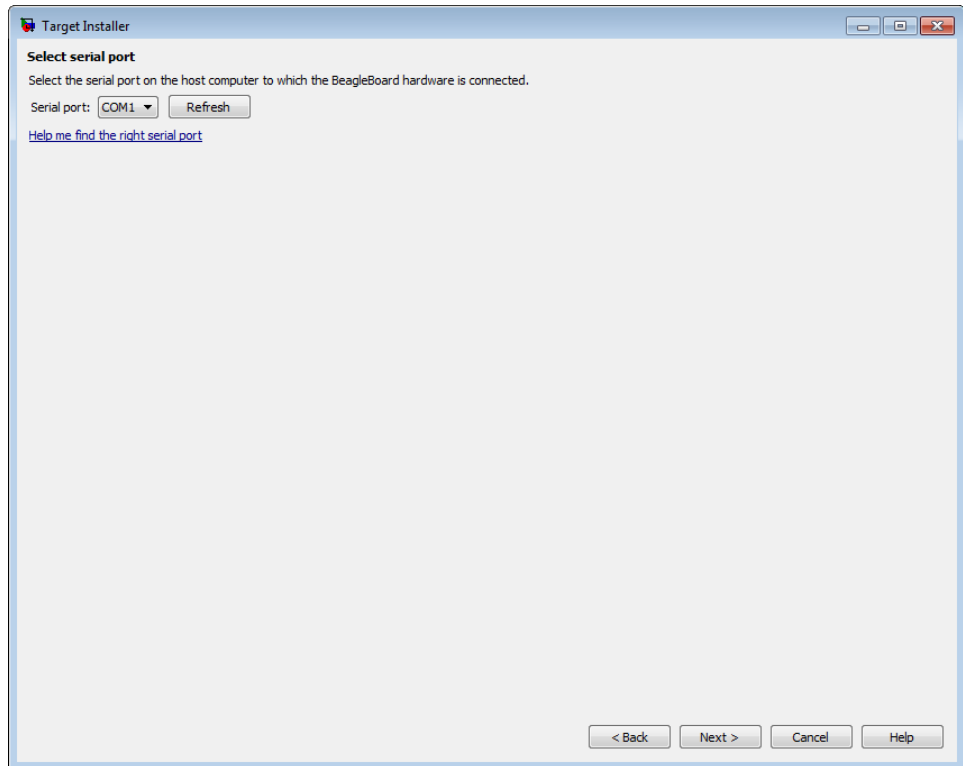


---

**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.

---

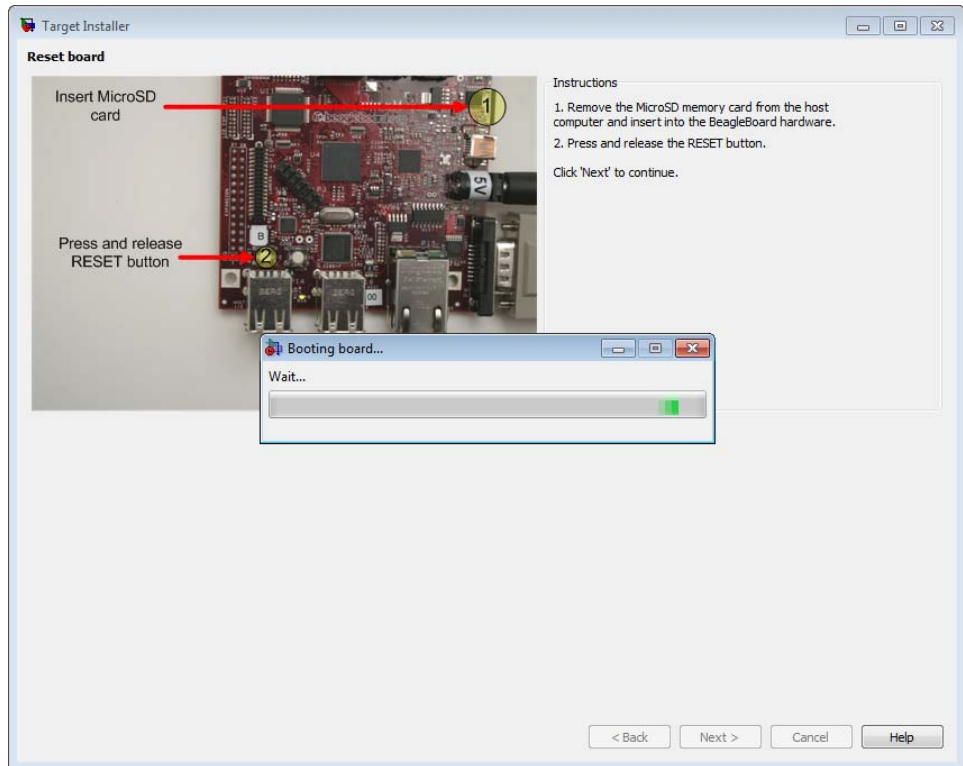
- 10 Target Installer does not automatically choose the COM port of the serial connection. After you get the COM port of the serial connection from Windows Device Manager, return to Target Installer, set **Serial port** to the COM port, and click **Next >**.



- 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 be 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:

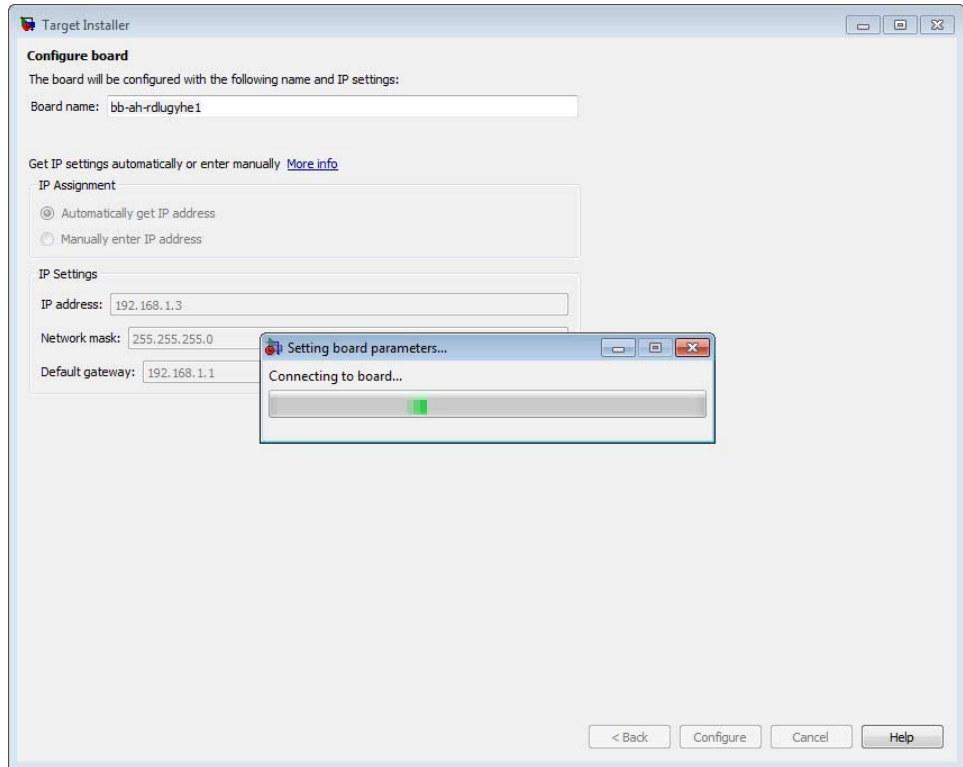
- The value of the subnet mask must be the same for all devices on the network.
- The value of the IP address must be unique for each device on the network.

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:

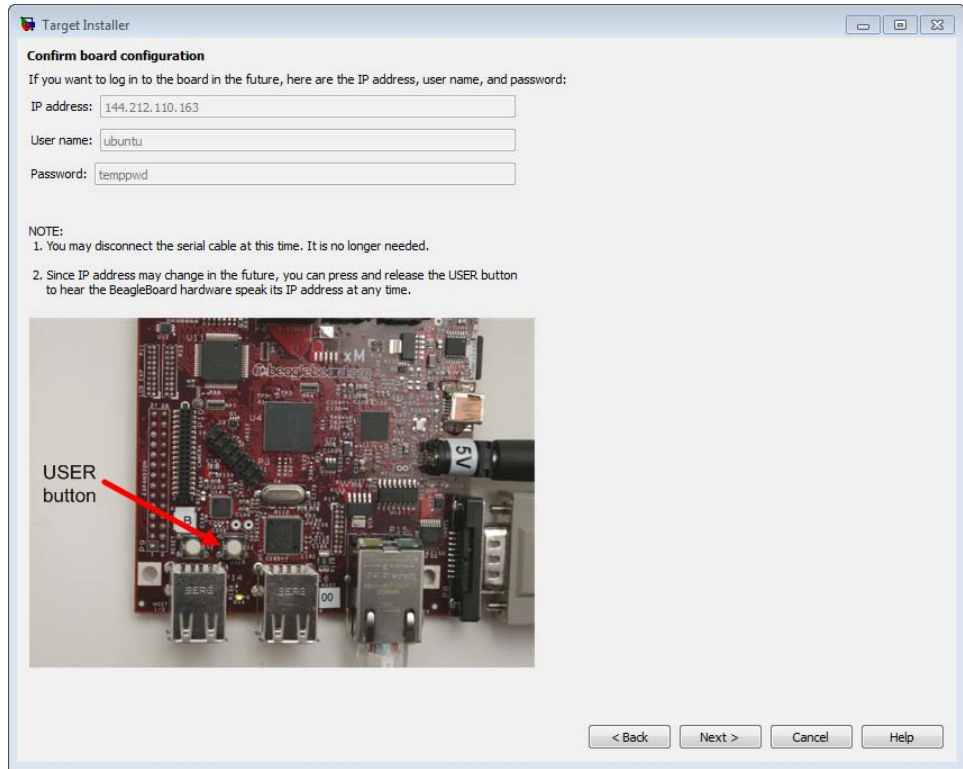
- **Network mask** to use the same network mask value, 255.255.255.0.
- **IP address** to an unused IP address, between 192.168.1.2 and 192.168.1.254.

When you click **Configure**, the Target Installer opens a serial connection and applies the settings to the board.

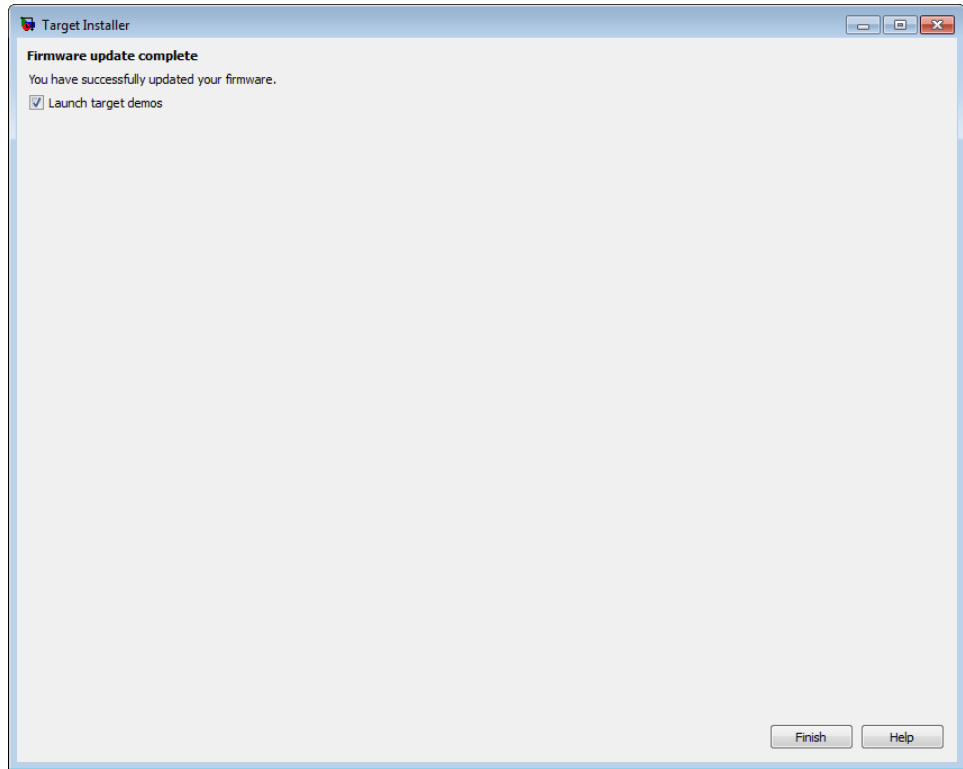




**13** Make a note of the board information. Then click **Next >**.



**14** Click **Finish**. If **Launch target demos** is enabled, the Target Installer opens the demo page for BeagleBoard hardware.



## Open a Serial Command Line Session with the BeagleBoard Hardware

This topic shows you how to create a serial connection and open a command line session with the BeagleBoard hardware (the “board”). 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 “Connect the BeagleBoard Hardware to a Network and Configure IP Settings” on page 37-29 topic.

This procedure requires a serial cable to connect to the serial connector on the board. You can use a “USB to DB9 serial adapter cable” or a “DB9 low profile null modem M-F cable”.

---

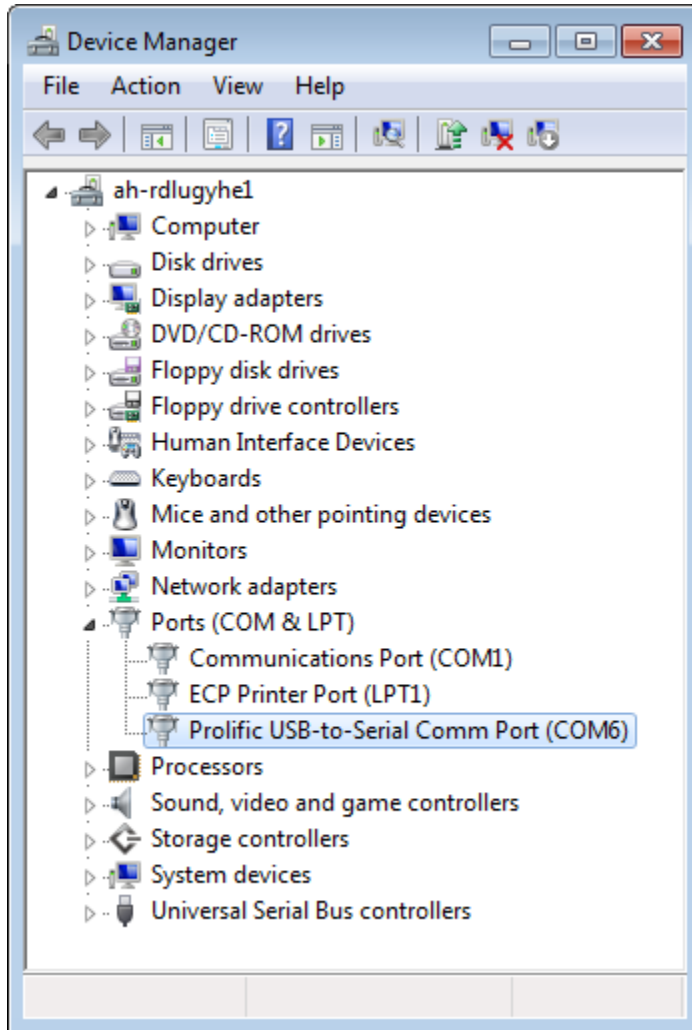
**Note** Some USB-to-serial adapters do not appear in the list of serial connections immediately after you install the software drivers. To solve this issue, disconnect/reconnect the adapter, or reboot your host computer.

---

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.



---

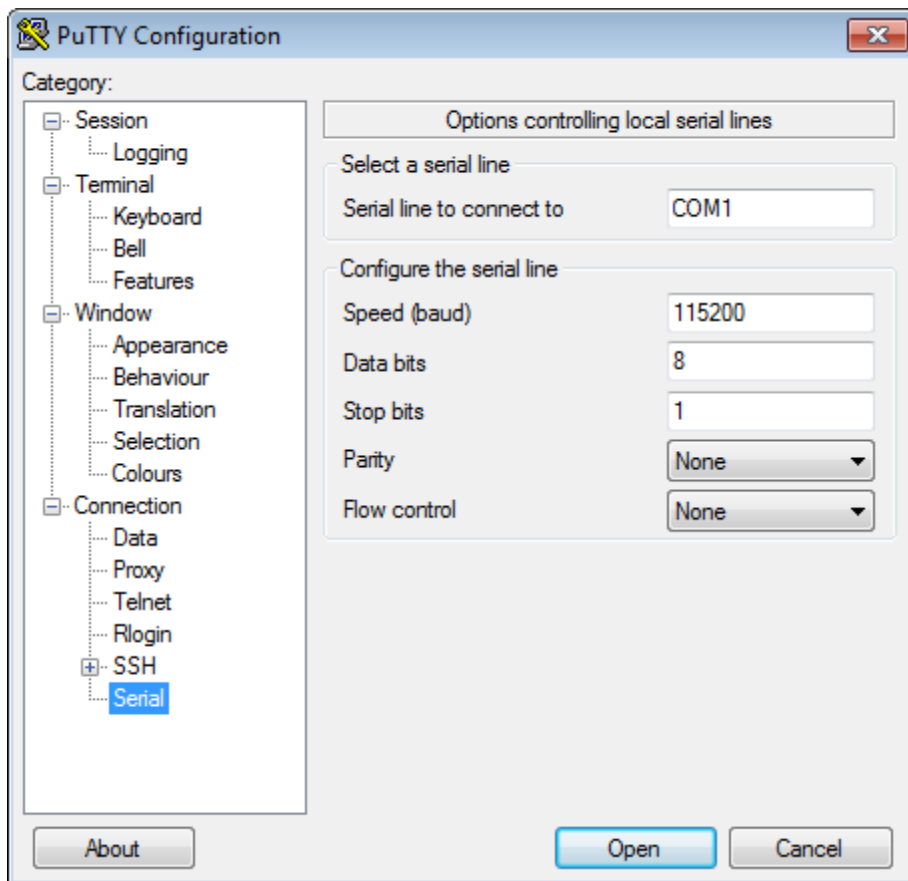
**Note** If you have trouble locating the COM port number, search the Windows “Help and Support” for “Device Manager”.

---

**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.

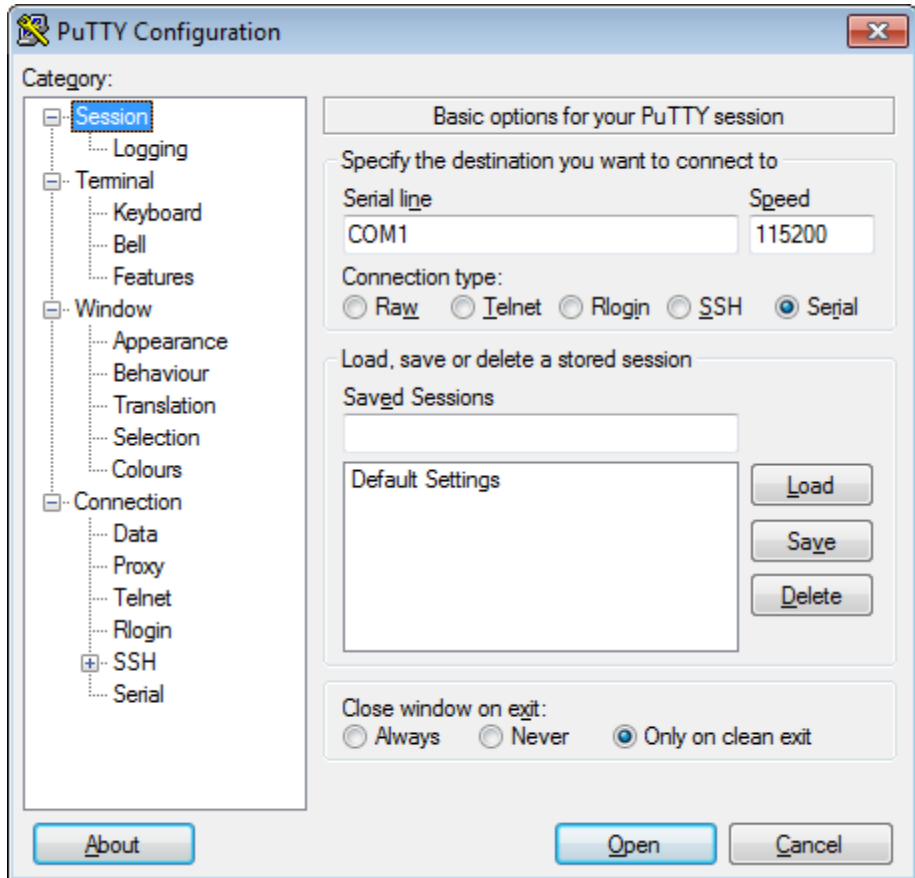


5 Set the following values:

- **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.

---

8 When a terminal window opens, press the **Enter** key on your keyboard. Then enter the username and password for the root user on the board. By default, these are:

- **Username:** ubuntu
- **Password:** tempwd

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

- “Connect the BeagleBoard Hardware to a Network and Configure IP Settings” on page 37-29
- For more information about PuTTY, see:  
<http://www.chiark.greenend.org.uk/~sgtatham/putty/>



## Connect the BeagleBoard Hardware to a Network and Configure IP Settings

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 the Firmware on the BeagleBoard Hardware” on page 37-9.

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 “Open a Serial Command Line Session with the BeagleBoard Hardware” on page 37-24

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: tempwd)

**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 a Model on BeagleBoard Hardware” on page 37-38
- “Get the IP Address of the BeagleBoard Hardware” on page 37-33

## Get the IP Address of the 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 a Model on BeagleBoard Hardware” on page 37-38.

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 “Open a Serial Command Line Session with the BeagleBoard Hardware” on page 37-24.

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**

- “Open a Serial Command Line Session with the BeagleBoard Hardware” on page 37-24
- “Run a Model on BeagleBoard Hardware” on page 37-38
- “Connect the BeagleBoard Hardware to a Network and Configure IP Settings” on page 37-29

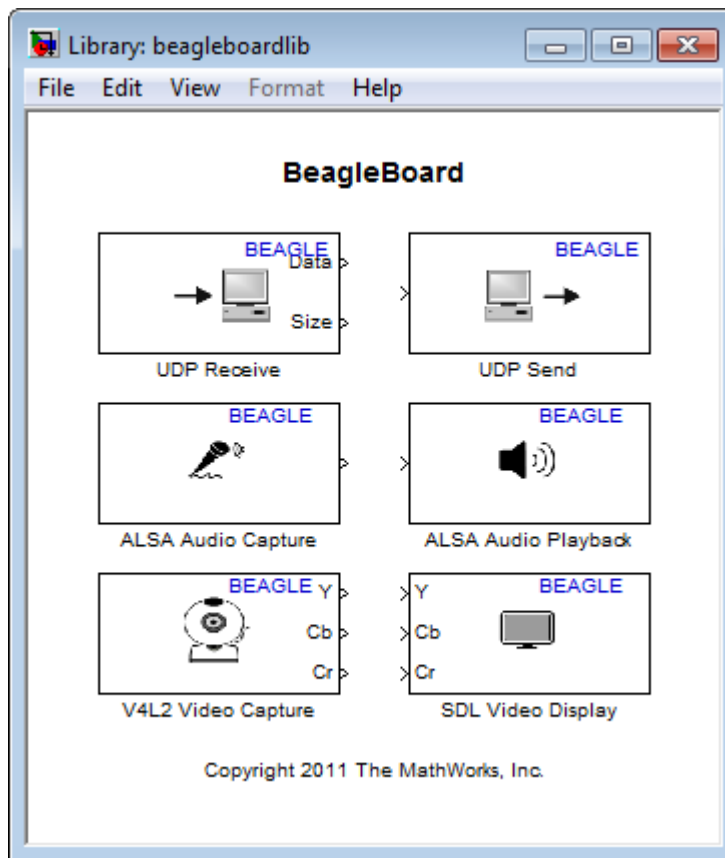
## Open the Block Library for BeagleBoard Hardware

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.



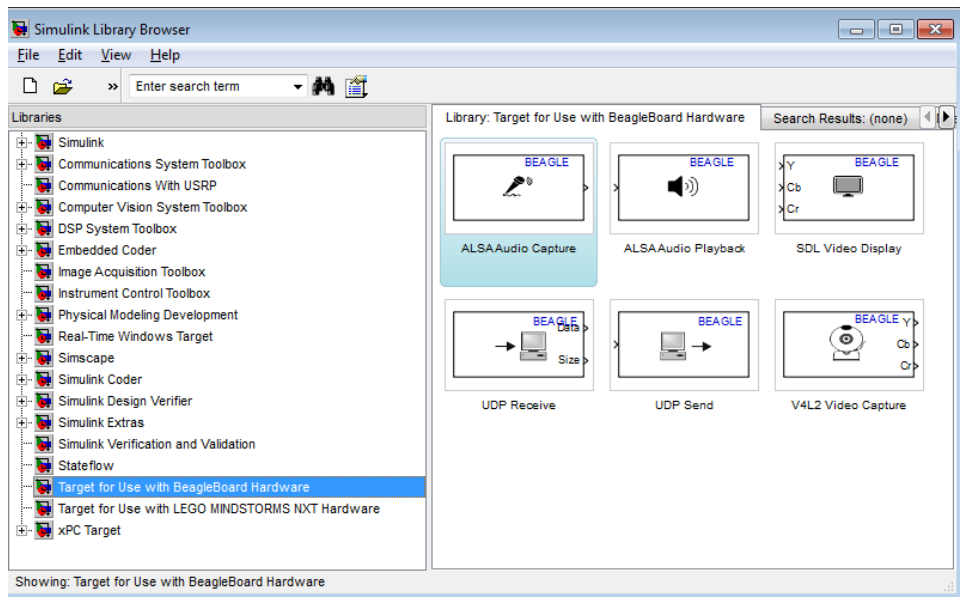
To open the block library from the Simulink Library Browser:



- 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 a 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 **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 **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.

**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 the Firmware on the BeagleBoard Hardware” on page 37-9.

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 Chapter 5, “Referencing a Model”

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

- “Creating a Simulink Model”
- “Connect the BeagleBoard Hardware to a Network and Configure IP Settings” on page 37-29
- “Tune Parameters and Monitor Data in a Model Running on BeagleBoard Hardware” on page 37-41
- Chapter 5, “Referencing a Model”

# Tune Parameters and Monitor Data in a Model Running on BeagleBoard Hardware

## In this section...

“About External Mode” on page 37-41

“Run Your Simulink Model in External Mode” on page 37-42

“Stop External Mode” on page 37-43

## About External Mode

You can use External mode to tune parameters and monitor data in a model running on your target hardware.

External mode enables you to fine tune your model on the actual hardware platform and with actual data inputs it will use when deployed. This real-time tuning on hardware cannot be achieved in a pure simulation environment.

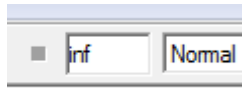
External mode also accelerates parameter tuning. When you develop an algorithm, you typically try a range of parameter values in order to find the optimal settings. Without External mode, you must re-run the model on the target hardware to evaluate the effects of each change. With External mode, you can adjust parameter values, monitor data, and evaluate the results until you find the optimal value, without re-running the model.

When you change the parameter values in the model on your host computer, External mode applies those changes to the model running on target hardware.

You can monitor data from the model running on the target hardware using sink blocks, such as Display or Scope blocks. 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 them.

## Run Your Simulink Model in External Mode

- 1 Create a network connection between the BeagleBoard hardware and your host computer. See “Connect the BeagleBoard Hardware to a Network and Configure IP Settings” on page 37-29
- 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 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 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.

---



# Work with LEGO MINDSTORMS NXT Hardware

---

- “Install Target for Use with LEGO MINDSTORMS NXT Hardware” on page 38-2
- “Replace the Firmware on the NXT Brick” on page 38-7
- “Open the Block Library for LEGO MINDSTORMS NXT Hardware” on page 38-11
- “Run a Model on LEGO MINDSTORMS NXT Hardware” on page 38-14
- “Remotely Control and Monitor a Model Running on LEGO MINDSTORMS NXT Hardware” on page 38-16
- “Detect and Fix Task Overruns on LEGO MINDSTORMS NXT Hardware” on page 38-27
- “Exchange Data Between Two NXT Bricks” on page 38-28

## Install Target for Use with 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**.
- Demos

For convenience, this document occasionally refers to LEGO MINDSTORMS NXT hardware as an “NXT brick” or as “target hardware”.

---

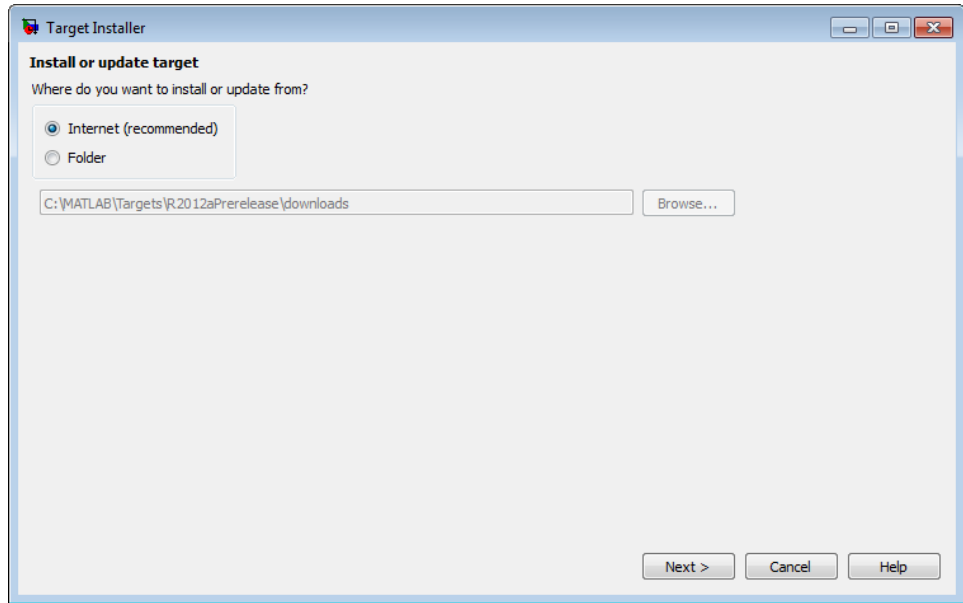
**Note** You can only use this target on a host computer running 32-bit or 64-bit version of Windows that Simulink supports.

---

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 is in a read-only folder, copy the support package zip file to a writable folder before continuing. For example, copy `rtt_legomindstormsnext_r20*.zip` from a read-only network drive to the `C:\MATLAB\Targets\R20*\downloads` folder on your host computer.

---

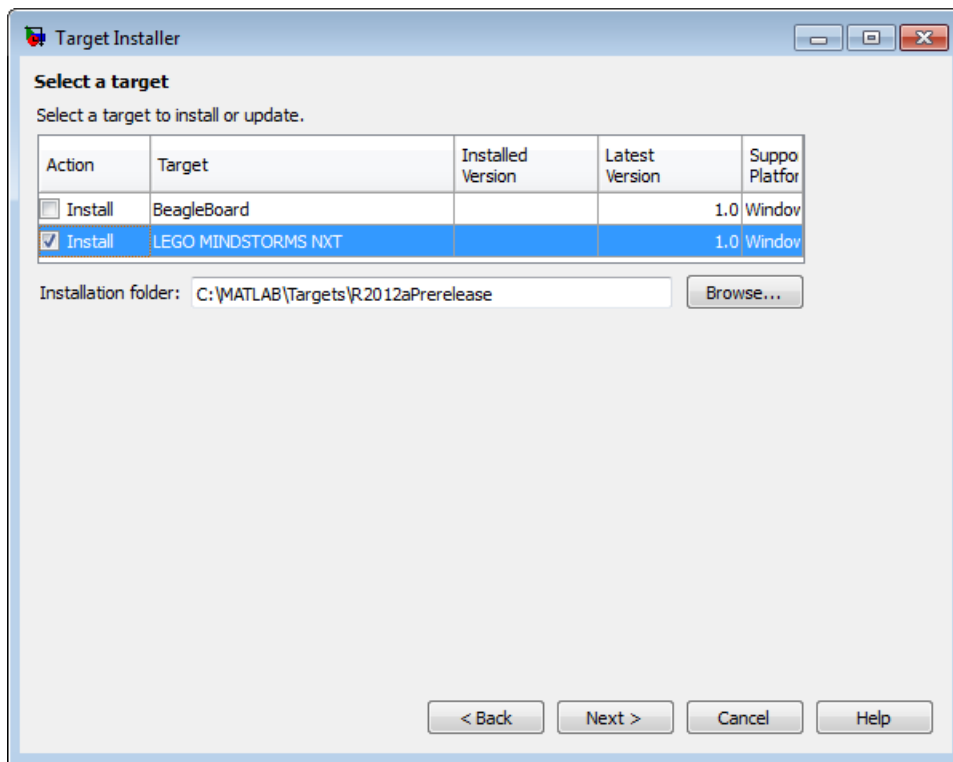
---

**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.

---

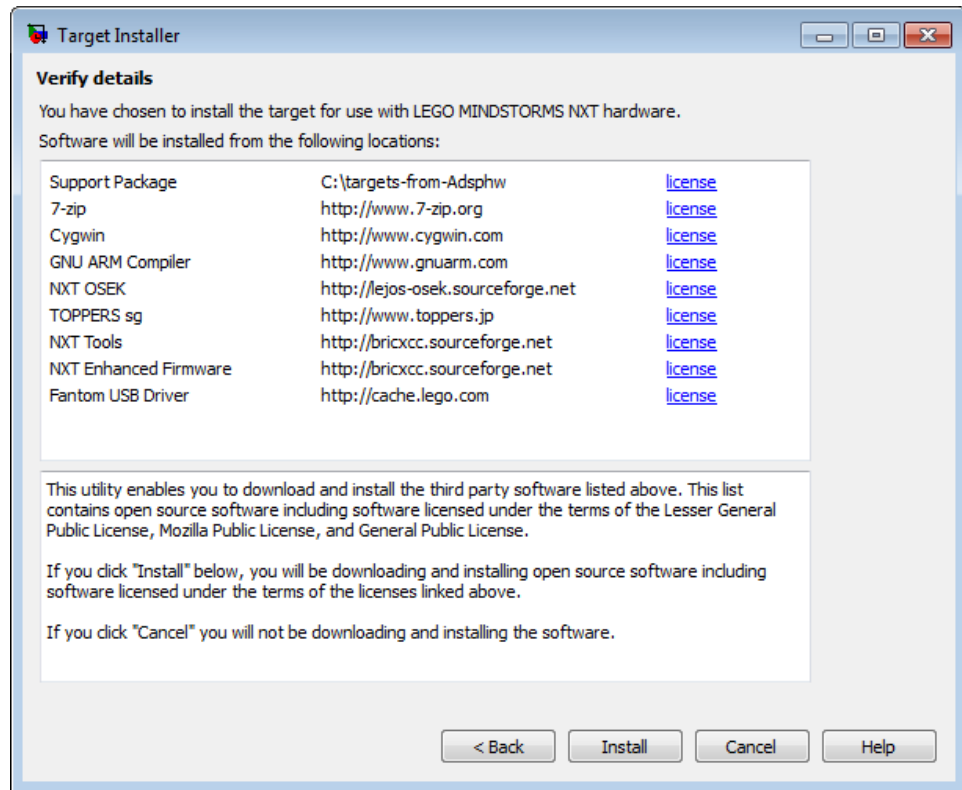
- 3 Select the LEGO MINDSTORMS NXT checkbox and click **Next >**.

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.

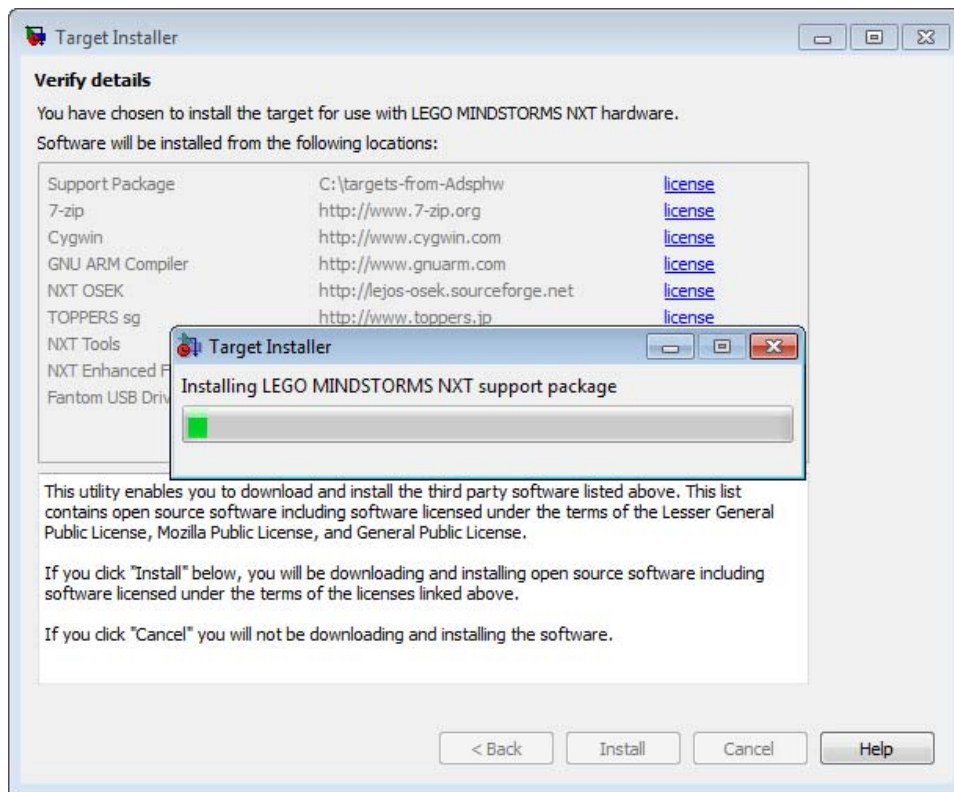


- 4 Target Installer states that you have chosen to install the support package for LEGO MINDSTORMS NXT and lists third-party software it will install.

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 the Firmware on the NXT Brick” on page 38-7. Otherwise, click **Close**.



## Replace the Firmware on the NXT Brick

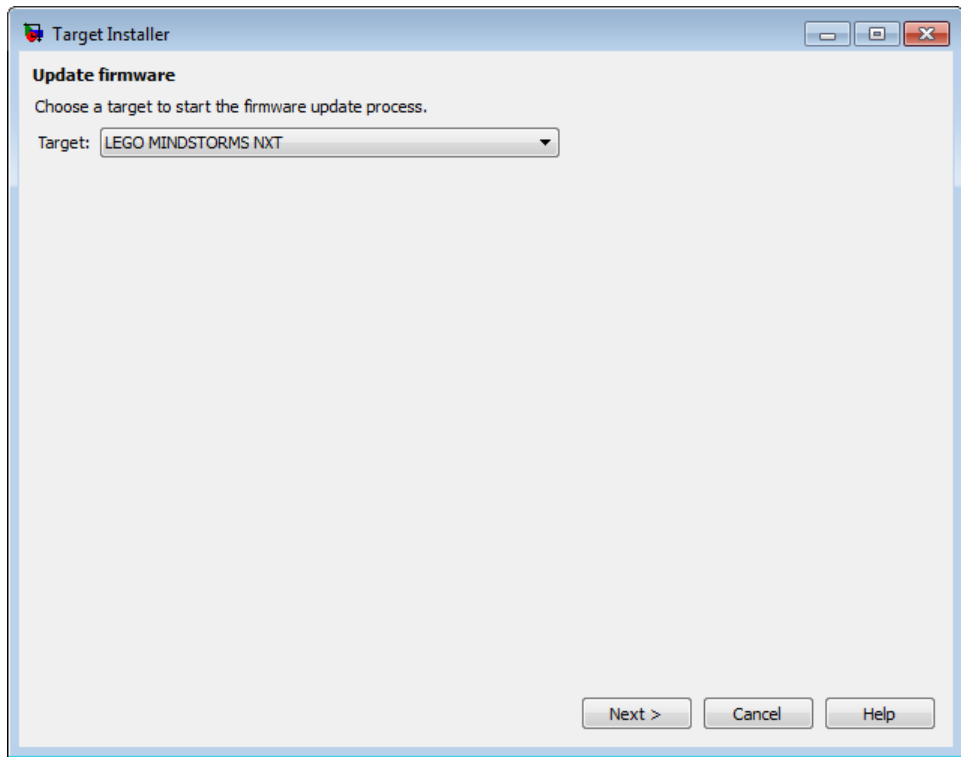
This topic shows how to replace the firmware on the NXT brick with enhanced firmware that can run Simulink models. The enhanced firmware can run

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 a Model on LEGO MINDSTORMS NXT Hardware” on page 38-14.

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.

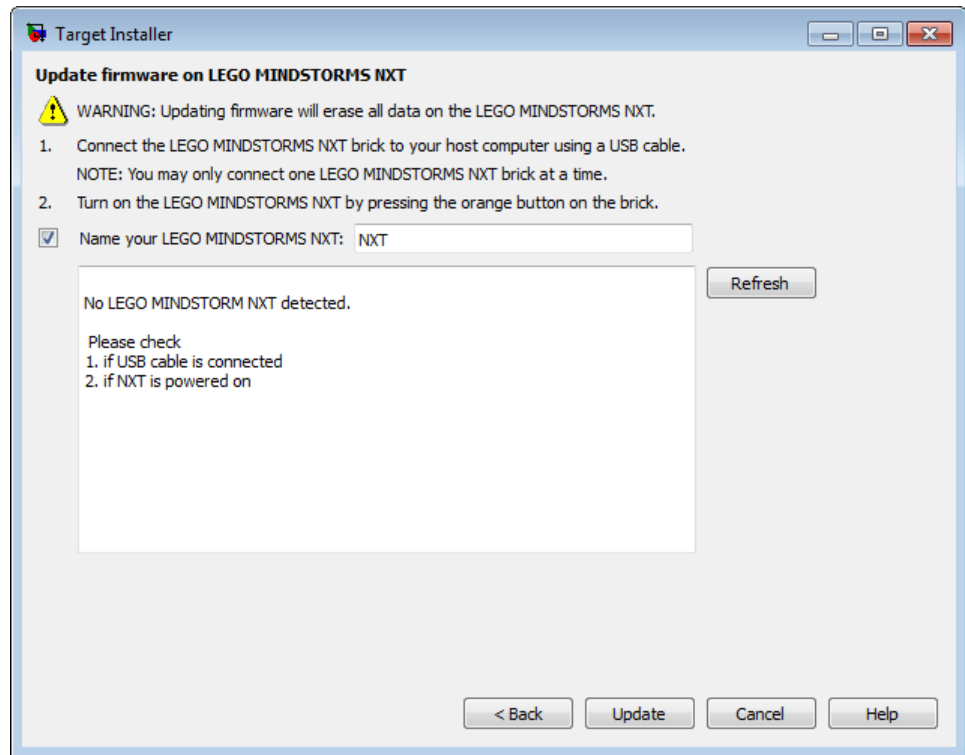
- 1** Open the **Update firmware** screen in the Target Installer using one of the following methods:
  - Click **Continue >** in the **Install/update complete** screen of the Target Installer.
  - In a model, select **Tools > Run on Target Hardware > Update firmware....**
  - In a MATLAB Command Window, 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.

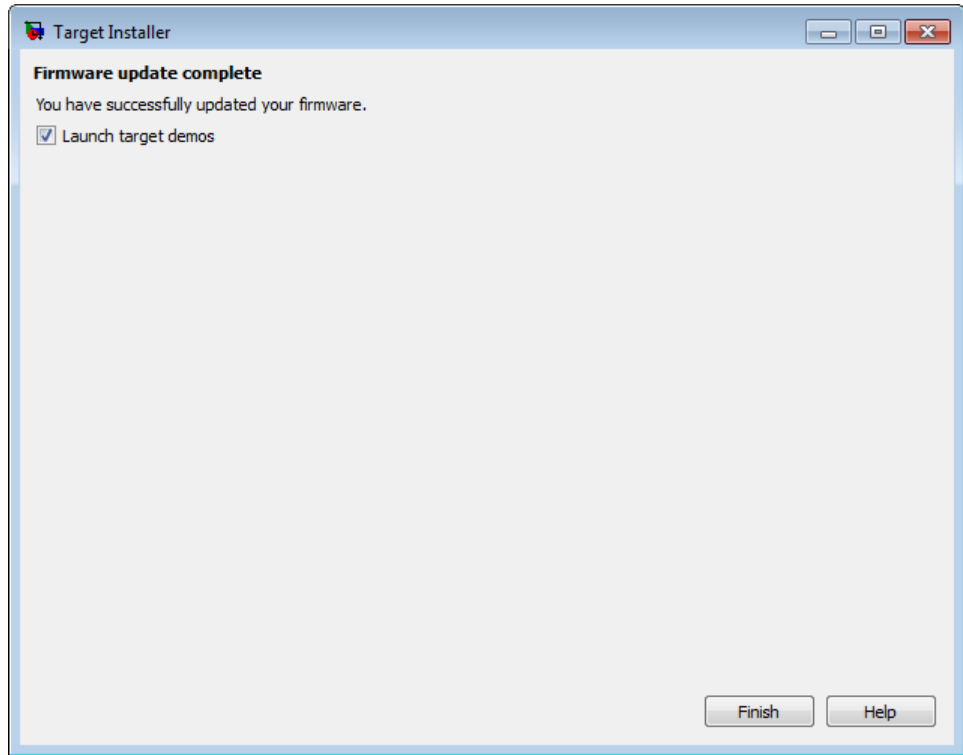
Enter a unique name for the **Name your LEGO MINDSTORMS NXT** parameter, and click **Next >**.



During the firmware update, the NXT brick emits a faint ticking sound and the LCD screen 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 demos.



## Open the 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.

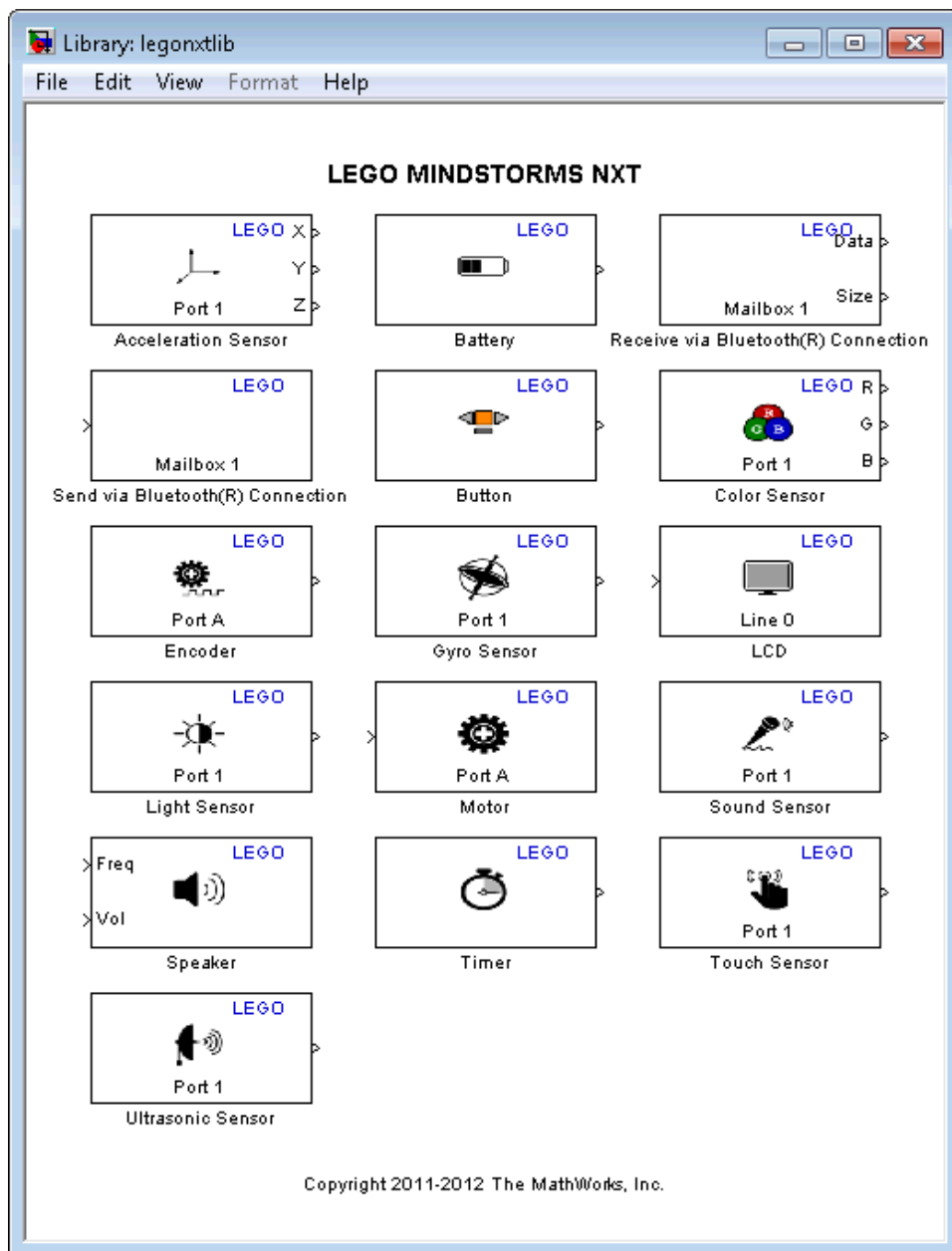
There are two ways to open the block library for LEGO MINDSTORMS NXT hardware:

- 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.



2 In the MATLAB Command Window, enter:

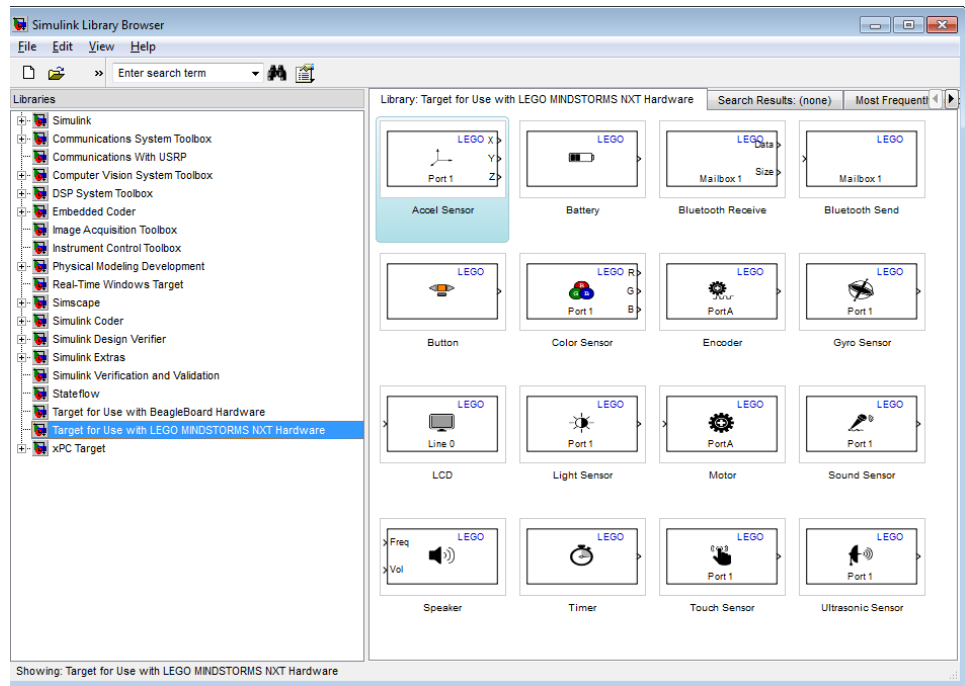
```
simulink
```

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 a Model on LEGO MINDSTORMS NXT Hardware

This example shows how to prepare, configure, and run a simple model on an NXT brick.

Before starting this procedure:

- Connect your NXT brick to the host computer using a USB cable.
- Create or open a Simulink 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 LEGO MINDSTORMS NXT.
- 4** 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.

---

- 5** Select **Tools > Run on Target Hardware > Run**. This action automatically downloads and runs your model on the NXT brick. If the model does not contain an LCD block, the LCD on the NXT brick displays “I am running ...” followed by the model name. If the model contains one or more LCD blocks, the LCD on the NXT brick displays the block input values and labels for each LCD block.



---

**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 Chapter 5, “Referencing a Model”

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.

## Remotely Control and Monitor a Model Running on LEGO MINDSTORMS NXT Hardware

### In this section...

“About External Mode” on page 38-16

“Set up Bluetooth on Windows” on page 38-17

“Run Your Simulink Model in External Mode” on page 38-21

“Stop External Mode” on page 38-23

“Set the COM Port Number Manually” on page 38-23

### 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.

## Set up Bluetooth on Windows

External mode uses a Bluetooth® device on your host computer to communicate with the built-in Bluetooth device on the NXT brick.

---

### Note

- Details for adding a Bluetooth device vary from one of version of Windows to another. If needed, search the Microsoft help for additional information.
- 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 website.
- External mode does not support models that use the Bluetooth device on the NXT bricks. See “Exchange Data Between Two NXT Bricks” on page 38-28.
- 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.

---

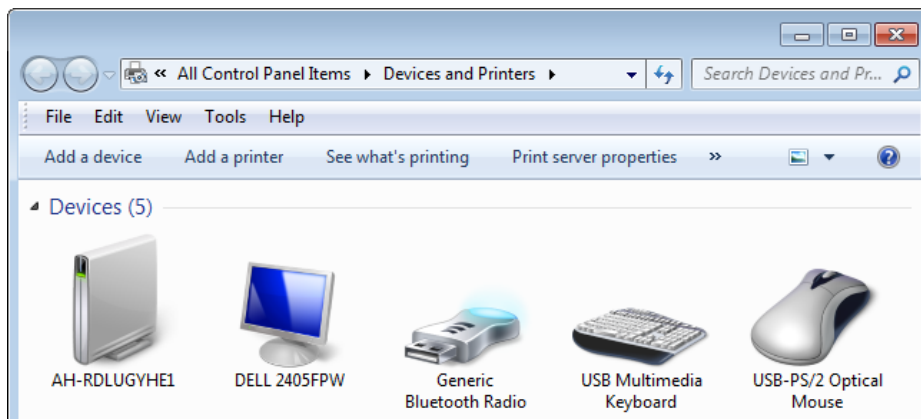
Set up a Bluetooth on your Windows host:

- 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 B-shaped Bluetooth symbol is visible in the upper left corner of the LCD screen.

If the Bluetooth symbol isn't 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 see if the NXT brick is already listed.

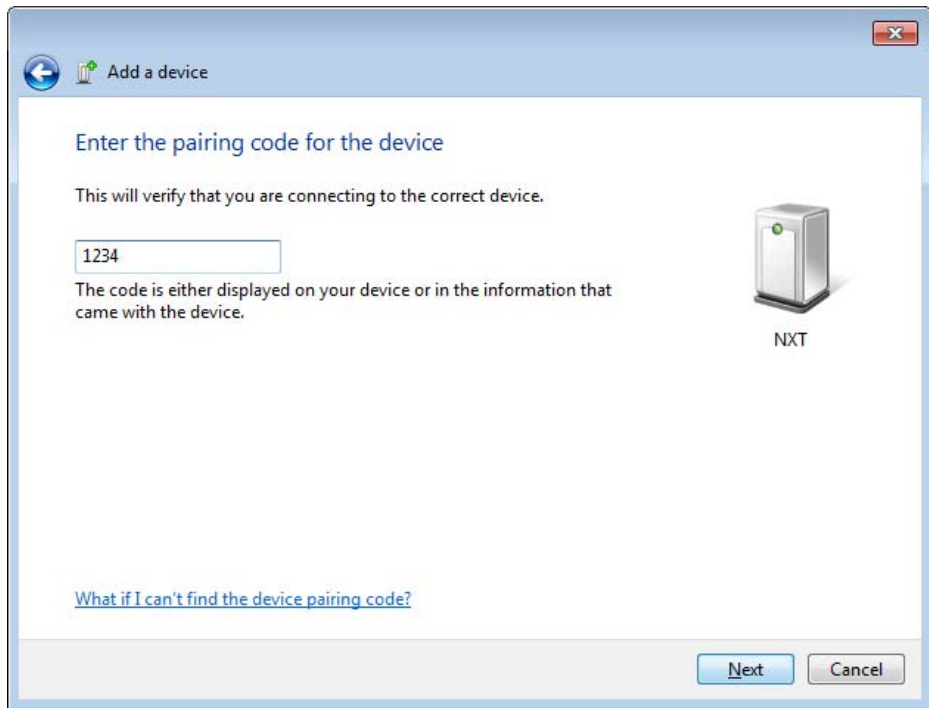


- 4 If the NXT brick is not among the devices, click **Add a device**.
- 5 Select your NXT Bluetooth device and click **Next**.



**Note** To avoid confusion when multiple NXT bricks are nearby, assign a unique name to the NXT brick during the firmware update process, as described in “Install Target for Use with LEGO MINDSTORMS NXT Hardware” on page 38-2.

- 6** On the NXT brick, the LCD displays a default passkey, 1234. Press the Orange button to accept the passkey.
- 7** In the Windows **Add a device** dialog box, enter the passkey from the NXT brick as the pairing code, and click **Next**.



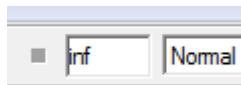
- 8 Click **Close**. The Bluetooth connection between your host computer and the NXT brick will be available whenever both devices are turned on.



If you have trouble with the Bluetooth connection, try removing the device from Devices and Printers and repeating this process.

## Run Your Simulink Model in External Mode

- 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**.

**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.

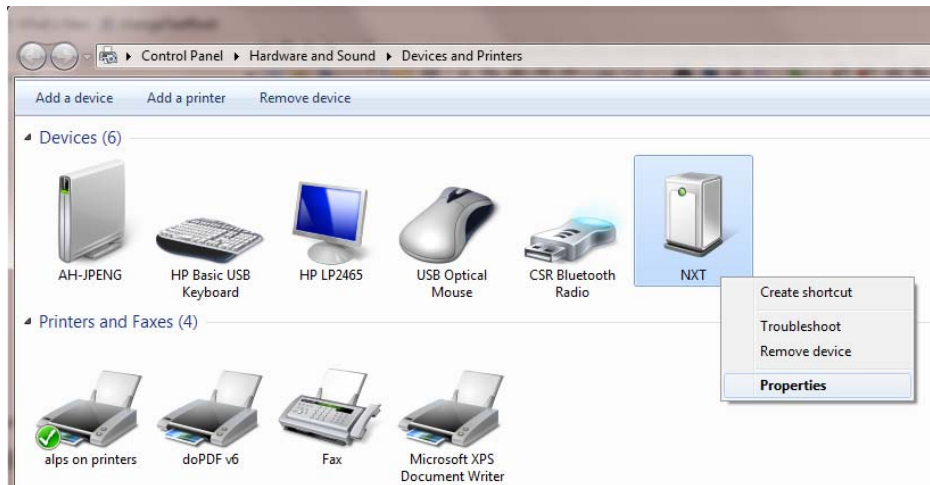
## Set the COM Port Number Manually

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.

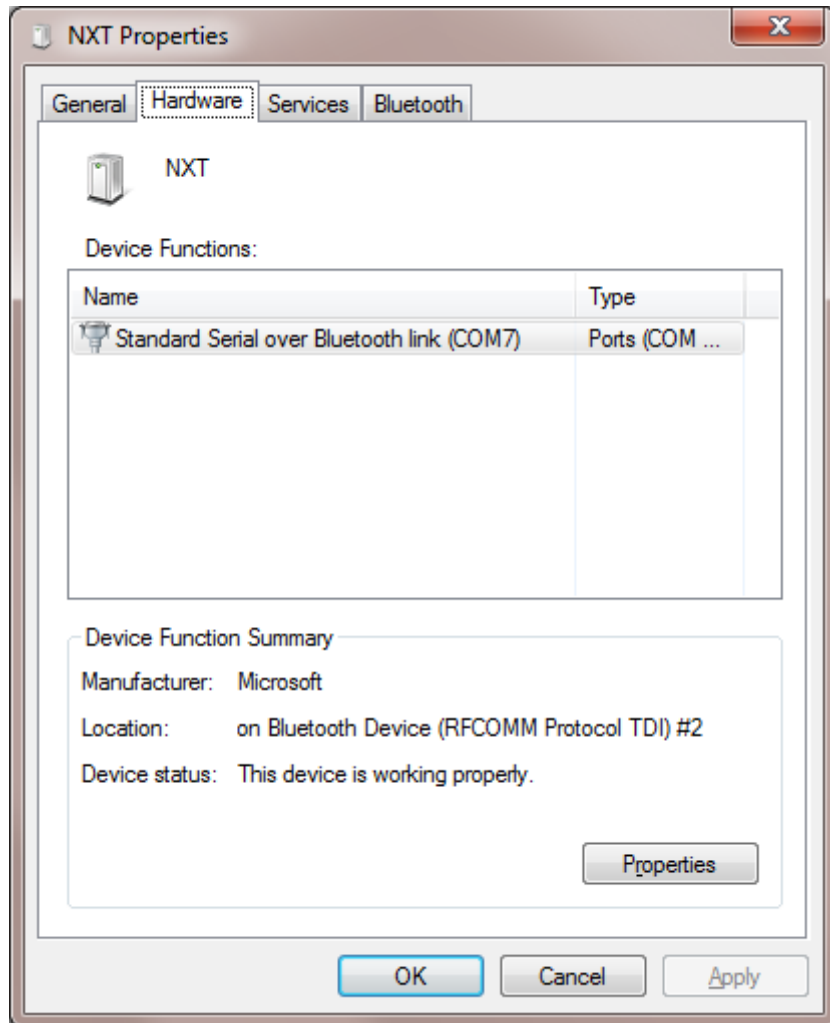
- 1** In Windows, locate the NXT brick under **Control Panel > Hardware and Sound > Devices and Printers**.

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 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 LEGO MINDSTORMS NXT 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** 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...

“Tips for Use Bluetooth Blocks” on page 38-28

“Add Bluetooth Blocks to your Models” on page 38-29

“Configure a Bluetooth Slave” on page 38-34

“Configure a Bluetooth Master” on page 38-35

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 “Remotely Control and Monitor a Model Running on LEGO MINDSTORMS NXT Hardware” on page 38-16.

---

**Note** Because External mode requires a Bluetooth connection between the host computer and the NXT brick, you cannot use External mode with models that contain Send via Bluetooth Connection or Receive via Bluetooth Connection blocks.

---

### Tips for Use Bluetooth Blocks

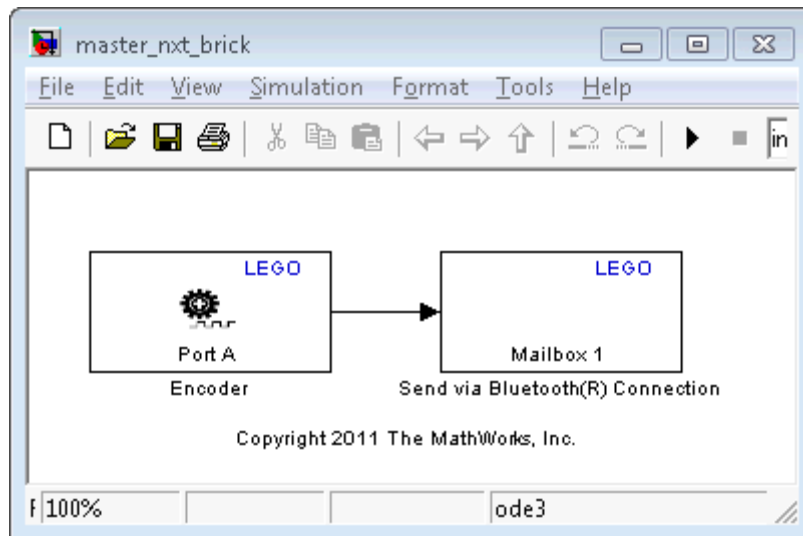
Here are some tips for using the Send via Bluetooth Connection block and Receive via Bluetooth Connection block:

- 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.

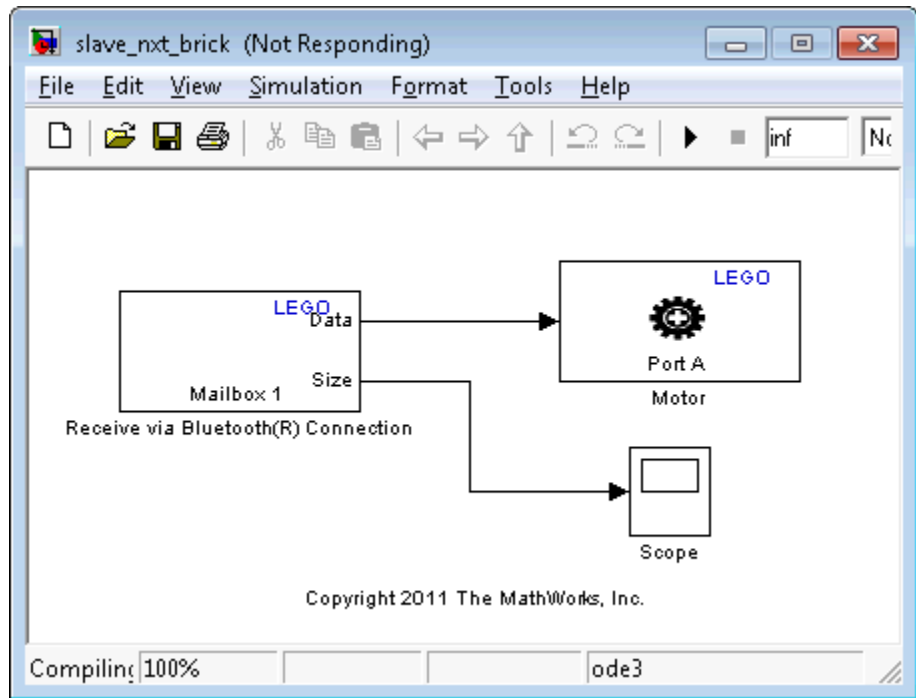
## Add Bluetooth Blocks to your Models

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.

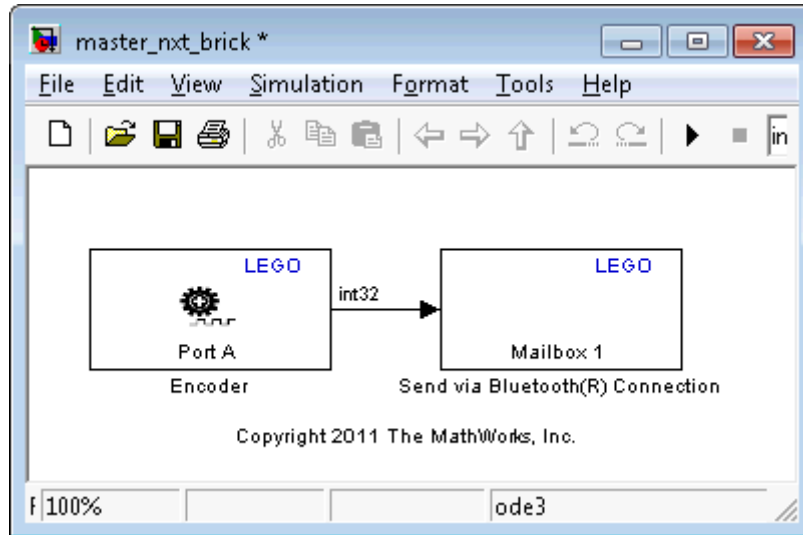


- 4 Add a Receive via Bluetooth Connection block to the other model, and connect it to the data sinks, as shown in the following example.

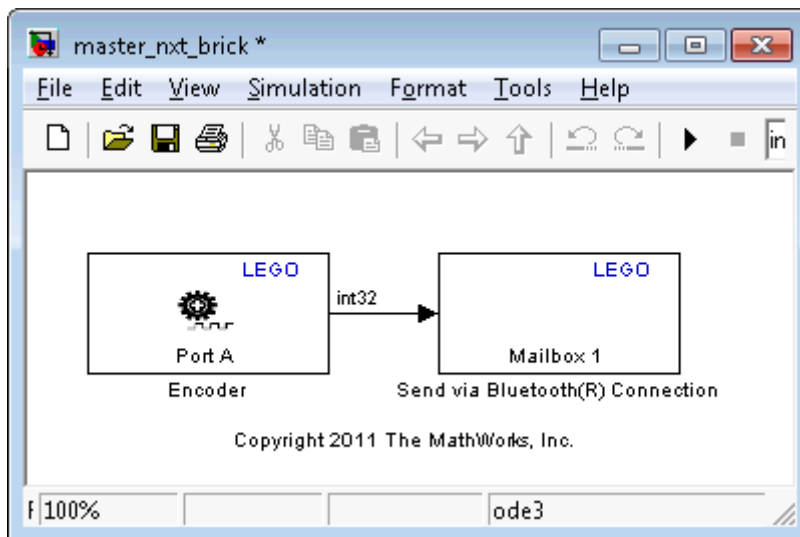


- 5 In the model that contains the Send via Bluetooth Connection block, select the **Format > Port/Signal Displays > Port Data Types** menu item. Then select **Edit>Update Diagram Ctrl+D**. Observe the data type that appears above the connector attached to the Send via Bluetooth Connection block. For example “int32” in the following example.

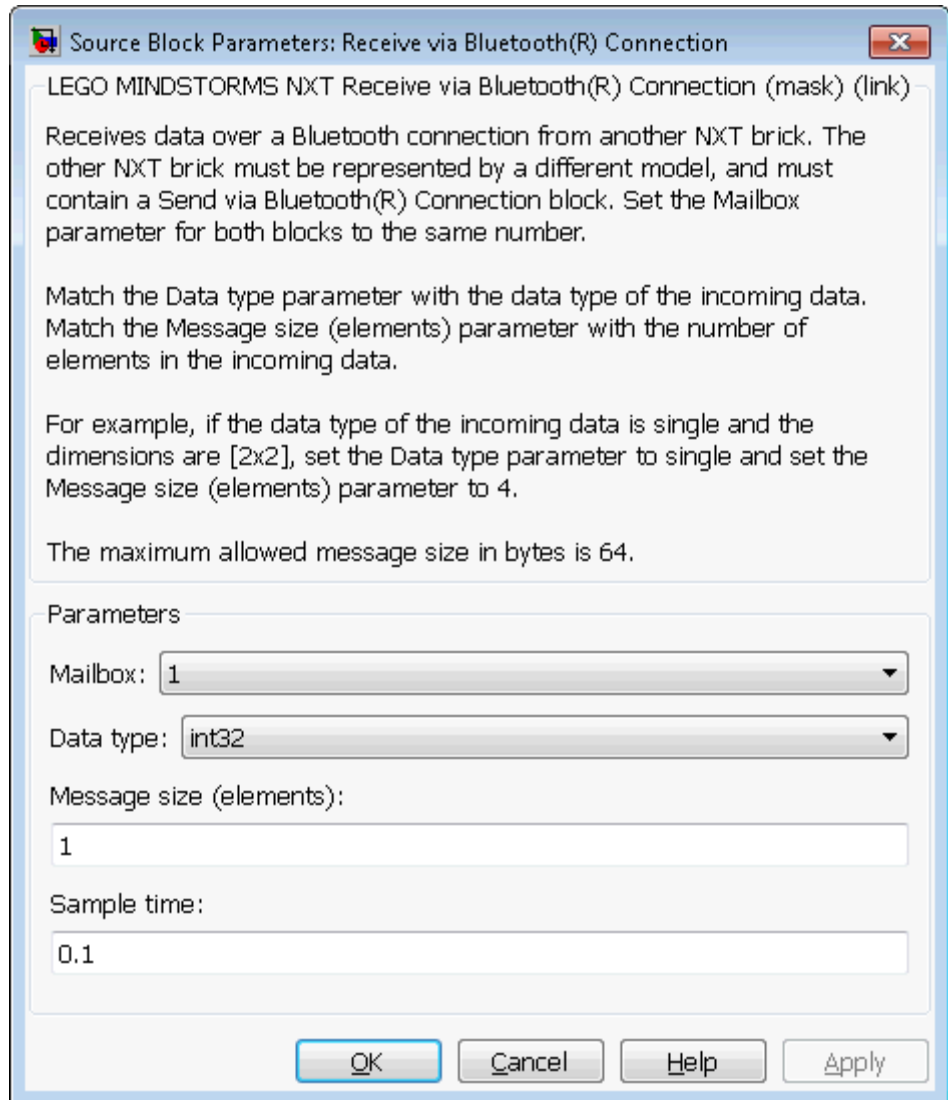




- 6 Open the Receive via Bluetooth Connection block in the other model. Apply the data type from the previous step to the **Data type** parameter in the Receive via Bluetooth Connection block.
- 7 In the model that contains the Send via Bluetooth Connection block, select the **Format > Port/Signal Displays > Signal Dimensions** menu item. Then select **Edit > 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, as shown in the following example. 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.



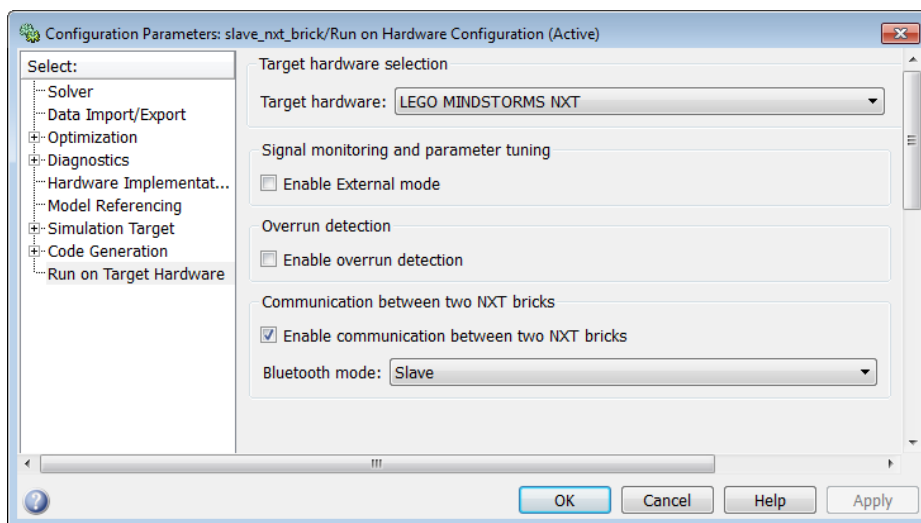
- 9 Save all of your changes and leave the models open.

## Configure a 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.



- 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.

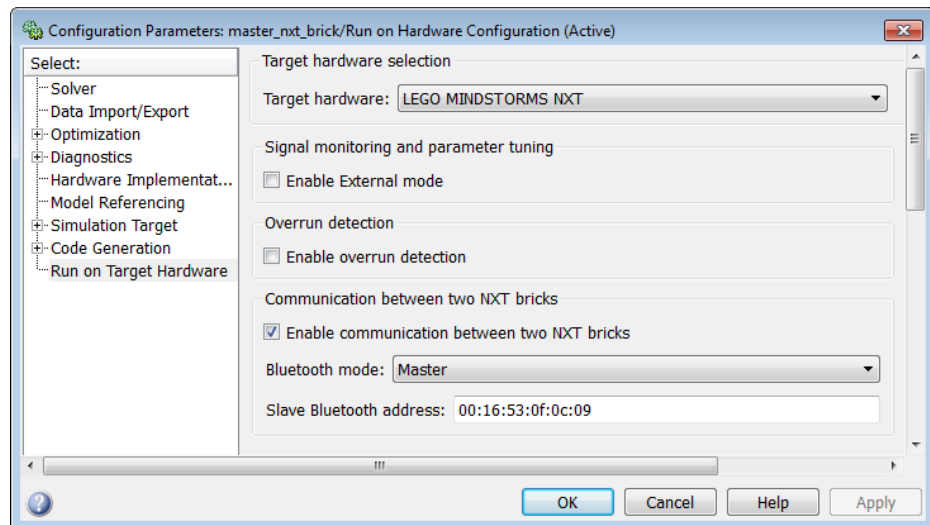
- 5 When Simulink software finishes downloading the application to the slave NXT brick, the LCD displays “Waiting...”.

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 a 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.
- 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.

# Examples

---

Use this list to find examples in the documentation.

## **Simulink Basics**

“Updating a Block Diagram” on page 1-32

“Updating a Block Diagram” on page 1-32

“Positioning and Sizing a Diagram” on page 1-36

“Print Command” on page 1-41

“Adding Items to Model Editor Menus” on page 34-2

“Disabling and Hiding Model Editor Menu Items” on page 34-13

“Disabling and Hiding Dialog Box Controls” on page 34-15



## **How Simulink Works**

“Algebraic Loops” on page 2-40

“How Propagation Affects Inherited Sample Times” on page 4-29

“How Propagation Affects Inherited Sample Times” on page 4-29

## **Creating a Model**

- “Creating a Model Template” on page 3-2
- “Creating Annotations Programmatically” on page 3-35
- “Creating a Subsystem by Grouping Existing Blocks” on page 3-38
- “How to Discretize Blocks from the Simulink Model” on page 3-129
- “Enabled Subsystems” on page 6-4
- “Enabled Subsystems” on page 6-4
- “Triggered Subsystems” on page 6-17
- “Triggered Subsystems” on page 6-17
- “Triggered and Enabled Subsystems” on page 6-21
- “Triggered and Enabled Subsystems” on page 6-21
- “Conditional Execution Behavior” on page 6-28
- “Conditional Execution Behavior” on page 6-28
- “Data Store Examples” on page 30-22

## **Executing Commands From Models**

“Loading Variables Automatically When Opening a Model” on page 3-64

“Executing a MATLAB Script by Double-Clicking a Block” on page 3-65

“Executing Commands Before Starting Simulation” on page 3-65

## **Working with Lookup Tables**

“Example Output for Lookup Methods” on page 22-26

“Example of a Logarithm Lookup Table” on page 22-63

## **Creating Block Masks**

“Masked Subsystem Example” on page 23-5

“Setting Masked Block Dialog Box Parameters” on page 23-64

“Self-Modifying Mask Example” on page 23-69

## **Creating Custom Simulink Blocks**

“Tutorial: Creating a Custom Block” on page 24-18

## **Working with Blocks**

“Making Backward-Compatible Changes to Libraries” on page 25-23





## Symbols and Numerics

% 35-16  
< > 35-16

## A

Abs block  
    zero crossings 2-36  
absolute tolerance  
    definition 13-22  
    simulation accuracy 17-11  
accelbuild command  
    building Accelerator MEX-file 19-25  
Acceleration  
    code regeneration 19-7  
    compilation overhead 17-5  
    debugger advantages 19-28  
    decision tree 19-13  
    designing for 19-15  
    how to run debugger with 19-28  
    inhibiting 19-18  
    numerical precision 19-16  
        verses normal mode 19-16  
    trade-offs 19-10  
Accelerator  
    description 19-2  
    determining why it rebuilds 19-7  
    how it works 19-3  
    making run time changes 19-24  
    Simulink blocks whose performance is not  
        improved by 19-15  
    switching back to normal mode 19-29  
    using with Simulink debugger 19-28  
Accelerator and Rapid Accelerator  
    choosing between 19-10  
    comparing 19-10  
Accelerator mode  
    keywords 19-19  
Accelerators  
    customizing build process 19-21

    interacting programmatically 19-25  
    running 19-22  
Action Port block  
    in subsystem 3-45  
activating  
    configuration references 9-17  
Adams-Bashforth-Moulton PECE solver 13-19  
Add button 35-14  
adding  
    cells 35-12  
    rows 35-11  
    text to cells 35-14  
    variable information to cells 35-14  
**Algebraic loop** diagnostic 2-44  
algebraic loop solver  
    limitations 2-51  
    line-search algorithm 2-51  
    operations 2-50  
    trust-region algorithm 2-51  
algebraic loops  
    artificial  
        atomic subsystems causing 2-56  
        bundled signals causing 2-58  
        eliminating using Simulink 2-67  
        problems caused by 2-44  
    avoiding discontinuities in 2-52  
    changing block priorities effect on 2-55  
    definition 2-41  
    direct feedthrough blocks 2-40  
    displaying 2-44 to 2-46  
    highlighting 18-43  
    identifying blocks in 18-40  
    mathematical definition of 2-42  
    physical meaning of 2-43  
    problems caused by 2-44  
    simulation speed 17-3  
    using Algebraic Constraint blocks to  
        remove 2-55  
    using IC blocks to remove 2-55  
aligning

- information in cells 35-18
- aligning blocks 20-11
- annotations
  - changing font 3-27
  - creating 3-26
  - definition 3-26
  - deleting 3-27
  - editing 3-27
  - moving 3-27
  - using symbols and Greek letters in 3-33
  - using TeX formatting commands in 3-33
  - using to document models 11-7
- artificial algebraic loops
  - atomic subsystems causing 2-56
  - bundled signals causing 2-58
- Assignment block
  - and For Iterator block 3-51
- associating
  - bus objects
    - with model entities 32-16
- asynchronous sample time 4-18
- atomic subsystem 2-12
- attaching
  - configuration references 9-14
  - to additional models 9-32
- attributes format string 3-23
- AttributesFormatString block
  - parameter 20-21
- avoiding
  - mux/bus mixtures 32-102

## B

- Backlash block
  - zero crossings 2-36
- backpropagating sample time 4-31
- Backspace key
  - deleting annotations 3-27
  - deleting blocks 20-14
  - deleting labels 31-23
- Band-Limited White Noise block
  - simulation speed 17-3
- block
  - simulation terminated or suspended 13-5
- block callback parameters 3-58
- block callbacks
  - adding custom functionality 24-37
- Block data tips 20-2
- block diagram
  - updating 1-32
- block diagram entry 35-15
- block diagrams
  - panning 1-27
  - printing 1-34
- block libraries
  - adding to Library Browser 25-36
  - creating 25-21
  - locking 25-22
  - modifying 25-22
  - searching 3-5
- block methods
  - invoking 20-35
- block names
  - changing location 20-27
  - copied blocks 20-10
  - editing 20-27
  - flipping location 20-27
  - generated for copied blocks 20-10
  - hiding and showing 20-28
  - location 20-26
  - rules 20-26
- block parameters
  - about 21-1
  - displaying beneath a block 20-48
  - modifying during simulation 13-31
  - scalar expansion 31-38
  - setting 21-4
- block priorities
  - assigning 20-48
  - effect on algebraic loops 2-55

- rules 20-49
- Block Properties dialog box 20-15
- blocks
  - aligning 20-11
  - assigning priorities 20-48
  - associating user data with 27-79
  - autoconnecting 3-15
  - bus-capable 32-14
  - callback routines 3-54
  - changing font 20-27
  - changing font names 20-27
  - changing location of names 20-27
  - checking connections 2-19
  - connecting automatically 3-15
  - connecting manually 3-18
  - copying from Library Browser 3-6
  - copying into models 20-9
  - custom, Simulink 24-2
    - categories 24-3
    - code generation requirements 24-8
    - designing 24-18
    - examples 24-43
    - incorporating legacy code 24-6
    - modeling requirements 24-7
    - simulation requirements 24-8
    - tutorial 24-18
    - using block callbacks 24-37
    - using MATLAB functions 24-3
    - using S-functions 24-4
    - using Subsystems 24-4
  - deleting 20-14
  - disconnecting 3-23
  - displaying sorted order on 20-35
  - drop shadows 20-26
  - duplicating 20-13
  - grouping to create subsystem 3-38
  - hiding block names 20-28
  - input ports with direct feedthrough 2-40
  - invoking methods 20-35
  - moving between windows 20-11
  - moving in a model 20-10
  - names
    - editing 20-27
  - orientation 20-22
  - resizing 20-25
  - reversing signal flow through 11-8
  - rotating 20-22
  - rules for priorities 20-49
  - showing block names 20-28
  - updating 2-19
- <>blocks 20-26
  - See also* block names
- borders
  - creating 35-11
  - important note about 35-11
- bounding box
  - grouping blocks for subsystem 3-39
  - selecting objects 3-7
- branch lines 3-19
- Break Library Link menu item 25-18
- breaking links to library block 25-18
- breakpoints
  - setting 18-28
  - setting at end of block 18-31
  - setting at timesteps 18-32
  - setting on nonfinite values 18-32
  - setting on step-size-limiting steps 18-32
  - setting on zero crossings 18-32
- Browser 8-77
- building models
  - tips 11-6
- Bus Editor 32-15
  - opening 32-19
- bus objects
  - associating
    - with model entities 32-16
  - creating
    - with the API 32-55
    - with the Bus Editor 32-23
  - using 32-15

- bus signals
  - created by Mux blocks 32-94
  - used as vectors 32-95
- Bus to Vector block
  - backward compatibility 32-101
- bus-capable blocks 32-14
  - sorted order and 20-45
- buses 32-59
  - connecting to inports 32-59
  - mixing with muxes 32-93
  - nesting 32-12
- busses used as muxes
  - correcting 32-99
- C**
- C compiler
  - set up for code generation 26-199
  - set up for code generation from MATLAB 26-170
- callback routines 3-54
- callback routines, referencing mask parameters in 3-58
- callback tracing 3-55
- canvas, editor 1-21
- cells
  - adding 35-12
  - adding text to 35-15
  - adding variable information to 35-15
  - changing information in 35-18
  - deleting 35-12
  - resizing 35-12
  - selecting 35-11
  - splitting 35-12
- center alignment button 35-18
- changing
  - fonts 35-20
  - information in cells 35-18
  - values using configuration references 9-18 9-34
- characters, special 35-15
- classes
  - enumerated 28-1
- Clear menu item 20-14
- Clipboard block callback parameter 3-59
- Clock block
  - example 16-3
- CloseFcn block callback parameter 3-59
- CloseFcn model callback parameter 3-56
- closing PrintFrame Editor 35-7
- code generation for MATLAB
  - comparing to MATLAB S-functions 24-5
- Code Generation from MATLAB
  - C compiler set up 26-170 26-199
  - getting started tutorial prerequisites 26-164 26-193
- coder.extrinsic
  - using to debug MATLAB code 26-201
- color of text 35-20
- colors for sample times 4-31
- command line debugger for MATLAB Function block 26-18
- commands
  - undoing 1-25
- Compare To Constant block
  - zero crossings 2-36
- Compare To Zero block
  - zero crossings 2-36
- compiled sample time 4-20
- Compiled Size property for MATLAB Function block variables 26-69
- compilers
  - supported for MATLAB Function blocks (code generation) 26-10
  - supported for MATLAB Function blocks (simulation) 26-10
- composite signals 32-2
- conditional execution behavior 6-28
- conditionally executed subsystem 2-12
- conditionally executed subsystems 6-2

- configurable subsystem 3-123
  - Configuration Parameters dialog box
    - increasing Accelerator performance 17-9
  - configuration references
    - activating 9-17
    - and building models 9-20
    - and generating code 9-20
    - attaching 9-14
      - to additional models 9-32
    - changing values with 9-18 9-34
    - creating 9-14
    - limitations 9-26
    - obtaining handles 9-35
    - obtaining values with 9-34
  - configuration sets
    - copying 9-30
    - reading from an M-file 9-31
    - referencing 9-14
    - using 9-8
  - connecting
    - buses to inports 32-59
    - buses to root-level inports 32-59
  - connecting blocks 3-18
  - ConnectionCallback
    - port callback parameters 3-63
  - constant sample time 4-16
  - context menu 1-22
  - ContinueFcn model callback parameter 3-56 3-59
  - continuous sample time 4-15
  - control flow diagrams
    - do-while 3-49
    - for 3-50
    - if-else 3-44
    - switch 3-46
    - while 3-47
  - control flow subsystem 6-2
  - control input 6-2
  - control signal 6-2
  - Control System Toolbox
    - linearization 16-6
  - controlling run-time checks
    - MATLAB Function block 26-161
  - Copy menu item 20-9
  - CopyFcn block callback parameter 3-59
  - copying
    - blocks 20-9
    - configuration sets 9-30
    - signal labels 31-23
  - copying information among cells 35-19
  - correcting
    - buses used as muxes 32-99
  - Created model parameter 3-114
  - creating
    - bus objects
      - with the API 32-55
      - with the Bus Editor 32-23
    - configuration references 9-14
    - custom Simulink blocks 24-2
    - freestanding configuration sets 9-30
  - creating print frames 35-7
  - Creator model parameter 3-114
  - custom blocks
    - creating 24-2
  - Customizing Accelerator Build
    - AccelVerboseBuild 19-27
    - SimCompilerOptimization 19-27
  - Cut menu item 20-11
- ## D
- data
    - enumerated 28-1
  - data range checking
    - MATLAB Function blocks 26-20
  - data types
    - displaying 27-28
    - enumerated 28-1
    - propagation definition 27-28
    - specifying 27-8

- data types of MATLAB Function variables 26-63
- data, adding to MATLAB Function blocks 26-33
- date entry 35-15
- Dead Zone block
  - zero crossings 2-36
- debugger
  - highlighting algebraic loops using 2-46
  - running incrementally 18-20
  - setting breakpoints 18-28
  - setting breakpoints at time steps 18-32
  - setting breakpoints at zero crossings 18-32
  - setting breakpoints on nonfinite values 18-32
  - setting breakpoints on step-size-limiting steps 18-32
  - skipping breakpoints 18-25
  - starting 18-11
  - stepping by time steps 18-23
- debugging
  - breakpoints in MATLAB Function block
    - function 26-15
  - display variable values in MATLAB Function block
    - function 26-18
  - displaying MATLAB Function block variables in MATLAB 26-18
  - MATLAB Function block example 26-14
  - MATLAB Function block function 26-14
  - operations for debugging MATLAB functions 26-20
  - stepping through MATLAB Function block
    - function 26-16
- decimation factor
  - saving simulation output 29-14 to 29-15
- default print frame 35-6
- Delete key
  - deleting blocks 20-14
  - deleting signal labels 31-23
- DeleteChildFcn block callback parameter 3-59
- DeleteFcn block callback parameter 3-59
- deleting
  - cells 35-12
  - rows 35-11
- dependency analysis 8-80 12-60
  - best practices 12-78
  - comparing manifests 12-72
  - editing manifests 12-69
  - exporting manifests 12-73
  - file manifests 12-75
  - generating manifests 12-61
  - viewing dependencies 8-80
- Derivative block
  - linearization 16-9
- Description model parameter 3-114
- Description property
  - MATLAB Function blocks 26-33
- designing
  - custom Simulink blocks 24-18
  - designing print frames 35-8
- DestroyFcn block callback parameter 3-60
- diagnosing simulation errors 13-39
- diagnostics
  - for mux/bus mixtures 32-94
- diagonal line segments 3-20
- diagonal lines 3-19
- direct feedthrough blocks 2-40
- direct-feedthrough ports
  - sorted order and 20-46
- disabled subsystem
  - output 6-7
- disconnecting blocks 3-23
- discrete blocks
  - in enabled subsystem 6-10
  - in triggered systems 6-20
- discrete sample time 4-14
- discrete states
  - initializing 31-52
- discretization methods 3-121
- discretizing a Simulink model 3-117
- dlinmod function
  - extracting linear models 16-5
- do-while control flow diagram 3-49

Docking Scope Viewer 15-16

Document link property

    MATLAB Function blocks 26-33

drop shadows 20-26

duplicating blocks 20-13

## E

editing

    MATLAB Function block function code 26-23

    mode 35-14

    text in cells 35-18

editing look-up tables 22-28

editor 1-16

    canvas 1-21

    toolbar 1-17

Enable block

    creating enabled subsystems 6-5

    outputting enable signal 6-10

    states when enabling 6-9

    zero crossings 2-36

enabled subsystems 6-4

    initializing output of 31-56

    setting states 6-9

ending Simulink session 1-47

enlarging display 35-6

entries for information 35-16

enumerated data types 28-1

Enumerations 28-1

error checking

    MATLAB Function blocks 26-10

error tolerance 13-22

    simulation accuracy 17-11

    simulation speed 17-3

ErrorFcn block callback parameter 3-60

example using print frames 35-26

examples

    Clock block 16-3

    continuous system 11-8

    converting Celsius to Fahrenheit 11-15

    equilibrium point determination 16-11

    linearization 16-5

    multirate discrete model 4-22

    Outport block 16-3

    return variables 16-3

    structures in a MATLAB Function  
    block 26-76

    To Workspace block 16-3

    Transfer Function block 11-9

    working with frame-based signals in  
    MATLAB Function blocks 26-117

execution context

    defined 6-30

    displaying 6-31

    propagating 6-30

Exit MATLAB menu item 1-47

extrinsic functions

    calling in MATLAB Function block  
    functions 26-6

## F

Fcn block

    simulation speed 17-3

figure file 35-6

    saving 35-22

file

    .fig 35-22

    opening 35-22

    saving 35-22

file name

    maximum length 1-10

file name entry 35-15

files

    writing to 13-5

fixed in minor step 4-15

fixed-point data 27-4

    properties 26-64

    properties in Simulink model 27-19

fixed-step solvers

- definition 2-23
- Flip Name menu item 20-27
- floating Display block 13-31
- floating Scope block 13-31
- font
  - annotations 3-27
  - block 20-27
  - block names 20-27
  - special characters 35-15
  - symbols 35-15
- Font menu item
  - changing block name font 20-27
- font size, setting for Model Explorer 8-5
- font size, setting for Simulink dialog boxes 8-5
- fonts, changing 35-20
- for control flow diagram 3-50
- For Iterator block
  - and Assignment block 3-51
  - in subsystem 3-50
  - output iteration number 3-51
  - specifying number of iterations 3-51
- frame-based signals
  - adding frame-based data to MATLAB Function blocks 26-116
  - examples of use in MATLAB Function blocks 26-117
  - using in MATLAB Function blocks 26-115
- frameedit
  - opening print frame 35-22
  - starting 35-6
- frames 35-2
- freestanding configuration sets
  - creating 9-30
- From File block
  - zero crossings 2-36
- From Workspace block
  - zero crossings 2-36
- full file name entry 35-15
- full system name entry 35-15

- function call outputs, adding to MATLAB Function blocks 26-43
- Function-Call Split blocks
  - sorted order and 20-44
- function-call subsystems
  - sorted order and 20-42
- fundamental sample time 13-11

## G

- Generator
  - attaching 15-23
  - performing common tasks 15-23
  - removing 15-24
- get\_param command
  - checking simulation status 14-7
- Go To Library Link menu item 25-7
- Greek letters 35-15
  - using in annotations 3-33
- grouping blocks 3-37

## H

- handles on selected object 3-7
- held output of enabled subsystem 6-7
- held states of enabled subsystem 6-9
- Hide Name menu item
  - hiding block names 20-28
  - hiding port labels 3-42
- Hide Port Labels menu item 3-41
- hiding block names 20-28
- hierarchy of model
  - advantage of subsystems 11-7
  - replacing virtual subsystems 2-19
- highlighting
  - requirements in a model 8-94
- Hit Crossing block
  - notification of zero crossings 2-38
- how to disable run-time checks
  - MATLAB Function block 26-162



hybrid systems  
 integrating 4-25

## I

If block  
 connecting outputs 3-45  
 data input ports 3-45  
 data output ports 3-45  
 zero crossings  
 and Disable zero crossing detection  
 option 2-37

if-else control flow diagram 3-44

important note about print frames 35-9

importing initial states 29-99

information  
 adding to cells 35-14  
 copying among cells 35-19  
 in print frames 35-8  
 mandatory 35-15  
 multiple entries in a cell 35-16  
 removing 35-19

information list box 35-14

inherited sample time 4-15

inheriting MATLAB Function block variable  
 size 26-69

inheriting MATLAB Function variable  
 types 26-62

InitFcn block callback parameter 3-60

InitFcn model callback parameter 3-56

initial conditions  
 specifying 29-94

Initial State check box 29-99

initial states  
 loading 29-99

initial step size  
 simulation accuracy 17-11

initial values  
 tuning 31-54

inlining S-functions using the TLC

and Accelerator performance 19-16

Inport block  
 in subsystem 3-38  
 linearization 16-6  
 supplying input to model 29-61

inports  
 connecting to buses 32-59  
 root-level  
 connecting to buses 32-59

input triggers, adding to MATLAB Function  
 blocks 26-39

inputs  
 loading from a workspace 29-61  
 mixing vector and scalar 31-39  
 scalar expansion 31-38

Integer Delay blocks  
 use in removing algebraic loops 2-52

integer overflow and underflow  
 and simulation targets in MATLAB Function  
 blocks 26-30  
 in MATLAB Function blocks 26-29 to 26-30

Integrator block  
 example 11-8  
 sample time colors 4-31  
 simulation speed 17-3  
 zero crossings 2-37

Interpreted MATLAB Function block  
 simulation speed 17-3

invalid loops, avoiding 11-2

invalid loops, detecting 11-3

## J

Jacobian matrices 13-21

## K

keyboard actions summary 1-48

Keywords  
 acceleration 19-19

**L**

- labeling signals 31-22
- labeling subsystem ports 3-41
- LastModifiedBy model parameter 3-115
- LastModifiedDate model parameter 3-115
- left alignment button 35-18
- libinfo command 25-7
- libraries 11-17
- library blocks
  - breaking links to 25-18
  - finding 25-7
  - getting information about 25-16
- Library Browser
  - adding libraries to 25-36
  - copying blocks from 3-6
- library links
  - disabling 25-11
  - displaying 25-8
  - self-modifying 25-7
  - showing in Model Browser 8-79
  - status of 25-16
  - unresolved 25-19
- line segments 3-20
  - diagonal 3-20
  - moving 3-20
- line vertices
  - moving 3-21
- line-search algorithm
  - Simulink algebraic loop solver 2-51
- linear models
  - extracting
    - example 16-5
- linearization 16-5
- lines
  - branch 3-19
  - connecting blocks 3-15
  - diagonal 3-19
  - dragging 35-12
  - moving 20-10
  - selecting 35-11
  - signals carried on 13-31
- linked blocks
  - about 25-4
  - creating 25-4
  - modifying 25-6
  - updating 25-5
- links
  - breaking 25-18
- LinkStatus block parameter 25-16
- linmod function
  - example 16-5
- LoadFcn block callback parameter 3-60
- loading from a workspace 29-61
- location of block names 20-26
- Lock Editor property
  - MATLAB Function blocks 26-30
- logging signals 29-19
- look-up tables, editing 22-28
- Lookup Table Editor 22-28
- lookup tables
  - blocks 22-5
  - components 22-4
  - data characteristics 22-18
  - data entry 22-11
  - definition 22-2
  - estimation 22-23
  - examples for Prelookup and Interpolation
    - Using Prelookup blocks 22-66
  - extrapolation 22-24
  - interpolation 22-23
  - rounding 22-25
  - selection guidelines 22-7
  - terminology 22-77
- loops, algebraic. *See* algebraic loops
- loops, avoiding invalid 11-2
- loops, detecting invalid 11-3

**M**

- magnifying display 35-6

- manifest 12-75
- margins 35-9
- masked blocks
  - parameters
    - referencing in callbacks 3-58
  - showing in Model Browser 8-79
- masked subsystems
  - showing in Model Browser 8-79
- mathematical symbols 35-15
  - using in annotations 3-33
- MATLAB
  - terminating 1-47
- MATLAB file S-functions
  - simulation speed 17-3
- MATLAB function block
  - MATLAB Function report keyboard shortcuts 26-57
- MATLAB Function block
  - calling MATLAB code 26-201
  - controlling run-time checks 26-161
  - how to disable run-time checks 26-162
  - resolving signal objects 26-73
  - using 26-172 26-201
  - when to disable run-time checks 26-161
- MATLAB Function Block Editor
  - description 26-8
- MATLAB Function block fimath
  - MATLAB Function blocks 26-32
- MATLAB Function blocks 26-46
  - adding data using the Ports and Data Manager 26-33
  - adding frame-based data 26-116
  - adding function call outputs using the Ports and Data Manager 26-43
  - adding input triggers using the Ports and Data Manager 26-39
  - and embedded applications 26-6
  - and standalone executables 26-6
  - breakpoints in function 26-15
  - built-in data types 26-63
  - calling extrinsic functions 26-6
  - calling MATLAB functions 26-6
  - creating model with 26-7
  - data range checking 26-20
  - debugging 26-14
  - debugging example 26-14
  - debugging function for 26-14
  - debugging operations 26-20
  - description 26-3 26-46
  - Description property 26-33
  - diagnostic errors 26-10
  - display variable value 26-18
  - displaying variable values in MATLAB 26-18
  - Document link property 26-33
  - example containing structures 26-76
  - example model with 26-7
  - example program 26-8
  - inherited data types and sizes 26-6
  - inheriting variable size 26-69
  - Lock Editor property 26-30
  - MATLAB Function Block Editor 26-8 26-23
  - MATLAB Function block fimath 26-32
  - MATLAB run-time library of functions 26-6
  - Model Explorer 26-12
  - Name property 26-29
  - parameter arguments 26-72
  - Ports and Data Manager 26-27
  - Saturate on integer overflow property 26-29
  - setting properties 26-28
  - simulating function 26-14
  - Simulink input signal properties 26-31
  - sizing variables 26-69
  - sizing variables by expression 26-70
  - stepping through function 26-16
  - subfunctions 26-5
  - supported compilers for code
    - generation 26-10
  - supported compilers for simulation 26-10
  - typing variables 26-60
  - typing with other variables 26-64

- Update method property 26-29
- variable type by inheritance 26-62
- variables for 26-12
- why use them? 26-6
- working with frame-based signals 26-115
- working with structures and bus signals 26-75
- MATLAB Function report keyboard shortcuts
  - MATLAB Function report 26-57
- MATLAB Function reports 26-46
  - description 26-46
- MATLAB functions
  - calling in MATLAB Function block functions 26-6
- MATLAB run-time library functions 26-6
- mdl files 1-9
- Memory block
  - simulation speed 17-3
- memory issues 11-7
- menus 1-21
  - context 1-22
- Minimize algebraic loop occurrences**
  - parameter 2-61
- Minimize algebraic loop** parameter 2-61
- MinMax block
  - zero crossings 2-37
- mixed continuous and discrete systems 4-25
- mixing
  - muxes, and buses 32-93
- model
  - editor 1-16
- Model Advisor
  - and mux/bus mixtures 32-98
- Model Browser 8-77
  - showing library links in 8-79
  - showing masked subsystems in 8-79
- model callback parameters 3-55
- model configuration preferences 8-11
- model dependencies 8-80 12-60
  - best practices 12-78
  - comparing manifests 12-72
  - editing manifests 12-69
  - exporting manifests 12-73
  - file manifests 12-75
  - generating manifests 12-61
  - viewing 8-80
- model dependency viewer 8-80
- model discretization
  - configurable subsystems 3-123
  - discretizing a model 3-117
  - overview 3-116
  - specifying the discretization method 3-121
  - starting the model discretizer 3-118
- Model Explorer
  - Apply Changes 8-68
  - Auto Apply/Ignore Dialog Changes 8-68
  - Dialog pane 8-67
  - font size 8-5
  - MATLAB Function blocks 26-12
- model file name, maximum size of 1-10
- model files
  - mdl file 1-9
- model navigation commands 3-40
- model parameters for version control 3-114
- model referencing 11-17
- ModelCloseFcn block callback parameter 3-60
- modeling strategies 11-7
- modeling techniques 11-17
- models
  - callback routines 3-54
  - creating 3-2
  - creating change histories for 3-112
  - creating templates 3-2
  - editing 1-4
  - highlighting requirements in 8-94
  - navigating 3-40
  - navigating to requirements documents
    - from 8-97
  - organizing and documenting 11-7
  - printing 1-34

- properties of 3-105
  - saving 1-8
  - selecting entire 3-8
  - tips for building 11-6
  - version control properties of 3-114
- ModelVersion model parameter 3-115
- ModelVersionFormat model parameter 3-115
- ModifiedBy model parameter 3-115
- ModifiedByFormat model parameter 3-115
- ModifiedComment model parameter 3-115
- ModifiedDate model parameter 3-115
- ModifiedDateFormat model parameter 3-115
- ModifiedHistory> model parameter 3-115
- Monte Carlo analysis 14-2
- mouse actions summary 1-48
- MoveFcn block callback parameter 3-60
- multiple entries in a cell 35-16
- multirate discrete systems
  - example 4-23
- Mux blocks
  - used to create bus signals 32-94
- mux/bus mixtures
  - and Model Advisor 32-98
  - avoiding 32-102
  - diagnostics for 32-94
- muxes
  - correcting busses used as 32-99
  - mixing with buses 32-93

**N**

- Name property
  - MATLAB Function blocks 26-29
- NameChangeFcn block callback parameter 3-60
- names
  - blocks 20-26
  - copied blocks 20-10
- navigating
  - from model to requirements documents 8-97
- nesting

- buses 32-12
- New menu item 3-2
- non-bus signals
  - treated as bus signals 32-97
- nonvirtual buses
  - compared with virtual 32-56
  - specifying 32-56
- nonvirtual subsystem 2-12
- number of pages entry 35-15
- numerical differentiation formula 13-21
- numerical integration 2-20

## O

- objects
  - selecting more than one 3-7
  - selecting one 3-7
- obtaining
  - configuration reference handles 9-35
  - values using configuration references 9-34
- ode113 solver
  - hybrid systems 2-8
- ode113 solver
  - advantages 13-19
  - Memory block
    - and simulation speed 17-3
- ode15s solver
  - advantages 13-21
  - and stiff problems 17-3
  - hybrid systems 2-8
  - Memory block
    - and simulation speed 17-3
    - unstable simulation results 17-11
- ode23 solver
  - hybrid systems 2-8
- ode23s solver
  - advantages 13-21
  - simulation accuracy 17-11
- ode45 solver
  - hybrid systems 2-8

- Open menu item 1-4
- OpenFcn block callback parameter
  - purpose 3-60
- opening
  - print frame file 35-22
  - PrintFrame Editor 35-6
  - Subsystem block 3-39
  - the Bus Editor 32-19
- orientation of blocks 20-22
- Output block
  - example 16-3
  - in subsystem 3-38
  - linearization 16-6
- output
  - additional 29-17
  - between trigger events 6-19
  - disabled subsystem 6-7
  - enable signal 6-10
  - smoother 29-16
  - specifying for simulation 29-18
  - subsystem initial output 6-5
  - trajectories
    - viewing 16-2
  - trigger signal 6-19
  - writing to file
    - when written 13-5
  - writing to workspace
    - when written 13-5
- output ports
  - Enable block 6-10
  - Trigger block 6-19
- P**
- page number entry 35-15
- page setup 35-9
- panning block diagrams 1-27
- paper orientation and type 35-9
- PaperOrientation model parameter 1-36
- PaperPosition model parameter 1-36
- PaperPositionMode model parameter 1-36
- PaperType model parameter 1-36
- parameter arguments for MATLAB Function blocks 26-72
- Parameter values
  - checking
    - using get\_param 21-8
- parameters
  - block 21-1
  - setting values of 21-4
  - tunable
    - definition 2-9
- ParentCloseFcn block callback parameter 3-61
- Paste menu item 20-9
- PauseFcn model callback parameter 3-56 3-61
- performance
  - comparing Acceleration to Normal Mode 17-7
- ports
  - default port rotation 20-23
  - labeling in subsystem 3-41
  - physical port rotation 20-23
- Ports and Data Manager
  - adding data to MATLAB Function blocks 26-33
  - adding function call outputs to MATLAB Function blocks 26-43
  - adding input triggers to MATLAB Function blocks 26-39
- Ports and Data Manager, MATLAB Function Block 26-27
- PostLoadFcn model callback parameter 3-56
- PostSaveFcn block callback parameter 3-61
- PostSaveFcn model callback parameter 3-56
- PostScript files
  - printing to 1-42
- PreCopyFcn block callback parameter 3-61
- PreDeleteFcn block callback parameter 3-61
- preferences, model configuration 8-11
- PreLoadFcn model callback parameter 3-57
- PreSaveFcn block callback parameter 3-61

- PreSaveFcn model callback parameter 3-57
  - print command 1-34
  - print frames
    - defined 35-2
    - designing 35-8
    - important note about 35-9
    - process for creating 35-7
    - size of 35-12
  - Print menu item 1-34
  - PrintFrame Editor
    - closing 35-7
    - interface for 35-6
    - starting 35-6
  - printing to PostScript file 1-42
  - printing with print frames
    - block diagrams 35-23
    - multiple use 35-8
  - Priority block parameter 20-48
  - process for creating print frames 35-7
  - produce additional output option 29-17
  - produce specified output only option 29-18
  - profiler
    - enabling 19-32
  - Profiler
    - how it works 19-30
  - properties
    - setting for MATLAB Function blocks 26-28
  - properties of Scope Viewer 15-17
  - purely discrete systems 4-22
- Q**
- Quit MATLAB menu item 1-47
- R**
- Random Number block
    - simulation speed 17-3
  - Rapid Accelerator
    - description 19-2
    - determining why it rebuilds 19-7
    - how to run 19-21
    - Simulink blocks not supported 19-15 to 19-16
    - visualization 19-17
  - Rapid Accelerator mode
    - how to run 19-21
    - keywords 19-19
  - rate transitions 4-28
  - reading
    - configuration sets from an M-file 9-31
  - Redo menu item 1-25
  - referencing
    - configuration sets 9-14
  - refine factor
    - smoothing output 29-16
  - Relational Operator block
    - zero crossings 2-37
  - relative tolerance
    - definition 13-22
    - simulation accuracy 17-11
  - Relay block
    - zero crossings 2-37
  - removing information 35-19
  - requirements
    - features available in Simulink 8-93
    - features requiring Simulink Verification and Validation license 8-93
    - highlighting 8-94
    - in subsystems 8-94
    - navigating to 8-97
    - navigating to, from System Requirements block 8-98
    - viewing details 8-96
  - Requirements Management Interface (RMI)
    - Simulink Verification and Validation license required for 8-93
  - Reserved
    - accelerator mode keywords 19-19
  - reset

- output of enabled subsystem 6-7
- states of enabled subsystem 6-9
- resizing blocks 20-25
- resizing rows and cells 35-12
- resolving
  - signal objects for MATLAB Function blocks 26-73
- return variables
  - example 16-3
- reversing direction of signal flow 11-8
- right alignment button 35-18
- root-level inports
  - connecting to buses 32-59
- Rosenbrock formula 13-21
- Rotate Block>Clockwise menu item 20-22
- Rotate Block>Counter-clockwise menu item 20-22
- rotating a block 20-22
- rows
  - adding 35-11
  - deleting 35-11
  - resizing 35-12
  - selecting 35-11
  - splitting 35-12

## S

- sample time
  - backward propagating 4-31
  - colors 4-31
  - fundamental 13-11
  - simulation speed 17-3
- Sample Time Colors menu item
  - updating coloring 3-13
- Sample Time Legend 4-10
- sample time propagation 4-29
- saturate
  - on integer overflow in MATLAB Function blocks 26-29
- Saturate on integer overflow property
  - MATLAB Function blocks 26-29
- saturation block
  - zero crossings
    - how used 2-38
- Saturation block
  - zero crossings 2-37
- Save As menu item 1-9
- Save menu item 1-9
- save\_system command
  - breaking links 25-18
- saving 35-22
- scalar expansion 31-38
- Scope block
  - example of a continuous system 11-9
- Scope blocks and viewers
  - differences between 15-3
- Scope Viewer 15-1
  - adding multiple signals to 15-8
  - attaching 15-6
  - axes 15-17
  - data markers 15-19
  - displaying signals 15-20
  - how to display 15-9
  - legends 15-12
  - limiting data 15-19
  - line styles 15-20
  - performance 15-21
  - performing common tasks 15-6
  - properties dialog 15-17
  - refresh 15-20
  - saving axes settings
    - gui 15-16
  - scroll 15-18
  - signal logging 15-19
  - simulation speed 17-4
  - toolbar 15-15
  - trace colors 15-20
  - zooming 15-10
- Scopes
  - using with Rapid Accelerator 19-17



- Second-Order Integrator, zero crossings 2-37
- Select All menu item 3-8
- selecting cells, rows, and lines 35-11
- Set Font dialog box 20-27
- set\_param command
  - breaking link 25-18
  - controlling model execution 19-25
  - running a simulation 13-3 14-7
  - setting block parameters within MATLAB
    - S-functions 24-33
  - setting simulation mode 19-25
- setting breakpoints 18-28
- shadowed files 11-4
- Shampine, L. F. 13-21
- Shape preservation
  - improving solver accuracy 2-24
- Show Name menu item 20-28
- show output port
  - Enable block 6-10
  - Trigger block 6-19
- showing block names 20-28
- Sign block
  - zero crossings 2-37
- Signal Builder
  - snap grid 31-106
- Signal Builder block
  - zero crossings 2-37
- Signal Builder time range
  - about 31-108
  - changing 31-108
- Signal Builder window 31-69
- signal groups 31-68
  - activating 31-110
  - copying and pasting 31-73
  - creating a custom waveform in 31-72
  - creating a set of 31-75
  - creating and deleting 31-71
  - creating signals in 31-71
  - deleting 31-74
  - discrete 31-113
  - editing 31-68
  - exporting to workspace 31-109
  - final values 31-111
  - hiding waveforms 31-71
  - moving 31-71
  - outputting 31-72
  - renaming 31-71
  - renaming signals in 31-110
  - running all 31-110
  - simulating with 31-110
  - specifying final values for 31-111
  - specifying sample time of 31-113
  - time range of 31-108
- signal labels
  - copying 31-23
  - creating 31-22
  - deleting 31-23
  - editing 31-22
  - moving 31-22
  - using to document models 11-7
- signal logging, enabling 29-21
- signal objects
  - resolving for MATLAB Function blocks 26-73
  - using to initialize signals 31-53
- signals
  - composite 32-2
  - initializing 31-52
  - labeling 31-22
  - labels 31-22
  - names 31-19
  - reversing direction of flow 11-8
  - virtual 31-11
- signals, creating 31-3
- signals, logging 29-19
- sim command
  - comparing performance 17-7
  - simulating an accelerated model 19-26
  - syntax 14-3
- simulation
  - accuracy 17-11

- checking status of 14-7
- displaying information about
  - algebraic loops 18-36
  - block execution order 18-40
  - block I/O 18-34
  - debug settings 18-43
  - integration 18-39
  - nonvirtual blocks 18-42
  - nonvirtual systems 18-41
  - system states 18-38
  - zero crossings 18-42
- execution phase 2-20
- MATLAB Function block 26-14
- parameters
  - specifying 13-39
- running incrementally 18-20
- running nonstop 18-25
- speed 17-3
- status bar 1-22
- stepping by breakpoints 18-28
- stepping by time steps 18-23
- unstable results 17-11
- Simulation Diagnostics Viewer 13-39
- simulation errors
  - diagnosing 13-39
- Simulation Options dialog box 31-111
- simulation time
  - compared to clock time 13-8
- Simulink
  - custom blocks, creating 24-2
  - ending session 1-47
  - icon 1-2
  - menus 1-21
  - starting 1-2
  - terminating 1-47
- Simulink block library. *See* block libraries
- simulink command
  - starting Simulink 1-2
- Simulink dialog boxes
  - font size 8-5
- Simulink input signal properties
  - MATLAB Function blocks 26-31
- Simulink Profiler
  - purpose 19-30
- Simulink, printing with print frames 35-2
- Simulink.BlockDiagram.getChecksum command
  - determining why the Accelerators rebuilds with 19-8
- size of
  - cells 35-12
  - print frame 35-9
  - print frame page setup 35-12
  - rows 35-12
  - text 35-20
- size of block
  - changing 20-25
- sizing MATLAB Function block variables by
  - expression 26-70
- sizing MATLAB Function block variables by
  - inheritance 26-69
- sizing MATLAB Function variables 26-69
- smart guides 20-12
- snap grid, Signal Builder 31-106
- solvers
  - fixed-step
    - definition 2-23
  - ode113
    - advantages 13-19
    - and simulation speed 17-3
  - ode15s
    - advantages 13-21
    - and simulation speed 17-3
    - and stiff problems 17-3
    - simulation accuracy 17-11
  - ode23s
    - advantages 13-21
    - simulation accuracy 17-11
- sorted order
  - bus-capable blocks and 20-45
  - direct-feedthrough ports and 20-46

- displaying 20-35
- Function-Call Split blocks and 20-44
- function-call subsystems and 20-42
- how Simulink® determines 20-46
- notation 20-36
- virtual blocks and 20-41
- special characters 35-15
- specifying
  - nonvirtual buses 32-56
- speed of simulation 17-3
- splitting rows and cells 35-12
- stairs function 4-24
- Start menu item 11-16
- start time 13-8
- StartFcn block callback parameter 3-62
- StartFcn model callback parameter 3-57
- starting
  - PrintFrame Editor 35-6
- starting Simulink 1-2
- starting the model discretizer 3-118
- states
  - between trigger events 6-19
  - importing initial 29-99
  - when enabling 6-9
- states, discrete
  - initializing 31-52
- static information in cells 35-8
- status
  - checking simulation 14-7
- status bar 1-22
- Step block
  - zero crossings 2-37
- step size
  - simulation speed 17-3
- stiff problems 13-21
- stiff systems
  - simulation speed 17-3
- stop time 13-8
- StopFcn block callback parameter 3-62
- StopFcn model callback parameter 3-57
- structures
  - using in MATLAB Function blocks 26-75
- style of text 35-20
- subfunctions
  - in MATLAB Function block functions 26-5
- subscript 35-15
- subsystem
  - atomic 2-12
  - conditionally executed 2-12
  - initial output 6-5
  - nonvirtual 2-12
  - virtual 2-11
- Subsystem block
  - adding to create subsystem 3-38
  - opening 3-39
- Subsystem Examples block library 11-2
- subsystem ports
  - labeling 3-41
- subsystem sample time
  - sample time 4-21
- subsystems 11-17
  - controlling access to 3-42
  - creating 3-37
  - displaying parent of 3-41
  - highlighting requirements in 8-94
  - labeling ports 3-41
  - model hierarchy 11-7
  - opening 3-40
  - triggered and enabled 6-21
  - underlying blocks 3-39
  - undoing creation of 3-40
- summary of mouse and keyboard actions 1-48
- superscript 35-15
- Switch block
  - zero crossings 2-37
- Switch Case block
  - zero crossings
    - and Disable zero-crossing detection option 2-37
- switch control flow diagram 3-46

- SwitchCase block
  - adding cases 3-46
  - connecting to Action subsystem 3-46
  - data input 3-46
- symbols 35-15
- system name entry 35-15
- System Requirements block 8-98

## T

- terminating MATLAB 1-47
- terminating Simulink 1-47
- terminating Simulink session 1-47
- test point icons 29-28 31-61
- test points 31-59
- TeX commands
  - using in annotations 3-33
- TeX sequences 35-15
- text
  - adding to cells 35-15
  - editing 35-18
  - editing mode 35-14
  - size of 35-20
  - special characters 35-15
  - style of 35-20
- tic command
  - comparing performance 17-7
- time entry 35-15
- time interval
  - simulation speed 17-3
- time range
  - of a Signal Builder block 31-108
- tips for building models 11-6
- To Workspace block
  - example 16-3
- toc command
  - comparing performance 17-7
- toolbar
  - editor 1-17
- total pages entry 35-15
- Trace colors
  - Scope Viewer 15-20
- Transfer Fcn block
  - example 11-9
- Transport Delay block
  - linearization 16-9
- Trigger and Enabled Subsystem
  - zero crossings 2-38
- Trigger block
  - creating triggered subsystem 6-19
  - outputting trigger signal 6-19
  - showing output port 6-19
  - zero crossings 2-38
- triggered and enabled subsystems 6-21
- triggered sample time 4-18
- triggered subsystems 6-17
- triggers
  - control signal
    - outputting 6-19
  - events 6-17
  - input 6-17
  - type parameter 6-19
- trust-region algorithm
  - Simulink algebraic loop solver 2-51
- tunable parameters
  - definition 2-9
- tutorial
  - creating a customized saturation block 24-18
- typing MATLAB Function block variables with
  - other variables 26-64
- typing MATLAB Function variables 26-60

## U

- Undo menu item 1-25
- UndoDeleteFcn block callback parameter 3-62
- undoing commands 1-25
- units for margins 35-9
- unstable simulation results 17-11
- Update Diagram menu item

- fixing bad link 25-20
  - out-of-date linked block 25-5
  - recoloring model 3-13
- Update method property
  - MATLAB Function blocks 26-29
- updating a block diagram 1-32
- updating a diagram programmatically 14-7
- user
  - specifying current 3-104
- user data 27-79
- UserData 27-79
- UserDataPersistent 27-79
- using
  - bus objects 32-15

**V**

- variable information
  - adding to cells 35-15
  - defined 35-8
  - format for 35-16
- variable sample time 4-17
- variables
  - creating for MATLAB Function blocks 26-12
- vector length
  - checking 2-19
- vectors
  - bus signals used as 32-95
- version control model parameters 3-114
- vertices
  - moving 3-21
- Viewers
  - using with Rapid Accelerator 19-17
- Viewers and generators
  - when to use 15-4
- viewing output trajectories 16-2
- viewing sample time information
  - Sample Time Display 4-9
- virtual blocks 20-2
  - sorted order and 20-41

- virtual buses
  - compared with nonvirtual 32-56
- virtual signals 31-11
- virtual subsystem 2-11
- visualization
  - Rapid Accelerator limitations 19-17
- Visualizing
  - simulation results 15-1

**W**

- when to disable run-time checks
  - MATLAB Function block 26-161
- while control flow diagram 3-47
- While Iterator block
  - changing to do-while 3-49
  - condition input 3-49
  - in subsystem 3-48
  - initial condition input 3-49
  - iterator number output 3-49
- window reuse 3-41
- workspace
  - loading from 29-61
  - writing to
    - simulation terminated or suspended 13-5

**Z**

- zero
  - zero-crossing threshold 2-35
- zero crossing detection 2-24
- zero crossings
  - disabled by non-double data types 27-30
  - saturation block 2-38
- zero-crossing
  - adaptive 2-34
  - algorithms 2-34
  - blocks that register 2-36
  - demonstrating effects 2-25

missing events 2-31  
nonadaptive 2-34  
preventing excessive 2-31  
threshold 2-35

zero-crossing detection 2-24  
zero-crossing slope method 6-5  
zooming 35-6